A Two-Period Unionized Mixed Oligopoly Model:

Public-private wage differentials and "Eurosclerosis" reconsidered

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Abstract

In the context of a two-period unionized mixed oligopoly we propose that – due to the public sector's role in the market – public-private wage differentials in favour of the public sector employees emerge over the business cycle, under either an asymmetric or a symmetric firing restrictions regime across the public and the private sector. Under the former regime firing costs are higher than (equal to) hiring costs in the public (private) sector, whilst under the latter regime firing/hiring costs are equal everywhere. The structure of the – product and labour market – equilibria, as well as the volume and the distribution of welfare, are however quite different under the two regimes. In contrast to conventional beliefs, the asymmetric – compared to the symmetric – regime entails higher aggregate output and employment over the business cycle. Moreover, a typical measure of social welfare dictates that the asymmetric regime should be sustained unless demand conditions significantly deteriorate during recession.

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1. Introduction

The public-private wage differential is typically defined as the positive difference between the public sector wage and the private sector wage regarding equally productive employees. According to conventional wisdom, such wage differentials reflect cross - sector intrinsic differences in jobs/tasks and/or different optimization problems: Public firms subject to political goals whilst private firms simply aim at profit maximization.

So far, however, there has not been any explicit hypothesis concluding whether higher (lower) pay in the public (private) sector constitutes, or not, a socially efficient arrangement. Whereas, various empirical studies suggest that public-private wage differentials in favour of the public sector's employees have for long been sustained in many countries.[1] Yet, more recently, and as in particular regards the European economies, an adequate reasoning – on efficiency grounds – for the sustainment of such wage differentials seems to be of paramount importance. According to the European Commission (2014), since wages comprise a big part of government spending the privileged status of public over private wages may significantly contribute to debt, as well as to competiveness, problems. Justification is therefore required about why the public sector must pay higher wages than the private sector, at least in those countries that are in need of international financial assistance [Muller and Schulten (2015)].[2]

On the other hand, the sustainment of firing restrictions regardless of the business cycle has for long been alleged as "Eurosclerosis" [Giersch (1985)]. The term standing for insufficient flexibility which prevents the labour market from adjusting to persistent deterioration in the aggregate demand conditions, thus, explaining the European poor employment performance in the 1980's [see, e.g., Blanchard *et al* (1986)] as well as today. However, according to Bertola (1990), and Bentolila and Bertola (1990), "Eurosclerosis" does not seem to be "so bad" in a second-best world. High enough

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[1] Evidence comes from Canada [Mueller (1998)], UK [Disney and Gosling (1998), Vinay and Turon (2007)], Italy [Dell' Aringa et al (2007)], Austria, Greece, Poland, Slovenia, Belgium, Spain, Portugal, Cyprus, Ireland, Luxemburg [Castro et al. (2013)], as well as from several Latin American countries: Colombia, Costa Rica, El Salvador, Ecuador, Honduras, Paraguay [Panizza and Zhen Wei Qiang (2005)].

[2] Eurostat analysis regards the 2006-2010 period. Controlling for individual characteristics such as age, gender, and educational attainment, concludes that high per capita wages in the public sector, if not justified by differences in labor skills or occupational position, may entail inefficiencies on several fronts.

firing costs tend to increase employment in bad times and, since the effect of hiring costs in good times is always lower than the effect of firing costs in bad times, firing restrictions would rather increase than decrease the long-run average employment level.

In the present paper we develop a two-period unionized mixed duopoly model, furnished with second period- demand shocks, where decentralized firm-specific wage bargains are struck in each period before product market competition is in place. Regarding the costs of adjusting employment across periods, we consider two alternative firing/hiring restrictions regimes. An asymmetric one, under which the public (private) firm faces lower (equal) employment adjustment- costs when hiring than when firing (when firing and hiring). And a symmetric one, under which firing is equally costly to hiring for both firms.

In this context, our findings suggest that – driven by the public firm's role in the product market – public-private wage differentials in favour of the public firm's employees endogenously emerge over the business cycle irrespective to the considered firing restrictions regime. Hence, public sector - "sclerosis" in the labour market must not be confused with "preferential" treatment of the public sector's employees regarding wages. However, the structure of the product and labour market equilibria, as well as the volume and the distribution of welfare across the public and private agents, are quite different under the two regimes. Most importantly, as it comes to the alleged adverse effects of firing restrictions on employment performance our findings rather object that scepticism. Alike Bentolila and Bertola (1990), yet in a quite different context than theirs, we suggest that the higher firing than hiring costs in only the public sector entail higher aggregate output and employment, hence, consumer surplus over the business cycle, than the everywhere symmetric firing/hiring costs. Yet, on the other hand, when demand conditions deteriorate the former (latter) regime may entail lower (higher) profits and incomes for the public (private) firms and their workers' unions. Still, nonetheless, our findings suggest that the asymmetric firing restrictions regime should be sustained by utilitarian policy makers, unless demand conditions significantly deteriorate during recession. Regarding the aggregate employment performance, it can be therefore concluded that, insofar the term regards the public sector, "Eurosclerosis" is really bad only under bad enough demand circumstances. Whilst, on the other hand, when demand conditions improve or do not much deteriorate, it redistributes profits and labour income from the private sector to the public sector.

The rest of the paper is organized as follows. In section 2 we address our structural model and the game arising in its context. In section 3 we investigate the equilibrium under an asymmetric, and a symmetric, firing restrictions regime across the public and the private sector. To explore the policy implications that arise from our findings, we subsequently proceed to welfare analysis in section 4. In section 5 we conclusively evaluate our present work and provide some future research hints.

2. The model

We consider a two-period mixed oligopoly model where two firms (firm 1; the private firm, firm 2; the public firm), producing horizontally differentiated goods, compete in quantities. Each firm produces with *C.R.S* technology, in the labor input, given that the deployed capital input is always sufficient to produce the good. Effectively that is, each firm possesses a *Leontief* technology. Thus, the production function of firm $i = 1{,}2$ is $q_i = kL_i$, where q_i denotes output, L_i is the number of employees, and $k > 0$ represents labor productivity – assumed to be symmetric across firms. For simplicity we normalize $k \equiv 1$. Labor is unionized and there exist two firm-specific labor unions $i = 1{,}2$, one in each firm.

Competition in the product market takes place *a la Cournot* in homogenous outputs over two consecutive periods $t \in [0{,}1]$. Consumer preferences in each period are represented by a Dixit (1979) quasi-linear specification, hence, the first period $(t = 0)$ private and public firms', inverse demand functions respectively are,

$$P_{10} = 1 - q_{10} - q_{20} \tag{1a}$$

$$P_{20} = 1 - q_{20} - q_{20} \tag{2a}$$

In the first period $(t = 0)$ demand is observed but there is uncertainty about the future (e.g., demand in the second period). Let, hence, the private and the public firm's expected demand function (s) in the second period $(t = 1)$ respectively be,

$$P_{11} = v - q_{11} - q_{21} \tag{1b}$$

$$P_{21} = v - q_{21} - q_{11} \tag{2b}$$

Where, $v = \rho(1 + \theta) + (1 - \rho)(1 - \theta)$ and θ $[-\theta]$ is a stochastic positive (negative) demand shock [of equal magnitude, $\theta \in (0{,}1)$], with probability to occur ρ $[(1 - \rho)]$;

$\rho \in [0,1]$. Thus $E(\theta) = \theta(2\rho - 1)$; $Var(\theta) = 4(1-\rho)\rho\theta^2$. We moreover assume a discount factor $\delta^t = 1$.

In the labour market firm-specific wages bargains between each firm's management and each firm's worker's union are struck in each period. Therefore, our envisaged game – of product and labour market interaction – is deployed in two periods and five stages, as follows.

At stage one, first period $(t = 0)$, a policy maker evaluates the performance of alternative firing restrictions regimes (frr_x), in terms of social welfare, by means of an evaluation/objective function (Ev) – to be defined later on. The policy maker establishes (or sustains) the particular frr_x which maximizes Ev.

At stage two, first period $(t = 0)$, the two pairs of contracting agents in the labour market[3], i.e., the private (public) firm and the private (public) firm's labour union, bargain independently and simultaneously (e.g., in parallel sessions) about firm-specific wages, leaving the firm-specific output/employment decisions to the firm's discretion. We assume that each union possesses unit bargaining power over the wage, e.g. it behaves as a firm-specific monopoly union which unilaterally sets the firm-specific wage.[4]

At stage three, first period $(t = 0)$, given the firm-specific wage, each firm decides on, and adjusts, its optimal level of employment and output in the – current – first period, for any employment/output level of its rival firm in the same period.

At stage four, second period $(t = 1)$, the two pairs of contracting agents in the labour market, i.e., the private (public) firm and the private (public) firm's labour union, re-bargain independently and simultaneously (e.g., in parallel sessions), about firm-specific wages (alike in the second stage).

At stage five, second period $(t = 1)$, given the re-bargained firm-specific wages firms compete *a la* Cournot, in the – current– second period.

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[3] As this bargaining structure is dominant in the majority of the European industrial relations systems [see, e.g. Petrakis and Vlassis (2004) and the references therein], we assume that firm-union bargaining is decentralized.

[4] That is, for analytical convenience, we undertake the *monopoly union* variant of the *right-to-manage* hypothesis. This is a regular restriction in the union-oligopoly literature and it is not expected to qualitatively affect our analysis [see Petrakis and Vlassis (2004)].

We solve the game by backwards induction to ensure sub-game perfection.[5]

3. Equilibrium

3.1. Regime *frr₁*: Asymmetric Firing Restrictions in the Public versus the Private sector

Let the policy maker's institutional choice (frr_1) be defined by the following intertemporal (period2=1; period1=0) employment adjustment-cost schedules, $AdjC_1$, $AdjC_2$, respectively for the private and the public firm,

$$AdjC_1 = c_1\left(\frac{(q_{10}-q_{11})^2}{2}\right) \quad (3)$$

$$AdjC_2 = c_2\left(\frac{(q_{20}-q_{21})^2}{2} - (q_{21}-q_{20})\right) \quad (4)$$

Where, $c_i = 1,2 > 0$ denotes a cost parameter of period - to - period adjusting employment according to the state-mandated firm-specific $AdjC_{i\neq j=1,2}$ rules. Given that the two firms are assumed to be symmetric in technology, this parameter is further assumed to be symmetric across firms, e.g., $c_1 = c_2 = c$. It follows that the private and the public firm's total cost schedule(s) over the two-period production game, respectively are,

$$TC_1 = w_{10}q_{10} + w_{11}q_{11} + c\left(\frac{(q_{10}-q_{11})^2}{2}\right) \quad (5)$$

$$TC_2 = w_{20}q_{20} + w_{21}q_{21} + c\left(\frac{(q_{20}-q_{21})^2}{2} - (q_{21}-q_{20})\right) \quad (6)$$

Where, $w_{it}; \mathrm{i} = 1,2, \mathrm{t} = 0,1$ is the firm (i)/period (t) – specific bargained wage.

[5] While subgame perfection ensures that at each stage of the game each agent takes into account the consequences of his/her actions on the subsequent stages of the game, we moreover (for simplicity) assume that, at stages two and three ($t = 0$), both firms and unions discount the forthcoming demand of stage five ($t = 1$) with $\delta^t = 1$. Note also that wage bargaining takes place without delay at stages two ($t = 0$) and four ($t = 1$) just before – first- and second- period – market competition is in place – at stages three ($t = 0$) and five ($t = 1$), respectively.

Under frr_1, the public firm faces strict – relative to the private firm – firing restrictions over the business cycle. To grasp it suppose that in the second period ($t = 1$) both firms' employment/output, q_{i1} is lower than that of the first period ($t = 0$), q_{i0}. Then, through the quadratic term, $c\frac{(q_{i0}-q_{i1})^2}{2}$, each firm suffers extra (e.g., above its total wage bill) employment adjustment costs.[6] However, through $c(q_{20} - q_{21})$, the public firm suffers higher firing costs relative to its private rival; the opposite happening if q_{21} is higher than q_{20}.[7] This is a major novelty of our analysis, capturing the idea of an asymmetric firing restrictions regime accrediting to public firms the role of protecting employment during recession.[8] Given (5) and (6), the private and the public firm's profit(s) over the two-period game are subsequently defined by,

$$\Pi_1 = TR_{10} + TR_{11} - TC_1 \tag{7}$$

$$\Pi_2 = TR_{20} + TR_{21} - TC_2 \tag{8}$$

Where, $TR_{10} = P_{10}q_{10}$ ($TR_{11} = P_{11}q_{11}$) are the private firm's first (second) period total revenues and $TR_{20} = P_{20}q_{20}$ ($TR_{21} = P_{21}q_{21}$) respectively are the public firm's first (second) period total revenues.

At any stage of the game both firms act independently. The private firm is maximizing its profits for the entire game, whilst – like in Barcena-Ruiz (2012) – the

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[6] This is a standard in the literature specification for the employment adjustment (firing/hiring) costs [see e.g., Hamermesh (1996)], suggesting that, whether $q_{i1} > q_{i0}$ or $q_{i1} < q_{i0}$ emerges in the second period, firms face the same employment adjustment costs. In our context, however, this holds true only regarding the private firm.

[7] That is, as $q_{i1} > q_{i0}$, the public firm's hiring costs become lower (by $c[q_{21} - q_{20}]$) than the private firm's counterpart. Of course, if $q_{i1} = q_{i0}$, then the firing/hiring restrictions are not operative, i.e., no extra (above total labour) costs occur for either firm.

[8] Regarding private firms, firing costs in the form of state-mandated redundancy payments and/or maximum permissible layoffs (as a % of firm-specific total employment), were introduced from the late 50s to the early 70s, and are (still) present, in many European countries [see, e.g., Bentolila and Bertola (1990), Lazear (1990), Layard, Nickell and Jackman (1991), Cook (1997), Nickell (1998), Nickell, Nunziata and Quintini (2001)]. As on the other hand regards public firms they face higher than private firms state-mandated firing costs, as it is evident through the various tenure schemes which are prevalent in the public sector. Whereas hiring costs, arising for instance from employee registration with social insurance, are typically higher for the private than for the public firms.

public firm maximizes a social welfare objective (SW_2), that is, a weighted sum of the private firm's profits (*Π1*) the public firm's profits (*Π2*) and consumer surplus (*CS*), given by equation (9),

$$SW_2 = \alpha_1 \Pi 1 + \alpha_2 \Pi 2 + \alpha_3 CS \tag{9}$$

Following White (2002), we assume that the weight parameters α_1, α_2, α_3 ; $\alpha_1 + \alpha_2 + \alpha_3 = 1$ are all positive ($\alpha_1 > 0$, $\alpha_2 > 0$, and $\alpha_3 > 0$), because the public firm should not intend to harm either group of the private agents by assigning it a negative weight, and that $\alpha_2 \geq \alpha_1$, α_3, i.e., the public firm's profits should always be weighted by at least as high as α_1 or α_3. The latter qualification assures that the public firm always produces a positive output (e.g., stays in business) in the mixed oligopoly. To simplify our analysis, we moreover assume that the public sector cares equally about the private firm's profits ($\Pi 1$) and consumer surplus (CS), namely that, $\alpha_1 = \alpha_3$. Therefore, in what follows, $\alpha_2 \in [\frac{1}{2}, 1)$.[9]

In light of the above, inducting backwards, from the *foc*s of (7) and (9) *w.r.t* q_{11}, q_{21}, we get the - second period /stage four - reaction functions, respectively for the private and the public firm,

$$RF_{11}: \mathrm{q}_{11} = \frac{v + c\mathrm{q}_{10} - \mathrm{q}_{21} - \mathrm{w}11}{2 + c} \tag{10}$$

$$RF_{21}: q_{21} = \frac{2(v + c)\,\alpha_2 + (1 - \alpha_2)\mathrm{q}_{10} + (1 - \alpha_2 + 2c\alpha_2) q_{20} - 2\, q_{11}\, \alpha_2 - 2\alpha_2\, w_{21}}{-1 + 5\,\alpha_2 + 2c\alpha_2} \tag{11}$$

Note that, if $\alpha_2 = 1 \rightarrow \alpha_1 = \alpha_3 = 0,$ and $c = 0$, (10) and (11) reduce to a standard system of reaction functions under - twin period - Cournot competition among two symmetric (private) firms. Hence, it is clear from the outset that any emerging asymmetry among the two firms in the equilibrium stems from two sources. First, from the assumption that (the public) firm 2 maximizes (9) instead of its own profits ($\alpha_2 \in [\frac{1}{2}, 1)$). Second, from the assumption that that the two firms face a, here asymmetric, output/employment adjustments costs regime (*c*>0: $TC_1 \neq TC_2, TC_{i=1,2} \geq$

[9]Since $\alpha_1 + \alpha_2 + \alpha_3 = 1$, and $\alpha_1 = \alpha_3, \alpha_2 = 1 - 2\alpha_1 > 0 \rightarrow \alpha_1 < 1/2$. Moreover, since $1 > \alpha_2 \geq \alpha_1$, we can consider $\alpha_2 \in [\frac{1}{2}, 1)$ throughout our subsequent analysis.

$\sum_{t=0}^{1} w_{it}q_{it}$). With this in mind, we solve the system of (10) and (11), to get the optimal q_{11}, q_{21}, rules in the second period.

$$q_{11} = \frac{v + (2c - 3v - 2cv)\alpha_2 - 2w_{21}\alpha_2 + q_{20}(1 - \alpha_2 + 2c\alpha_2) + w_{11}(5\alpha_2 + 2c\alpha_2 - 1) + q_{10}(1 + c - \alpha_2 - c(5 + 2c)\alpha_2)}{(2 + c) - (8 + c(9 + 2c))\alpha_2} \quad (12)$$

$$q_{21} = \frac{(4c + 2c^2 + 2v + 2cv)\alpha_2 + 2\alpha_2 w_{11} + q_{10}(2 + c - 2\alpha_2 - 3c\alpha_2) - w_{21}(4\alpha_2 + 2c\alpha_2) + q_{20}(2 + c)(1 - \alpha_2 + 2c\alpha_2)}{\big(8 + c(9 + 2c)\big)\alpha_2 - (2 + c)} \quad (13)$$

By simply inspecting (12) and (13), it can be easily noted that the intertemporal allocation of production/employment, across the public and the private firm, is expected to be asymmetric in the equilibrium. Moreover that, this allocation depends on the public firm's role in the product market, i.e., the α_2 value, for any given c. To find out how exactly the equilibrium would be like, let however proceed to the remaining steps of our backwards induction.

Having assumed firm-specific monopoly unions, at stage four each union i, unilaterally and independently from union $j \neq i = 1,2$, sets the firm-specific wage, w_{i1}, taking into account how that its decision will affect the competitiveness of its own firm, hence, the union's members' employment prospects, in the subsequent – product market – game. Thus, given (12) and (13), union i chooses[10],

$$w_{i1} = argmaxUi = w_{i1}.q_{i1}, i \neq j = 1,2 \qquad (14)$$

Solving the system accruing from the *focs* of (14) *w.r.t* $w_{i0}; i = 1,2$, we obtain the following system of the second period - optimal rules for the firm-specific wage contracts, w_{11}, w_{21}, respectively for the public and the private firm.

[10] U_i, in equation (14), is a standard (in the trade unions literature) union-rent maximand (see, e.g., Oswald (1982)), $(w_{i1} - w_c)q_{i1}$, which is here reduced to the union members' total wage bill, $w_{i1}.q_{i1}$, by –for simplicity – normalizing to zero the threshold wage, w_c.

$$w_{11} = \frac{(4+2c)v+(4c+2c^2-14v-16cv-4c^2v)\alpha_2+q_{20}(2+c-2\alpha_2+3c\alpha_2+2c^2\alpha_2)+q_{10}(2+5c+2c^2-2\alpha_2-19c\alpha_2-18c^2\alpha_2-4c^3\alpha_2)}{2(4+2c-19\alpha_2-18c\alpha_2-4c^2\alpha_2)} \tag{15}$$

$$w_{21} = \frac{(4c+2c^2+3v+2cv-18c\alpha_2-18c^2\alpha_2-4c^3\alpha_2-13v\alpha_2-16cv\alpha_2-4c^2v\alpha_2)\alpha_2+q_{10}(2+c-11\alpha_2-11c\alpha_2-2c^2\alpha_2+9a_2^2+14ca_2^2+4c^2a_2^2)+q_{20}(2+c-11\alpha_2-6c\alpha_2+9a_2^2-9ca_2^2-16c^2a_2^2-4c^3a_2^2)}{2\alpha_2(4+2c-19\alpha_2-18c\alpha_2-4c^2\alpha_2)} \tag{16}$$

Thus, a – still undefined – public-private wage differential emerges in the subgame perfect equilibrium.[11]

$$w_{21} - w_{11} = \frac{(4c+2c^2-v+(v-22c-20c^2-4c^3)\alpha_2)\alpha_2+q_{20}(2+c-(13+7c)\alpha_2+(11\alpha_2-12c\alpha_2-18c^2\alpha_2-4c^3\alpha_2)\alpha_2)+q_{10}\left(2+c-(13+16c-4c^2)\alpha_2+(11+33c+22c^2+4c^3)a_2^2\right)}{2\alpha_2\left(2(2+c)-\left(19+2c(9+2c)\right)\alpha_2\right)}$$

To explicitly check for the above differential along with the emerging distribution of production/employment and wages – across periods and firms – let subsequently proceed at first period/ stage three. Substituting (12), (13), (15) and (16) into (7) and (9), from the *foc$_s$* of the derived Π_1, SW_2, formulae *w.r.t.* q_{10}, q_{20}, respectively, we obtain the first period reactions functions, (17) and (18).

$$RF_{10}: q_{10} = \frac{1+cq_{11}-q_{20}-w_{10}}{2+c} \tag{17}$$

$$RF_{20}: q_{20} = \frac{2(1-c)\alpha_2-2\alpha_2 q_{10}+(1-\alpha_2)q_{11}+(1-\alpha_2+2c\alpha_2)q_{21}-2\alpha_2 w_{20}}{-1+5\,\alpha_2+2c\alpha_2} \tag{18}$$

Then, substituting (12) and (13), respectively for q_{11}, q_{21}, into (17) and (18), and solving the accruing reduced forms, we get the first period-optimal $q_{i0}(\alpha_2, c, w_{i0})$ rules, so that, moving our analysis one more step backwards – at stage two/first period

[11] Note however that – ignoring the intertemporal output ($q_{i0} \leftrightarrow q_{i1}$) effects (e.g., setting $q_{i0} = q_{j0} = 0$)– a wage differential in favour of the public sector wage emerges for any given value of $\alpha_2 \in [\frac{1}{2}, 1)$; for instance, if $\alpha_2 = 2/3 \rightarrow [w_{21} - w_{11}] = \frac{2c(16+c(17+4c))+v}{52+4c(15+4c)} > 0$. Implying that, what drives to public-private wage differentials in equilibrium is the public firm's role in the product market which is here captured by an α_2 value less than unity.

– each union i, unilaterally and independently from union $j \neq i = 1,2$, sets the firm-specific first period- wage, w_{i0}: [12]

$$w_{i0} = argmaxUi = w_{i0}.\,q_{i0}(\alpha_2, c, \mathrm{w}_{i0}) \quad , i \neq j = 1,2 \qquad (19)$$

Solving the system accruing from the *focs* of (19) *w.r.t* $w_{i0}; i = 1,2$, we obtain a unique stable solution for the first period- firm-specific wage contracts, w_{10}^*, w_{20}^*, respectively for the public and the private firm. We may subsequently derive the equilibrium values of all our endogenous variables, by substituting w_{10}^*, w_{20}^*, into (17) and (18)- to get q_{i0}^* , then the q_{i0}^* values into (15) and (16) - to get w_{i1}^*, and finally the w_{i1}^* values into (12) and (13) - to get the q_{i1}^* values. Consequently, we may derive the equilibrium U_i^*, Π_i^*.[13]

Proposition 1 summarizes our findings.

Proposition 1

Under frr1:

(i) *The public firm always produces a higher (lower) quantity in the second (first) period, and always produces a higher total quantity than the private firm over the business cycle.*

(ii) *The private firm produces a higher quantity than the public firm in the first period, if the second period- product demand significantly deteriorates and the c value is high enough. Otherwise, the public firm produces a higher quantity than the private firm also in the first period.*

(iii) *Under any second period-demand circumstances, a wage differential in favour of the public firm's wage emerges in the second period. In contrast, a wage differential in favour of the private firm's wage emerges in the first period, unless the second period- product demand significantly improves and the c value is sufficiently low. Nonetheless, an aggregate differential in favour of the public firm's wage always emerges over the business cycle*

[The proof appears in the Appendix]

[12] The $q_{i0}(\alpha_2, c, \mathrm{w}_{i0})$ formulae are available by the authors upon request.

[13] The derived q_{i0}^*, q_{i1}^*, w_{i0}^*, w_{i1}^*, as well as the U_i^*, Π_i^*, CS^*, SW^*, EV^*, formulae are available by the authors upon request.

The intuition behind these findings is as follows. As already mentioned, the as above emerging asymmetries among firms in the equilibrium stem from two sources: First, since $\alpha_2 < 1$, the public firm under any circumstances produces more than the private firm over the business cycle. Hence, since the public (the private) firm's union faces a higher (lower) labour demand, the public firm's total wage is higher than the private firm's wage, over the business cycle. Second, the – as above asymmetric across firms –, period-to period allocation of production/employment is due to the asymmetric firing/hiring restrictions regime, *frr1*, which penalizes firing more than (equally to) hiring for the public (the private) firm. Thus, since – in terms of minimum employment adjustment costs – is indifferent about to produce more or less, in the first or in the second period, the private firm is expected to pro-cyclically allocate its own production/employment across periods. However, the public firm's idiosyncratic employment adjustment costs are minimized under production/employment expansion in the second period. Therefore, and given that adjusting employment is expensive enough (i.e., the c value is sufficiently high), the public firm will be driven to produce even less than the private firm in the first period, if the second period-demand circumstances are expected to significantly deteriorate. As a consequence, the wage charged by the private firm' s union will be then higher than the wage charged by the public firm's union, in the first period. Otherwise, i.e., if the forthcoming demand conditions improve, or do not significantly deteriorate, the public firm will be driven to produce more than the private firm in the first, as well as in the second, period. The driving force behind that being the dominance of the public firm's role in the product market over its own output's optimal intertemporal allocation under the asymmetric firing restrictions regime. Hence, a public-private wage differential in favour of the wage charged by the public firm's union emerges in both periods.

Moving backwards to the first stage of the game, it is now time to define the policy maker's evaluation function, as a typical utilitarian objective, given by equation (20).

$$Ev\{= CS + \Pi_1 + \Pi_2 + U_1 + U_2\} = CS + \Pi_1 + \Pi_2 + U_1 + U_2 \qquad (20)$$

The Ev^* value, under frr_1, can be now directly calculated as a sum of components which have already been determined in the preceding analysis. Yet, unless an alternative value of (20) exists, to compare with, the subgame perfect Nash equilibrium of stage one, hence of the entire game, is still to come, on welfare grounds. We thus proceed by assuming that an – alternative to frr_1 –firing/hiring restrictions regime has been the policy maker's institutional choice at stage one, and run again our backwards induction algorithm.

3.2. Regime frr_2: Symmetric Firing Restrictions in the Public and in the Private sector

Assume that the policy maker's institutional choice, at the first stage, has been the one of symmetric firing/hiring restrictions (frr_2) for either the public and the private firm.[14] Effectively, let the employment - adjustment cost schedule of both the public and the private firm be,

$$AdjC_{i\neq j=1,2} = c\left[\frac{(q_{i1}-q_{i0})^2}{2}\right] \quad (21)$$

It follows that the - twin period - cost schedule, of both the public and the private firm is given by equation (22).

$$TC_{i\neq j=1,2} = w_{i0}q_{i0} + w_{i1}q_{i1} + c\left(\frac{(q_{i0}-q_{i1})^2}{2}\right) \quad (22)$$

By virtue of (22) – instead of (5) and (6) – our backwards induction routine (from stage five to stage two) subsequently delivers the equilibrium values of w_{i0}^*, q_{i0}^*, w_{i1}^*, q_{i1}^*, U_i^*, Π_i^*, under frr_2.[15]

Proposition 2 summarizes our relevant findings.

Proposition 2

Under frr_2:

(i) *The public firm produces a higher quantity than the private firm in both periods. Yet, the public (the private) firm's total quantity over the business cycle is lower (higher) under frr_2 than under frr_1. Moreover, the aggregate*

[14] For instance, the policy maker could abandon the existing tenure schemes in the public sector and/or impose the same % of maximum permissible lay-offs in the public and the private sector.

[15] These (very long and complicated) formulae are available by authors upon request.

output and employment, hence, consumer surplus, over the business cycle is lower under frr_2 than under frr_1.

(ii) *A wage differential in favour of the public firm's wage emerges in each period. Hence, an aggregate wage differential in favour of the public firm's wage also emerges over the business cycle. Yet, the wage(s) paid in both the public and the private firm(s), in both periods, are higher under frr_2 than under frr_1.*

[The proof appears in the Appendix]

Proposition 2 pictures a quite different equilibrium structure in both the product and the labour market under the symmetric firing restrictions regime (frr_2) – in comparison to the asymmetric firing restrictions regime (frr_1). The intuition behind is the following. Under the symmetric regime, the public firm has got rid of the idiosyncratic incentive to overshoot production/employment in the second period, whatever be the second period's, relative to the first period's, demand conditions. Hence, like it does the private firm, it now allocates its own production/employment pro-cyclically across periods, whilst it produces a lower output over the business cycle, than under frr_1. Therefore, due to strategic substitutability among the firms' products, the private firm's output, over the business cycle, is now higher than it was under frr_1. Yet, since $\alpha_2 < 1$, the public firm still produces a higher output than the private firm, in each period and over the business cycle and, thus, a public-private wage differential similarly arises. As said, nonetheless, the public firm's – twin period – output is lower, driving the equilibrium to a lower total output, under frr_2 than under frr_1. What, therefore, seems a bit surprising is that the wages paid in both the public and the private firms are higher under frr_2 than under frr_1. To grasp why is so, however, recall that the private firm's output, henceforth, its labour demand, is higher under frr_2 than under frr_1, leading the private firm's union to similarly charge a higher wage. Therefore, since firm-specific wages are strategic complements from each union's point of view, the public firm's union will be driven to also charge a higher wage under frr_2 than under frr_1.[16]

[16]At this point, it must be noted that strategic complementarity among the firm-specific union charged wages arises because we have assumed a decentralized firm-specific wage bargaining setup. Under which, each firm-specific union does not internalize the effects of its decisions to the other union (s). Under a centralized wage bargaining setup, however, where the firm-specific union decisions are coordinated, our findings might be quite different. This issue is left for future research.

4. Welfare Analysis

By virtue of the U_i^*, $\Pi_i^*, q_i^* \rightarrow CS^*$, hence, Ev^*, outcomes, under frr_1 and frr_2, we can now proceed to the final step of our analysis to examine what could be the policy maker's choice at the first stage of the game. Our findings regarding the distribution and the volume of welfare under the alternative firing restrictions regimes are summarized in Proposition 3.

Proposition 3

(i) *Under frr_1, the profits of the public firm are higher (lower) than the profits of the private firm, if the second period- product demand significantly improves (deteriorates) and the c value is sufficiently high (low). Yet, the public firm's union's welfare is higher than the private firm's union's welfare over the business cycle.*

(ii) *Under frr_2, the profits of the public firm (the public firm's union's welfare) are higher (is lower) than the profits of the private firm (the private firm's union's welfare) over the business cycle. Yet, unless the second period- product demand significantly deteriorates (improves) the public (the private) firm's profits, as well as the public (the private) firm's union's welfare, are lower (higher), under frr_2 than under frr_1.*

(iii) *The Ev function retains lower values under frr_2 than under frr_1, unless the second period- product demand significantly deteriorates.*

[The proof appears in the Appendix]

Proposition 3 conveys few clear policy messages. First, that the asymmetric – compared to the symmetric – firing restrictions regime entails higher total output and employment, hence, consumer surplus, over the business cycle. Yet, on the other hand, when demand conditions deteriorate the former (latter) regime may entail lower (higher) profitability and income, respectively for the public (private) firms and their workers' unions. Still, nonetheless, unless the second period- product demand significantly deteriorates, the sum of the above welfare elements is higher under the asymmetric, than under the symmetric, regime. It follows that a policy maker, who is neutral in his/her evaluation of the individual contributions to social welfare, i.e., his/her decision criterion is formed by a simple – utilitarian – welfare aggregate, like

Ev, must be expected to establish/sustain the asymmetric firing restrictions regime unless he/she faces a business cycle profile where demand conditions significantly deteriorate during recession.

Hence, our analysis suggests that regarding aggregate output and employment the notorious public sector - "sclerosis" – in the form of asymmetric public-private firing restrictions – is really bad only under bad enough demand circumstances. Yet, unless demand conditions improve or do not much deteriorate during recession, such a regime is harmful for the public firms' profits and their workers' income, at the benefit of the private firms' profits and their workers' income. The latter redistributive effects of the asymmetric firing restrictions regime clearly suggest that it must not be confused with the public-private wage differentials which under either regime arise because of the public firms' role in the product market.

5. Conclusions

In the present paper we have developed a union-oligopoly model within which various issues regarding the public sector's role and effects in the product market and the social welfare can be addressed in an intertemporal context of analysis. So far, in this context, we have coherently examined the issues of the public-private wage differentials and of the asymmetric public-private firing restrictions regimes, which are both evidenced to survive in many (European) economies over the last decades. The findings of our analysis seem to confirm and object the traditional views, as follows.

First, aligned with the conventional wisdom, we suggest that the public-private wage differentials sustain over the business cycle because of the public sector's role in the product market, under any of the considered firing restrictions regimes.

Second, in contrast to what is generally believed, we propose that aggregate output and employment over the business cycle are higher under conditions of higher labour market "sclerosis." The latter stemming from the fact that, whilst the private sector faces symmetric firing/hiring costs, the public sector faces higher costs when firing than when hiring.

Third, since such public sector - "sclerosis" may moreover entail redistributive welfare effects among the public and the private agents, we further propose that a utilitarian policy maker should afford it – by sustaining the asymmetric firing restrictions regime – so long as social welfare improves, e.g., the aggregate output effect dominates the redistributive effects over the business cycle.

Fourth, since our findings show that social welfare as above improves when demand conditions do not much deteriorate during recession, our analysis seems to explain why "Eurosclerosis" might not have been so bad in the past. Whilst, on the other hand, our findings raise questions on whether it may be considered to be, or not, so bad in the present. The latter in fact is an empirical inquiry, since the sustainment, or not, of the asymmetric firing restrictions regime should – as we suggest – depend on the business cycle profile during recession.

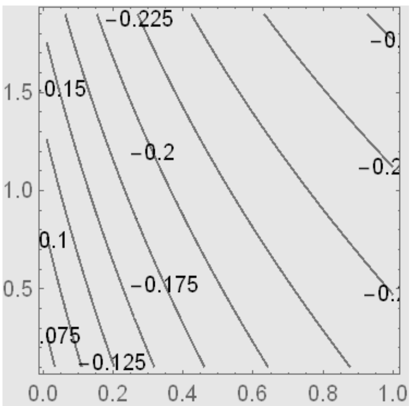
In brief, our analysis proposes that the establishment/sustainment of firing asymmetries across the private and the public sector should not be considered as a long-run – good or bad – institutional resolution. It must be rather treated as one – out of the many – policy tool to deal with unemployment over the business cycle which entails both merits and drawbacks. The most prevalent of the latter being the harm to the public firms' profitability and their workers' incomes in economies suffering from sharp recessionary periods. Hence, in contrast to the public opinion, we suggest that the public sector's "privileges" have rather been a curse than a blessing – for its agents – during the recent economic crisis. As a corollary, we propose that before any criticism could be accepted or rejected, a comparative analysis of the possible institutional alternatives is needed. To this end, our context of analysis can as well accommodate a number of relevant issues. One such extension is to assume a – quite realistic over the recent years – "pay freeze" scheme in only the public sector along with the sustainment, or abandonment, of the asymmetric firing restrictions regime. A second one is to assume the public firm's privatization (e.g., set $\alpha_2 = 1$) along with keeping the asymmetric firing restrictions regime regarding the ex- public firm only. And, as already pointed out (see footnote 17), of particular interest seems to examine how any of the considered hypotheses might lead to quite different results if it was accompanied by unions' coordination over the firm- specific wage bargains.

Appendix

Recall footnote (9) according which, $\alpha_2 \in [\frac{1}{2}, 1)$. In what follows we consider $\alpha_2 = 2/3$. Yet, our results hold irrespective to the value of α_2, provided that $\alpha_2 \in [\frac{1}{2}, 1)$. Moreover, we consider an interval for v, $v \in [0.1,1.9]$, so as to capture the forthcoming -second period- positive (negative) demand shocks by $v > 1$ ($v < 1$). Note also that we restrict the value of *c*: $c \in (0,1]$ in order to ensure interior solutions. Nonetheless, the choice of these *v* and *c* intervals, given $\alpha_2 = 2/3$, is illustrative, since there are many other similar intervals such that interior solutions are ensured, for $\alpha_2 \in [\frac{1}{2}, 1)$.

Proof of Proposition 1:

(i) To check for the validity of the sign configurations of the public-private output differentials, $\boldsymbol{D}q^*_{121} = [q^*_{11r1} - q^*_{21r1}] < 0$ and $\boldsymbol{D}Q^*_{12} = [Q^*_{1r1}\{= q^*_{10r1} + q^*_{11r1}\} - Q^*_{2r1}\{= q^*_{20r1} + q^*_{21r1}\}] < 0$, we have performed numerous successful tests over the prescribed grid of our parameter space, e.g., for $\{c, v\}$ such that all our endogenous variables to retain positive values (no corner solutions) in the equilibrium. *Figure 1* and *Figure 2* respectively illustrate the iso-contours $v(c)$ of $\boldsymbol{D}q^*_{121}$, $\boldsymbol{D}Q^*_{12}$, for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.



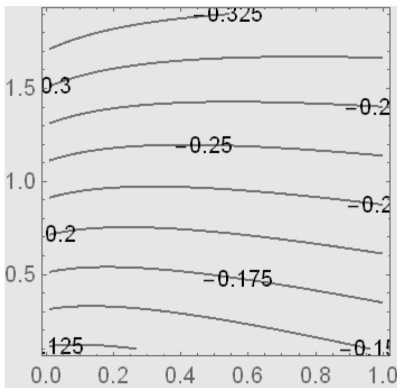


Figure 1: $\boldsymbol{D}q^*_{121} = [q^*_{11r1} - q^*_{21r1}] < 0$ *Figure 2:* $\boldsymbol{D}Q^*_{12} = [Q^*_{1r1} - Q^*_{2r1}] < 0$

(ii) To check whether $\boldsymbol{D}q^*_{120} = [q^*_{10r1} - q^*_{20r1}] \geq or < 0$, define $v(c)$ as the value of v for a given $c \in [0.01,1]$ such that $\boldsymbol{D}q^*_{120}(c, v(c)) = 0$. For a given $c \in [0.01,1]$, $\boldsymbol{D}q^*_{120}(v, c)$ is decreasing with v; and for a fixed v,

$\boldsymbol{D}q^*_{120}(v,c)$ is increasing with c. Therefore, $c(v) = v(c)^{-1}$, with $\frac{dv}{dc} > 0\ \forall\ c \in [0.01,1]$. Moreover, provided that $1 \geq c > 0.2$, $lim_{v\to 0.1}\boldsymbol{D}q^*_{120}(v,c) \geq 0$ and $lim_{v\to\bar{v}(>0.1)}\ \boldsymbol{D}q^*_{120}(v,c) < 0$. Hence, $\boldsymbol{D}q^*_{120}(v,c) \geq 0$ if $v \leq v(c)$, and $\boldsymbol{D}q^*_{120}(v,c) < 0$ if $v > v(c)$. (See *Figure 3* for illustration)

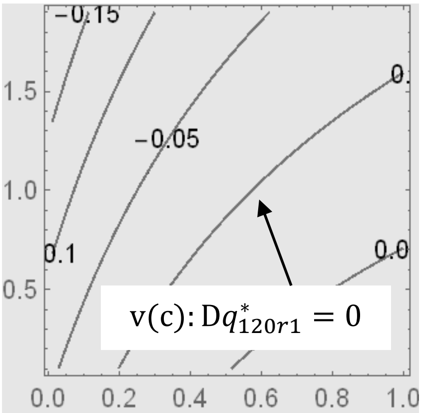
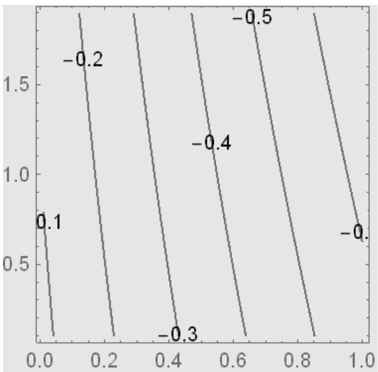


Figure 3: $\boldsymbol{D}q^*_{120} = [q^*_{10r1} - q^*_{20r1}] \geq or < 0$

(iii) Regarding the validity of the sign configuration(s) of the – second period – public-private wage differential, $\boldsymbol{D}w^*_{121} = [w^*_{11r1} - w^*_{21r1}] < 0$, and the – lifetime – (twin period) public-private wage differential, $\boldsymbol{D}\Sigma w^*_{12} = [\{w^*_{10r1} + w^*_{11r1}\} - \{w^*_{20r1} + w^*_{21r1}\}] < 0$, all our performed tests over the prescribed $\{c, v\}$ grid have been successful. *Figures 4* and *5* respectively illustrate the iso-contours $v(c)$ of $\boldsymbol{D}w^*_{120}$, $\boldsymbol{D}w^*_{121}$, for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.



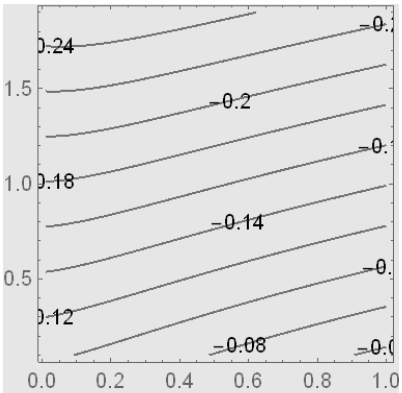


Figure 4: $\boldsymbol{D}w^*_{121} = [w^*_{11r1} - w^*_{21r1}] < 0$ *Figure 5*: $\boldsymbol{D}\Sigma w^*_{12} < 0$

To check whether $\boldsymbol{D}w_{120}^{*} = [w_{10r1}^{*} - w_{20r1}^{*}] \geq or < 0$, define $v(c)$ as the value of v for a given $c \in [0.01,1]$ such that $\boldsymbol{D}w_{120}^{*}\big(c, v(c)\big) = 0$. For a given $c \in [0.01,1]$, $\boldsymbol{D}w_{120}^{*}(v, c)$ is decreasing with v; and for a fixed v, $\boldsymbol{D}w_{120}^{*}(v, c)$ is increasing with c. Therefore, $c(v) = v(c)^{-1}$, with $\frac{dv}{dc} > 0 \ \forall \ c \in [0.01,1]$. Moreover, provided that $c < 0.1$, $lim_{v \to 0.1} \boldsymbol{D}w_{120}^{*}(v, c) \geq 0$ and $lim_{v \to \bar{v}(\geq 1)} \boldsymbol{D}w_{120}^{*}(v, c) < 0$. Hence, $\boldsymbol{D}w_{120}^{*}(v, c) \geq 0$ if $v \leq v(c)$, and $\boldsymbol{D}w_{120}^{*}(v, c) < 0$ if $v > v(c)$. (See *Figure 6* for illustration)

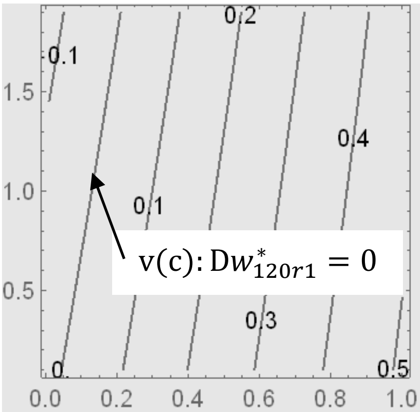
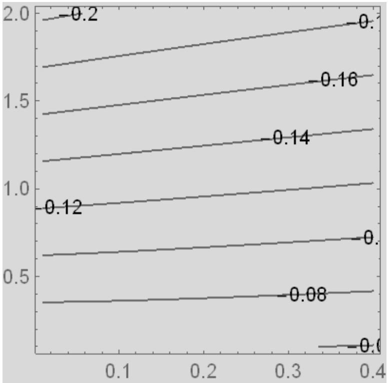


Figure 6: $\boldsymbol{D}w_{120}^{*} = [w_{10r1}^{*} - w_{20r1}^{*}] \geq or < 0$

Proof of Proposition 2:

(i) To check for the validity of the sign configurations of the, first and second period-, public-private output differentials, under *frr*2, $\boldsymbol{D}q_{120}^{*} = [q_{10r2}^{*} - q_{20r2}^{*}] < 0$ and $\boldsymbol{D}q_{121}^{*} = [q_{11r2}^{*} - q_{21r2}^{*}] < 0$, we have performed numerous successful tests over the prescribed grid of our parameter space, e.g., for $\{c, v\}$ such that all our endogenous variables to retain positive values (no corner solutions) in the equilibrium. *Figure 7* and *Figure 8* respectively illustrate the iso-contours $v(c)$ of $\boldsymbol{D}q_{120}^{*}$, $\boldsymbol{D}q_{121}^{*}$, for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.



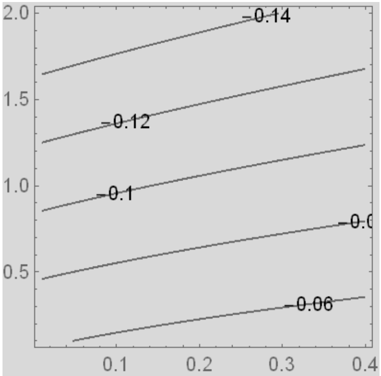
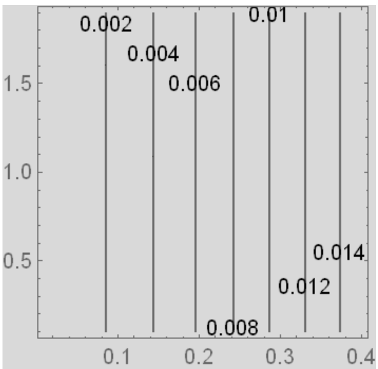


Figure 7: $\boldsymbol{D}q^*_{120} = [q^*_{10r2} - q^*_{20r2}] < 0$ *Figure 8*: $\boldsymbol{D}q^*_{121} = [q^*_{11r2} - q^*_{21r2}] < 0$

To check for the validity of the sign configurations of the public (the private) firm's total output differential, across the – *frr₁* and *frr₂* – alternative regimes, $\boldsymbol{D}\Sigma q^*_{2r12} = [\{q^*_{20r1} + q^*_{21r1}\} - \{q^*_{20r2} + q^*_{21r2}\}] > 0$ ($\boldsymbol{D}\Sigma q^*_{1r12} = [\{q^*_{10r1} + q^*_{11r1}\} - \{q^*_{10r2} + q^*_{11r2}\}] < 0$), we have performed numerous successful tests over the prescribed grid of our parameter space, e.g., for $\{c, v\}$ such that all our endogenous variables to retain positive values (no corner solutions) in the equilibrium. *Figure 9* (*Figure 10)* illustrates the iso-contours $v(c)$ of $\boldsymbol{D}\Sigma q^*_{2r12}$ ($\boldsymbol{D}\Sigma q^*_{1r12}$), for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.



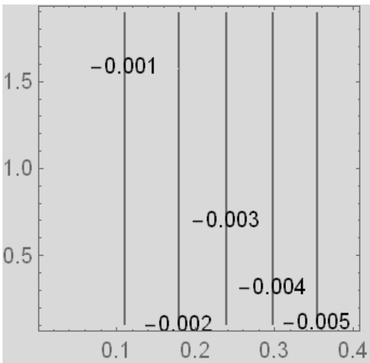


Figure 9: $\boldsymbol{D}\Sigma q^*_{2r12} > 0$ *Figure 10:* $\boldsymbol{D}\Sigma q^*_{1r12} < 0$

To check for the validity of the sign configuration of the total output differential, across the – *frr₁* and *frr₂* – alternative regimes, $\boldsymbol{D}\Sigma q^*_{1r12} + \boldsymbol{D}\Sigma q^*_{2r12} > 0$, we have performed numerous successful tests over the prescribed grid of our parameter space, e.g., for $\{c, v\}$ such that all our endogenous variables to retain positive values (no corner solutions) in the equilibrium. *Figure 11* illustrates the iso-contours $v(c)$ of $\boldsymbol{D}\Sigma q^*_{2r12}$ ($\boldsymbol{D}\Sigma q^*_{1r12}$), for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.

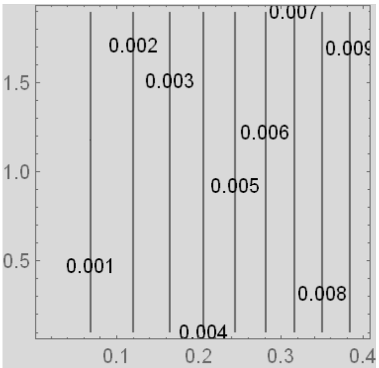


Figure 11: $\boldsymbol{D}\Sigma q^*_{1r12} + \boldsymbol{D}\Sigma q^*_{2r12} > 0$

(ii) To check for the validity of the sign configurations of the, first and second period-, public-private wage differentials, under *frr₂*, $\boldsymbol{D}w^*_{120} = [w^*_{10r2} - w^*_{20r2}] < 0$ and $\boldsymbol{D}w^*_{121} = [w^*_{11r2} - w^*_{21r2}] < 0$, we have performed numerous successful tests over the prescribed grid of our parameter space, e.g., for $\{c, v\}$ such that all our endogenous variables to retain positive values (no corner solutions) in the equilibrium. *Figure 12* and *Figure 13* respectively illustrate the iso-contours $v(c)$ of $\boldsymbol{D}w^*_{120}$, $\boldsymbol{D}w^*_{121}$, for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.

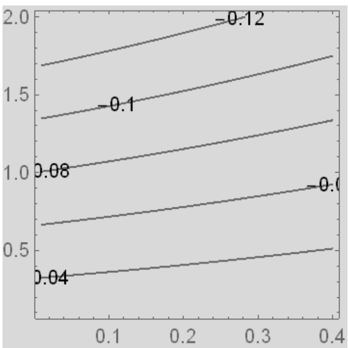


Figure 12 : $\boldsymbol{D}w^*_{120} < 0$

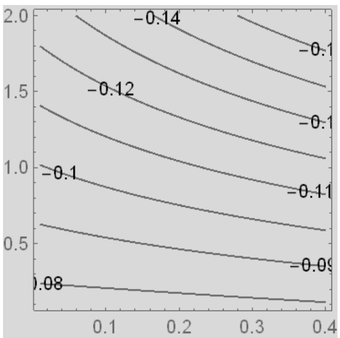


Figure 13: $\boldsymbol{D}w^*_{121} < 0$

To check for the validity of the sign configuration of the public (the private) firm's total wage differential, across the – *frr₁* and *frr₂* – alternative regimes, $\boldsymbol{D}\Sigma w^*_{2r12} = [\{w^*_{20r1} + w^*_{21r1}\} - \{w^*_{20r2} + w^*_{21r2}\}] < 0$, ($\boldsymbol{D}\Sigma w^*_{1r12} = [\{w^*_{10r1} + w^*_{11r1}\} -$

$\{w_{10r2}^* + w_{11r2}^*\}] < 0)$ we have performed numerous successful tests over the prescribed grid of our parameter space, e.g., for $\{c, v\}$ such that all our endogenous variables to retain positive values (no corner solutions) in the equilibrium. *Figure 14 (Figure 15)* illustrates the iso-contours $v(c)$ of $\boldsymbol{D}\Sigma w_{2r12}^*$ $(\boldsymbol{D}\Sigma w_{1r12}^*)$ for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.

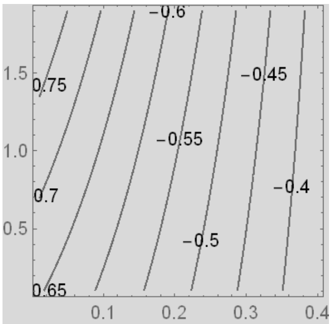


Figure 14: $\boldsymbol{D}\Sigma w_{2r12}^* < 0$

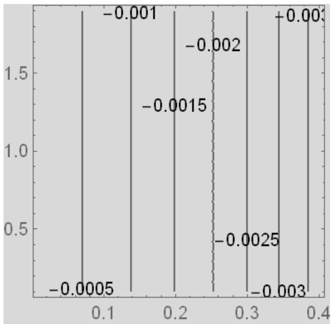


Figure 15: $\boldsymbol{D}\Sigma w_{1r12}^* < 0$

Proof of Proposition 3:

(i) To check for the sign configuration of the private - public profit differential over the business cycle, $\boldsymbol{D}\Pi_{12}^* = [\Pi_{1r1}^* - \Pi_{2r1}^*]$, define $v(c)$ as the value of v for a given $c \in [0.01,1]$ such that $\boldsymbol{D}\Pi_{12}^*\big(c, v(c)\big) = 0$. For a given $c \in [0.01,1]$, $\boldsymbol{D}\Pi_{12}^*(v, c)$ is decreasing with v; and for a fixed v, $\boldsymbol{D}\Pi_{12}^*(v, c)$ is either increasing or decreasing with c. Therefore, $c(v) = v(c)^{-1}$, with $\frac{dv}{dc} < 0 \; or \; \frac{dv}{dc} > 0$ for $c \in [0.01,1]$. Moreover, provided that $0.02 < c \leq 0.7$, $lim_{v \to 0.1} \boldsymbol{D}\Pi_{12}^*(v, c) > 0$ and $lim_{v \to \bar{v}(\cong 0.5)} \boldsymbol{D}\Pi_{12}^*(v, c) \leq 0$. Hence, $\boldsymbol{D}\Pi_{12}^*(v, c) \leq 0$ if $v \geq v(c)$, and $\boldsymbol{D}\Pi_{12}^*(v, c) > 0$ if $v < v(c)$. (See *Figure 16* for illustration)

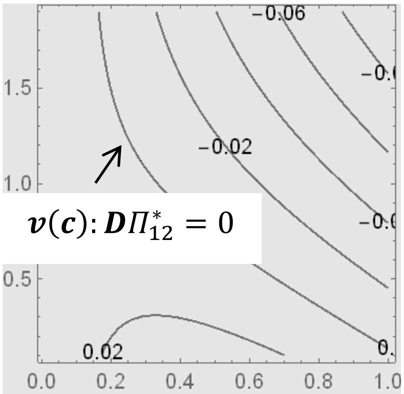


Figure 16: $\boldsymbol{D}\Pi^*_{12} = [\Pi^*_{1r1} - \Pi^*_{2r1}] \leq 0 \ or > 0$

Regarding the validity of the sign configuration of the public - private union welfare differential, $\boldsymbol{D}U^*_{12} = [U^*_{1r1} - U^*_{2r1}] < 0$, all our performed tests over the prescribed $\{c, v\}$ grid have been successful. *Figure 17* illustrates the iso-contours $v(c)$ of $\boldsymbol{D}w^*_{120}$, $\boldsymbol{D}w^*_{121}$, for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.

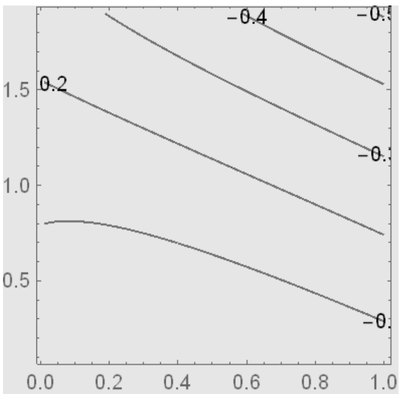
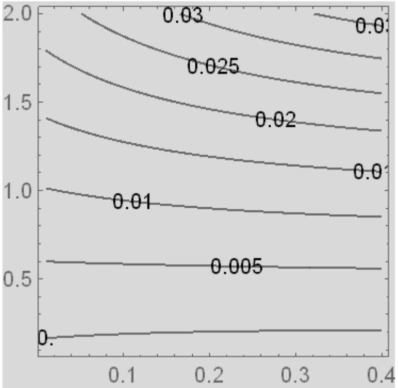


Figure 17: $\boldsymbol{D}U^*_{12} = [U^*_{1r1} - U^*_{2r1}] < 0$

(ii) Regarding the validity of the sign configuration(s) of the public-private profit differential, $\boldsymbol{D}\Pi_{12r2} = [\Pi^*_{1r2} - \Pi^*_{2r2}] > 0$, and public-private union's welfare differential, $\boldsymbol{D}U_{12r2} = [U^*_{1r2} - U^*_{2r2}] < 0$, all our performed tests over the prescribed $\{c, v\}$ grid have been successful. *Figures 18* and *19* respectively illustrate the iso-contours $v(c)$ of $\boldsymbol{D}\Pi_{12r2}$, $\boldsymbol{D}U_{12r2}$, for $c \in [0.01, 1]$ and $v \in [0.1, 1.9]$.



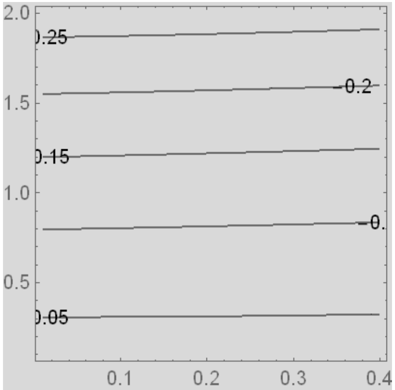
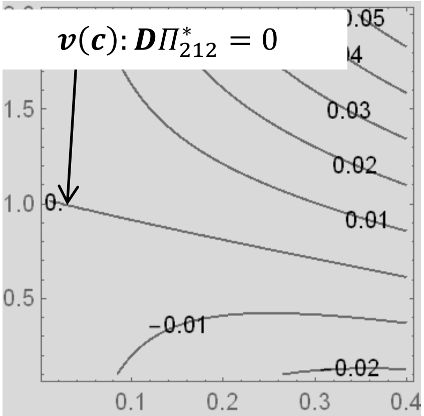


Figure 18: $\boldsymbol{D}\Pi_{12r2} = [\Pi^*_{1r2} - \Pi^*_{2r2}] > 0$ *Figure 19*: $\boldsymbol{D}U_{12r2} = [U^*_{1r2} - U^*_{2r2}] < 0$

To check for the sign configuration of the public (private) firm's profit differential, across the alternative regimes, $\boldsymbol{D}\Pi^*_{212} = [\Pi^*_{2r1} - \Pi^*_{2r2}]$ ($\boldsymbol{D}\Pi^*_{112} = [\Pi^*_{1r1} - \Pi^*_{1r2}]$) define $v(c)$ as the value of v for a given $c \in [0.01,1]$ such that $\boldsymbol{D}\Pi^*_{i12}(c, v(c)) = 0$. For a given $c \in [0.01,1]$, $\boldsymbol{D}\Pi^*_{212}(v,c)$ ($\boldsymbol{D}\Pi^*_{112}(v,c)$) is increasing (decreasing) with v; whilst for a fixed v, $\boldsymbol{D}\Pi^*_{212}(v,c)$ ($\boldsymbol{D}\Pi^*_{112}(v,c)$) may either decrease (increase) or increase (decrease) with c. Therefore, $c(v) = v(c)^{-1}$, with $\frac{dv}{dc} < 0 \; or \; \frac{dv}{dc} > 0$ for $c \in [0.01,1]$. Moreover, $lim_{v\to 0.1}\boldsymbol{D}\Pi^*_{212}(v,c) < 0$ ($\boldsymbol{D}\Pi^*_{112}(v,c) > 0$) and $lim_{v\to\bar{v}(\cong 0.6)}\,\boldsymbol{D}\Pi^*_{212}(v,c) \geq 0$ ($lim_{v\to\bar{v}(\cong 1)}\boldsymbol{D}\Pi^*_{112}(v,c) \leq 0$). Hence, $\boldsymbol{D}\Pi^*_{212}(v,c) \geq 0$ ($\boldsymbol{D}\Pi^*_{112}(v,c) \leq 0$) if $v \geq v(c)$ and $\boldsymbol{D}\Pi^*_{212}(v,c) < 0$ ($\boldsymbol{D}\Pi^*_{112}(v,c) > 0$) if $v < v(c)$. [See *Figure 20* (*Figure 21*) for illustration]



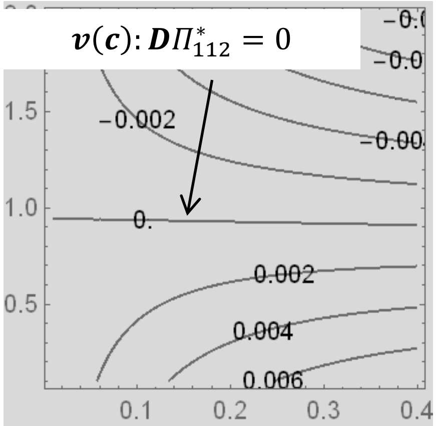


Figure 20:

$\boldsymbol{D}\Pi^*_{212} = [\Pi^*_{2r1} - \Pi^*_{2r2}] \geq 0 \ or < 0$

Figure 21:

$\boldsymbol{D}\Pi^*_{112} = [\Pi^*_{1r1} - \Pi^*_{1r2}] \leq 0 \ or > 0$

To check for the sign configuration of the public (private) union's welfare, across the alternative regimes, $\boldsymbol{D}U^*_{212} = [U^*_{2r1} - U^*_{2r2}]$ ($\boldsymbol{D}\Pi^*_{112} = [U^*_{1r1} - U^*_{1r2}]$) define $v(c)$ as the value of v for a given $c \in [0.01,1]$ such that $\boldsymbol{D}U^*_{i12}(c, v(c)) = 0$. For a given $c \in [0.01,1]$, $\boldsymbol{D}U^*_{212}(v,c)$ ($\boldsymbol{D}U^*_{112}(v,c)$) is increasing (decreasing) with v; whilst for a fixed v, $\boldsymbol{D}U^*_{212}(v,c)$ ($\boldsymbol{D}U^*_{112}(v,c)$) either decreases (increases) or increases (decreases) with c. Therefore, $c(v) = v(c)^{-1}$, with $\frac{dv}{dc} < 0 \ or \ \frac{dv}{dc} > 0$ for $c \in [0.01,1]$. Moreover, $lim_{v\to 0.1}\boldsymbol{D}U^*_{212}(v,c) < 0$ ($\boldsymbol{D}U^*_{112}(v,c) > 0$) and $lim_{v\to\bar{v}(\cong 0.4)}\ \boldsymbol{D}U^*_{212}(v,c) \geq 0$ ($lim_{v\to\bar{v}(\cong 0.9)}\boldsymbol{D}U^*_{112}(v,c) \leq 0$). Hence, $\boldsymbol{D}U^*_{212}(v,c) \geq 0$ ($\boldsymbol{D}U^*_{112}(v,c) \leq 0$) if $v \geq v(c)$ and $\boldsymbol{D}U^*_{212}(v,c) < 0$ ($\boldsymbol{D}U^*_{112}(v,c) > 0$) if $v < v(c)$. [See *Figure 22* (*Figure 23*) for illustration]

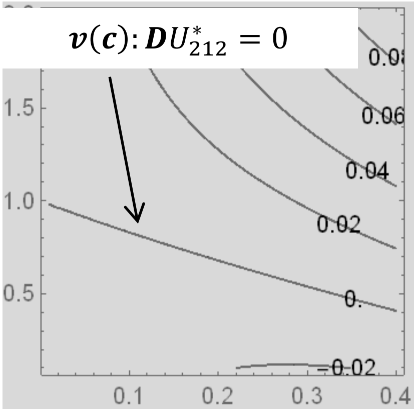


Figure 22:

$\boldsymbol{D}U^*_{212} = [U^*_{2r1} - U^*_{2r2}] < 0 \ or \geq 0$

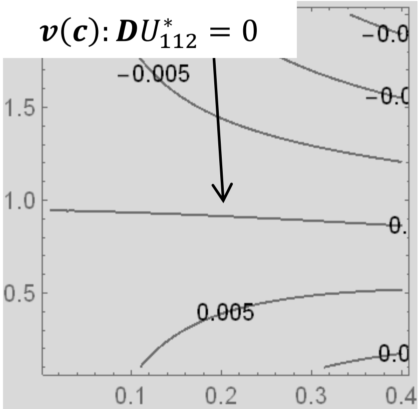


Figure 23:

$\boldsymbol{D}U^*_{112} = [U^*_{1r1} - U^*_{1r2}] < 0 \ or \geq 0$

(iii) To check for the sign configuration of the *Ev* function - differential across the alternative regimes, $\boldsymbol{D}Ev^*_{12} = [Ev^*_1 - Ev^*_2]$**,** define $v(c)$ as the value of v for a given $c \in [0.01,1]$ such that $\boldsymbol{D}Ev^*_{12}(c, v(c)) = 0$. For a given $c \in [0.01,1]$, $\boldsymbol{D}Ev^*_{12}(v,c)$ is increasing with v; and for a fixed *v*, $\boldsymbol{D}Ev^*_{12}(v,c)$ is either increasing or decreasing with c. Therefore, $c(v) = v(c)^{-1}$, with $\frac{dv}{dc} < 0 \ or \ \frac{dv}{dc} > 0$ for $c \in [0.01,1]$. Moreover, $lim_{v \to 0.1}\boldsymbol{D}Ev^*_{12}(v,c) < 0$ and $lim_{v \to \bar{v}(\cong 0.025)} \boldsymbol{D}Ev^*_{12}(v,c) \geq 0$. Hence, $\boldsymbol{D}Ev^*_{12}(v,c) \geq 0$ if $v \geq v(c)$, and $\boldsymbol{D}Ev^*_{12}(v,c) < 0$ if $v < v(c)$. (See *Figure 24* for illustration)

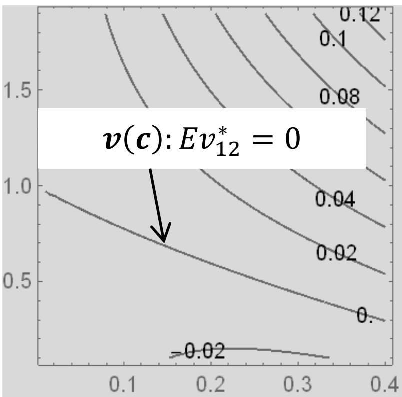


Figure 24: $\boldsymbol{D}Ev^*_{12} = [Ev^*_1 - Ev^*_2] \geq 0 \ or < 0$

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