LABOUR-SAVING INNOVATION : UNION ATTITUDES UNDER OLIGOPOLISTIC COMPETITION

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ABSTRACT

The response of union utility to labour-saving innovation is analyzed within a framework of oligopolistic competition in the product market, taking account of wage bargaining under several alternative structures of industrial relations. Conditions are established under which either wages or employment will rise or fall in response to innovation. Union opposition tends to occur when labour demand is inelastic and union preferences are weighted in favour of jobs. Centralisation of bargaining from firm to industry level is likely to engender union resistance to (or support for) innovation if products are strategic substitutes (or complements).

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1. Introduction

Labour opposition to technological change goes back at least as far as the early days of the British industrial revolution which provoked the Luddite machine-breaking of 1800 and 1812. More modern manifestations have been observed in the Fleet Street print unions' mass pickets directed against the introduction of electronic typesetting in London and tram operators blocking the streets of Melbourne in protest against the introduction of single-operator trams. Accounts of labour resistance to major innovations are frequently publicised in the media, leading to a popular perception of unions as the modern luddites.

In contrast, it is common in the industrial relations literature to argue that union cooperation may actually lower the costs of implementation[1]. Such union cooperation has been documented by, for example, David Simpson el al. (1987) who report "On several occasions we found that shop stewards had actively assisted in the deployment of new technology" (p.58). Union assistance or resistance may particularly affect the costs of implementation when innovation involves a series of small changes to working procedures and practices and when monitoring and enforcement costs are high. Paul Willman (1986, p.44) cites evidence from cross-national studies that union attitudes affect the rate of diffusion of new technology.

This paper examines the attitudes of unions faced with a labour-saving innovation. Innovation of this type provides an obvious potential threat to employment and we focus on employment and wage effects. These are two of the three major concerns identified by Simpson et al. (1987, pp 60-61) in their survey of union attitudes to new technology. Other concerns may be related to working conditions, the pace of work, the degree of job control and autonomy or even a fear of 'the new'.

We provide a broad treatment of costs, demand and the wage determination process. For much of the paper, the only restriction on a union's utility is that it be increasing in the wage and in employment. We start with the assumption (empirically relevant in some cases) that the given wage levels are independent of technical change. In the subsequent analysis, the wage is determined endogenously through Nash bargaining between each firm and its union. This second model encompasses the extreme case, sometimes referred to as the 'monopoly union' model, where the union can set the wage. Some attention is given to the possibility that there is only one unionised firm in the industry. This situation could occur if the firms are located in different countries or if a non-unionised firm has recently entered a market previously controlled by a unionised monopoly firm. The paper also features a rather general treatment of the imperfectly competitive market for final products. Both Cournot and Bertrand equilibria with differentiated products and general numbers of firms are encompassed as well as simple monopoly behaviour. For most of the paper, we allow for general demand conditions and for more than one factor of production.

An important preliminary result is that a labour-saving innovation will reduce employment if labour demand is inelastic and wages are exogenous. In these circumstances, unions will oppose innovation. However, when unions bargain over wages, they commonly win some compensation for job losses. They tend not to oppose innovation unless the union places a particularly high value on employment, perhaps reflecting members' aversion to risk.

In many countries where trade unionism is prevalent, it is an important issue as to how much trade unions should be able to influence wage outcomes and whether wage bargaining should take place at the firm level or whether it should be managed more centrally. Some of these issues have been analyzed in relation to macroeconomic wage flexibility by Lars Calmfors and John Driffil (1988) and others. We extend this analysis to the area of technological progress and economic growth by considering the attitude of both industry-wide and enterprise level unions towards innovation. If products are strategic substitutes and wages are fixed, a union operating on an industry-wide basis will face a less elastic demand for labour and view innovation less favourably than an enterprise level union. However, when products are strategic substitutes, we also demonstrate that an industry-wide union will win a higher wage settlement under Nash wage bargaining than would separate enterprise level unions. This enhanced ability to raise the wage tends to make the industry-wide union view innovation more favourably. We nevertheless are able to show that in a linear Cournot example, the industry-wide union is indeed more likely to oppose a labour-saving innovation.

Although we do not analyse explicitly the innovation decision of firms, we do examine the conditions under which the bargained wage will rise or fall in response to innovation. We find no general presumption that union wage bargaining must lower returns to innovation. This finding mirrors the ambiguous conlcusions of the literature concerned with the impact of union rent- seeking behaviour on firms' incentives to invest. Grout (1984), for instance, finds that unions discourage investment when bargaining covers both wages and employment and the union is unable to pre-commit itself to future bargaining outcomes (or to sell membership rights). The union effect on investment incentives can, however, be positive as in Tauman and Weiss (1987), where the higher cost of union labour can induce labour-saving innovation, or in Anderson and Devereux (1988) where strategic pre-commitment to a higher capital stock can lower the subsequently determined union wage. In Ulph and Ulph (1988) the presence of a strong union can help a firm to win a patent race.

These previous analyses have focused almost exclusively on post-innovation labour costs[2], whereas we focus on the union attitude towards innovation during the planning and implementation stage. As suggested in the industrial relations literature, union attitudes at this stage may have significant implications for the costs of implementation. Accordingly our analysis should be regarded as complementary to the analyses of post-innovation outcomes inasmuch as together they will determine the impact of unions on firms incentives to innovate. This analysis may help to explain the diversity of econometric results concerning the net effect of unions on the rate of innovation.[3]

The model structure is set out in Section 2. Section 3 concerns the product market and labour demand. In Section 4, we set out the framework for analyzing the attitudes of unions towards innovation. Sections 5 to 8 analyze the cases of exogenous wages, the wage-setting union, enterprise wage bargaining and industry wage bargaining respectively. Further results are obtained in Section 9 by the use of an illustrative example based on Cournot competition and linear demand. Finally, Section 10 contains our concluding remarks.

2. Model Structure and the Sequence of Decisions

The source of the labour-saving technological improvement is taken as exogenous to the model. In a broader setting, firms themselves might invest in the development of new technology or may purchase patent right from other firms. We mostly present the analysis as if technology is firm specific. Each firm could hold the patent rights to its own technology or the technological improvement itself may apply only to the product produced by a particular firm. We also consider the possibility that the technological improvement is available industry-wide. However, this distinction is not important for the results, basically because it does not change individual decision making by enterprise level unions at the stage 1, Nash equilibrium in technology. Whilst we do not explicitly analyze the costs of innovation, our motivating assumption is that union opposition increases implementation costs and makes it less likely that the firm will choose to innovate.

The model of firm and union behaviour incorporates three stages of decision. Decisions are taken at each stage anticipating the outcome of subsequent stages. We first describe the game between firms and enterprise level unions.

<u>Stage 1</u>: Each union determines its attitude towards implementation of a labour-saving innovation that would improve labour efficiency within the firm. In making this assessment, each enterprise level union takes the technology of other firms as given.

<u>Stage 2</u>: Wages may be fixed, or determined endogenously by Nash wage bargaining between a firm and its union, taking own and other firm's technology as given. If more than one firm is unionised, wage bargaining takes place simultaneously across firms with each firm and its union taking the wages in other firms as given. There is a non-cooperative Nash equilibrium in wage bargaining across firms. If a firm is not unionised, we assume that workers receive their opportunity wage.

<u>Stage 3</u>: Each firm decides on its level of output and optimal factor inputs given the technology and factor prices as determined in the prior stages. Firms play a non-cooperative oligopolistic game (which could be Cournot or Bertrand) in the output market.

In stage 1, the game with an industry-wide union is similar except that the union considers its attitude to the simultaneous adoption of new technology in all the firms that have access to the new technology. The nature of the stage 2 wage bargaining is presented in Section 8. An important difference is that in determining its attitude to the new technology and in wage bargaining, an industry-wide union takes into account the utility of all its members, not just those in an individual firm.

We suggest that our assumed sequence is of considerable, if not universal, empirical relevance. The assumption that the decision on innovation precedes wage determination reflects the idea that a firm and its union will often be unable to credibly commit to future wages when new production processes are introduced; this corresponds to Ulph and Ulph's (1990) notion of ex-post rather than ex-ante bargaining. The assumption that wage bargaining precedes the determination of output and employment[4] reflects a common observation that wage contracts are fixed in the short-term and evidence, eg Oswald (1985), that employers do not typically make explicit deals with unions over jobs.

3. Product Market Equilibrium and the Demand for Labour

Product market

We consider changes in technology that augment a firm's labour input. More specifically, we define a firm specific technology parameter θ^i, that augments firm i's actual labour input, denoted by L^i, to produce $\ell^i = \theta^i L^i$ units of effective labour input. An improvement in the labour-saving technology applicable to firm i is modelled by a small increase in θ^i. In practice, implementation of technology may often involve a fixed cost independent of the extent of the technical change. Adding in a fixed cost would have the obvious effect of raising the gross profit threshold required for technical change to be worthwhile for the firm. In a broader dynamic model in which technical improvements take place over time, a fixed cost that is independent of the extent of the improvement in technology would tend to make the implementation of changes take place in discrete jumps once a significant body of knowledge had been accumulated. We do not directly consider the effect of a large discrete change in technology, but the analysis could be extended to this case by integrating over a sequence of small changes in θ^i.

The price of effective labour (the 'effective wage') in firm i is denoted by $\omega^i = w^i/\theta^i$ where w^i represents the actual wage. Cost-minimizing choice of inputs, given the technology θ^i, then defines the total cost of firm i as a function of output y^i and the effective wage: $C^i = C^i(y^i, \omega^i)$. For convenience, we omit the prices of other factors of production as explicit arguments. Unless otherwise specified, we allow factor prices to differ across firms. This captures the idea that factor markets may be geographically separated (the firms may be located in different countries) or there may be firm-specific union effects on the wage.

Recognizing that its price depends on the output of all the other firms, firm i's total revenue (price times output) is $R^i(y^1,y^2,..y^n)$, where n is the number of firms in the industry. Products may be differentiated across firms or homogeneous. If competition is of the Bertrand type, we assume that products are differentiated (otherwise both firm and union rents will be reduced to zero). In stage 3, each firm chooses its decision variable (price if Bertrand, output if Cournot) to maximize its own profit. Assuming that the second order and uniqueness conditions hold, the first order conditions for profit maximization define the equilibrium levels of output of each firm as a function of its own effective wage and the effective wages of all the other firms in the industry: $y^i = y^i(\omega^1,\omega^2,..\omega^n)$. At these equilibrium output levels, the third stage equilibrium profit of firm i is

$$\pi^i(\omega^1,\omega^2,..\omega^n) = R^i(y^1, y^2,..y^n) - C^i(y^i, \omega^i). \tag{3.1}$$

We assume that firm i's output and profit is decreasing in own marginal cost. Also, firm i's profit is increased by an increase in the marginal cost of a rival firm (subscripts denote partial derivatives).

$$\partial y^i/\partial\omega^i \equiv y^i_i < 0,\ \pi^i_{\omega i} < 0 \text{ and } \pi^i_{\omega j} > 0 \text{ for all } j \neq i. \tag{3.2}$$

These relationships commonly hold under both Cournot and Bertrand competition but do impose some restrictions on the equilibrium in addition to the usual requirements for uniqueness and stability[5]

The cross-partial derivatives $\partial y^i/\partial\omega^j \equiv y^i_j$ where $j \neq i$ may take either sign. Letting dy^i/dy^j represent the total effect of an increase in y^j on y^i allowing the outputs of all firms to vary, we can write

$$y^i_j = (dy^i/dy^j)y^j_j. \tag{3.3}$$

That is to say, an increase in the rival's effective cost of labour affects own output through its effect in reducing the rival's output. If own output is increased by a reduction in the rival's output, then $y^i_j > 0$ and under Cournot competition, the products are referred to as strategic substitutes. For convenience we refer generally to "strategic substitutes" whenever $y^i_j > 0$, and to "strategic complements" when $y^i_j < 0$. If firms behave as Bertrand competitors, products are commonly strategic complements in price space. This does not, however, imply that they are strategic complements in output space (the sense in which we are using the term). If one firm reduces its price and expands its output as a consequence of the introduction of a labour-saving innovation, other firms will respond by reducing their prices (if the products are strategic complements in price space), but their outputs do not necessarily rise. In particular, when demand is linear, both Bertrand and Cournot firms view the products as strategic substitutes in output space[6].

Labour Demand

To derive the demand for labour, we first specify the firm's production function $y^i = f^i(\ell^i, K^i)$ where K^i represents some other input which we label capital. Assuming that the production function is homogeneous of degree λ^i, we can write $y^i = (\ell^i)^{\lambda i} f^i(1,k^i)$ where $k^i = K^i/\ell^i$, the capital to effective labour ratio, depends only on the effective factor price ratio ω^i/ρ^i. Setting output at its third stage equilibrium level, we obtain the demand for effective labour in firm i as a function of the effective wage in each firm:

$$\ell^i = [y^i/h(k^i)]^{1/\lambda i} \equiv \ell^i(\omega^1, \omega^2, .. \omega^n) \tag{3.4}$$

where $h^i(k) \equiv f^i(1,k^i)$ and the arguments in ρ^i are again omitted. It is easily shown[7] that the firm demands fewer effective labour units as its own effective wage rises, both because it substitutes away from labour by increasing its capital usage per unit of output and because its equilibrium level of output falls. The sign of cross-price effects depends on whether the products are strategic substitutes or complements:

$$\ell^i_{\omega i} < 0 \text{ and sign } \ell^i_{\omega j} = \text{sign } y^i_j. \tag{3.5}$$

Since $L^i = \ell^i/\theta^i$, the demand for actual workers, can be expressed as a function of the actual own wage w^i, own technology as represented by θ^i and the vector $\underline{\omega}^j$ of effective wages in the other n-1 firms:

$$L^i(w^i, \theta^i, \underline{\omega}^j) = \ell^i(\omega^1, \omega^2, .. \omega^n)/\theta^i. \tag{3.6}$$

From (3.5) and (3.6), an increase in the own wage always reduces the firm's demand for workers, whereas an increase in a rival's effective wage again has an ambiguous effect depending on whether the products are strategic substitutes or complements:

$$L^i_{wi} = \ell^i_{\omega i}/[\theta^i]^2 < 0 \text{ and } L^i_{\omega j} = \ell^i_{\omega j}/\theta^i. \tag{3.7}$$

Letting $\eta \equiv - wL^i_{wi}/L^i$ denote the positive value of the elasticity of labour demand with respect to own wage, it follows from (3.6) and (3.7) that η is equal to the corresponding elasticity of effective labour demand with respect to own effective wage and thus can be written as a function of effective wage levels:

$$\eta \equiv - wL^i_{wi}/L^i = - \omega^i \ell^i_{\omega i}/\ell^i = \eta(\omega^i, \underline{\omega}^j). \tag{3.8}$$

In considering union attitude towards technological change, an obvious first step is to determine the effect of the technological change on the demand for the services of union members. In this connection, a small labour-saving innovation has two opposing effects. It reduces the effective wage which tends to increase the firm's demand for effective labour, but since the efficiency of each worker rises, the overall effect on the demand for workers is ambiguous. As we show in Proposition 1, whether labour demand rises or falls depends critically on the elasticity η.

<u>Proposition 1</u>: Labour demand increases (decreases) in response to a labour-saving innovation if the own-wage response of labour demand is elastic (inelastic).

<u>Proof</u>: From (3.6), (3.7) and (3.8),

$$L^i_{\theta i} \;=\; - [\omega^i \ell^i_{\omega i} + \ell^i]/[\theta^i]^2 = [L^i/\theta^i][\eta - 1] \tag{3.9}$$

***

Proposition 1 tells us that an own wage elasticity of unity provides the dividing line between a positive or negative response of labour demand to the innovation. If the own wage elasticity is unity, a small proportionate reduction in the effective price of labour gives rise to the same proportionate increase in the firm's demand for effective labour. In this case, the increased demand for effective labour (brought about by a labour-saving innovation) can just be met by employing the existing workers, who are now more efficient[8].

The effect of innovation on the demand for labour is particularly easy to analyze in the special case where demand is linear in the wage, since the elasticity of a straight line is greater than unity above the mid-point and less than unity below the mid-point. Applying Proposition 1, it is evident that a labour-saving innovation causes a clockwise rotation around the mid-point of the labour demand curve. In this special case, it can be seen that labour-saving innovation makes the labour demand curve steeper, that is to say it has the effect of reducing the own wage elasticity of labour demand. Indeed, this result is generally true as long as the labour demand elasticity is increasing in the wage. Such innovation-induced changes in the elasticity of labour demand will be seen to have an important influence on stage two wage bargaining.

4. Union Attitudes to Innovation

We use a very general formulation for union utility, assuming it to be simply an increasing function of both wages and employment above a reservation wage, v^i:

$$V^i = V(w^i,L^i); \qquad V_w>0, V_L>0 \text{ if } w^i>v^i;\ V^i = 0 \text{ if } w^i \leq v^i \tag{4.1}$$

This general form incorporates both the "expected utility" union utility function and the Stone-Geary utility function as discussed in Oswald (1985). These restricted functional forms, which are required for some of our later results, are $V^i = L^i[u(w^i)-u(v^i)]$ and $V^i = L^i(w^i-v^i)^\gamma$ respectively. We denote the utility of an industry-wide union by $V^I \equiv \sum_i V^i$.

The willingness of a union to trade off jobs for a higher wage is measured by the elasticity of the union's indifference curve, denoted by $\phi \equiv -(w/L)(dL/dw)\|_V$. We drop the superscript i here and elsewhere where there is no ambiguity. It proves useful to relate the union's elasticity of substitution ϕ to the (partial) elasticities of union utility with respect to employment and the wage:

$$\phi(w,L) = wV_w/LV_L = \varepsilon^V_w/\varepsilon^V_L \tag{4.2}$$

where $\varepsilon^V_L \equiv (L/V)V_L$ and $\varepsilon^V_w \equiv (w/V)V_w$. Taking into account the response of labour demand, we then obtain the effect on union utility of an increase in the own wage, holding other wages constant:

$$dV^i/dw^i \,\|_{\omega j} = V^i_{wi} + V^i_{Li}L^i_{wi} = \varepsilon^{Vi}_{Li}(V^i/w^i)[\phi - \eta]. \tag{4.3}$$

This implies that union utility is increasing in the own wage if and only if the union's willingness to trade off jobs for a higher wage, as measured by ϕ, exceeds the actual rate of trade-off as measured by η, the own wage elasticity of labour demand.

We are interested in the attitude of the union to technological innovation at Stage 1 of the decision process. The union anticipates that the innovation may affect both the wage and labour demand. We analyze particular wage-setting mechanisms in some detail later, for the moment though we write the Stage 2 wage decision in its most general form as a function of the own firm technology decision and the vector of effective wages $\underline{\omega}^j$ in other firms:

$$w^i = w^i(\theta^i, \underline{\omega}^j) \qquad i = 1...n, \; j \neq i \tag{4.4}$$

where the effective wage $\omega^j = w^j/\theta^j$. The Nash equilibrium in wage determination is the solution to these n wage reaction functions. Substituting the labour demand function (3.6) and the wage reaction function (4.4) into the union utility function, the total effect of an increase in θ^i on union utility is

$$dV^i/d\theta^i = (dV^i/dw^i)(dw^i/d\theta^i) + V^i_{Li}L^i_{\theta i} + \textstyle\sum_j V^i_{Li}L^i_{\omega j}(d\omega^j/d\theta^i), \; j \neq i \tag{4.5}$$

The first term in (4.5) captures the direct wage effect of innovation; the second term captures the direct employment effect; the third term captures the indirect employment effect, acting through wage effects in other firms and the cross-price elasticities of labour demand.

Using the notation $\varepsilon^x_y \equiv (x_y)(y/x)$ to represent the partial elasticity of x(y,..) with respect to y and $E^x_y \equiv (dx/dy)(y/x)$ to represent the total elasticity, the union gain from innovation as represented by (4.5) can be rearranged into two highly useful forms. To derive these expressions, we first relate the total elasticity of the effective wage with respect to innovation to the corresponding elasticity of the actual wage: totally differentiating $\omega^i = w^i/\theta^i$ with respect to θ^i, it follows that

$$E^{\omega i}_{\theta i} \equiv (\omega^i/\theta^i)(d\omega^i/d\theta^i) = E^{wi}_{\theta i} - 1 \tag{4.6}$$

Substituting (3.9) and (4.3) into (4.5), we obtain (4.7a); then using (4.6) in (4.7a) we obtain (4.7b):

$$dV^i/d\theta^i = (V^i/\theta^i)\varepsilon^{Vi}_{Li}\{(\phi-\eta)E^{wi}_{\theta i} + \eta - 1 + \textstyle\sum_j \varepsilon^{Li}_{\omega j} E^{\omega j}_{\theta i}\} \tag{4.7a}$$

or

$$dV^i/d\theta^i = (V^i/\theta^i)\varepsilon^{Vi}_{Li}\{(\phi-\eta)E^{\omega i}_{\theta i} + \phi - 1 + \textstyle\sum_j \varepsilon^{Li}_{\omega j} E^{\omega j}_{\theta i}\}. \tag{4.7b}$$

Since ε^{Vi}_{Li} is positive, the union will gain as a result of a marginal increase in innovation if and only if the expressions in the curly brackets are positive.

The signs of the expressions (4.7) depend on wage setting behaviour. In subsequent sections we will examine three wage setting mechanisms: (1) the wage is determined exogenously; (2) the wage is set by the union; (3) the wage is determined by Nash bargaining between the union and the employer. Within the third category, we consider four further cases: (i) workers in just one firm are unionised or (ii) there are n independent enterprise unions; or else an industry-wide union represents all workers in the industry and bargains either (iii) with each firm individually or (iv) with a central employer body.

5. Exogenous wages

There are a number of situations in which unions and firms will consider industry wages to be independent of technological decisions. One example might occur where efficiency wage criteria are dominant in the wage determination process. The efficiency wage is independent of the technology parameter θ if the quantity of effective labour can be written as $\ell \equiv \Gamma(w)\theta L$ where $\Gamma(w)$ is the 'labour efficiency' function[9]. As in Stiglitz (1987), the wage is set where the elasticity of the efficiency wage function, $w\Gamma'(w)/\Gamma(w)$, is unity. Government regulation of wages according to non-market criteria provides a further situation in which industry wages might be independent of technological innovation.

If a labour-saving innovation does not change the actual wage, the union attitude depends only on the impact of the innovation on employment (we ignore the trivial case where the union wage is set at the reservation wage). As we know from Proposition 1, this employment response depends critically on the elasticity of demand for labour.

Proposition 2: *If the wage is unaffected by technological innovation, then an enterprise level union will favour (or be indifferent) to labour-saving innovation if and only if the demand for the labour of its members is elastic (or unitary elastic).*

Proof: (i) Since wages are independent of technology, $E^{wi}_{\theta i} = E^{\omega j}_{\theta i} = 0$. The sign of (4.7a) is therefore the sign of η-1. ***

Unions or union branches may operate at the firm level, but it is also not uncommon for workers to be organized on broad functional or industrial lines that cut across firm level boundaries. Thus the attitudes of unions based at the industry level can be highly important in achieving technical change. Proposition 3 contrasts the reactions of an industry-wide union and an enterprise level union to the introduction of new technology. As we show, it does not matter for the results whether the new technology applies to just one firm or is broadly available to all firms in the industry.

Proposition 3: *An industry-wide union is more likely than an enterprise level union to*

(i) lose from innovation if products are strategic substitutes in output space.

(ii) gain from innovation if products are strategic complements in output space.

Proof: Since wages are exogenous, it follows from (4.1) that union attitudes to innovation depend only on the anticipated employment effects. The effect on industry employment, given by $L^I \equiv \sum_k L^k(w^k,\theta^k,\underline{\omega}^j)$ where $k = 1,..n$, $k \neq j$, of a small innovation in firm i is

$$dL^I/d\theta^i = L^i_{\theta i} + \Sigma_{k \neq i} L^k_{\omega i}(d\omega^i/d\theta^i) \qquad (5.1)$$

where $d\omega^i/d\theta^i = - w^i/[\theta^i]^2 < 0$. The corresponding effect of an industry-wide innovation, represented by a change in $\theta = \theta^i$ for $i = 1..n$, is $\sum_i dL^I/d\theta^i$. The employment effect of own innovation as perceived by an enterprise level union is represented by $L^i_{\theta i}$ in (5.1). Results (i) and (ii) follow because the second term of (5.1) is negative iff $L^k_{\omega i} > 0$ (strategic substitutes). In this case, it is possible for the anticipated industry wide employment effects to be negative whilst the firm-specific effects are all positive (and vice versa for the case of strategic complements).***

As Proposition 3 shows, the attitude of an industry-wide union towards technical change (relative to an enterprise level union) is critically affected by the nature of strategic competition in the output market. When the final products are strategic substitutes in output space, an expansion in, say, firm j's output (due to the technical change within firm j) causes a contraction in firm i's output and its demand for labour (making $L^i_{\theta i} < 0$); workers in firm i are made worse off. Since an industry-wide union is concerned about the utility of all workers, an industry-wide union would be then more likely to oppose an innovation than would a union located in the innovating firm itself. As previously mentioned, when demand is linear, the products are strategic substitutes under both Cournot and Bertrand competition. Hence the distinction between Cournot and Bertrand behaviour is not important for the proposition. The opposite situation obtains when the final outputs are strategic complements in output space; expansion by one firm then causes the other firm to expand, increasing its demand for labour.

6. A single wage-setting union

We consider now the case where a union can choose the wage subject only to the restrictions imposed by the employer's labour demand curve. This is the "monopoly union" model. Our analysis allows here for either a single enterprise union (in firm i) or a single industry union which sets a uniform industry wage $w=w^I$. In the first case, the wages in the non-union sector are assumed to be given exogenously by the opportunity cost of labour.

Proposition 4: If there is a single wage-setting union in an industry, necessary and sufficient conditions for the union to oppose innovation are:

i) that the union faces inelastic labour demand; or,

ii) that the union's elasticity of substitution ,ϕ, is less than unity.

Proof The final term in (4.7a&b) is zero since $E^{\omega j}_{\theta i} = 0$. The wage setting union chooses $w = \arg.\max.V(w^i,L^i)$ s.t. $L^i = L(w^i,\theta^i,\underline{\omega}^j)$ where technology is given from stage 1 and other wages are exogenous. Assuming an interior solution, the first order condition is $dV^i/dw^i = 0$ which implies $\phi = \eta$ from (4.3). Thus from (4.7a&b), $dV^i/d\theta^i < 0$ iff $\eta - 1 < 0$ or equivalently iff $\phi - 1 < 0$.***

Since the union chooses the wage in stage 2, its only concern when facing innovation is with the effect on labour demand, which will be negative if and only if labour demand is inelastic. The wage setting union chooses a wage where its indifference curve is tangential to labour demand, so the elasticity of substitution is the same as the elasticity of labour demand.

In general the elasticities of labour demand and of substitution are determined endogenously. If, however, either labour demand or the union indifference curve is everywhere either elastic or inelastic, this condition will determine the union's attitude towards innovation. One case in particular deserves attention, the rent-maximising union. It has been argued (as discussed in Pencavel, 1985) that a union which can costlessly redistribute income amongst its members should have as its objective the maximization of economic rents: $L(w-v)$. This is a special case of our general union utility function with the interesting feature that the elasticity of substitution is everywhere greater than one if the opportunity cost of labour is strictly positive, since $\phi = w/(w-v)$. Indeed, it is simple to extend this result to the more general case of the non risk-averse union: $V = L[u(w)-u(v)]$, $u'' \geq 0$. Proposition 5 then follows from Proposition 4.

Proposition 5: A wage setting union which is a rent-maximizer or, more generally, is non risk-averse will not lose from labour-saving innovation.

Proof: Convexity of u(w) implies $u'(w) \geq [u(w)-u(v)]/[w-v]$. Thus from (4.2), $\phi = wu'(w)/[u(w)-u(v)] \geq w/[w-v]$. Since $\phi > 1$, the result follows from Proposition 4.***

7. Bargaining over the Wage: enterprise unions

For the general case where wages are neither exogenous nor determined solely by the union, we assume asymmetric Nash bargaining between a firm and its enterprise level union. This bargaining solution is derived axiomatically by Svejnar (1986) and is shown by Binmore, Rubinstein and Wolinsky (1986) to be the limiting case of a sequential non-cooperative game between two players as the period between successive offers reduces to zero. The stage 2 bargaining covers only the wage; both the union and the firm anticipate the outcome of the stage 3 output and employment decisions. At the bargaining solution within firm i, the chosen wage is:

$$w^i = \text{arg.max. } Z^i(w^i,\underline{\omega}^j) \equiv \alpha \ln\{V^i(w^i,L(w^i,\theta^i,\underline{\omega}^j)\} + [1 - \alpha]\ln\{\pi^i(\omega^i,\underline{\omega}^j)\} \; ; \quad 0<\alpha\leq 1 \qquad (7.1)$$

We normalise π here relative to some exogenously given disagreement profit level. Since we do not analyze the influence of disagreement utilities, omitting them from the notation involves no loss of generality. The parameter α represents union bargaining strength, reflecting relative rates of discounting or attitudes to risk. In the special case where $\alpha = 1$ the union has all the bargaining power and, in effect, is able to unilaterally set the wage. This is the case of the wage setting union as previously analyzed. We assume that $\alpha > 0$ to avoid the trivial case in which the firm sets the alternative wage v^i and the union is indifferent to innovation.

In determining the stage 2 equilibrium wage, each firm and its union are assumed to take the wages in other firms as given. Since wage bargaining occurs after technology is installed, this implies that the vector $\underline{\omega}^j$ of effective wages in other firms is taken as given. Thus, assuming a finite internal solution[10], the wage w^i satisfies the first order condition (using $d\pi^i/dw^i = \pi^i_{\omega i}/\theta^i$),

$$Z^i_{wi}(w^i,\theta^i,\underline{\omega}^j) = \alpha(dV^i/dw^i)/V^i - (1-\alpha)h^i(\omega^i,\underline{\omega}^j)/w^i = 0 \qquad (7.2)$$

where $h^i(\omega^i,\underline{\omega}^j) \equiv -\omega^i\pi^i_{\omega i}/\pi^i > 0$ since $\pi^i_{\omega i} < 0$ from (3.2). The term $h^i(\omega^i,\underline{\omega}^j)$ represents the elasticity with respect to a change in the effective wage of the firm's profit π^i (above its threat point). If there are n unionised firms, the n conditions (7.2) define the Nash equilibrium wage relationships[11] $w^i = w(\theta^i,\underline{\omega}^j)$ for $j\neq i$ and $i = 1,..n$. We use (4.3) to express (7.2) in the convenient form:

$$Z_w(w,\theta,\underline{\omega}^j) = (\alpha/w)[\varepsilon^V_L(\phi-\eta) - h^i(\omega^i,\underline{\omega}^j)(1-\alpha)/\alpha] = 0 \qquad (7.3)$$

Typically one might expect that an increase in labour productivity will cause the bargained wage to rise somewhat, but not so much as to nullify the cost reduction effects of innovation. This latter condition is particularly appealing since a firm will not want to implement the innovation unless it reduces labour costs[12]. Proposition 6 applies in these circumstances.

Proposition 6: If there is a single union in an industry and a labour saving innovation reduces the effective wage w/θ but does not reduce the bargained wage w:

i) a necessary condition for the union to oppose innovation is that the elasticity of labour demand $\eta<1$;

ii) a sufficient condition for union opposition is that the unions elasticity of substitution $\phi<1$.

Proof: With only one union, $E^{\omega j}_{\theta i}=0$ so the final term of (4.7) is zero. Since $(1-\alpha)h^i \geq 0$, (7.3) implies $\phi-\eta\geq 0$. Thus (4.7a) is positive if $\eta\geq 1$ and $E^{w}_{\theta}\geq 0$; (4.7b) is negative if $\phi<1$ and $E^{\omega}_{\theta}<0$.***

To simplify the comparative static analysis (in this section), we restrict union utility as follows:

$$\varepsilon^{Vi}_{Li} = 1 \Rightarrow \qquad V(w^i,L^i) = L^i g(w^i). \tag{7.4}$$

This utility function has the useful property that $\phi(w^i) = wg'(w^i)/g(w^i)$ is a function solely of the unions own wage. Note that this formulation is still sufficiently general to encompass the expected-utility, the Stone-Geary and the rent-maximising functional forms. Setting $\varepsilon^{Vi}_{Li}=1$ in (7.3) gives the revised first order condition:

$$(w/\alpha)Z_w(w,\theta,\underline{\omega}^j) = [\phi(w) - H(\omega,\underline{\omega}^j)] = 0, \tag{7.5}$$

where $H(\omega,\underline{\omega}^j) \equiv \eta + h(\omega,\underline{\omega}^j)(1-\alpha)/\alpha$. At the bargained wage, the union's elasticity of substitution is equal to $H(\omega,\underline{\omega}^j)$, the weighted sum of the elasticities of labour demand and profit. The term H has the useful property that it depends only on the vector of effective wages.

We proceed to examine the circumstances under which the effective wage falls in response to innovation. Using $w^i_{\theta i}(\theta^i,\underline{\omega}^j) = - Z_{w\theta}/Z_{ww}$ and (7.5), the partial elasticity $\varepsilon^{wi}_{\theta i}$ of the wage w^i with respect to innovation in firm i (holding other wages fixed) is

$$\varepsilon^{wi}_{\theta i} \equiv (\theta^i/w^i)w^i_{\theta i} = (H_\omega/\theta)/[(H_\omega/\theta) - \phi_w] \tag{7.6}$$

where $Z_{ww} < 0$ implies $(H_\omega/\theta) - \phi_w > 0$. The partial elasticity of the effective wage is given by $\varepsilon^{\omega i}_{\theta i} = \varepsilon^{wi}_{\theta i} - 1$ (analogously with (4.6)). Thus, using (7.6), we obtain

$$\varepsilon^{\omega i}_{\theta i} \equiv \phi_w/[(H_\omega/\theta) - \phi_w]. \tag{7.7}$$

If only one firm is unionised, then wages in other firms remain fixed and (7.7) implies that the effective wage in the unionised firm falls if and only if $\phi_w<0$: an increase in the wage then makes the union less willing to trade-off jobs for higher wages. Proposition 7 generalizes this result to allow for the possibility that wages in other firms vary.

Proposition 7 : Suppose $\varepsilon^{Vi}_{Li} = 1$. The own effective wage falls in response to innovation if and only if the union's elasticity of substitution, ϕ, is decreasing in the wage.

Proof: From $\omega^i = w(\theta^i,\underline{\omega}^j)/\theta^i = \omega(\theta^i,\underline{\omega}^j)$, the total effect of the innovation on the own effective wage is:

$$d\omega^i/d\theta^i = \omega^i_{\theta i} + \sum_j (\partial\omega^i/\partial\omega^j)(d\omega^j/d\theta^i) \tag{7.8}$$

Innovation in firm i changes the effective wage in firm j only through changes in ω^i. So the total effect of innovation on a rival's effective wage is:

$$d\omega^j/d\theta^i = (d\omega^j/d\omega^i)[d\omega^i/d\theta^i] \tag{7.9}$$

where, allowing all wages to vary, $d\omega^j/d\omega^i = \partial\omega^j/\partial\omega^i + \sum_k (\partial\omega^j/\partial\omega^k)(d\omega^k/d\omega^i)$ for $k \neq i \neq j$. Substituting (7.9) into (7.8) and using (7.7), the total elasticity of ω^i with respect to θ^i is:

$$E^{\omega i}_{\theta i} = \varepsilon^{\omega i}_{\theta i}/(1-\psi) = \phi_w/(1-\psi)[H_\omega/\theta - \phi_w], \tag{7.10}$$

where $\psi \equiv \sum_j (\partial\omega^i/\partial\omega^j)(d\omega^j/d\omega^i)$. The stability requirement of the Nash equilibrium in wages ensures $|\psi| < 1$ (the indirect effect of an increase in own effective wage on own effective wage through the wage reactions of other firms is less that 1 in absolute value). Thus $E^{\omega i}_{\theta i} < 0$ iff $\phi_w < 0$. ***

Although ϕ_w may sometimes be positive, there are reasons to expect it to be usually negative. First, $\phi(w)=wg'(w)/g(w)$ is infinite at $w=v>0$, since $g(v)=0$. So we may expect $\phi(w)$ to be decreasing when the wage is in the vicinity above v. Second, ϕ_w is unambiguously negative if $w>v>0$ and if union utility takes the Stone-Geary functional form or if it takes the expected utility form with constant relative risk-aversion[13]. We therefore expect that the effective wage will typically fall with the introduction of labour-saving innovation. It is of interest to note that exceptions to this rule, where the wage response outweighs the direct cost saving effect of the innovation, are determined solely by the structure of union preferences. There is no presumption, for instance, that a strong union, as represented by a high value of α, is any more likely than a weak union to nullify the cost-saving effect of innovation.

The firm's benefit from the innovation depends on the costs of innovation and on the extent of the induced cut in effective labour costs and also on the response of wage bargaining in other firms which may counteract the direct benefit of a reduction in own labour costs. We assume that the partial effect of the own effective wage dominates[14]. So Proposition 7 defines the circumstances under which the firm can potentially benefit from introducing the innovation.

We examine next the conditions under which a union will win a wage increase allowing for the possibility that wages in other firms may vary in response to a firm specific innovation. Substitution of (7.10) into $E^{wi}_{\theta i} = E^{\omega i}_{\theta i} + 1$ (from (4.6)) gives:

$$E^{wi}_{\theta i} = [(1-\psi)H_\omega/\theta + \psi\phi_w]/(1-\psi)(H_\omega/\theta - \phi_w) \tag{7.11}$$

where $\psi \equiv \sum_j (\partial\omega^i/\partial\omega^j)(d\omega^j/d\omega^i)$ represents the adjustment in ω^i due to changes in the wages paid by other firms. Since the denominator of (7.11) is positive (see (7.6) and (7.10)), the sign of the own wage response is the sign of the numerator of (7.11) which may, in general, be either positive or negative.

If there is a single wage setting union (α=1 and ψ=0), then H equals the elasticity of labour demand and expression (7.11) tells us that the wage rises in response to innovation if and only if the elasticity of demand is increasing in the wage. This is the condition for the innovation to reduce the elasticity of labour demand. The diminution of the threat of job losses encourages the union to choose a higher wage. This condition holds for certain if the labour demand function is linear or concave, and it holds for a wide class of convex functions[15]. When there is actual bargaining ($\alpha < 1$), however, the response of the wage depends, in addition, on the effect of ω on the elasticity of the firm's bargaining rent $h(\omega,\underline{\omega}^j)$. The adjustment ψ is non zero if wages in other firms vary. Since the signs of h_ω and ψ are ambiguous, we cannot say in general whether innovation increases or decreases the wage. This is an important general result since it implies that union wage bargaining need not necessarily lower firms' returns to innovation.

Industry-wide wage effects alter union attitudes in two ways in comparison with the single union case. First, as we have shown, the own wage response to innovation will be modified by the anticipated wage changes in other firms. Second, there will be an indirect employment effect through the cross-price elasticity of labour demand as represented by the final term in the expressions (4.7). Recognizing that firms affect each other's decisions only though changes in effective wages, this final term in (4.7) can be expressed as:

$$\sum_j \varepsilon^{Li}{}_{\omega j} E^{\omega j}{}_{\theta i} = \sum_j \varepsilon^{Li}{}_{\omega j} E^{\omega j}{}_{\omega i} E^{\omega i}{}_{\theta i}. \tag{7.12}$$

To sign (7.12), recall that $E^{\omega i}{}_{\theta i}$ must be negative if the firm is to regard the innovation as profitable. The term $\varepsilon^{Li}{}_{\omega j}$ is positive or negative as outputs are strategic substitutes or complements. The sign of the middle term, the slope of the wage reaction function, is in general ambiguous. However, we may tentatively sign this term on the assumption that an increase in labour demand leads to an increase in the bargained wage. If products are strategic substitutes, then a rise in the wage in firm i will lead to an increase in output in firm j. Because of our assumption that the production function is homogeneous, an increase in own output is associated with an increase in the own demand for labour holding the wage fixed. By assumption this leads to an increase in the wage in firm j. By similar reasoning, the first two terms in (7.12) are each negative when products are strategic complements. It follows that there is a presumption, though no certainty, that the indirect employment effect of wage bargaining in other firms will reduce a union's incentive to accept innovation.

8. Wage Bargaining with an Industry-wide Union

In considering bargaining by an industry-wide union, we make the convenient assumption that technology is the same across firms ($\theta^i = \theta$ for all i) and that firms are otherwise symmetric. Products may differ in some attribute, but price, output and wage levels are the same.

Because of its industry-wide nature, it is reasonable to assume that, in bargaining over the (common) wage, the industry-wide union recognizes the interconnection between wages across firms. We consider two possibilities with respect to the nature of the employer body that it faces. The first possibility is that union bargains with each firm individually and that each firm takes the wages set in other firms as given, just as it did when bargaining with its own enterprise level union. This case captures the minimum change that would be associated with the formation of an industry - wide union; it has the advantage that any differences in outcome can be clearly attributed to the change in the behaviour of the union. The second possibility considered is that the union bargains with an industry wide employers' body. In this case, both parties assume that the bargained wage applies to all workers in the industry. This is equivalent to a situation where one firm acts as a bargaining leader, recognising that the same wage settlement will apply to other firms in the industry.

Letting $\pi^I \equiv n\pi^i(\omega^i,\underline{\omega}^j)$ represent industry profit (I for industry) and w^I the common industry wage then, assuming Nash bargaining, w^I maximizes $Z^I = \alpha\ln V^I(w,L^I) + (1-\alpha)\ln\pi^x$ where $\pi^x = \pi^i$ when the industry-wide union bargains with firm i (case (i)) and $\pi^x = \pi^I$ when the union bargains with a central employers group (case (ii)). To relate these two cases, we use $d\pi^i/dw = [\pi^i_{\omega i} + (n-1)\pi^i_{\omega j}]/\theta$ to show that

$$h^I(\omega,\underline{\omega}^j) = -\omega(d\pi^i/d\omega)/\pi^i = h^i(\omega,\underline{\omega}^j) - (n-1)h^i_j(\omega,\underline{\omega}^j);\ j\neq i \qquad (8.1)$$

where $h^I \equiv -w(d\pi^I/dw)/\pi^I$ denotes the elasticity of industry profit with respect to the (common) wage; $h^i \equiv -\omega\pi^i_{\omega i}/\pi^i$ and $h^i_j \equiv \omega(\pi^i_{\omega j})/\pi^i$ represent firm level direct and cross elasticities respectively.

Assuming a finite internal solution, the bargained wage satisfies the first order condition,

$$dZ^I/dw = \alpha(dV^I/dw)/V^I - (1-\alpha)h^x(\omega,\underline{\omega}^j)/w = 0 \qquad (8.2)$$

where x = i,I for cases (i) and (ii) respectively. Now letting $\eta^I \equiv -w(dL^I/dw)/L^I$ denote the (positive) elasticity of demand for all labour L^I in the industry, it follows that (see (4.2) and (4.3))

$$dV^I/dw = \varepsilon^{VI}_{LI}[V^I/w][\phi^I - \eta^I] \text{ where } \phi^I = \varepsilon^{VI}_w/\varepsilon^{VI}_{LI} = \phi. \qquad (8.3)$$

We have $\phi^I = \phi$ because, with symmetry of firms, $V^I = nV^i(w,L^i)$ implies $\varepsilon^{VI}_w = \varepsilon^{Vi}_w$ and $\varepsilon^{VI}_{LI} = \varepsilon^{Vi}_{Li}$. Then, using $L^I_w = n[L^i_{wi}+(n-1)L^i_{\omega j}/\theta]$, we obtain $\eta^I = \eta-(n-1)\varepsilon^{Li}_{\omega j}$. Hence, from (8.3) and (8.2),

$$(w/\alpha)dZ^I/dw = \varepsilon^{Vi}_{Li}[(\phi - \eta) + (n-1)\varepsilon^{Li}_{\omega j}] - h^x(1-\alpha)/\alpha = 0 \qquad (8.4)$$

for x = i,I. In case (i), condition (8.4) differs from the equivalent condition (7.3) for an enterprise level union only because the industry - wide union is concerned with the elasticity of demand for all workers in the industry, not just those in any particular firm.

Proposition 8 compares the equilibrium wage levels w^x that arise under each of our scenarios (denoting x = IF (for firm level) in case (i) and x = II in case (ii)) with the wage w^i that arises under enterprise level bargaining.[16]

<u>*Proposition 8*</u>*: Assume n > 1. (i) Suppose that the industry-wide union bargains with individual firms.*

When products are strategic substitutes, the (common) wage w^{IF} exceeds the wage w^i bargained by separate enterprise level unions. Conversely, if products are strategic complements then $w^{IF} < w^i$.

(ii) The wage is always higher when an industry-wide union bargains with a central employer body, than when it bargains with individual firms: $w^{II} > w^{IF}$

Proof: (i) Imposing the first order condition (7.5), from (8.4), $dZ^I/dw = [\alpha/w]\varepsilon^{Vi}_{Li}(n-1)\varepsilon^{Li}_{\omega j}$ at w^i. This expression is positive when the products are strategic substitutes, and since $d^2Z^I/(dw)^2 < 0$ (from the second order condition), (8.4) is satisfied only if $w^{IF} > w^i$. When the products are strategic complements, $\varepsilon^{Li}_{\omega j} < 0$ and $w^{IF} < w^i$ by a similar argument. (ii) Since $\pi^i_{\omega j} > 0$ (from (3.2)), (8.1) implies $h^I < h^i$. Thus, from (8.2) for case (ii), $dZ^I/dw > 0$ at w^{IF}.***

Proposition 8(i) follows because an increase in the effective wage in one firm increases employment in other firms, if and only if the products are strategic substitutes. An industry - wide union takes this interconnection between workers in different firms into account, raising the wage in the strategic substitutes case, and lowering it in the strategic complements case. Proposition 8(ii) follows because an industry-wide wage increase is less damaging to a typical firm's profits than an increase in that firm's wage alone; an industry employers' group has less incentive to hold the line on wages.

Turning now to the union attitude to innovation, for both cases IF and II, the effect of an innovation θ (simultaneously introduced by all firms in the industry) on the utility of an industry-wide union (using (8.3) and $L^I_\theta = [L^I/\theta][\eta^I-1]$ from (3.9)) is

$$dV^I(w,L^I)/d\theta = (V^I/\theta)\varepsilon^{Vi}_{Li}\{(\phi - \eta^I)E^w_\theta + \eta^I - 1\}. \qquad (8.5)$$

This expression is identical in form to the analogous condition (4.7a) for a single enterprise level union and it is easy to show that, except for Proposition 3, all our previous propositions apply to this case. To compare the attitudes of an industry-wide union with enterprise level unions (analogously to Proposition 3), take the simplest case in which each union sets its own wage (making the first term of (8.5) zero) and assume that products are strategic substitutes. If wages were the same under both structures, the relatively inelastic demand for labour at the industry level would make the industry-wide union more likely to oppose innovation than its enterprise level counterparts[17]. However, wages are not same. The higher wage negotiated by the industry-wide union will increase the elasticity of demand at the industry level in the broad class of cases (including linear demand) in which the elasticity of demand is increasing in the wage making the outcome of the comparison far from obvious.

We carry out further analysis by making some simplifying assumptions, including Cournot competition in the output market and linear demand. These restrictions enable us to directly compare the attitudes of an industry-wide union with an enterprise level union as well as facilitating some additional results concerning the number of firms in the industry and union attitudes to the risk of job loss.

9. A simplified Cournot model

Assuming linear demand, price is $p = a - bY$, where Y is the total output of a homogeneous good produced by the n firms in the industry. Each firm operates under constant returns to scale with labour as the only input. Firm i's profit is $\pi^i = (p - \omega^i)y^i$ where $y^i = \ell^i$ and employment is $L^i = y^i/\theta^i$. Given Cournot competition in stage 3, output y^i for $i = 1...n$ satisfies the first order condition

$$\partial\pi^i/\partial y^i = -2by^i - b\{\textstyle\sum_j y^j\} + a - \omega^i = 0 \quad \text{for } j \neq i \tag{9.1}$$

Solving the n equations (9.1), firm i's equilibrium output and profits are:

$$y^i = [a + \textstyle\sum_j \omega^j - n\omega^i]/(n+1)b \text{ and } \pi^i = b(y^i)^2 \text{ for } j \neq i \tag{9.2}$$

where $y^i_{\omega i} = \ell^i_{\omega i} = -n/(n+1)b$ and $y^i_{\omega j} = \ell^i_{\omega j} = 1/(n+1)b$. From (9.2), $\pi^i_{\omega i} = 2by^i\ell^i_{\omega i}$ and $d\pi^i/d\omega = 2by^i(d\ell^i/d\omega)$. So, assuming that firm i's alternative profit $\underline{\pi}^i = 0$, $h^i \equiv -\omega^i\pi^i_{\omega i}/\pi^i$ and from (7.5) and (8.1), we obtain particularly simple forms for the terms

$$h^i = 2\eta,\ H^i = \eta(2 - \alpha)/\alpha \text{ and } h^I = 2\eta^I \tag{9.3}$$

where, from (9.2), $\eta = n\omega^i/[a+\sum_j\omega^j-n\omega^i]$ and $\eta^I = \omega/(a-\omega)$.

In order to derive tractable results we assume that union utility takes the Stone-Geary functional form (as discussed in, for instance, Oswald, 1985): $V^i = (w^i - v^i)^\gamma L^i$ where $\gamma > 0$. From (4.2), this utility function is associated with an elasticity of substitution $\phi(w^i) = \gamma w^i/(w^i - v^i)$. A value of $\gamma = 1$ gives the rent-maximizing case; smaller values of γ imply that the union is less concerned about wages and more concerned about jobs.

With enterprise level unions, setting $\phi = H^i$ as in (7.5) and using (9.3), Nash wage bargaining implies

$$\omega^i - v^i = \alpha\gamma[a+\sum_j\omega^j-nv^i]/\beta \quad j \neq i, \text{ where } \beta \equiv n[\alpha\gamma+(2-\alpha)] \tag{9.4}$$

where the effective reservation wage $v^i \equiv v^i/\theta^i$. We consider two separate enterprise union structures: the first is where there is only one enterprise union, i=1, and all non-union wages are set at v. The second scenario has all enterprises unionised. We index the outcomes for the single enterprise union and the n union case 1 and i respectively. Assuming $v^i = v$ for all i, (9.4) yields the following results:

$$\omega^1 - v = \alpha\gamma(a - v)/\beta^1 \quad \text{where } \beta^1 \equiv \beta. \tag{9.5}$$

$$\omega^i - v = \alpha\gamma(a - v)/\beta^i \quad \text{where } \beta^i \equiv \alpha\gamma+n(2-\alpha). \tag{9.6}$$

Substituting $L^i = y^i/\theta$ into V^i using (9.2), the utility of union i can be expressed as:

$$V^i = \theta^{\gamma-1}(a+\sum_j\omega^j-n\omega^i)(\omega^i-v)^\gamma/(n+1)b. \tag{9.7}$$

Then using $a+\sum_j\omega^j-n\omega^i = [a+\sum_j\omega^j-nv]n(2-\alpha)/\beta$ from (9.4), (9.7) implies that in both cases 1 and i,

$$\ln\{V^i(\theta^i,v)\} = (\gamma-1)\ln\{\theta^i\} + (\gamma+1)\ln\{a+\sum_j\omega^j-nv\} + \ln\{\rho\} \tag{9.8}$$

where $\rho \equiv (\alpha\gamma/\beta)^\gamma n(2-\alpha)/\beta(n+1)b$.

Turning now to the industry-wide union, we consider two cases, as in Section 8: i) the union bargains separately with each individual enterprise; ii) the union bargains with an industry-level employers' body. In each case we assume a symmetric cost structure: w^i=w and θ^i=θ i=1..n. We first take the case of an industry union bargaining with individual firms (indexed 'IF'). Since $\varepsilon^{Vi}_{Li} = 1$, $\phi = \eta^I + h^i(1-\alpha)/\alpha$ from (8.4) and, from (9.3), the effective wage is

$$\omega^{IF} - v = \alpha\gamma(a - v)/\beta^{IF} \quad \text{where } \beta^{IF} \equiv \alpha(\gamma+1)+2n(1-\alpha). \tag{9.9}$$

The demand for labour at the firm level becomes more elastic as the level of competition rises, making the wage sensitive to the number of firms.

When bargaining takes place at the industry level, with both sides anticipating that the wage will be set on an industry -wide basis, we index variables 'II'. Setting $\phi = \eta^I + h^I(1-\alpha)/\alpha$ (from (8.4)) and using (9.2) and (9.3), Nash wage bargaining yields the solution:

$$\omega^{II} - v = \alpha\gamma(a - v)/\beta^{II} \quad \text{where } \beta^{II} \equiv \alpha(\gamma+1)+2(1-\alpha). \tag{9.10}$$

The wage w^{II} is independent of the number of firms. This follows because in this model the bargained wage depends only on the elasticities of labour demand and of profits at the industry level and these elasticities are independent of the number of firms given our assumption of zero fixed costs[18]. From (9.9), (9.10) and (9.7), indexing the two cases by x, where x = IF,II, union utility is:

$$\ln V^x = \ln\{nV^i\} = (\gamma-1)\ln\{\theta\} + (\gamma+1)\ln\{a - \nu\} + \ln\{\rho^x\} \tag{9.11}$$

where $\rho^x \equiv n(\alpha\gamma/\beta^x)^\gamma[\beta^x-\alpha\gamma]/\beta^x(n+1)b$.

Comparison of the two industry union outcomes ((9.5) and (9.6)) with the two enterprise union outcomes ((9.9) and (9.10)) gives a clear ranking of wage levels when there are two or more firms in the industry: $w^{II} \geq w^{IF} \geq w^i \geq w^1$. The equalities hold if and only if n=1, in which case $\beta^x=\beta$ for x = II,IF,i,1. In accordance with Proposition 8, wages are highest when unions and firms co-ordinate their bargaining. Wages are lower if employers do not coordinate their bargaining, because firms act 'tougher' when they do not recognise that any concessions they make will be matched by similar concessions from their rivals. Wages are lower still when unions do not co-ordinate their bargaining, because enterprise unions compete over shares in industry employment. Union wages are lowest of all when there is only a single enterprise union because the unionised firm faces more intense competition if wage levels in rival firms do not follow any upward movement in the union wage.

To compare union attitudes to innovation under the different bargaining structures, we assume that firms simultaneously introduce new (identical) technology. An industry-wide union takes account of the effect of this simultaneous introduction whereas, each enterprise level union takes the technology of other firms as given. We measure the responses of the different level unions using elasticities which we write as EV^x.

Taking the case of enterprise level unions first, from differentiation of (9.8) holding ω^j constant, union i will (weakly) favour a labour-saving innovation if and only if

$$d\ln(V^i)/d\ln(\theta^i) = \gamma - 1 + (\gamma+1)[n\nu)+\theta^i\textstyle\sum_j\{d\omega^j/d\theta^i\}]/(a+\sum_j\omega^j-n\nu) \geq 0. \tag{9.12}$$

Allowing w^j but not θ^j to vary, it can be shown[19] that,

$$d\omega^j/d\theta^i = -\alpha\gamma(2-\alpha)n\nu/\theta^i\beta^i(n\alpha\gamma+\beta^i). \tag{9.13}$$

If all firms are unionised, from (9.13) using (9.12) and (9.6), the elasticity of union i's utility with respect to own innovation is

$$EV^i \equiv \theta^i(dV^i/d\theta^i)/V^i = \gamma - 1 + (\gamma+1)[v/(a-v)]Z \qquad (9.14)$$

where[20] $Z = [(n+1)\alpha\gamma + n^2(2-\alpha)]/[(n+1)\alpha\gamma + n(2-\alpha)]$. If only one firm is unionised, then $d\omega^j/d\theta^i = 0$ and from (9.12), the elasticity of the union's utility with respect to own innovation is given by:

$$EV^1 \equiv \theta^1(dV^1/d\theta^1)/V^1 = \gamma - 1 + (\gamma+1)[v/(a-v)]n \qquad (9.15)$$

When there is an industry-wide union, we derive the elasticity of utility with respect to innovation in the two cases by totally differentiating (9.11) for x = IF,II with respect to θ:

$$EV^{IF} = EV^{II} = \gamma - 1 + (\gamma+1)[v/(a-v)]. \qquad (9.16)$$

In each of the expressions (9.14-9.16) we have an explicit function for the elasticity of union utility in terms of the exogenous parameters of the model: $EV^x(a,v,\gamma,n)$ where x indexes the four possible bargaining structures. We now examine the relationship between these parameters and the sign of the union response to innovation. We say that a factor makes union opposition more likely if that factor reduces the magnitude of EV^x and can make it negative for some constant values of the other parameters.

Proposition 9: *A necessary condition for a union to oppose innovation is that the Stone-Geary parameter γ is less than unity.*

Proof: If $\gamma \geq 1$, the first terms in (9.14-9.16) are positive. The second term must always be positive because strictly positive output and employment requires, from (9.2), that $a>v$.***

In particular, we get the strong result from this model that a rent-maximising or risk-neutral union (γ=1) will always benefit from innovation whatever its bargaining strength and whatever the bargaining structure. A union will oppose innovation only if $\gamma<1$, implying that a union is strongly concerned about employment (akin to risk-aversion in the expected utility framework).

Proposition 10: *A union is more likely to oppose innovation under the following circumstances:*

i) the smaller the number of firms in the industry (with enterprise unions);

ii) the lower the value of the Stone-Geary parameter γ;

iii) the higher the value of the demand parameter a or the lower the value of the reservation price of effective labour, v.

Proof: From (9.14-9.16), $d(EV^x)/dn > 0$ for x=i,1 proving (i); $d(EV^x)/d\gamma > 0$, $d(EV^x)/dv > 0$ and

$d(EV^x)/da < 0$ for x=i,1,II,IF, proving (ii) and (iii).***

Part i) of the proposition is related to our Proposition 6 which states that inelastic labour demand is a precondition for union opposition. Given strategic substitutes in product space, any reduction in the number of firms in the industry has the effect of lowering the elasticity of product demand, hence lowering the elasticity of the derived labour demand, at firm level. This effect is relevant only if unions are organised on an enterprise basis.

Part ii) of the proposition indicates that the loss of employment implied by innovation (if labour demand is inelastic) outweighs the wage gains for any union whose utility function is heavily weighted in favour of jobs.

Part iii) reflects a feature of linear demand, namely that if the effective reservation wage is sufficiently high relative to the product demand intercept, ($v>a/2$), the wage will always be in the upper (elastic) section of the industry labour demand schedule. Hence labour demand at the level of the firm will always be elastic and unions will always gain from innovation. Reductions in the ratio v/a will lower the bargained wage towards the inelastic demand region.

Proposition 11*: i) An industry union is more likely to oppose innovation than an enterprise union. ii) An enterprise union is more likely to oppose innovation if the other enterprises in the industry are unionised.*

Proof: From (9.14-9.16), noting that $1 \le Z \le n$, we can rank the elasticity of union utility to innovation under the four bargaining structures as follows: $EV^{II} = EV^{IF} \le EV^{i} \le EV^{1}$. The equalities hold only if n=1 (in which case there is no difference between the four bargaining structures) or if the opportunity cost of labour, v, is zero. ***

This proposition extends Proposition 3 (for the case of strategic substitutes) to allow for wage bargaining. It also supports our conjecture in Section 7 that the presence of other bargaining unions in an industry will tend to reduce an enterprise union's gains from innovation.

10. Concluding remarks

A broad summary of our analysis suggests that union opposition to labour-saving innovation is likely to occur when labour demand is inelastic and unions are strongly concerned about employment.

Increased labour productivity implies lower employment for any given output, but if labour demand is elastic, the labour demand curve shifts outwards in response to labour-saving innovation. As long as the wage does not fall, the union must then gain from the innovation. However, unless wages are determined exogenously, inelastic labour demand is not a sufficient condition for unions to oppose innovation. Even if labour demand contracts as a result of innovation, the union may enjoy some of the economic rents associated with innovation by bargaining up the wage. This points to the ability of a union to bargain over wages as likely to encourage a positive attitude towards labour-saving innovation. Conversely, government imposition of fixed wage levels or limits to nominal wage increases, is likely to induce union opposition to innovation when labour demand is inelastic.

If products are strategic substitutes in output space (the more usual case), labour demand at the industry level is less elastic than at the level of the firm. Moreover, there is a tendency for labour demand at the firm level to be less elastic the smaller the number of firms in the industry. It follows that enterprise unions in a competitive industry environment are likely to face elastic labour demand and hence to favour labour-saving innovation. Union opposition is more likely to occur in industries which are concentrated or protected from foreign competition or where a single union covers the whole industry.

It is possible to take this analysis one stage further and to speculate that a union body which represents all industries in an economy (such as the peak union bodies which negotiate with government and employers in Sweden or Australia) might view innovation more favourably than a union just representing all workers in an industry. The real income gains to workers in a particular industry from price reductions in that industry (as a result of innovation) could reasonably be viewed as small and our analysis abstracts from this effect. These gains could become significant when the utility of all workers in the economy is taken into account, giving a peak union body an additional motivation to welcome innovation. In this case, our analysis suggests that the relationship between union attitudes to innovation and the degree of centralization of union decision-making may be non-monotonic: an industry- level union is the least likely to welcome innovation (at least in the case where products are strategic substitutes), whereas either a firm-level union or a peak union body are more likely to view the innovation more favourably. This prediction complements the analysis of Calmfors and Driffil (1988) who find empirical support for a non-monotonic relationship between the degree of centralization of wage-bargaining and macroeconomic wage flexibility.

It seems likely that this analysis of union centralisation could be readily extended to the case of multi-unionism within a firm (or plant) where we might expect craft unions to be more or less in favour of innovation than an encompassing union according to whether the different types of labour are substitutes or complements in production. Furthermore, whilst our analysis has taken the structure of industrial relations as given it has implications for the strategic evolution of both union organisation and the organisation of industrial relations within firms. In particular, we predict that to the extent that groups of workers, differentiated by skills or location, are substitutes, the firm will tend to gain both lower wage outcomes and a more favourable response to innovation when bargaining is decentralised.

It is interesting to note that bargained wages may sometimes fall in response to innovation, even in the presence of a strong union. Furthermore, there appears to be no systematic relationship between union bargaining strength and their attitudes to innovation. Rather, it is the structure of union preferences towards wages and employment which is important. A union which can bargain over wages is likely to oppose innovation only if its elasticity of substitution between wages and jobs is less than one, that is to say if it places relatively greater weight on jobs. It is the union dominated by members' fears of job losses, rather than the strong union, which is likely to behave in a Luddite fashion.

One problem is that the elasticity of substitution between employment and wages is unlikely to be directly observable. A reasonable prediction, however, is that a union that has an income-sharing scheme for its members, providing insurance against unemployment, may well behave as a rent-maximizer and thus welcome labour-saving innovation under a broad range of circumstances. Indeed, any unemployment insurance, whether provided by the union or by government, is likely to reduce union concern about the threat of job losses and hence to encourage positive attitudes towards innovation. Furthermore, we note the arguments of Carmichael and MacLeod (1988) that multi-skilling, as practised in Japanese firms, which reduces the anticipated cost to workers of loss of employment in one craft or set of skills, may also reduce union opposition.

The costs of implementation and supervision of innovation can be quite significant, especially when innovation takes the form of a series of piecemeal adjustments to new equipment, new techniques and new working practices. Active opposition and obstruction by a union and its members could substantially increase these costs. Two radically different alternatives are likely to reduce implementation costs. On the one hand, costs are likely to be lower when industrial concentration is low perhaps because firms compete on the world market, and when unions bargain over wages at the enterprise rather than industry level. In such a situation unions are likely to face elastic labour demand and to cooperate with firms in implementing labour-saving innovation. On the other hand, union cooperation may also be enhanced by centralization of union decision making and bargaining to the level of the national economy and by the provision of unemployment insurance and skill re-training schemes. These alternatives may be loosely labelled the liberal and the corporatist approaches to labour markets and industrial relations, typified on the one hand by the USA and on the other by the Swedish approach. Both approaches appear in theory (and in their results) to have considerable advantages in terms of technological progress over the (pre-Thatcher) 'British disease' of strong unions in monopolistic, protected industries.

Footnotes

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1. See for instance, Sean Flaherty (1987) or Brian Bemmels (1987).

2. An exception is Carmichael and Macleod (1988), which argues that multi-skilling practices within Japanese firms reduces opposition by workers to technological change.

3. Econometric evidence concerning the impact of unions on either productivity levels of rates of technological progress is mixed, ranging from the positive findings of Robert Mefford (1986) through the neutral findings of Machin and Wadhwani (1991) to the negative findings highlighted by John Addison and Barry Hirsch (1989).

4. We extend the model developed by Brander and Spencer (1988) to encompass more general oligopoly at the output stage.

5. Letting μ represent the stage 3 conjecture of the rival's output response dy^j/dy^i (zero under Cournot, negative under Bertrand), equilibrium output levels satisfy the first order conditions: $\partial\pi^i/\partial y^i = R^i_i + \sum_k R^i_k\mu - C^i_{yi} = 0$. Totally differentiating (3.1), we obtain $\pi^i_{\omega i} = -\ell + [R^i_i - C^i_{yi}]y^i_i + \sum^{n-1}_k R^i_k y^k_i$ and, substituting in the first order condition, it follows that $\pi^i_{\omega i} = -\ell + s < 0$ if $s < \ell$ where s is a strategic term capturing the effects on revenue of shifting the rival's equilibrium output: $s = \sum^{n-1}_k R^i_k y^i_i[dy^k/dy^i - \mu]$. The cross effect $\pi^i_{\omega j} = R^i_j y^j_j[1 - \mu(dy^i/dy^j)] + \sum_k R^i_k(dy^k/dy^j - \mu dy^i/dy^j)y^j_j$ where $j \neq i$ and $k \neq i \neq j$ is positive under both Cournot and Bertrand competition provided both dy^i/dy^j and μ are between $-1/(n-1)$ and 1. The lower limit would ensure that when products are homogeneous, an increase in own output increases industry output taking into account the reactions of other firms.

6. From footnote 3, equilibrium output levels satisfy $\partial\pi^i/\partial y^i = R^i_i + \sum_k R^i_k\mu - C^i_{yi} = 0$, where $R^i_i = p^i + y^i(\partial p^i/\partial y^i)$ and p^i is the price of product i. When demand is linear, $\partial(\partial\pi^i/\partial y^i)/\partial y^j = R^i_{ij} + \sum_k R^i_{kj}\mu = \partial p^i/\partial y^j < 0$, ensuring that $dy^i/dy^j < 0$ under both Bertrand and Cournot competition.

7. From (3.5) and $dk^i/d\omega^i > 0$, we obtain $\ell^i_{\omega i} = [y^i/h(k^i)]^{(\lambda-1)/\lambda}[h(k^i)y^i_i - y^i h'(k^i)dk^i/d\omega^i]/\lambda[h(k^i)]^2 < 0$ and $\ell^i_{\omega j} = [y^i/h(k^i)]^{(\lambda-1)/\lambda}y^i_j/\lambda h(k^i)$.

8. Dobbs, Hill and Waterson (1987) obtain a similar result using a cost function and defining the elasticity of demand conditional on output.

9. When $\ell \equiv \Gamma(w)\theta L$, the effective wage $\omega^i = w^i/\Gamma(w^i)\theta^i$. Taking $\underline{\omega}^j$ as given, firm i sets w^i to satisfy $d\pi^i/dw^i = \pi^i_{\omega i}[d\omega^i/dw^i] = 0$ where $d\omega^i/dw^i = [\Gamma(w^i) - w^i\Gamma'(w^i)]/[\Gamma(w^i)]^2\theta^i$ and $\pi^i_{\omega i} < 0$ (see (3.2)). Thus the efficiency wage satisfies $w^i\Gamma'(w^i)/\Gamma(w^i) = 1$ and is independent of θ.

10. There may be no internal solution if, for example, the labour demand curve is elastic throughout the relevant range in which $w \geq v$ and the internal solution would call for a wage in the inelastic section of the demand curve. If the elasticity of demand were increasing in the wage (holds for linear demand), the constrained solution would then be $w = v$.

11. We do not define the equilibrium wage in each firm as a function of $\theta^1 .. \theta^n$ directly because w^j and θ^j affect w^i only through changes in ω^j.

12. Assumption (3.2) rules out the technically feasible possibility, as in Seade (1985) or Stern (1987), that firm profits are increasing in own costs.

13. Stone-Geary utility implies that $\phi=\gamma w/(w-v)$ which is strictly decreasing in w if $w > v$. With the expected utility function $V = [u(w)-u(v)]L$, if the coefficient of relative risk aversion $r \equiv -wu''(w)/u'(w)$ is constant, then $u(w,r) = w^{1-r}/1-r$ if $r \neq 1$ *or* $u(w) = \ln(w)$ if $r = 1$. The elasticity of substitution is given by $\phi(w,r) = (1-r)w^{1-r}/(w^{1-r} - v^{1-r})$ if $r \neq 1$, *or* $1/[\ln(w)-\ln(v)]$ if $r = 1$. $\phi_w(w,r) = -(1-r)^2 w^{-r} v^{1-r}/[w^{1-r} - v^{1-r}]^2$ if $r \neq 1$, or $\phi_w = -1/w[\ln(w) - \ln(v)]^2$ if $r=1$. $\Rightarrow \phi_w \leq 0$.

14. We assume that each firm determines its attitude to new technology in stage 1 anticipating the outcomes of the second stage wage bargaining and the third stage product market equilibrium. Taking the technology θ^j of other firms as given, firm i takes account of the actual effect of own innovation on own and other wages: $d\pi^i/d\theta^i = [d\pi^i/d\omega^i][d\omega^i/d\theta^i]$ where $d\pi^i/d\omega^i = \pi^i_{\omega i} + \sum_j \pi^i_{\omega j} d\omega^j/d\omega^i$. Whether an increase in ω^i decreases π^i partly depends on the wage reactions in other firms. Assuming that the partial effect $\pi^i_{\omega i} < 0$ dominates making $d\pi^i/d\omega^i < 0$, the firm will want to introduce the innovation if ω^i falls. Unless a firm gains by reducing its own costs, it is not interested in cost reducing innovation.

15. From $\eta = -\omega\ell_\omega/\ell$, $\partial(\eta)/\partial\omega = -[\ell_\omega/\ell][1+_\eta+\omega\ell_{\omega\omega}/\ell_\omega] > 0$ if $\ell_{\omega\omega} \leq \eta(\eta+1)\ell/\omega^2$.

16. The effect of union centralisation on wage bargaining is also discussed in Mishel (1986) and in Dowrick (1989).

17. From (8.5) and (4.7a), an industry - wide union is more likely to lose from innovation iff $\eta^I = \eta-(n-1)\varepsilon^{Li}_{\omega j} < \eta+(n-1)\varepsilon^{Li}_{\omega j}E^{\omega j}_{\theta i}$. Supposing $w^I = w^i$, given $E^{\omega j}_{\theta i} > -1$, the result follows from $\varepsilon^{Li}_{\omega j} > 0$.

18. Dowrick (1989) obtained a similar result, but with a different model structure.

19. Noting that $d\omega^j/d\theta^i = (d\omega^j/d\omega^i)(d\omega^i/d\theta^i)$, we first obtain $d\omega^j/d\omega^i = \alpha\gamma/(\alpha\gamma+\beta^i)$. (This follows since $d\omega^j/d\omega^i = (\partial\omega^j/\partial\omega^i)/[1 - (n-2)(\partial\omega^j/\partial\omega^k)]$ from (7.9) and $\partial\omega^j/\partial\omega^i = \alpha\gamma/\beta$ from (9.4)). Then, using this and (9.4) we obtain $d\omega^i/d\theta^i = -\{(2-\alpha)n[\underline{w}/(\theta)^2](\alpha\gamma+\beta^i)\}/\beta^i(n\alpha\gamma+\beta^i)$.

20. This follows from simplification of $Z = n[\beta^i(n\alpha\gamma+\beta^i) - \alpha\gamma(n-1)(2-\alpha)]/[n-1)\alpha\gamma+\beta^i][n\alpha\gamma+\beta^i]$.

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