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Union Attitudes to Labor-saving Innovation: When Are Unions Luddites?

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The response of union utility to labor-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 wages and employment will rise or fall in response to innovation. Union opposition tends to occur when union preferences are weighted in favor of jobs and labor demand is perceived to be inelastic. Thus opposition is more likely with industry- or craft-based union organization in noncompetitive industries and is less likely with enterprise unionism in competitive industries.

I. Introduction

Labor 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. Accounts of labor resistance to major innovations are frequently publicized in the media, leading to a popular perception of unions as the modern Luddites. By way of contrast, in the industrial relations literature it is often argued that union cooperation

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is commonplace and that it may actually lower the costs of implementing new technology.[1]

Willman (1986, p. 44) cites evidence that union attitudes vary across countries and do affect the rate of diffusion of new technology. A diversity of union attitudes toward innovation within a country is highlighted by the British Workplace Industrial Relations Survey of 1984, the results of which are summarized in Daniel (1987) and analyzed in more detail in Dowrick and Machin (1993). Out of 775 plants surveyed, 6% of union representatives were reported to have been strongly resistant to technical change, 27% were slightly resistant, and union representatives from the remaining two-thirds of plants were reported as either slightly in favor or strongly in favor.

Our purpose here is to analyze the conditions that make union opposition or cooperation more likely. A dominant industrial relations view is characterized by Sorge and Streeck (1988, p. 35) as operating "on the premise that resistance to change . . . is caused by informal, fragmented, decentralized, disorderly industrial relations privileging conservative short-term over enlightened long-term interests of workers." They go on to argue that such resistance may be rational given a rigid division of labor and structural conditions that reduce exposure to competitive product markets. It is this possibility, that structural conditions may make resistance rational from the perspective of the individual union, that we explore here.

Labor-saving innovation provides an obvious potential threat to employment through "technological redundancy." It is definitionally true that, if output and wages are fixed, a labor-saving innovation will reduce demand for labor—in which case it may be expected to incur opposition from workers who earn rents or quasi rents. But both output and wages will usually change in response to innovation, and under some conditions they may rise sufficiently so as to leave the union better off. In attempting to identify those conditions that make innovation beneficial to the union we address the following questions: Does the structure of union organization matter, particularly whether the union is organized on a craft, firm, or industry basis? Does the opportunity to bargain over wages make the union more likely to accept innovation, or could postinnovation bargaining actually lead to reduced wages? Does the structure of the product market matter—for instance, the number of firms and the elasticity of product demand? Do union preferences matter, particularly the relative weights attached to employment and wages?

A major stream within the economics literature has focused on the different, but related, question of whether the presence of unionism affects

[1] See, e.g., Bemmels (1987); Flaherty (1987); and Simpson, Love, and Walker (1987).

either static or dynamic efficiency and productivity. Freeman and Medoff (1984), for instance, suggest that unions raise labor productivity not only because of increasing capital intensity induced by union wages but also because of increased efficiency in workplace organization due to voice/response effects. They suggest (p. 170) that "current empirical evidence offers little support for the assertion that unionization is associated with lower (or higher) productivity advance." Addison and Hirsch (1986, 1989), however, emphasize evidence that union presence reduces the rate of growth of total factor productivity. A number of such studies are summarized in Pencavel (1991). Although these studies tell us much about the impact of unions and union wages on innovation, we learn little about the impact of innovation on unions. While the determinants of union attitudes have been of concern to industrial relations, they appear to have been neglected in the economics literature.[2] For example, Freeman and Medoff (1984, p. 169) claim that, "because unions that succeed in blocking technological change go out of business, the general union attitude toward new technology is a far cry from the myth promulgated by the self-proclaimed critic," but they offer no guidance as to when or why union attitudes might vary. Our finding that the union attitude depends on both the structure of industrial relations and the structure of the product market may help to explain the diversity of econometric results concerning the net effect of unions on the rate of innovation.

Our analysis is restricted to the employment and wage effects of innovation. 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 important concerns that lie outside the scope of this article 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 this article, the only restriction on a union's utility is that it be increasing in the wage and in employment. Both Cournot and Bertrand equilibria with differentiated products and general numbers of firms are encompassed, as well as simple monopoly behavior. For most of this essay we allow for general demand conditions and for more than one factor of production. A consequence of our use of a nonparameterized model of interactions between oligopolistic firms and unions is that our formal results have to be stated in terms of a number of sufficient and/or necessary conditions. We do also analyze a linear parameterized model from which we can derive explicit solutions.

[2] One of the few economic analyses that does address this question is Carmichael and MacLeod (1993), who argue that multiskilling practices within Japanese firms reduce opposition by workers to technological change.

Drawing on both the general model and the simplified linear version, we are able to summarize the broad thrust of our results in table 1. In response to the question, "Will unions gain from labour-saving innovation?" we are, for instance, able to reply "yes, if wages are exogenous and labor demand is elastic," but "no, if labor demand is inelastic and a single union is able to set its own wage." The table is sprinkled liberally with "? yes" or "? no," where the question mark indicates that the conditions are necessary but not sufficient, or else that they are sufficient conditions only within the linear model. The phrases "less likely" and "more likely" indicate the direction in which a change from, say, an enterprise union to an industry union is likely to work. This tabulation of our results necessarily involves considerable simplification, so the reader should look to the later sections for formal propositions and proofs. The remainder of this section will attempt an intuitive explanation.

The important preliminary result that drives most of the subsequent analysis is that a labor-saving innovation will reduce employment if labor demand is inelastic and wages are exogenous. In these circumstances, unions that care about jobs will lose from innovation. It follows that a structural change that has the effect of decreasing the elasticity of demand for labor will make a union less likely to gain from innovation. We argue that an industry union will usually face less elastic demand than an enterprise union, inferring that the industry union will therefore tend to be more conservative in its attitude to innovation. Our conjecture that labor demand is typically less elastic at the industry level than at the firm level is supported

Table 1
Will Unions Gain from Labour-saving Innovation?

	Wage-setting Mechanism			
		Single Union		
	Exogenous Wages	Wage Setting	Bargaining	Multiple Unions, Bargaining
Union preferences:				
Weighted to wages	no effect	yes	? yes	? yes
Rent maximization	no effect	yes	? yes	? yes
Weighted to jobs	no effect	? no	? no	? no—less likely
Labour demand:				
Elastic	yes	yes	yes	. . .
Inelastic	no	no	? no	. . .
Union organization:				
Enterprise	more likely	. . .	. . .	. . .
Industry	less likely	. . .	. . .	. . .
Craft	less likely	. . .	. . .	. . .
Industry structure:				
Monopolistic	less likely	. . .	. . .	. . .
Competitive	more likely	. . .	. . .	. . .

by the findings of Hamermesh (1986), who reports on a variety of studies that typically yield estimates that industry-level labor demand is highly inelastic (six out of eight estimates are below 0.5, and four are below 0.3). There is further indirect support for this conjecture from the findings of Mishel (1986) that union wages are typically higher when they are bargained at industry rather than firm level.

We can extend this analysis to suggest that craft-based unions will also tend to be more conservative than enterprise unions. Although the formal analysis in the following sections deals only with enterprise and industry unions, it is straightforward to provide a similar treatment of craft unionism, as in Dowrick (1993). Craft organization within a firm is likely to be based on complementary groups according to the arguments of Horn and Wolinsky (1988). In this case, the craft union will face less elastic demand than the enterprise union; hence, it will tend to be more conservative.

The above arguments are straightforward when wages are exogenous. When unions bargain over wages, however, they commonly win some compensation for job losses, which should make the union more accepting of innovation. In particular, a union whose preferences are weighted in favor of wages might favor innovation if it can gain even a moderate wage raise in compensation for job losses. It is not obvious, however, that the union will necessarily be able to win a compensating wage increase after innovation has occurred if, as often is the case, unions and employers are unable to credibly commit to postinnovation wages. Moreover, union objectives are not necessarily dominated by wages. Pencavel (1991, p. 51) surveys research on union preferences and reports that "most studies find a greater weight attached to employment, greater, that is, compared with what rent maximization would imply." This implies that unions facing technological redundancy will typically require a rather large compensating wage increase and that the process of determining postinnovation wages is therefore of considerable importance.

A case that has attracted much attention in the theoretical literature, although we doubt its empirical relevance, is that of the "monopoly," or wage-setting, union. We find that the monopoly union favors innovation if and only if demand is elastic, exactly as in the case of exogenous wages, because it is indifferent to a marginal change in the optimally chosen wage. It follows that a monopoly union that aims to maximize rents will always favor innovation because it will never choose to be on an inelastic section of the labor demand curve.

In the subsequent analysis wage determination is treated more realistically, being subject to bargaining between union and employer. Here it becomes more difficult to state fully general results, but we do find support for the proposition that a union is less likely to gain from innovation if other unions in the industry are also bargaining over wages. This is because an enterprise union stands to gain an increased share of industry employment when its employing firm innovates and becomes more competitive, but that competitive gain is reduced if other firms can respond by cutting their costs through bargaining down their union wages.

We are able to confirm these results with a simplified linear model. In particular, with multiple union bargaining we are able to demonstrate that a necessary condition for union opposition is that the union place particular emphasis on jobs, over and above that implied by rent maximization. We go on to show that a more competitive industry, with a large number of firms, will present enterprise unions with more elastic demand than will a monopolistic industry, with one or a few firms. It follows that opposition to innovation is most likely to occur where industry- or craft-based unions operate within a monopolistic industry, while opposition is less likely where enterprise unions operate within more competitive industrial structures.

Although we do not analyze 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; indeed, we are able to specify conditions under which either unit wage costs will fall or actual wages per worker will fall. These findings mirror the ambiguous conclusions of the literature concerned with the impact of union rent-seeking behavior on firms' incentives to invest.[3]

The model structure is set out in Section II. Section III concerns the product market and labor demand. In Section IV, we set out the framework for analyzing the attitudes of unions towards innovation. Sections V–VII analyze the cases of exogenous wages, the wage-setting union, and enterprise wage bargaining, respectively. Further results are obtained in Section VIII by the use of an illustrative example based on Cournot competition and linear demand. Finally, Section IX contains our concluding remarks.

II. Model Structure and the Sequence of Decisions

The source of the labor-saving technological improvement is taken as exogenous to the model. Firm and union behavior incorporates three stages of decision. Decisions are taken at each stage anticipating the outcome of

[3] Grout (1984), e.g., finds that unions discourage investment when bargaining covers both wages and employment and the union is unable to precommit 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 labor can induce labor-saving innovation, or in Anderson and Devereux (1988), where strategic precommitment 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.

subsequent stages. We first describe the game between firms and enterprise level unions.

Stage 1. Each union determines its attitude toward implementation of a labor-saving innovation that would improve labor efficiency within the firm. In making this assessment, each enterprise level union takes the technology of other firms as given.

Stage 2. 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 unionized, wage bargaining takes place simultaneously across firms with each firm and its union taking the wages in other firms as given. There is a noncooperative Nash equilibrium in wage bargaining across firms.[4] If a firm is not unionized, we assume that workers receive their opportunity wage.

Stage 3. 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 noncooperative oligopolistic game (which could be Cournot or Bertrand) in the output market.

The game with an industrywide union is similar in stage 1, 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.

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 reflects a common observation that wage contracts are fixed in the short term and evidence (e.g., Oswald 1985) that employers do not typically make explicit deals with unions over jobs.[5]

III. Product Market Equilibrium and the Demand for Labor

We consider changes in technology that augment a firm's labor input. More specifically, we define a firm-specific technology parameter, θ^i, that augments firm i's actual labor input, denoted by L^i, to produce $\ell^i = \theta^i L^i$ units of effective labor input. An improvement in the labor-saving tech-

[4] Davidson (1988) shows that this is the subgame perfect equilibrium in a four-party game where unions and firms alternate wage offers until the other side accepts. This solution concept is used by Dowrick (1989) for n firms.

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

nology applicable to firm i is modeled by a small increase in θ^i.[6] The price of effective labor (the "effective wage") in firm i is denoted by $\omega^i = w^i/\theta^i$, where w^i represents the actual wage.

In the Appendix we detail a general treatment of interaction between firms in the product market, encompassing either Bertrand or Cournot competition with differentiated products and general demand. We also allow for more than one factor of production. For our purposes here it is sufficient to note that both profits and effective labor demand can be derived as functions of the vector of effective wages $\underline{\omega} = (\omega^1, \omega^2, \ldots, \omega^n)$. Considering the profit function, denoted by $\pi^i(\underline{\omega})$, we take the usual case in which an increase in the effective wage in firm i decreases own profits and increases profits in other firms. Using subscripts to represent partial derivatives, this implies

$$\pi^i_{\omega i} < 0 \text{ and } \pi^i_{\omega j} > 0 \quad \text{for all } j \neq i. \tag{1}$$

Turning to the labor demand function, effective labor demand is decreasing in the own effective wage. The sign of cross-wage effects can, however, be either positive or negative depending on the nature of strategic interaction between firms in the product market. The most usual case, which certainly holds when demand is linear, is for a rise in the effective wage within one firm to shift the oligopolistic equilibrium to a new position where that firm has lower output and the rival firm has both higher output and higher employment. In this case, we refer to labor as substitutable between firm i and firm j. As shown in the Appendix, this case arises when the firm's products are strategic substitutes in output space, in the sense that an increase in the output of any one firm reduces the output of the other firms. We do, however, allow for the less usual case where labor is complementary across firms, a case that might arise if the firms' products are strategic complements (as defined in the Appendix):

$$\left.\begin{array}{l} \ell^i_{\omega i} < 0; \qquad \ell^i_{\omega j} > 0 \text{ if substitutable labor;} \\ \qquad\quad \ell^i_{\omega j} < 0 \text{ if complementary labor.} \end{array}\right\} \tag{2}$$

[6] 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.

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

$$L^i(w^i, \theta^i, \underline{\omega}^j) = \ell^i(\omega^1, \omega^2, \ldots, \omega^n)/\theta^i. \tag{3}$$

From (2) and (3), 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:

$$L^i_{wi} = \ell^i_{\omega i}/[\theta^i]^2 < 0 \qquad \text{and} \qquad L^i_{\omega j} = \ell^i_{\omega j}/\theta^i. \tag{4}$$

Letting $\eta \equiv -w^i L^i_{wi}/L^i$ denote the absolute elasticity of labor demand with respect to own wage, it follows from (3) and (4) that η is equal to the corresponding elasticity of effective labor demand with respect to own effective wage and can thus be written as a function of effective wages:

$$\eta \equiv -w^i L^i_{wi}/L^i = -\omega^i \ell^i_{\omega i}/\ell^i = \eta(\omega^i, \underline{\omega}^j). \tag{5}$$

In considering union attitude toward innovation, 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 labor-saving innovation has two opposing effects. It reduces the effective wage, which tends to increase the firm's demand for effective labor, but the efficiency of each worker rises, and so the overall effect on the demand for workers is ambiguous. As we show in proposition 1, whether labor demand rises or falls depends critically on the elasticity η.

PROPOSITION 1. Labor demand increases (decreases) in response to a labor-saving innovation if the own-wage response of labor demand is elastic (inelastic).

Proof. From (3), (4), and (5),

$$L^i_{\theta i} = -[\omega^i \ell^i_{\omega i} + \ell^i]/[\theta^i]^2 = [L^i/\theta^i][\eta - 1]. \tag{6}$$

Q.E.D.

Proposition 1 tells us that an own-wage elasticity of unity provides the dividing line between a positive or negative response of labor demand to the innovation. If the own-wage elasticity is unity, a small proportionate reduction in the effective price of labor gives rise to the same proportionate increase in the firm's demand for effective labor. In this case, the increased demand for effective labor (brought about by a labor-saving innovation) can just be met by employing the existing workers, who are now more efficient.[7]

The effect of innovation on the demand for labor 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 midpoint and less than unity below the midpoint. Applying proposition 1, it is evident that a labor-saving innovation causes a clockwise rotation around the midpoint of the labor demand curve. In this special case, it can be seen that labor-saving innovation makes the labor demand curve steeper; that is to say, it has the effect of reducing the own-wage elasticity of labor demand. Indeed, this result is generally true as long as the labor demand elasticity is increasing in the wage. Such innovation-induced changes in the elasticity of labor demand will be seen to have an important influence on stage 2 wage bargaining.

IV. Union Attitudes to Innovation

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

$$V^i = V(w^i, L^i); \quad V_w > 0,\ V_L > 0 \text{ if } w^i > v^i; \quad V^i = 0 \text{ if } w^i \le v^i. \tag{7}$$

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 industrywide union by $V^I \equiv \sum_i V^i$.

The willingness of a union to trade off jobs for a higher wage can be 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:

$$\phi(w, L) = wV_w/LV_L = \varepsilon_w^V/\varepsilon_L^V, \tag{8}$$

where $\varepsilon_L^V \equiv (L/V)V_L$ and $\varepsilon_w^V \equiv (w/V)V_w$. Taking into account the response

[7] Dobbs, Hill, and Waterson (1988) obtain a similar result using a cost function and defining the elasticity of demand conditional on output.

of labor demand, we then obtain the effect on union utility of an increase in the own wage, holding other wages constant:

$$dV^i/dw^i\|_{\omega j} = V^i_{wi} + V^i_{Li}L^i_{wi} = \varepsilon^{Vi}_{Li}(V^i/w^i)[\phi - \eta]. \qquad (9)$$

This tells us that union utility is increasing in the own wage if and only if (iff) 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 labor 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 labor 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:

$$w^i = w^i(\theta^i, \underline{\omega}^j), \quad i = 1, \ldots, n, j \neq i. \qquad (10)$$

The Nash equilibrium in wage determination is the solution to these n wage reaction functions. Substituting the labor demand function (3) and the wage reaction function (4) into the union utility function, the total effect of an increase in θ^i on union utility is

$$\frac{dV^i}{d\theta^i} = \frac{dV^i}{dw^1}\cdot\frac{dw^i}{d\theta^i} + V^i_{Li}L^i_{\theta i} + \sum_j V^i_{Li}L^i_{\omega j}\frac{d\omega^j}{d\theta^i}, \quad j \neq i. \qquad (11)$$

The first term in (11) 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 labor demand.

Using the notation $\varepsilon^x_y \equiv (x_y)(y/x)$ to represent the partial elasticity of $x(y, \ldots)$ 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 (11) 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

$$E^{\omega i}_{\theta i} \equiv \frac{\omega^i}{\theta^i}\cdot\frac{dq^i}{dw^1} = E^{wi}_{\theta i} - 1. \qquad (12)$$

Substituting (6) and (9) into (11), we obtain (13a); then using (12) we obtain (13b):

$$\frac{dV^i}{d\theta^i} = \frac{V^i}{\theta^i}\,\varepsilon_{Li}^{Vi}\{(\phi - \eta)E_{\theta i}^{wi} + \eta - 1 + \sum_j \varepsilon_{\omega j}^{Li}E_{\theta i}^{\omega j}\}; \tag{13a}$$

$$\frac{dV^i}{d\theta^i} = \frac{V^i}{\theta^i}\,\varepsilon_{Li}^{Vi}\{(\phi - \eta)E_{\theta i}^{\omega i} + \phi - 1 + \sum_j \varepsilon_{\omega j}^{Li}E_{\theta i}^{\omega j}\}. \tag{13b}$$

Since ε_{Li}^{Vi} 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 (13) depend on wage-setting behavior. 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 unionized, or (ii) there are n independent enterprise unions; or else an industrywide union represents all workers in the industry and bargains either (iii) with each firm individually or (iv) with a central employer body.

V. 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 labor can be written as $\ell \equiv \Gamma(w)\theta L$, where $\Gamma(w)$ is the "labor efficiency" function. As in Stiglitz (1987), a profit-maximizing firm will set the wage where the elasticity of the efficiency wage function, $w\Gamma'(w)/\Gamma(w)$, is unity. Government regulation of wages according to nonmarket criteria provides a further situation in which industry wages might be independent of technological innovation.

If a labor-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 labor.

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

Proof. (i) Since wages are independent of technology, $E_{\theta i}^{wi} = 0$. The sign of (13a) is therefore the sign of $\eta - 1$. Q.E.D.

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 industrywide 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 industrywide union is more likely than an enterprise-level union to (i) lose from innovation if labor is substitutable across firms and (ii) gain from innovation if labor is complementary across firms.

Proof. Since wages are exogenous, it follows from (7) 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 $k = 1, \ldots, n$, $k \neq j$, of a small innovation in firm i is

$$dL^I/d\theta^i = L^i_{\theta i} + \sum_{k \neq i} L^k_{\omega i}(d\omega^i/d\theta^i), \tag{14}$$

where $d\omega^i/d\theta^i = -w^i/[\theta^i]^2 < 0$. The corresponding effect of an industrywide innovation, represented by a change in $\theta = \theta^i$ for $i = 1, \ldots, n$, 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 (14). Results (i) and (ii) follow because the second term of (14) is negative iff $L^k_{\omega i} > 0$ (substitute labor). In this case, it is possible for the anticipated industrywide employment effects to be negative while the firm-specific effects are all positive (and vice versa for the case of complements). Q.E.D.

We have argued in Section I that there is empirical support for our conjecture that labor is usually substitutable across firms. In this case, 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 labor; so workers in firm i are made worse off. Since an industrywide union is concerned about the utility of all workers, an industrywide union would be then more likely to oppose an innovation than would a union located in the innovating firm itself.

VI. 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 labor 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 that sets a uniform industry wage $w = w^I$. In the first case, the wages in the nonunion sector are assumed to be given exogenously by the opportunity cost of labor.

PROPOSITION 4. If there is a single wage-setting union in an industry, and if the wage is set above the reservation level, a necessary and sufficient condition for the union to oppose innovation is that the union's elasticity of substitution, ϕ, is less than unity.

Proof. The final term in (13a) and (13b) is zero since $E^{\omega j}_{\theta i} = 0$. The wage-setting union chooses $w = \text{argmax}\ V(w^i, L^i)$ subject to $L^i = L(w^i, \theta^i, \underline{\omega}^j)$, 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 (9). Thus from (13a) and (13b), $dV^i/d\theta^i < 0$ iff $\eta - 1 < 0$, or, equivalently, iff $\phi - 1 < 0$. Q.E.D.

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

In general the elasticities of labor demand and of substitution are determined endogenously. If, however, either labor demand or the union indifference curve is everywhere either elastic or inelastic, this condition will determine the union's attitude toward innovation. One case in particular deserves attention, the rent-maximizing union. It has been argued (as discussed in Pencavel [1985]) that a union that can costlessly redistribute income among 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 labor 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 that is a rent maximizer or, more generally, is non-risk-averse, will not lose from labor-saving innovation.

Proof. Convexity of $u(w)$ implies $u'(w) \geq [u(w) - u(v)]/[w - v]$. Thus from (8), $\phi = wu'(w)/[u(w) - u(v)] \geq w/[w - v]$. Since $\phi > 1$, the result follows from proposition 4. Q.E.D.

VII. 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 noncooperative 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

$$w^i = \operatorname{argmax} Z^i(w^i, \underline{\omega}^j)$$
$$\equiv \alpha \ln\{V^i(w^i, L(w^i, \theta^i, \underline{\omega}^j))\} + [1-\alpha]\ln\{\pi^i(\omega^i, \underline{\omega}^j)\}; \quad (15)$$
$$0 < \alpha \leq 1.$$

We normalize 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 both employment and 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, the wage w^i satisfies the first-order condition (using $d\pi^i/dw^i = \pi^i_{\omega i}/\theta^i$)

$$Z^i_{wi}(w^i, \theta^i, \underline{\omega}^j) = \alpha(dV^i/dw^i)/V^i - (1-\alpha)h^i(\omega^i, \underline{\omega}^j)/w^i = 0, \quad (16)$$

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 (1). 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 unionized firms, the n conditions (16) define the Nash equilibrium wage relationships $w^i = w(\theta^i, \underline{\omega}^j)$ for $j \neq i$ and $i = 1, \ldots, n$. We use (9) to express (16) in the convenient form

$$Z_w(w, \theta, \underline{\omega}^j) = (\alpha/w)[\varepsilon^V_L(\phi - \eta) - h^i(\omega^i, \underline{\omega}^j)(1-\alpha)/\alpha] = 0. \quad (17)$$

Typically one might expect that an increase in labor 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 labor costs.[8] Proposition 6 applies in these circumstances.

PROPOSITION 6. If there is a single union in an industry, and a labor-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 labor demand is inelastic, and (ii) a sufficient condition for union opposition is that the union's elasticity of substitution $\phi < 1$.

Proof. With only one union, $E_{\theta i}^{\omega j} = 0$, so the final term of (13) is zero. Since $(1 - \alpha)h^i \geq 0$, (17) implies $\phi - \eta \geq 0$. Thus (13a) is positive if $\eta \geq 1$ and $E_\theta^w \geq 0$; (13b) is negative if $\phi < 1$ and $E_\theta^\omega < 0$. Q.E.D.

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

$$\varepsilon_{Li}^{Vi} = 1 \Rightarrow V(w^i, L^i) = L^i g(w^i). \qquad (18)$$

This utility function has the useful property that $\phi(w^i) = wg'(w^i)/g(w^i)$ is a function solely of the union's own wage. Note that this formulation is still sufficiently general to encompass the expected-utility, Stone-Geary, and rent-maximizing functional forms. Setting $\varepsilon_{Li}^{Vi} = 1$ in (17) gives the revised first-order condition

$$(w/\alpha)Z_w(w, \theta, \underline{\omega}^j) = [\phi(w) - H(\omega, \underline{\omega}^j)] = 0, \qquad (19)$$

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 labor 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 $w_{\theta i}^i(\theta^i, \underline{\omega}^j) = -Z_{w\theta}/Z_{ww}$ and (19), the partial elasticity $\varepsilon_{\theta i}^{wi}$ of the wage w^i with respect to innovation in firm i (holding other wages fixed) is

$$\varepsilon_{\theta i}^{wi} \equiv (\theta^i/w^i)w_{\theta i}^i = (H_\omega/\theta)/[(H_\omega/\theta) - \phi_w], \qquad (20)$$

where $Z_{ww} < 0$ implies $(H_\omega/\theta) - \phi_w > 0$. The partial elasticity of the effective wage is given by $\varepsilon_{\theta i}^{\omega i} = \varepsilon_{\theta i}^{wi} - 1$ (analogously with [12]). Thus, using (20), we obtain

[8] Assumption 1 rules out the technically feasible possibility, as in Seade (1985) or Stern (1987), that firm profits are increasing in own costs.

$$\varepsilon_{\theta i}^{\omega i} \equiv \phi_w/[(H_\omega/\theta) - \phi_w]. \tag{21}$$

If only one firm is unionized, then wages in other firms remain fixed, and (21) implies that the effective wage in the unionized 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 $\varepsilon_{Li}^{Vi} = 1$. Under wage bargaining, 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

$$d\omega^i/d\theta^i = \omega_{\theta i}^i + \sum_j (\partial\omega^i/\partial\omega^j)(d\omega^j/d\theta^i). \tag{22}$$

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

$$d\omega^j/d\theta^i = (d\omega^j/d\omega^i)[d\omega^i/d\theta^i], \tag{23}$$

where, allowing all wages to vary, $d\omega^j/d\omega^i = \partial\omega^j/\partial\omega^i + \sum_k (\partial\omega^j/\partial\omega^k) \times (d\omega^k/d\omega^i)$ for $k \neq i \neq j$. Substituting (23) into (22) and using (21), the total elasticity of ω^i with respect to θ^i is

$$E_{\theta i}^{\omega i} = \varepsilon_{\theta i}^{\omega i}/(1 - \psi) = \phi_w/(1 - \psi)[(H_\omega/\theta) - \phi_w], \tag{24}$$

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. The stability requirement of the Nash equilibrium in wages ensures $|\psi| < 1$ (the indirect effect of an increase in own effective wage through the wage reactions of other firms is less than one in absolute value). Thus $E_{\theta i}^{\omega i} < 0$ iff $\phi_w < 0$. Q.E.D.

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. We therefore expect that the effective wage will typically fall with the introduction of labor-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.

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 (24) into $E_{\theta i}^{wi} = E_{\theta i}^{\omega i} + 1$ (from [12]) gives

$$E_{\theta i}^{wi} = [(1 - \psi)H_{\omega}/\theta + \psi\phi_{w}]/(1 - \psi)(H_{\omega}/\theta - \phi_{w}), \qquad (25)$$

where $|\psi| < 1$. Since the denominator of (25) is positive (see [20] and [24]), the sign of the own wage response is the sign of the numerator of (25), which may, in general, be either positive or negative.

If there is a single wage-setting union ($\alpha = 1$ and $\psi = 0$), then H equals the elasticity of labor demand, and expression (25) 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 precisely the condition for the innovation to reduce the elasticity of labor demand at any given wage. The diminution of the threat of job losses encourages the union to choose a higher wage. This condition holds for certain if the labor demand function is linear or concave, and it holds for a wide class of convex functions.[9] 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 nonzero 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 the presence of a wage-bargaining union need not necessarily lower firms' returns to innovation. It contrasts with the result for short-term bargaining over wages and jobs, as in Grout (1984), where there is a presumption that unions do reduce incentives to innovate.

Industrywide 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 labor demand as represented by the final term in the expressions (13). Recognizing that firms affect each other's decisions only though changes in effective wages, this final term in (13) can be expressed as

$$\sum_{j} \varepsilon_{\omega j}^{Li} E_{\theta i}^{\omega j} = \sum_{j} \varepsilon_{\omega j}^{Li} E_{\omega i}^{\omega j} E_{\theta i}^{\omega i}. \qquad (26)$$

To sign (26), recall that the last term, $E_{\theta i}^{\omega i}$, must be negative if the firm is to regard the innovation as profitable. The first term, $\varepsilon_{\omega j}^{Li}$, is positive if labor

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

is substitutable between firm i and firm j and negative if labor is complementary. The middle term, $E^{\omega j}_{\omega i}$, represents the slope of the wage reaction function and is in general ambiguous in sign. However, assuming that an increase in labor demand leads to an increase in the bargained wage, the middle term can be shown to have the same sign as the first term: if labor is substitutable, a rise in the wage in firm i will lead to an increase in output in firm j, which raises firm j's demand for labor and the bargained wage w^j; conversely, if labor is complementary, a rise in the wage in firm i leads to a reduction in the demand for labor in firm j, and w^j falls; thus expression (26) is negative overall, whether labor is substitutable or complementary. 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.

VIII. Wage Bargaining, Union Structure, and Industry Structure: A Linear Cournot Example

In this section, we analyze the effects of moving from enterprise to industry unionism under wage bargaining, complementing the analysis of Section V where wages were assumed exogenous. We make some simplifying assumptions, including Cournot competition in the output market and linear demand, which allow us to derive explicit solutions and yield some additional results concerning the number of firms in the industry and union attitudes to the risk of job loss. A more general treatment of wage bargaining in the context of an industrywide union is found in an earlier version of this essay (Dowrick and Spencer 1991). Comparisons of wage outcomes for industrywide bargaining and enterprise-level bargaining are provided allowing for general functional forms. The earlier version also contains a more detailed derivation of the results in this section.

In considering bargaining by an industrywide 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. The union coordinates its bargaining strategy across all firms, so it knows there will be a common wage. We can then define the utility of the industry union $V^I = V(w, L^I)$, where w is the common industry wage and L^I is industry employment. Furthermore, the industry union threat point is zero as in the case of the firm union because failure to reach an agreement in one firm will result in an industrywide strike.[10]

[10] We use a simple model of industry bargaining because our principal concern is not so much with the wage bargaining outcome as with the union's attitude to innovation. A different model, as in Davidson (1988), would allow the union to negotiate separate deals with each employer, in which case the union's threat point in negotiations with firm i would depend on the response of employment in the

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 labor as the only input. Firm i's profit is $\pi^i = (p - \omega^i)y^i$, where output is measured in the same units as effective labor, so $y^i = \theta^i L^i$. Given Cournot competition in stage 3, output y^i for $i = 1, \ldots, n$ satisfies the first-order condition

$$\partial\pi^i/\partial y^i = -2by^i - b\{\sum_j y^j\} + a - \omega^i = 0 \quad \text{for } j \neq i. \tag{27}$$

Solving the n equations (27), firm i's equilibrium output and profits in stage 3 are a function of the predetermined effective wages:

$$\left.\begin{aligned} y^i &= [a + \sum_j \omega^j - n\omega^i]/(n+1)b \\ \text{and} \qquad \pi^i &= b(y^i)^2 \quad \text{for } j \neq i. \end{aligned}\right\} \tag{28}$$

In order to derive tractable results for stage 2 wage bargaining, we assume that union utility takes the Stone-Geary functional form: $V^i = (w^i - v^i)^\gamma L^i$, where $\gamma > 0$. From (8), 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. We note the evidence of Pencavel (1991) that γ is usually less than unity.

We are now in a position to derive explicit solutions to the wage-bargaining problem using the first-order conditions in (19) for enterprise unions and equivalent conditions for the industry union. We consider four cases, indexed by x. First, there is a single enterprise union, and wages in all other firms are set at a uniform reservation wage, v. Second, each firm in the industry bargains with its own enterprise union. Third, an industry union bargains separately with each firm, each firm taking the wages in other firms as exogenous. Fourth, an industry union bargains over a common industry wage with a representative of all firms who aims to maximize joint profits. The general form for the equilibrium industry wage, w^x, defining the effective reservation wage as $\nu = v/\theta$, is

$$w^x = \nu + \alpha\gamma(a - \nu)/\beta^x, \quad x = 1, \ldots, 4. \tag{29}$$

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rest of the industry to a strike in firm i. This threat point effect will enhance (reduce) the union's wage-bargaining position in the case of strategic substitutes (complements), but it does not alter substantially the thrust of our analysis with regard to innovation.

We can also derive the general form for union utility in equilibrium under each bargaining structure. We are interested in the comparative statics for union utility with respect to changes in the technology parameter θ. It is most convenient to present these in elasticity form as E_θ^{Vx}:

$$E_\theta^{Vx} = (\gamma - 1) + (\gamma + 1)[\nu/(a - \nu)]Z^x, \quad x = 1, \ldots, 4. \qquad (30)$$

The values of β^x and Z^x for each of the four cases are listed in table 2.

Comparison of the two industry union outcomes with the two enterprise union outcomes—using (29) and the values of β^x in table 2—gives the ranking of wage levels when there are two or more firms in the industry: $w^4 > w^3 > w^2 > w^1$. Wages are highest when unions and firms coordinate their bargaining. Wages are lower if employers do not coordinate their bargaining because firms act "tougher" when they do not recognize that any concessions they make will be matched by similar concessions from their rivals. Wages are lower still when unions do not coordinate 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 unionized firm faces more intense competition if wage levels in rival firms do not follow any upward movement in the union wage.

The results in the final column of table 2 allow us to examine the relationship between the parameters of the model 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 E_θ^{Vx} and can make it negative for some constant values of the other parameters.

PROPOSITION 8. A necessary condition for a union to oppose innovation is that the Stone-Geary parameter γ is less than unity.

Proof. If $\gamma > 1$, the first term in (30) is positive. The second term must always be positive because strictly positive output and employment requires, from (28), that $a > \nu$. Q.E.D.

Table 2
Comparing Effects of Bargaining Structures on Wages and Union Utility

Bargaining Structure	Index $x =$	$\beta^x =$	$Z^x =$
Single enterprise union	1	$n[\alpha\gamma + 2 - \alpha]$	n
n enterprise unions	2	$\alpha\gamma + n(2 - \alpha)$	$\dfrac{(n+1)\alpha\gamma + n^2(2-\alpha)}{(n+1)\alpha\gamma + n(2-\alpha)}$
Industry union bargaining with individual enterprises	3	$\alpha(\gamma + 1) + 2n(1 - \alpha)$	1
Industry union bargaining with industry body	4	$\alpha(\gamma + 1) + 2(1 - \alpha)$	1

In particular, we get the strong result from this model that a rent-maximizing or risk-neutral union ($\gamma = 1$) 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.

PROPOSITION 9. A union is more likely to oppose innovation under the following circumstances: (i) the smaller the number of firms are in the industry (with enterprise unions); (ii) the lower the value of the Stone-Geary parameter γ is; or (iii) the higher the demand parameter a or the lower the effective reservation wage, ν, is.

Proof. From (30) and table 2, $d(E_\theta^{Vx})/dn > 0$ for $x = 1, 2$, proving (i); $d(E_\theta^{Vx})/d\gamma > 0$, $d(E_\theta^{Vx})/d\nu > 0$, and $d(E_\theta^{Vx})/da < 0$ for $x = 1, \ldots, 4$, proving (ii) and (iii). Q.E.D.

Part i of the proposition is related to our proposition 6, which states that inelastic labor demand is a precondition for union opposition. Given labor that is substitutable across firms, any reduction in the number of firms in the industry has the effect of lowering the elasticity of derived labor demand at firm level. This effect is relevant only if unions are organized on an enterprise basis.

Part ii of the proposition indicates that the loss of employment implied by innovation (if labor demand is inelastic) outweighs the wage gains for a union whose utility function is heavily weighted in favor 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, ($\nu > a/2$), the wage will always be in the upper (elastic) section of the industry labor demand schedule. Hence labor demand at the level of the firm will always be elastic, and unions will always gain from innovation. Reductions in the ratio ν/a will lower the bargained wage toward the inelastic demand region.

PROPOSITION 10. (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 unionized.

Proof. From (30) and table 2, noting that $1 > Z^2 > n$ for all $n > 1$, we can rank the elasticity of union utility to innovation under the four bargaining structures as follows: $E_\theta^{V4} = E_\theta^{V3} < E_\theta^{V2} < E_\theta^{V1}$. Q.E.D.

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

IX. Concluding Remarks

In Section V we analyzed the effect of centralizing union organization from firm to industry level in the context of exogenous wages and concluded that such a move will increase union opposition to innovation if labor is substitutable across firms but will decrease opposition if labor is complementary. In Section VIII we found that the first part of this conclusion still holds under wage bargaining with linear demand (which implies substitutable labor). It seems likely that the analysis of union centralization could be extended to the case of multiunionism within a firm or plant. Where union divisions reflect complementary labor, we would expect craft unions to be less in favor of innovation than an encompassing union. Such a hypothesis would help explain the perception, referred to in the introduction, that fragmented craft unionism is inimical to technical change.

We can take the analysis of union structure one stage further, along the lines of Calmfors and Driffill (1988), who find a nonmonotonic relationship between the degree of centralization of wage-bargaining and macroeconomic wage flexibility. We can speculate that a union body that represents all industries in an economy, such as the peak union bodies that negotiate with government and employers in Sweden or Australia, might view innovation more favorably 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 become highly 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. It follows that the relationship between union attitudes to innovation and the degree of centralization of union decision making may be nonmonotonic: an industry-level union is the least likely to welcome innovation (at least in the case where labor is substitutable across firms), whereas either a firm-level union or a peak union body are more likely to view the innovation more favorably.

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 union attitudes to innovation. Rather, it is the structure of union organization and the underlying preferences toward wages and employment that is important. A union that can bargain over wages is likely to oppose innovation only if it places relatively high 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.

A reasonable prediction from our analysis 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 labor-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 toward innovation. Furthermore, we note the arguments of Carmichael and MacLeod (1993) that union opposition is likely to be reduced by multiskilling, as practiced in Japanese firms, which reduces the anticipated cost to workers of loss of employment in one craft or set of skills.

These various arguments suggest that the social costs of union opposition to innovation might be minimized by two radically different sets of institutions and policies. On the one hand, costs are likely to be lower in a setting where industries are competitive—for instance, where firms compete on the world market—and where unions are organized by enterprise rather than by industry or craft. In such a situation unions are likely to face elastic labor demand because they are, in effect, competing with each other for shares in industry employment. So it is individually rational for each union to cooperate with its employing firm in implementing labor-saving innovation. On the other hand, union cooperation may also emerge in a setting where union decision making and bargaining take place at the level of the national economy and where unemployment insurance and retraining opportunities are provided. These alternatives may be loosely labeled the "liberal" and the "corporatist" approaches to labor markets and industrial relations, typified by the United States and Sweden, respectively. Either approach appears to have considerable advantages in terms of technological progress over the (pre-Thatcher) "British disease" of industry- and craft-based unionism in monopolistic, protected industries.

Appendix

Derivation of Labor Demand and Profit Function under Oligopolistic Competition

Cost-minimizing choice of inputs, given the technology θ^i, 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 $R^i(y^1, y^2, \ldots, y^n)$, 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 i chooses its decision variable (price if Bertrand, output if Cournot) to maximize its own profit, given by $\pi^i = R^i(y^1, y^2, \ldots, y^n) - C^i(y^i, \omega^i)$.

Now using the conjectural variation approach, we can express the first-order conditions determining output levels for both market structures as

$$\partial\pi^i/\partial y^i = R^i_i + \sum_{k\neq i} R^i_k\mu - C^i_{yi} = 0, \tag{A1}$$

where subscripts denote partial derivatives and μ denotes each firm's conjecture as to a rival's output response, dy^j/dy^i (zero if Cournot, negative if Bertrand). Assuming the second-order and uniqueness conditions hold, conditions (A1) 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: $y^i = y^i(\underline{\omega})$ where $\underline{\omega} = (\omega^1, \omega^2, \ldots, \omega^n)$. Standard comparative static analysis shows that own output is always decreasing in own effective wage: $\partial y^i/\partial\omega^i \equiv y^i_i < 0$, but the cross effects, $\partial y^i/\partial\omega^j \equiv y^i_j$ where $i \neq j$, can take either sign. We give further consideration to the sign of the cross effects after deriving the demand functions for effective labor.

Let $y^i = f^i(\ell^i, K^i)$ represent the production function of firm i where K^i denotes the quantity of some other input which we label "capital." Assuming that the production function is homogeneous of degree λ^i, we can write $y^i = (\ell^i)^{\lambda i} f^i(\ell, k^i)$, where $k^i = K^i/\ell^i$, the capital to effective labor ratio, depends only on the effective factor price ratio ω^i/ρ^i. Rearranging this expression and imposing the equilibrium levels of output define firm i's demand for effective labor as a function of the effective wage in each firm:

$$\ell^i = [y^i(\underline{\omega})/h(k^i(\underline{\omega}))]^{1/\lambda i} \equiv \ell^i(\underline{\omega}), \tag{A2}$$

where $h^i(k) \equiv f^i(1, k^i)$ and the arguments in ρ^i are again omitted.

It follows from (A2) (noting that $\partial k^i/\partial\omega^i > 0$) that each firm demands fewer effective labor units as its own effective wage rises, both because it substitutes away from labor by increasing its capital usage per unit of output and because its equilibrium level of output falls. Thus, using subscripts to denote partial derivatives,

$$\ell^i_{\omega i} = [y^i/h(k^i)]^{(\lambda-1)/\lambda}\cdot[h(k^i)y^i_i - y^i h'(k^i)dk^i/d\omega^i]/\lambda[h(k^i)]^2 < 0. \tag{A3}$$

Similarly, the cross-wage effect is given by

$$\ell^i_{\omega j} = [y^i/h(k^i)]^{(\lambda-1)/\lambda}\cdot y^i_j/\lambda h(k^i) < 0 \quad \text{iff } y^i_j < 0. \tag{A4}$$

As (A4) shows, an increase in the effective wage ω^j in firm j increases the demand for effective labor in firm i, making $\ell^i_{\omega j} > 0$, if and only if output in firm i rises ($y^i_j > 0$). We say that labor is "substitutable" across firms if $\ell^i_{\omega j} > 0$ and "complementary" if $\ell^i_{\omega j} < 0$.

It is useful to establish the link between these cross-wage effects in labor demand and the terminology of "strategic substitutes" and "strategic complements" that is commonly used in the industrial organization literature with reference to interactions in output markets. To do this, we first recognize that an increase in the rival's effective cost of labor (holding own costs constant) affects own output entirely through its effect in reducing the rival's output:

$$y^i_j = (dy^i/dy^j)y^i_j, \tag{A5}$$

where dy^i/dy^j represents the total effect of an increase in y^j on y^i allowing the outputs of all firms to vary. If the partial effect $\partial y^i/\partial y^j$ is negative (holding other outputs fixed), then, under Cournot competition, product i is referred to as a strategic substitute for product j in output space—that is, firm i's reaction function slopes downward. The partial effect, $\partial y^i/\partial y^j$, has the same sign as the total effect, dy^i/dy^j, as long as the direct effect dominates the indirect effects of changes in other outputs on firm i's output, $\sum_{k\neq i}(\partial y^i/\partial y^k)(dy^k/dy^j)$. This condition is usually imposed as a requirement for stability of the Nash equilibrium. In this case, $\partial y^i/\partial y^j < 0$ implies $y^i_j > 0$ from (A5) and $\ell^i_{\omega j} > 0$ from (A4). Thus, if products are strategic substitutes in output space, labor is substitutable across firms. Conversely, if products are strategic complements in output space ($\partial y^i/\partial y^j > 0$), then labor is complementary across firms.

If firms behave as Bertrand competitors, products are commonly strategic complements in price space; that is, reaction functions in price space have positive slopes. This does not, however, imply that they must be strategic complements in output space. If one firm reduces its price and expands its output as a consequence of a labor-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, products are strategic substitutes in output space for both Cournot and Bertrand competition. Differentiating (A1), using $R^i_i = p^i + y^i(\partial p^i/\partial y^i)$, where p^i is the price of product i, we obtain $\partial(\partial\pi^i/\partial y^i)/\partial y^j = R^i_{ij} + \sum_k R^i_{kj}\mu = \partial p^i/\partial y^j < 0$ for linear demand. This ensures that $\partial y^i/\partial y^j < 0$, thus $dy^i/dy^j < 0$, implying that when demand is linear, labor is substitutable across firms for both Bertrand and Cournot competition.

Turning now to the profit effects of an increase in wages, we note that equilibrium profit can be expressed as a function of effective wages:

$$\pi^i(\omega^1, \omega^2, \ldots, \omega^n) = R^i(y^1(\underline{\omega}), y^2(\underline{\omega}), \ldots, y^n(\underline{\omega})) - C^i(y^i(\underline{\omega}), \omega^i). \tag{A6}$$

We assume throughout this article (see [1] of the text) that profit is decreasing in the own effective wage and increasing in a rival's effective wage; that is, $\pi^i_{\omega i} < 0$ and $\pi^i_{\omega j} > 0$ for all $j \neq i$. 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. We define below conditions that are sufficient to justify our assumptions about profit effects.

To derive an expression for $\pi^i_{\omega i}$, first differentiate (A6) to obtain $\pi^i_{\omega i} = -\ell + [R^i_i - C^i_{yi}]y^i_i + \sum_{k \neq i} R^i_k y^k_i$ and then, from (A1) and (A5), it follows that

$$\pi^i_{\omega i} = -\ell + s, \tag{A7}$$

where $s = \sum_{k \neq i} R^i_k y^i_i [dy^k/dy^i - \mu]$. Since $R^i_k < 0$ and $y^i_i < 0$, it follows from (A7) that $\pi^i_{\omega i} < 0$ if $dy^k/dy^i < \mu$. This condition always holds under Cournot competition ($\mu = 0$) when the products are strategic substitutes, and it also holds more generally provided $s < \ell$.

Similarly, from (A1) and (A6), the cross-wage effect on profit is

$$\pi^i_{\omega j} = \sum_{k \neq i} R^i_k (y^k_j - \mu y^i_j). \tag{A8}$$

If products are strategic complements in output space, then $y^i_j < 0$ and $y^k_j < 0$ for all $k \neq j$; since $\mu \leq 0$, $y^i_j < 0$ and $R^i_k < 0$, it follows that $\pi^i_{\omega j} > 0$. If products are strategic substitutes in output space, we can sign (A8) if all firms are assumed to face symmetric cost and demand conditions, that is, $y^k_j = y^i_j$ and $R^i_k = R^i_j$ for all i, $k \neq j$. Under these assumptions, (A8) can be expressed as

$$\pi^i_{\omega j} = R^i_j [\sum_k y^k_j - y^i_j (1 + (n-1)\mu)], \tag{A9}$$

where $\sum_k y^k_j = y^j_j + (n-1)y^i_j < 0$ since direct output effects dominate cross effects. With $y^i_j < 0$ (strategic substitutes), the condition $-1/(n+1) < \mu \leq 0$ is sufficient to ensure $\pi^i_{\omega j} > 0$.

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