Input suppliers, differential pricing and information sharing agreements[†]

Anthony Creane
Department of Economics
Michigan State University
East Lansing, Michigan 48824
Creane@msu.edu

It is common for firms to systematically share information with their input suppliers. Although such agreements with horizontal rivals have been thoroughly analyzed, there has been little work examining vertical sharing, and that analysis has focused on suppliers that set uniform prices. However, there has been a systematic change in the US policy towards vertical relationships in the past decades: both FTC inaction and courts rulings have curtailed the effect of Robinson-Patman, a law meant to prevent differential pricing. Furthermore, it is not clear if differential pricing reflects the suppliers' or the buyers' power. The interaction of these effects is examined in a wide range of environments.

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It is well known that some firms systematically share information with their rivals. The motives for this sharing have been extensively explored both theoretically and empirically.[1] However, some firms also systematically share information with their input suppliers. For example, there is ample evidence that firms share information with their workers or the unions that represent them. Fuess and Millea (2002) report that two-thirds of manufacturing establishments in Japan, and fifty-six percent of all establishments, share information. The impact of this type of sharing has been studied empirically either by itself (e.g., Kleiner and Bouillon 1988, and Morishima 1991a, 1991b who find a positive effect on labor productivity) or with other variables (e.g., Ichniowski, et al. 1997). Firms also systematically share information with their input suppliers (for examples[2] see Lee and Whang 2000 and Li 2002) as well as their banks, the effects of which have been studied empirically (see examples in, respectively, Chen 2003 and Herrera and Minetti 2006). Finally, even when a firm is not directly sharing information with its input suppliers, it may be doing so indirectly when it shares information with its rivals through trade associations or outside agencies.[3]

Even though firms often share information with their input suppliers, there has been little theoretical work examining why firms do this. A notable exception is Li (2002) who was the first to examine whether downstream firms would want to share information with each other and their monopoly supplier.[4] Though Li's introduction of a monopoly supplier is innovative, the firm's incentives to share firm-specific information are found to be inline with previous work such as Vives (1984) and Shapiro (1986). In addition, it is assumed that the upstream supplier charges a uniform

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[1] For an overview of the theoretical work see Vives (1990) and Raith (1996). Recent empirical work includes Armantier and Richard (2003), Doyle and Snyder (1999), and Genesove and Mullin (1999).

[2] Among their examples, Proctor & Gamble, Wal-Mart and others share information about inventories through a *Continuous Replenishment Program*: the input buyer provides inventory data to the supplier who manages the inventory under specified guidelines. Other times, inventory data is shared by outsourcing it to a third party (e.g., some Apple Computer's plants in the U.S. share information with some of their suppliers, using Fritz Companies as the third party).

[3] For example, *The Harbour Report* (www.harbourinc.com) publishes, among other information, labor hours per vehicle by assembly plant, which is obtained from each manufacturer.

[4] Zhang (2002) extends Li (2002) for the case of uncertainty regarding a *common* parameter to include price competition and differentiated goods. Creane (2006) examines how productivity information affects the outcomes.

price to all downstream firms, reflecting the Robinson-Patman Act which circumscribes differential pricing. However, since the 70's both inaction by the FTC and changes in the way that the Courts have interpreted this Act has increasingly limited Robinson-Patman's importance.[5] Moreover, unions are not covered by Robinson-Patman so that differential wage agreements are allowed.

If input prices can vary across downstream firms, new strategic effects arise when there is *firm specific* (that is, private-valued) information. To begin with, note when there is instead either uniform pricing or *common-valued* information, a firm's information normally has the same effect on its own input price that it has on its rival's input price. For example, a low cost observation from the firm leads to an input price increase for all firms. In contrast, with differential pricing and firm specific information, the effect on the own input price not only will be larger than on the rival's input price, but the sign may differ. For example, the same low cost observation now leads to a larger input price increase for the firm and an input price decrease for the rival. Thus, this information will also have a different effect on the rival's choice variable than it would have had with uniform pricing (or common valued information), which of course will have other strategic implications.

A different question is the impetus behind the differential pricing. For example, Wal-Mart is well known for its ability to obtain price concessions from suppliers and in *A&P v. FTC* (1979) it was A&P (the retailer) that obtain the price concession from Borden (the supplier) and not *vice versa*. The extent to which the differential pricing reflects the firms' power over the price rather than the suppliers' power (as assumed in Li 2002) could alter the above strategic effects, and hence whether information is shared and its welfare consequences.

To examine the effect differential pricing and pricing power have on the incentives to share

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[5] Since the 70's, the number of cases brought by the FTC have declined to zero and the courts have made it increasing difficult for plaintiffs to succeed so that it is now an example of "progressive contraction" (Kovacic 2003). In particular, since the Supreme Court ruling in *Brooke* (1993) (brought under Robinson-Patman, which requires price discrimination between different buyers) "no predatory pricing plaintiff has prevailed on the merits in the federal courts" (Bolton, et al 2000). Some have argued (Stoll and Goldfein 2005) that Robinson-Patman will be further restricted in the current *Volvo Truck* case before the Supreme Court.

information, we examine a monopolist (for ease referred to as the union) that supplies an input to two downstream firms that compete strategically. Initially each downstream firm has an unknown firm-specific parameter (either its costs or demand intercept) that it alone will learn. Before the firms observe their parameters, they can enter into a binding agreement to share that verifiable information (e.g., using an auditor) with the union and the firm's rival.[6] The firm then learns its parameter and, if it has agreed to do so, shares this information. Nature then determines whether the firms or the union set the input price (for ease called the wage), with this probability of setting the wage representing a side's pricing power.[7] After the wages are set, the firms compete in prices or quantities.

The introduction of differential pricing generates results that run counter to the literature and what Li (2002) found. First, if the union has sufficient pricing power, then the downstream firms *never* benefit from unilaterally sharing firm specific information. Specifically, neither the type of competition nor the type uncertainty alters this result, while in the literature changing either of these almost always led to the firm benefiting from information sharing if currently it was being harmed. (For example, if a firm was harmed by sharing information when it competed in prices, then it would benefit from sharing information if it competed in quantities.) Despite this, with close enough substitutes, the sum of union and firms profits in most settings increases in information sharing. Thus, the union (upstream supplier) would be willing to compensate the downstream firms.[8]

To help give insight to this result it is useful to deconstruct the effects of a firm sharing its

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[6] This is a simplifying assumption implicitly used in Li (2002) as well. However, it has been noted that in many environments suppliers do leak a firm's information to its rivals, including R&D (Bönte and Wiethaus 2005), supply-chain (Anand and Goyal 2004) and banking (von Rheinbaben and Ruckes 2004). Sometimes the information is actually *sold* without permission to rivals, which caused both Wal-Mart and Newbury Comics to stop selling their information to a third party (Anand and Goyal 2004). In a different setting, Ottaviani and Prat (2001) have shown that a policy of always making the information public increases a supplier's expected profits. Finally, even if the information is not directly leaked, when the union makes a wage offer to the rival, the offer will be a signal to the rival of the firm's private information. Similarly, the firm's publicly known wages is also a signal to the rival.

[7] The assumption of a linear contract follows Li (2002). Such contracts are one of the most common forms of contracting between firms and their unions (see Oswald 1993) and between firms (for examples, see Mills 2004).

[8] See Mills (2004) for examples where a downstream firm pays a linear price to the upstream firm and the upstream firm pays a fixed fee to the downstream firm (such as slotting allowances).

information by holding the rival's information constant. When a firm shares information with the union this will affect the wage the union sets for both the firm (own wage effect) and its rival (rival wage effect). For example, if the firm is hit by an increase in costs (or decrease in demand) and the union learns this, this "bad news" is ameliorated both by a lower wage for the firm and a higher wage for the rival. Likewise, "good news" is weakened by a higher wage for the firm and a lower one for its rival. Thus, net, these two wage effects reduce the firm's expected profit as it makes it less convex in the random variable. Notice that this intuition holds whether the firms compete in quantities or prices, or if the information is regarding the firm specific costs or demand intercept.

Comparing our environment to Li's (2002), we can see why our results diverge: the own wage effect is larger here than in Li and the rival wage effect here is the reverse of that in Li (2002). For example, a lower cost for the firm (good news) results in a greater increase in its own wage with differential pricing than it would with uniform pricing. Thus, the own wage effect dampens the firm's expected profits more with differential pricing than it does with uniform pricing. Second, with the differential pricing, the lower cost also results in a <u>lower</u> wage for the rival, further dampening expected profits; but with <u>uniform</u> pricing (as in Li 2002), the lower cost results in a <u>higher</u> wage for the rival, amplifying the good news, thereby making the firm's profits more convex and hence increasing its expected profits.

A second new result is that when the firms have some pricing power, a prisoner's dilemma can arise with firm specific information: it can be a dominant strategy for each firm not to share information about its demand intercept although joint profits would increase if they both shared information. This prisoner's dilemma arises both when the firms compete in prices and when they compete in quantities. It also arises with cost uncertainty when the firms compete in quantities.[9]

The intuition behind this second result turns on two aspects. First, by sharing information a

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[9] With cost uncertainty and price competition information sharing always reduces joint profits.

firm creates a positive externality for its rival; information increases the rival's expected profits. However, this effect is dampened when the union sets the wage. For example, when the firm learns it has high costs, this is good news for the rival. However, in response to this news, the union sets a lower wage for the firm and a higher wage for the rival, both which dampen this good news to the rival. Second, as the union has less pricing power this dampening effect lessens. Thus, as the pricing power weakens, the positive externality grows, eventually becoming greater than the loss the rival would incur by sharing its information (which is shrinking for a similar reason). At this point, while sharing its information makes the rival worse off – even if the firm is sharing its information – its expected profits are greater if both of them share information than if neither shares information.

Another new result is that there exists pricing power such that joint surplus (union and firms profits) increases from information sharing, but welfare decreases; and, in particular, this occurs under the conditions in Li (2002) that have both joint surplus and welfare increasing. This can arise with demand intercept uncertainty in both price and quantity competition and with cost uncertainty in quantity competition. In contrast, previous work has usually found that if joint producer surplus (union and firms surplus) increases, then welfare also increases from sharing firm specific information.[10] Thus, the relaxation of the Robinson-Patman constraint may have an unexpected welfare cost by encouraging welfare-reducing information sharing.

The cause of this third result also turns on the union's actions. When the union has the pricing power, information sharing reduces social welfare: the union raises the wage when a firm has lower costs. Hence, the wages shift output from the more efficient firm to the less efficient firm. On the other hand, when the firms have the pricing power, information sharing raises both producer surplus and social welfare with quantity competition or with price competition and unknown demand intercept. Since information sharing's effect on producer surplus is greater than on welfare, as the

[10] The exception being in Vives (1990) but a monopolist-competitive framework is used so the number of firm is large, i.e., each firm cannot influence aggregate market magnitudes.

pricing power shifts from the firms to the union, there is a level of pricing power such that social welfare decreases with information sharing even though producer surplus increases.

In the next section, the basic environment is described. In section three, the quantity competition model is considered, while the penultimate section considers price competition. The final section concludes.

2. Environment

There is a monopoly input supplier that sells a necessary input for a downstream duopoly that produces a differentiated good. There is uncertainty about firm specific parameters. For expositional purposes, the input is called labor and the upstream firm a union; however, it should be clear that the results hold for an upstream firm that produces an input. The firms maximize expected profits and the union expected wage bill. This interaction is modeled in five stages. In the initial stage each firm, before learning its parameter's value, simultaneously and independently chooses whether to enter an enforceable contract to share with the union and its rival any information that it may learn. To focus on the incentives to share information, it is assumed that the information can be shared in a verifiable way. In the second stage, nature randomly chooses the parameters' values and reveals to each firm only its own value.[11] If a firm entered the contract, in stage three it discloses this information to the union and its rival. In the fourth stage, with probability B, nature chooses the union to make a wage offer to each firm.[12] With probability $(1 - B)$ nature chooses the firms to make offers to the union. The other side may accept or reject. If the offer is rejected, the game ends. In the final stage, the firms simultaneously and independently compete in a strategic variable.

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[11] Many variations of the informativeness of the signal the firm receives or chooses to transmit have been examined in the information sharing literature without altering the basic results (see, e.g., Gal-Or 1986).

[12] As noted in the introduction, the focus here on linear contracts is for several reasons. First, simple wage bargaining that leaves the employment decision to the firm is far and away the most common form of union/firm negotiations (see Oswald 1993) and is common to many business relationships, in particular, wholesaler/retailer. Second, as the question of information sharing in this environment has hardly been examined, the simplest mechanism seems natural. Finally, this facilitates comparison to Li (2002) which uses linear contracts also.

The demand for the downstream firms' product is modeled with a representative consumer (Vives 1984). There is a continuum of identical consumers with separable, linear utility in the numeraire good and preferences for the differentiated goods represented by the quadratic function $U(q_a,q_b) = \alpha(q_a + q_b) - (½)(\beta q_a^2 + 2\delta q_a q_b + \beta q_b^2)$, $\alpha > 0$, $\beta \geq |\delta| > 0$, so that the goods are substitutes if $\delta > 0$.[13] For ease of reading and with no effect on the results let $\beta = 1$. The representative consumer maximizes $U(q_a,q_b)$ subject to prices p_a, p_b. Thus, inverse demand is $p_a = \alpha - q_a - \delta\cdot q_b$.

Producing one unit of the good requires one unit each of two inputs, one of which is labor which is only supplied by the union. The other input is competitively supplied with costs c_i. Let w_j be the wage for the labor. Firm a's cost function, then, is $(c_a + w_a)q_a$, and its profits are $\pi_a = (\alpha - q_a - \delta q_b - (w_a + c_a))q_a$. The union's opportunity cost of supply labor is zero. The union's wage bill then is $\omega = w_a\cdot q_a + w_b\cdot q_b$. Hence, welfare is $W(q_a,q_b) = \alpha\cdot(q_a + q_b) - (½)(q_a^2 + 2\cdot\delta\cdot q_a\cdot q_b + q_b^2) - c_a q_a - c_b q_b$. Since the interest here is in an active oligopoly, it is assumed that the values on the parameters are such that outputs are positive in equilibrium.

3. Quantity competition

With quantity competition, but not with price competition, firm specific uncertainty regarding cost is equivalent to that regarding the demand intercept. For ease, then, let the uncertainty be regarding the price c. Initially the values of c_a and c_b are unknown but are independently drawn from a known distribution $F_j(c)$ on support $[\underline{c}_j, \overline{c}_j]$ with the marginal density $f_j(c)$ and $\underline{c}_j > 0$. Denote $E[c_j] = c_{je}$ and $\sigma_j^2 = E[c_j^2] - c_{je}^2$. As asymmetry in variance has no qualitative effect on the results, for increased transparency, let $\sigma = \sigma_a^2 = \sigma_a^2$ and the minor effects that asymmetry would have will be noted. As usual, to derive the equilibrium requires first that the last stage is characterized for all possible outcomes and then to work back and derive each previous stage.

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[13] For a discussion of additional restrictions on the form see Vives (1984).

3.A The fifth stage

In the fifth stage each firm simultaneously sets output. A firm's profit maximizing output not only depends on its cost, but also its information and its rival's information. Thus, there are four outcomes that need to be characterized: when both firms share information, when neither shares information and when one shares but the other does not.

When both firms share information, the game is a standard Cournot game as each firm knows the other's costs. Firm *i* maximizes $(\alpha - q_i - \delta q_j - (w_i + c_i))q_i$ and from the usual calculus the Nash equilibrium outputs and profits can be derived for realized c's and w's:

$$q_a^C = [\alpha(2-\delta) - 2(w_a+c_a) + \delta(w_b+c_b)]/\Delta \qquad q_b^C = [\alpha(2-\delta) - 2(w_b+c_b) + \delta(w_a+c_a)]/\Delta$$

where the C superscript represents complete information and $\Delta = 4 - \delta^2$. Profits, wage bill, producer surplus (profits and wage bill) and welfare in the fifth stage are likewise evaluated at q_a^C, e.g., $\pi_a^C =$ $(\alpha - q_a^C - \delta q_b^C - (w_a + c_a))\, q_a^C$.

When neither firm shares information, the game is the typical Cournot game of incomplete information with respect to the other's input price c. The standard derivation yields the Bayesian-Nash equilibrium outputs:

$$q_a^I = [\alpha(2-\delta) - 2(w_a+c_a) + \delta(w_b+c_{be})]/\Delta \; + \; \delta^2(c_a-c_{ae})/2\Delta,$$

$$q_b^I = [\alpha(2-\delta) - 2(w_b+c_b) + \delta(w_a+c_{ae})]/\Delta \; + \; \delta^2(c_b-c_{be})/2\Delta.$$

with the profits π_a^I, etc. being derived analogously to when there is complete information. Finally, consider the case when only one firm shares information. Assume for concreteness that firm *a* shares information (firm *b* learns *a*'s cost) while firm *b* does not. This is a standard Cournot game of asymmetric information. The Bayesian-Nash equilibrium outputs and profits are

$$q_a^S = [\alpha(2-\delta) - 2(w_a+c_a) + \delta(w_b+c_{be})]/\Delta,$$

$$q_b^N = [\alpha(2-\delta) - 2(w_b+c_b) + \delta(w_a + c_a)]/\Delta \; + \; \delta^2(c_b-c_{be})/2\Delta,$$

where S indicates share and N not share.

Note that in the first stage that for given w_a and w_b, expected outputs are the same for all information structures: $\bar{q}_i \equiv [\alpha(2-\delta) - 2(w_i+c_{ie}) + \delta(w_j+c_{je})]/\Delta$. This implies that profits, wage bill and welfare, evaluated at the mean, are the same. That is, letting c_e denote the expected value of each cost, $\{c_{ae},c_{be}\}$, $\pi_i^C(c_e) = \pi_i^I(c_e) = \pi_i^S(c_e) = \pi_i^N(c_e)$, etc., which will be useful later.

3.B The fourth stage

In the penultimate stage the wage is determined. There are now eight possibilities based on which side nature chooses to make the wage offer (union or firm) and on the four possibilities as to whether information was shared in the third stage. Consider first the four possible environments when nature chooses the union to make the offer. To begin with, if information was shared by both firms in the third stage, then the union knows that the stage five equilibrium outputs will be q_a^C and q_b^C and so it chooses w_a and w_b to maximize the wage bill

$$\omega = q_a^C w_a + q_b^C w_b.$$

From the first order conditions, the optimal wages are

$$w_a^C = (\alpha - c_a)/2 \qquad\qquad w_b^C = (\alpha - c_b)/2.$$

This implies that in the last stage, the resulting outputs are

$$q_{a,U}^C = (\alpha(2-\delta) - 2c_a + \delta c_b)/2\Delta \qquad\qquad q_{b,U}^C = (\alpha(2-\delta) - 2c_b + \delta c_a)/2\Delta$$

where the subscripts $\{i,U\}$ indicate which firm and that the union set the wage. These outputs can be substituted into the definitions for profit (π_i^C) to obtain equilibrium profits, denoted $\pi_{U,i}^C$, wage bill (ω_U^C) and welfare (W_U^C).

If neither firm shares information, then the union's expects the fifth stage outputs to be $E[q_i^I]$

$= \bar{q}_i$. Hence the union maximizes

$$\omega_U^I = \bar{q}_a w_a + \bar{q}_b w_b.$$

Maximizing ω_U^I with respect to w_a and w_b obtains

$$w_a^I = (\alpha - c_{ae})/2 \qquad\qquad w_b^I = (\alpha - c_{be})/2$$

and so the fifth stage outputs are

$$q_{a,U}^I = [\alpha(2-\delta) - 2(2c_a - c_{ae}) + \delta c_{be})]/2\Delta + \delta^2(c_a - c_{ae})/2\Delta,$$

$$q_{b,U}^I = [\alpha(2-\delta) - 2(2c_b - c_{be}) + \delta c_{ae})]/2\Delta + \delta^2(c_b - c_{be})/2\Delta.$$

The corresponding profits, wage bill and welfare are denoted $\pi_{U,i}^I$, ω_U^I and W_U^I.

Finally, if firm *a* shares its cost observation but firm b does not, then the union knows that firm *a* will set output q_a^S as the union has the same information that firm *a* does. However, the union does not know the value of c_b so like firm *a* only has an expectation of firm *b*'s output: $E_a[q_b^N] = [\alpha(2-\delta) - 2(w_b+c_{be}) + \delta(w_a+c_a)]/\Delta$. Hence, the wage bill is

$$\omega_U^{SN} = q_a^S w_a + E_a[q_b^N]w_b$$

where the SN superscript indicates that firm *a* shares, but firm *b* does not. Optimal wages, then, are

$$w_a^{SN} = (\alpha - c_a)/2 \qquad\qquad w_b^{SN} = (\alpha - c_{be})/2.$$

The fifth stage outputs then are

$$q_{a,U}^S = (\alpha(2-\delta) - 2c_a + \delta c_{be})/2\Delta, \qquad q_{b,U}^N = [\alpha(2-\delta) - 2(2c_b - c_{be}) + \delta c_{ae})]/2\Delta + \delta^2(c_b - c_{be})/2\Delta$$

with the corresponding profits, wage bill and welfare denoted $\pi_{a,U}^S$, $\pi_{b,U}^N$ ω_U^{SN} and W_U^{SN}. The case when firm *b* shares but firm *a* does not follows symmetrically.

Even though the wages may vary, when they do, they are linear in the cost observation and, so in the first stage, the expected fourth stage wage are equal for each information structure. As a result, in the first stage the expected output are equal across information structures: $E[q^{C}_{a,U}] = E[q^{I}_{a,U}] = E[q^{S}_{a,U}] = E[q^{N}_{a,U}]$. For this reason, the profit, wage bill and welfare evaluated at the expected cost are equal. Thus, it is useful to define this: $\bar{\pi}_{i,U} \equiv \pi^{C}_{i,U}(c_e) = \pi^{I}_{i,U}(c_e) = \pi^{S}_{i,U}(c_e) = \pi^{N}_{i,U}(c_e)$; $\bar{\omega}_U \equiv \omega^{C}_{U}(c_e) = \omega^{I}_{U}(c_e) = \omega^{NS}_{U}(c_e)$; $\bar{W}_U \equiv W^{C}_{U}(c_e) = W^{I}_{U}(c_e) = W^{NS}_{U}(c_e)$.

Turning to the case when nature selects the firms to set the wage, it is immediate that each firm would offer the union a wage equal to the workers' opportunity cost. That is, the wage is for all information structure always $w_F = 0$. As a result, the firms' outputs are easy to calculate:

$$q^{C}_{a,F} = [\alpha(2-\delta) - 2c_a + \delta c_b]/\Delta \qquad q^{C}_{b,F} = [\alpha(2-\delta) - 2c_b + \delta c_a]/\Delta$$

$$q^{I}_{a,F} = [\alpha(2-\delta) - 2c_a + \delta c_{be}]/\Delta + \delta^2(c_a - c_{ae})\ 2\Delta, \quad q^{I}_{b,F} = [\alpha(2-\delta) - 2c_b + \delta c_{ae}]/\Delta + \delta^2(c_b - c_{be})/2\Delta.$$

$$q^{S}_{a,F} = [\alpha(2-\delta) - 2c_a + \delta c_{be}]/\Delta, \qquad q^{N}_{b,F} = [\alpha(2-\delta) - 2c_b + \delta c_a]/\Delta + \delta^2(c_b - c_{be})/2\Delta.$$

Profits, wage bill and welfare are defined analogously and denoted $\pi^{(\bullet)}_{i,F}$, $\omega^{(\bullet)}_{F}$, $W^{(\bullet)}_{F}$, with the superscripts indicating the information structure. Note that, analogous to when the union sets the wage, in the first stage $E[q^{C}_{a,F}] = E[q^{I}_{a,F}] = E[q^{S}_{a,F}] = E[q^{N}_{a,F}]$. As a result, profits, wage bill and welfare evaluated at the expected costs are the same, e.g., $\pi^{C}_{i,F}(c_e) = \pi^{I}_{i,F}(c_e) = \pi^{S}_{i,F}(c_e) = \pi^{N}_{i,F}(c_e)$. Following previous notation, denote these "mean" values as $\bar{\pi}_{i,F}$, $\bar{\omega}_{F,}$ and $\bar{W}_{F.}$ With the equilibrium profits for the eight possible outcomes characterized, the conditions for a firm to share information and its welfare effects can be derived.

3.C The first stage

In the first stage the firms chose whether to enter a contract to share information. If transfers between agents are possible, then there are several reasons why a firm might enter the contract. First, it might be a dominant strategy for a firm to unilaterally share information (i.e., regardless of what the rival decides). Second, joint profits may be greater if they both share than if neither shares, and so a quid pro quo arrangement may arise when there is a prisoner's dilemma. Finally, even if the firms' profits are lower with sharing, producer surplus may increase; the union's gain from the firms sharing may be greater than the firms' joint loss. In such a case, the union may be willing to pay up front fees to one or both firms to induce them to share the information.

Consider the effect on profits from information sharing. Given pricing (or bargaining) power *B*, there are four possibilities based on whether each firm entered the agreement to share information. If firm *a* chooses to share its information when its rival does not, then taking the expectation of the profits $\pi^S_{a,U}$ and $\pi^S_{a,F}$ from section *3.B* obtains

$$B\cdot \mathrm{E}[\pi^S_{a,U}] + (1-B)\cdot \mathrm{E}[\pi^S_{a,F}] = B\cdot[\bar{\pi}_{a,U} + \sigma^2/\Delta^2] + (1-B)\cdot[\bar{\pi}_{a,F} + 4\sigma^2/\Delta^2]. \tag{1}$$

If the firm does not share information when its rival does not, then taking the expectation, it is

$$B\cdot \mathrm{E}[\pi^I_{a,U}] + (1-B)\cdot \mathrm{E}[\pi^I_{a,F}] = \mathrm{B}\cdot[\bar{\pi}_{a,U} + \sigma^2/4] + (1-\mathrm{B})\cdot[\bar{\pi}_{a,F} + \sigma^2/4]. \tag{2}$$

On the other hand if it shares information when its rival also shares expected profits are

$$B\cdot \mathrm{E}[\pi^C_{a,U}] + (1-B)\cdot \mathrm{E}[\pi^C_{a,F}] = \mathrm{B}\cdot[\bar{\pi}_{a,U} + \sigma^2(4+\mathrm{d}^2)/4\Delta^2] + (1-\mathrm{B})\cdot[\bar{\pi}_{a,F} + 4\sigma^2(4+\mathrm{d}^2)/4\Delta^2], \tag{3}$$

while if it does not share when its rival shares its expected profits are

$$B\cdot \mathrm{E}[\pi^N_{a,U}] + (1-b)\cdot \mathrm{E}[\pi^N_{a,F}] = \mathrm{B}\cdot[\bar{\pi}_{a,U} + \sigma^2(\Delta^2+\mathrm{d}^2)/4\Delta^2] + (1-\mathrm{B})\cdot[\bar{\pi}_{a,F} + \sigma^2(\Delta^2+4\mathrm{d}^2)/ 4\Delta^2]. \tag{4}$$

Notice that in differencing either (1) and (2) or (3) and (4) that the mean profits ($\bar{\pi}_{a,(\bullet)}$) fall out.

Comparing equations (1-4) the condition for a firm to unilaterally share information or for firms to be jointly willing to share information can be obtain. Specifically,

Proposition 1: ***With quantity competition and uncertain firm specific cost or demand intercept, a firm unilaterally chooses to share information if and only if $B \le \delta^2(8-\delta^2)/12$. A firm's profit is greater when both share information than when neither share if and only if $B \le \delta^2(12-\delta^2)/3(4+\delta^2)$.***

Proof: From (1) and (2), firm a's expected profit when they both do not share less its expected profit when only firm a shares, is increasing in *B*, and equals zero at B = $\delta^2(8-\delta^2)/12$. From (3) and (4), the same is true for firm a's expected profit when only it does not share less its expected profit when they both share. For the second part, from (2) and (3), firm a's expected profit when they both do not share less its expected profit when they both share, is increasing in *B* and equals at $B = \delta^2(12-\delta^2)/3(4+\delta^2)$.// [14]

There are two effects that arise from a firm sharing its information. On one hand, the union can exploit the information to the firm's detriment. On the other hand, the information being shared with the rival creates a benefit. In the environment here, the gain from sharing is greater than the loss from the union learning, if the union is sufficiently weak or the products are sufficiently undifferentiated. It is interesting to contrast these results to those found in Li (2002) who assumes that the union has all of the pricing power and the products are perfect substitutes (equivalent to $B = 1$ and $\delta=1$). In contrast to the result here, Li (2002) finds that the firm's dominant strategy is to share information and profits are greater if all firms share information. The difference arises because here the union sets different wages, while in Li (2002) a uniform price is considered.[15] By setting a differential wage the extent to which the union can exploit the information is enhanced sufficiently to change the results found in Li.

Comparison of the pricing power (B) needed for joint profits to increase from information sharing ($\delta^2(12-\delta^2)/3(4+\delta^2)$) to that needed for an individual firm to unilaterally share information ($\delta^2(8-\delta^2)/12$), reveals that there are levels of pricing power such that there is a prisoner's dilemma. Interestingly, this only arises if the pricing power is more evenly divided.

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[14] If symmetry is not imposed on variance then the condition is for firm *i* when $\delta = 1$: B $\leq (7\sigma_i^2 + 4\sigma_j^2)/3(4\sigma_i^2 + \sigma_j^2)$. Thus, e.g., if firm a's cost were known by all ex ante, then firm *a* prefers complete information for all B and firm b prefers complete information only if B $\leq$ 7/12.

[15] Calculations showing this can be provided on request from the author.

__Corollary__: ***With quantity competition and uncertain cost or demand specific intercept, for all $\delta \in (0,1]$, there exists a pricing power B such that the firm's dominant strategy is to not share information, but joint profits increase if both firms share information.***

While an "information sharing" prisoner's dilemma among downstream firms has been found to arise regarding uncertainty of a *common* parameter (Vives 1984, Kirby 1988, Raith 1996), here it is regarding a *private* parameter. Furthermore, a prisoner's dilemma does not arise in Li (2002).[16] Finally, the prisoner's dilemma in previous work required either sufficiently differentiated goods (Vives 1984, Raith 1996) or convex costs (Kirby 1988), while here it can arise even with perfect substitutes and linear costs.

Turning to the effect product differentiation has, as δ decreases, the critical value for B decreases; as the products become more differentiated, information sharing is more likely to harm a firm, and in the limit only if the firms have all the pricing power would firms unilaterally share information. This is in contrast to the literature which finds that if anything, as the products become more differentiated, information sharing is more likely to __help__ a firm (Vives 1984, 1990). Part of the reason for this is that with private parameter uncertainty, the gain from sharing information with a rival decreases as products become more differentiated. The second part of the reason can be found in Zhang (2002) who shows that if there were only a monopoly downstream, then the downstream firm is always harmed.[17] The final part is the differential pricing here which increases the cost to the firm from the union's learning. Thus, as the products become more differentiated the firm gains less from its rival learning and is harmed more from the union learning.

Consider next the effect information sharing has on the wage bill and producer surplus.

[16] With uncertainty regarding a common parameter in quantity competition (Zhang 2002), a prisoner's dilemma arises if information is sufficiently imprecise and the goods are strong enough *complements* (but not if they are strong enough substitutes). Here whether the products are substitutes or complements has no effect.

[17] Though there is common parameter uncertainty in Zhang (2002), with a monopoly downstream, common and private parameter uncertainty are the same.

Although the firms are less likely to benefit from sharing information as union has more pricing power, the union's value from information sharing increases. If producer surplus increases – if the union's gain is greater than the firms' combined loss – then the union would be willing to pay the firms an upfront fee to induce them to share their information. Thus, consider the change in producer surplus from information sharing.

Given pricing power B, if both firms share their information then expected producer surplus is, where $\pi^C_{a,U} + \pi^C_{b,U} + \omega^C_U = \overline{\mathrm{PS}}_U$, etc.,

$$B\cdot \mathrm{E}[\pi^C_{a,U} + \pi^C_{b,U} + \omega^C_U] + (1-B)\cdot \mathrm{E}[\pi^C_{a,F} + \pi^C_{b,F} + \omega^C_F]$$

$$= B\cdot[\overline{\mathrm{PS}}_U + \sigma^2(4 + d^2)/4\Delta^2] + (1-B)\cdot[\overline{\mathrm{PS}}_F + \sigma^2/\Delta].^{18} \tag{5}$$

Expected producer surplus when both firms do not share information is

$$B\cdot \mathrm{E}[\pi^I_{a,U} + \pi^I_{b,U} + \omega^I_U] + (1-B)\cdot \mathrm{E}[\pi^I_{a,F} + \pi^I_{b,F} + \omega^I_F] = B\cdot[\overline{\mathrm{PS}}_U + \sigma^2/2] + (1-B)\cdot[\overline{\mathrm{PS}}_F + \sigma^2/2]. \tag{6}$$

Differencing (5) and (6) shows that

Proposition 2: ***With quantity competition and uncertain cost or demand specific intercept, producer surplus increases with information sharing if and only if $B \le \delta^2(12-\delta^2)/(4+5\delta^2)$.***

Straightforward algebra shows that the critical B for producer surplus is always greater than the critical B for joint profits; for all $\delta > 0$, there always exist B such that the firms jointly do not benefit from information sharing, but the union is willing to induce them to share. For example, with perfect substitutes, when the firms would not share information, a union can always profitably induce the firms to share information. Not surprisingly, then, from the condition in proposition 2, there is a a range of δ such that for all pricing power (B), producer surplus increases with information sharing.

[18] As the information is firm specific and the variances are identical, only the cases of either both sharing or neither sharing need be considered. The effect of asymmetric variances is analogous to that in footnote [16].

Specifically, $\delta^2(12-\delta^2)/(4+5\delta^2)$ is increasing in δ on $\delta\in[0,1]$, so solving for the δ such that $\delta^2(12-\delta^2)/(4+5\delta^2) = 1$, obtains:

<u>Corollary</u>: *With quantity competition and uncertain cost or demand specific intercept, if $\delta \geq (\sqrt{11} - \sqrt{3})/2$ ($\approx 4/5$), then for all pricing power producer surplus increases with information sharing.*

Stated in reverse, the corollary implies that as the products become more differentiated, it is more likely that producer surplus decrease with information sharing. In particular, with a double-sided monopoly ($\delta = 0$), an upstream monopolist can never induce the downstream monopolist to share information. This may be somewhat surprising as there is superior coordination in the union's wage setting from complete information. However, intuitively producer surplus decreases because it is convex in costs c_a: a small decrease in cost increases producer surplus more than an equivalent increase in cost reduces producer surplus. Since with complete information, the union's wage setting dampens the effect the cost change has (e.g., when cost c_a decreases, w_a increases), producer surplus decreases with the information.

Turning to welfare, *a priori* the effect of information sharing is unclear. Without the union information sharing increases welfare in this environment (Shapiro 1984). Likewise, with a union setting a uniform wage information sharing increases welfare (Li 2002). Finally, even with a union setting differential wages, producer surplus increases with information sharing when the products are sufficiently similar for all pricing powers *B*. To determine the net effect, note that if both firms share their information than expected welfare is

$$B\cdot E[W_U^C] + (1-B)\cdot E[W_F^C] = B\cdot[\overline{W}_U + (28-5\delta^2)\sigma^2/4\Delta] + (1-B)\cdot[\overline{W}_F + (12-\delta^2)\sigma^2/\Delta^2]. \tag{7}$$

Expected welfare when both firms do not share information is

$$B\cdot E[W_U^I] + (1-b)\cdot E[W_F^C] = B\cdot[\overline{W}_U + \sigma^2/2] + (1-B)\cdot[\overline{W}_F + \sigma^2/2]. \tag{8}$$

Equations (7) and (8) can be used to derive that, counter to the results in the literature, welfare can decrease with information sharing when the union has enough pricing power:

<u>**Proposition 3**</u>**:** ***With quantity competition and uncertain cost or demand specific intercept, welfare is greater when both firms share if and only if B < $\delta^2(20 - 3\delta^2)/(20 + \delta^2)$.***

Inspection of proposition 3 shows that there does not exist δ such that when the union has all of the pricing power (B=1), welfare increases with information sharing: for $\delta \in (-1,1)$, $\delta^2(20 - 3\delta^2)/(20 + \delta^2)$ is increasing in δ, and at δ=1, $\delta^2(20 - 3\delta^2)/(20 + \delta^2) = 17/21$. The intuition is that the information leads the union to induce output changes that are in the opposite direction of what would increase welfare. A lower cost firm receives a higher wage and so produces less, while a higher cost firm receives a lower wage inducing it to produce more. On the other hand, when the union has relatively little pricing power, welfare increases from information sharing because of the interaction between the firms. Thus, as δ decreases (so that the interaction between the firms decreases) information sharing is less likely to raise welfare.

That welfare decreases with information sharing when the union has the pricing power is the opposite of what is found in Li (2002), pointing to the effect of differential wages. Worse, comparing proposition 2 and 3 shows that the critical threshold in pricing power for producer surplus to increase is always greater than that for welfare. Thus,

<u>Corollary</u>: With quantity competition and uncertain cost or demand specific intercept, for all $\delta \in (0,1)$, there exists a pricing power B such that the union can profitably induce the firms to share, but welfare decreases.

4. Price competition

4.A Unknown demand

With price competition, in contrast to quantity competition, previous results depend on whether the uncertainty is regarding the firm specific cost or intercept. Consider first then what occurs when the intercept is unknown. For analytical symmetry, let demand be $q_i = A_i - p_i + d \cdot p_j$ with $d \in [0,1)$, which generates a utility of the form examined in the quantity competition model).[19] That is, now the values of A_a and A_b are initially unknown but are independently drawn from a known distribution $G_j(A)$ on support $[\underline{A}_j, \overline{A}_j]$ with the marginal density $g_j(A)$ and $\underline{g}_j >> 0$. As asymmetry in the mean and variance has no qualitative effect on the results, the distributions are assumed symmetric: $A_{ae} = A_{be} = A_e$ and $\sigma^2 = \sigma_a^2 = \sigma_a^2$. With no loss of generality, costs c_i are set to zero for the case of unknown intercept.

As the analysis is analogous to that with quantity competition, the derivations are left for the appendix and only the results are presented. The first result is quite surprising: the conditions for firms to share information or to benefit from sharing information with price competition and intercept uncertainty (PI) are identical to those in quantity competition.

Proposition 1(PI): ***With price competition and uncertain intercept, a firm unilaterally chooses to share information if and only if $B \le d^2(8-d^2)/12$. A firm's profit is greater when both share information than when neither share if and only if $B \le d^2(12-d^2)/3(4+d^2)$.***

Corollary: ***With price competition and uncertain c intercept, for all $d \in (0,1)$, there exists a pricing power B such that the firm's dominant strategy is to not share information, but joint profits increase if both firms share information.***

Since the conditions on the firms' profits are identical to those in quantity competition, it might be concluded that this case is trivial: that the remainder of the results would also be identical. However, with price competition the interaction between the union wage setting and the firms'

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[19] Specifically, this type of uncertainty would be generated by utility $[A_a \cdot (q_a + dq_b) + A_b \cdot (q_b + dq_a) - (½)(q_a^2 + 2 \cdot d \cdot q_a \cdot q_b + q_b^2)]/(1 - d^2)$.

pricing differs, which affects producer surplus and welfare in different ways. First, there is better coordination in pricing and so producer surplus is more likely to increase with information sharing. However, this same gain in coordination is more likely to lead to lower expected welfare.

Define d^* as the unique root of $\{d^6 - 11d^4 + 23d^2 - 4\}$ on the interval [0,1] ($d^* \approx 0.437$).

<u>Proposition 2(PI)</u>: ***With price competition and uncertain intercept, producer surplus increases with information sharing if and only if either*** $d \geq d^*$ ***or*** $d < d^*$ ***and*** $B \leq d^2(12-d^2)(1-d^2)/(4-11\delta^2-2d^4)$.

Though how the firms compete does not affect whether firms share information, how the firms compete does effect whether producer surplus increases with information sharing. In particular, producer surplus is more likely to increase with price competition (for all B when $d >$ .437) than with quantity competition ($\delta > .8$). The reason is that when the firms compete in prices the differential wage has a smaller deleterious effect on profits. This is because with substitutes an increase in own demand not only raises the firm's wage, but its rival's as well, thus mitigating the profit loss from a higher wage. (With complements, it lowers the rival's wage which mitigates the profit loss from a higher wage.) Both effects also induce a higher price from the rival. In contrast, with quantity competition an increase in the own wage results in the rival expanding its output. Finally, as the products become less differentiated, the unions profit is a greater fraction of the producer surplus and so its benefit dominates.

Turning to welfare, the condition again differs from that with quantity competition.

<u>Proposition 3(PI)</u>: ***With price competition and uncertain intercept, welfare is greater when both firms share if and only if*** $B \leq d^2(1-d^2)(d^2+4)/(20-7d^2-4d^4)$.

As compared to quantity competition, with price competition it is much less likely that information sharing raises welfare even though it is more likely that producer surplus increasess.

First, while in quantity competition the threshold pricing power increases in δ, here it is non-monotonic: increasing and then decreasing, which is the only instance of this. In particular, as $\delta \to 1$ with price competition, the threshold pricing power goes to zero with price competition, while with quantity competition it reaches its maximum. As the goods become less differentiated, the firms' profits go to zero and so do the relative gains from information sharing. What remains then is a union whose affect on wages in response to the information is detrimental to welfare: the lower cost firm sees a higher wage. Finally, the $\delta \in [0,1)$ that maximizes B is approximately .79. However, this maximum B is approximately 1/13, which is significantly smaller than the maximum B in quantity competition (17/21).

Since welfare is less likely to increase with information sharing, but producer surplus is more likely to increase, the final result of the previous section is even more likely to hold:

<u>Corollary</u>: *With price competition and demand specific intercept, for all $\delta \in (0,1)$, there exists a pricing power B such that the union can profitably induce the firms to share, but welfare decreases.*

4.B Unknown Cost

Firm *i*'s profits are now $(A - p_i + d \cdot p_j)(p_i - w_i - c_i)$. In the information sharing literature (i.e., there is no union), it is well known that in price competition, then firms are harmed by information sharing of costs and welfare decreases. As the previous results here show that the introduction of the upstream monopoly reduces the firms' benefit and welfare from sharing information, the implication is that for no *B* are joint profits or welfare greater with complete information. What is less clear is whether producer surplus can increase for any *B*. The equilibrium prices and expected profits are in the appendix from which can be derived the following.

<u>Proposition 1(PC):</u> *With price competition and uncertain cost, a firm never unilaterally chooses to*

share information and profits are always lower when both share information than when both do not share information.

<u>**Proposition 2(PC)**</u>**:** ***With price competition and uncertain cost, producer surplus always decreases with information sharing.***

<u>**Proposition 3(PC)**</u>**:** ***With price competition and uncertain intercept, welfare always decreases with information sharing.***

The most interesting result here is that producer surplus can never increase with information sharing while it does with unknown intercept – even when the goods are very close substitutes and so the firms' profits are relatively small. The reason is that with unknown cost, a change in the firm's cost does not change the rival's wage while with unknown intercept a change in the firm's intercept does affect the rival's wage. As a result, producer surplus does not increase with information sharing no matter the pricing power. However, simply because producer surplus decreases with information sharing does not mean it will not arise. If the union is able to institutionalize a structure that promotes information sharing, then it can still arise despite the firm's objections.

5. Conclusion

Given the prevalence of information sharing in vertical relationships (see, e.g., Lee and Whang 2000 and Fuess and Millea 2002) and the prevalence of work examining information sharing between horizontal rivals, there has been surprisingly little analysis of information sharing in vertical relationships, with the noteworthy exception of Li (2002) and Zhang (2002). While Li (2002) and Zhang (2002) assume that that supplier sets a uniform price, since the 1970's, there has been a gradual loosening of US policy towards differential pricing between input suppliers and downstream firms. In addition, differential pricing is allowed in labor agreements. A second issue is that it is not always clear if the differential pricing reflects the market power of the supplier or of the buyer.

This paper examined the effects of differential pricing on a firm's incentive to share private information with its rival and input supplier. This analysis was done in a range of environments. First, pricing power between the firm and the union was allowed to vary. Second, this paper examined both firms that compete in quantities and prices, as well as products that range from perfect complements to (nearly) perfect substitutes. Finally, both firm specific demand and cost uncertainty were examined.

It was found that the greater the pricing power of the firms, the more likely a firm is to unilaterally share information. Empirically, then, unilateral information sharing (e.g., Harbour Associates) should be more common, the more power the downstream firms have. However, a prisoner's dilemma can arise: there can be a range of pricing power such that the firms would not unilaterally share information, but joint profits increase with information sharing. Despite this, producer surplus can still increase with information sharing. Thus, the union could induce information sharing by paying upfront fees while the firms pay the per unit price for the input – a commonly observed relationship, e.g., in groceries with *slotting fees*.[20] On the other hand, with sufficiently differentiated goods, producer surplus is likely to decrease in the union's pricing power. Finally, though welfare is also likely to decrease in the union's pricing power, the relationship between pricing power, producer surplus and welfare is not uniform: there usually exists a level of pricing power such that producer surplus increases but welfare decreases with information sharing.[21]

Examining the interaction between the type of competition and pricing power, it was found that with price competition there is not only a greater range of pricing power such that producer surplus increases with demand uncertainty, but also a greater range in which welfare decreases. Thus, welfare-decreasing information sharing agreements may be more likely if the downstream

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[20] For additional examples of downstream firms paying suppliers a per unit price, while the supplier pays a fixed fee to the firm see Mills (2004). For examples in the labor market see Creane and Davidson (2006).

[21] The exception is if the firms compete in prices and the uncertainty is regarding costs (because welfare always decreases with information sharing in that case).

firms compete in prices. The reason why there is a greater range of pricing power such that producer surplus increases in price competition is because the union's differential pricing causes relatively less harm to the firms in price competition. For example, with substitutes, an increase in own demand raises the firm's wage, which in price competition leads to the rival's price increasing (to the firm's benefit), but in quantity competition this leads to the rival's output increasing (to the firm's harm). On the other hand, information sharing is more likely to decrease welfare when firms compete in prices ironically because there is greater competition between the firms, which is discussed next.

As the products become more differentiated, regardless of whether they are substitutes or complements, information sharing is more likely to reduce the firms' profits and producer surplus (though the union's surplus always increases), which runs counter to the results in the information sharing literature (Vives 1984, 1990). The reason for this is that as the products become very differentiated, each firm-supplier relationship essentially becomes independent of the other. So, first, any producer surplus gains from the rival's reaction to the firm's information approaches zero. Second, in each relationship, producer surplus becomes convex in the unknown cost or demand intercept. However, the union's response to this information (a higher wage for a lower costs), dampens this effect making producer surplus less convex in the unknown parameter and hence reducing expected producer surplus. For these reasons, as the products become more differentiated, welfare decreases if the firms compete in quantities.

Things are not as simple with price competition. Though welfare decreases if the products are becoming sufficiently differentiated, it also can decrease if the products are becoming sufficiently undifferentiated; there is a non-monotonic relationship between product differentiation and welfare with price competition. This is because as the products become close substitutes in price competition, the firms' profits go to zero and so do the gains to them from information sharing, while the own dampening effect of the union's pricing remains.

In addition to the effects that product differentiation and pricing power have on the outcomes, there are some surprising results given previous findings in information sharing literature regarding private valued information. First, an increase in producer surplus from an information sharing agreement does not imply that welfare increases. That is, previous work in information sharing finds that if producer surplus increases with information sharing, then welfare increases with oligopolistic firms. For example, with unknown costs and quantity competition, information sharing increases producer surplus and welfare both with (Li 2002), and without (Shapiro 1984) the information being shared with an upstream firm. However, it was found here that with differential pricing producer surplus can increase when welfare decreases.

A second new result is that if the union has sufficient pricing power, then firms never unilaterally share information. In the literature, if firms compete in quantities, or if the firms compete in prices with demand uncertainty, then in equilibrium they would unilaterally share information (e.g., Shapiro 1984), even if the upstream firm obtains the information (Li 2002). This result is also surprising in that it holds for all the environments examined – demand and cost uncertainty; price and quantity competition – while in the information sharing literature this type of a result almost always depends on the environment. For example, if sharing information increases the firms' profits in quantity competition, then it will decrease profits in price competition.

Finally, the finding here that information sharing reduces welfare when the union sets the wage is likely to be general because of how the union responds to the information: when firms are low cost producers, the union sets a higher wage, and so the more efficient firm produces less and the less efficient firm responds strategically by producing more. This effect overwhelms any welfare benefit from the information sharing between firms. Ironically, the welfare-reducing information sharing also reduces output variability, a sometime policy goal. That is, here the reduction in output variability is linked to the reduction in welfare.

Appendix A: Price competition with unknown intercept

Starting with the last stage, profits for firm *j* are $(A_i - p_i + d\cdot p_j)(p_i - w_i)$. First, when both firms share information, the equilibrium prices are

$$p_a^C = [2(A_a + w_a) + d(A_b + w_b)]/\Delta$$

$$p_b^C = [2(A_b + w_b) + d(A_a + w_a)]/\Delta$$

where the super and subscripts follow the previous sections notation and $\Delta = 4 - d^2$. Substituting these values into $q_i = A_i - p_i + d\cdot p_j$ obtains output (q_a^C) with which profits, producer surplus and welfare can be calculated, with the same notation as before, e.g., π_a^C, etc.

When neither firm shares information equilibrium prices are

$$p_a^I = [2(A_a + w_a) + d(A_e + w_b)]/2\Delta - d^2(A_a - A_e)/2\Delta,$$

$$p_b^I = [2(A_b + w_b) + d(A_e + w_a)]/2\Delta - d^2(A_b - A_e)/2\Delta,$$

from which, again, outputs, profits etc. in stage five can be derived. Finally, when firm a shares information while firm b does not yields prices (and symmetrically when only firm b shares)

$$p_a^S = [2(A_a + w_a) + d(A_e + w_b)]/\Delta,$$

$$p_b^N = [2(A_b + w_b) + d(A_e + w_a)]/2\Delta - d^2(A_b - A_e)/2\Delta.$$

As with quantity competition, given some w_a and w_b, in the first stage expected outputs are the same for all information structures and so profits, wage bill and welfare, evaluated at the mean, are the same. That is, $\pi_i^C(c_e) = \pi_i^I(c_e) = \pi_i^S(c_e) = \pi_i^N(c_e)$, etc.

Moving back to the fourth stage, when the union is selected to make the wage offer, the wage it charges depends on its information. If information is shared by both firms, from its maximizing the wage bill, the wages are

$$w_a^C = (A_a + d\cdot A_b)/2(1 - d^2) \qquad w_b^C = (A_b + d\cdot A_a)/2(1 - d^2).$$

What is notable is that now, the rival's firm specific information enters into the firm's wage, while with quantity competition it does not. If instead neither firm shares information, then the wages are

$$w_a^I = (A_e + d\cdot A_e)/2(1 - d^2) \qquad w_b^I = (A_e + d\cdot A_e)/2(1 - d^2).$$

Finally, if firm a shares its information but firm b does not, then wages are

$$w_a^{SN} = (A_a + d\cdot A_e)/2(1 - d^2) \qquad w_b^{SN} = (A_e + d\cdot A_a)/2(1 - d^2).$$

Since the first stage expectation of the wage is the same for each information set, its expectation of output is the same as well. Thus, profits, wage bill and welfare evaluated at the expected intercepts is the same across information structures. If instead nature selects the firms to set the wages, then w = 0 for all information structures.

Turning to the first stage consider the firm's profits from sharing information. For pricing power B, if it shares its information when its rival does not, then its expected profits are

$$B\cdot E[\pi_{a,U}^S] + (1-B)\cdot E[\pi_{a,F}^S] = B\cdot[\bar{\pi}_{a,U} + \sigma^2/\Delta^2] + (1-B)\cdot[\bar{\pi}_{a,F} + 4\sigma^2/\Delta^2]. \qquad \text{(A1)}$$

If neither share information it is

$$B\cdot E[\pi_{a,U}^I] + (1-B)\cdot E[\pi_{a,F}^I] = B\cdot[\bar{\pi}_{a,U} + \sigma^2/4] + (1-B)\cdot[\bar{\pi}_{a,F} + \sigma^2/4]. \qquad \text{(A2)}$$

If both share information, then firm a's expected profits are

$$B\cdot E[\pi_{a,U}^C] + (1-B)\cdot E[\pi_{a,F}^C] = B\cdot[\bar{\pi}_{a,U} + \sigma^2(4+d^2)/4\Delta^2] + (1-B)\cdot[\bar{\pi}_{a,F} + 4\sigma^2(4+d^2)/4\Delta^2]. \qquad \text{(A3)}$$

Finally, if it does not share when its rival shares, then its expected profits are

$$B\cdot E[\pi_{a,U}^N] + (1-B)\cdot E[\pi_{a,F}^N] = B\cdot[\bar{\pi}_{a,U} + \sigma^2(\Delta^2+d^2)/4\Delta^2] + (1-B)\cdot[\bar{\pi}_{a,F} + \sigma^2(\Delta^2+4d^2)/4\Delta^2]. \qquad \text{(A4)}$$

Equations (A1-A4) are analogous to (1-4) and by similar manipulations it follows that:

<u>Proposition 1(PI)</u>: With price competition and uncertain intercept, a firm unilaterally chooses to share information if and only if B ≤ $d^2(8-d^2)/12$. A firm's profit is greater when both share information than when both do not share information if and only if B ≤ $d^2(12-d^2)/3(4+d^2)$.

<u>Corollary</u>: With price competition and uncertain c intercept, for all d∈(0,1), there exists a pricing power B such that the firm's dominant strategy is to not share information, but joint profits increase if both firms share information.

If both firms share their information than expected producer surplus is

$B\cdot\mathrm{E}[\pi^C_{a,U} + \pi^C_{b,U} + \omega^C_U] + (1-B)\cdot\mathrm{E}[\pi^C_{a,F} + \pi^C_{b,F} + \omega^C_F]$

$= B\cdot[\overline{\mathrm{PS}}_U + \sigma^2(12-d^2-2d^4)/2\Delta^2(1-d^2)] + (1-B)\cdot[\overline{\mathrm{PS}}_F + \sigma^2 2(4+d^2)/\Delta^2].$ (A4)

Expected producer surplus when both firms do not share information is

$B\cdot\mathrm{E}[\pi^I_{a,U} + \pi^I_{b,U} + \omega^I_U] + (1-B)\cdot\mathrm{E}[\pi^I_{a,F} + \pi^I_{b,F} + \omega^I_F]$

$= B\cdot[\overline{\mathrm{PS}}_U + \sigma^2/2] + (1-B)\cdot[\overline{\mathrm{PS}}_F + \sigma^2/2].$ (A5)

Although a bit more manipulation is required, from (A4,A5) and defining | as the unique root of $\{d^6 - 11d^4 + 23d^2 - 4\}$ on the interval [0,1] ($\bar{d} \approx .437$):

<u>Proposition 2(PI)</u>: With price competition and uncertain intercept, producer surplus increases with information sharing if and only if either $d \geq d^*$ or $d < d^*$ and $B \leq d^2(12-d^2)(1-d^2)/(4-11\delta^2-2d^4)$.

<u>Proof:</u> The difference of complete information less incomplete information yields

$$\frac{(d^6 - d^4(13-2B) + d^2(12+11B) - 4B)}{2\Delta^2(1-d^2)}\sigma^2$$

the sign of which is determined by $d^6 - d^4(13-2B) + d^2(12+11B) - 4B$, which in turn is decreasing in B for $d < (3\sqrt{17} - 11)^{1/2}/2$ and is increasing for all B for $d > (3\sqrt{17} - 11)^{1/2}/2$. Evaluating $d^6 - d^4(13-2B) + d^2(12+11B) - 4B$ at B=1, the expression has a unique root on [0,1] denoted d^*. For $d \geq d^*$ ($\approx .437$) is the expression is always positive. For $d < d^*$, the expression is positive for $B < d^2(12-d^2)(1-d^2)/(4-11\delta^2-2d^4)$.//

Turning to welfare, recall that the inverse demand can be generated from utility of the form $[A_a\cdot(q_a + dq_b) + A_b\cdot(q_b + dq_a) - (½)(q_a^2 + 2\cdot d\cdot q_a\cdot q_b + q_b^2)]/(1 - d^2)$. Expected welfare with both firms sharing is

$$B\cdot E[W_U^C] + (1-B)\cdot E[W_F^C] =$$

$$B\cdot[\overline{W}_U + \sigma^2(28 + 3d^2 - 4d^2)/4\Delta^2(1-d^2)] + (1-B)\cdot[\overline{W}_F + \sigma^2(12 - d^2 - 2d^4)/\Delta^2(1-d^2)]. \quad \text{(A6)}$$

Expected welfare when both firms do not share information is

$$B\cdot E[W_U^I] + (1-b)\cdot E[W_F^C] = B\cdot[\overline{W}_U + \sigma^2(3 + d^2)/4(1-d^2)] + (1-B)\cdot[\overline{W}_F + \sigma^2(3 + d^2)/4(1-d^2)]. \quad \text{(A7)}$$

Algebraic manipulation of (A6-A7) yields

Proposition 3(PI): With price competition and uncertain intercept, welfare is greater when both firms share if and only if $B \leq d^2(1-d^2)(d^2+4)/(20-7d^2-4d^4)$.

Corollary: With price competition and demand specific intercept, for all $\delta\in(0,1)$, there exists a pricing power B such that the union can profitably induce the firms to share, but welfare decreases.

Because of the more complex condition in proposition 3(PI), showing this in price competition is a bit lengthier. First, for d > | producer surplus is positive while welfare is negative, and then for d < d′ the B for producer surplus is greater than that for welfare.

Appendix B: Equilibrium prices with price competition and uncertain costs

Complete information (both share):

$$p_a^C = [2(A + w_a + c_a) + d(A + w_b + c_b)]/\Delta$$

$$p_b^C = [2(A + w_b + c_b) + d(A + w_a + c_a)]/\Delta$$

Incomplete information (neither share):

$$p_a^I = [4(A + w_a + c_a) - d^2(c_a - c_e) + 2d(A + w_b + c_e)]/2\Delta,$$

$$p_b^I = [4(A + w_b + c_b) - d^2(c_b - c_e) + 2d(A + w_a + c_e)]/2\Delta,$$

Only firm a shares:

$$p_a^S = [2(A + w_a + c_a) + d(A + w_b + c_e)]/\Delta,$$

$$p_b^N = [4(A + w_b + c_b) - d^2(c_b - c_e) + 2d(A + w_a + c_a)]/2\Delta..$$

Union's wages with price competition and uncertain costs

$$w_a^C = (A - (1 - d)c_a)/2(1 - d) \qquad w_b^C = (A - (1 - d)c_b)/2(1 - d).$$

$$w_a^I = (A - (1 - d)c_e)/2(1 - d) \qquad w_b^I = (A - (1 - d)c_e)/2(1 - d).$$

$$w_a^{SN} = (A - (1 - d)c_a)/2(1 - d) \qquad w_b^{SN} = (A - (1 - d)c_e)/2(1 - d).$$

Expected profits stage 1 with price competition and uncertain costs

$$B\cdot E[\pi_{a,U}^S] + (1-B)\cdot E[\pi_{a,F}^S] = B\cdot[\bar{\pi}_{a,U} + \sigma^2(2-d^2)^2/4\Delta^2] + (1-B)\cdot[\bar{\pi}_{a,F} + \sigma^2(2-d^2)^2/\Delta^2]. \tag{B1}$$

$$B\cdot E[\pi_{a,U}^I] + (1- B)\cdot E[\pi_{a,F}^I] = B\cdot[\bar{\pi}_{a,U} + \sigma^2/4] + (1- B)\cdot[\bar{\pi}_{a,F} + \sigma^2/4]. \tag{B2}$$

$$B\cdot E[\pi_{a,U}^C] + (1-b)\cdot E[\pi_{a,F}^C] = B\cdot[\bar{\pi}_{a,U} + \sigma^2[(2-d^2)^2+d^2]/4\Delta^2]+(1-B)\cdot[\bar{\pi}_{a,F} + \sigma^2[(2-d^2)^2+d^2]/\Delta^2]. \tag{B3}$$

$$B\cdot E[\pi_{a,U}^N] + (1- B)\cdot E[\pi_{a,F}^N] = B\cdot[\bar{\pi}_{a,U} + \sigma^2(\Delta^2+d^2)/4\Delta^2] + (1- B)\cdot[\bar{\pi}_{a,F} + \sigma^2(\Delta^2+4d^2)/4\Delta^2]. \tag{B4}$$

Proposition 1(PC) follows from (B1-B4). Expected producer surplus in stage 1 with price competition and uncertain costs

$$B\cdot E[\pi_{a,U}^C + \pi_{b,U}^C + \omega_U^C] + (1-B)\cdot E[\pi_{a,F}^C + \pi_{b,F}^C + \omega_F^C]$$

$$= B\cdot[\overline{PS}_U + \sigma^2(12-9d^2+2d^4)/4\Delta^2] + (1-B)\cdot[\overline{PS}_F + \sigma^2 2[(2-d^2)^2+d^2]/\Delta^2]. \tag{B5}$$

$$B\cdot E[\pi_{a,U}^I + \pi_{b,U}^I + \omega_U^I] + (1-B)\cdot E[\pi_{a,F}^I + \pi_{b,F}^I + \omega_F^I]$$

$$= B\cdot[\overline{PS}_U + \sigma^2/2] + (1-B)\cdot[\overline{PS}_F + \sigma^2/2]. \tag{B6}$$

Proposition 2(PC) follows from (B5,B6). Expected welfare in stage 1 with price competition and uncertain costs

$$B\cdot\mathrm{E}[\,\mathrm{W}_{\mathrm{U}}^{\mathrm{C}}\,] + (1-B)\cdot\mathrm{E}[\,\mathrm{W}_{\mathrm{F}}^{\mathrm{C}}\,] =$$

$$B\cdot[\,\overline{\mathrm{W}}_{\mathrm{U}} + \sigma^2(28 - 21\mathrm{d}^2 + 4\mathrm{d}^2)/4\Delta^2] + (1-B)\cdot[\,\overline{\mathrm{W}}_{\mathrm{F}} + \sigma^2(12 - 9\mathrm{d}^2 + 2\mathrm{d}^4)/\Delta^2]. \qquad \text{(B7)}$$

$$B\cdot\mathrm{E}[\,\mathrm{W}_{\mathrm{U}}^{\mathrm{I}}\,] + (1-b)\cdot\mathrm{E}[\,\mathrm{W}_{\mathrm{F}}^{\mathrm{C}}\,] = B\cdot[\,\overline{\mathrm{W}}_{\mathrm{U}} + \sigma^2 3/4] + (1-B)\cdot[\,\overline{\mathrm{W}}_{\mathrm{F}} + \sigma^2 3/4]. \qquad \text{(B8)}$$

Proposition 3(PC) follows from (B7, B8).

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