The Strategic Value of Flexibility: Reducing the Ability to Compromise

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Production flexibility is achieved by the ability to change a process from one mode of operation to another. For example, a power generation plant can build in the ability to shift between the use of coal and oil. Manufacturing plants can have the ability to switch between using purchased electricity, co-generated electricity, and natural gas. Tire manufacturers can design processes capable of using either natural or synthetic rubbers. In a wide range of manufacturing applications there exists the ability to shift between labor-intensive and capital-intensive technologies.

It is well known that one of the most significant advantages of flexibility is to provide the production process with an ability to modify itself in the face of uncertainty. Recent studies have addressed the issue of the economic value of flexibility in terms of its *option* value. (See Robert McDonald and Daniel Siegel, 1985, 1986; Scott Mason and Robert Merton, 1985.) Nalin Kulatilaka, 1987, develops a general model of flexibility which synthesizes the above options literature. In these studies, random price realizations trigger the exercise of the option to switch from one mode to another. The option has value only if price is uncertain.

In this paper we examine the *strategic* value of flexibility in a world with incomplete contracting. The study of incomplete contracting is motivated by four factors: 1) In a world of complete contingent contracts, most (but not all) interesting strategic considerations disappear. 2) There is a significant literature that addresses the implications of bargaining under the assumption of incomplete contracting. 3) There are sound theoretical reasons why we would expect contracts to be incomplete. 4) Empirically, we observe that most contracts are indeed incomplete.

One such market in which incomplete contracting is the norm is the labor market. Typical labor contracts specify wage and working conditions, but allow employment levels and levels and types of capital expenditures to be set by the firm. (There are, of course, rare exceptions.) Other instances in which price and other characteristics are negotiated but quantity is left to the option of the purchaser can be found in the purchases of integrated circuits, natural gas, and automobile parts. For example, it is common for computer manufacturers and integrated-circuit suppliers to fix by contract the engineering specifications and the unit price. Thereafter, the computer manufacturer can choose the quantity of chips to be delivered.

The reason usually cited for the absence of complete contingent contracts is the transaction costs of contracting. For example, first-best contracting in the absence of transaction costs might result in contracts that specify price-quantity-investment schedules for a continuum of demand conditions, a continuum of cost conditions, and that are contingent on the random arrival of new technologies. Cost of negotiation, as well as imperfect or asymmetric information, make such contracts impossible in practice. In addition, complete *noncontingent* contracts, such as one that would guarantee a quantity level over all states of nature, may not represent the second-best solution. Firms facing uncertainty derive an option value from the ability to vary quantity with demand conditions, cost conditions, and the arrival of new technologies. That is, the value of the option

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to the purchaser may be greater than the value of a fixed supply contract to the supplier. In such a case the contract will allow the purchaser to choose quantity.

In addition, information asymmetries may make it impossible to fix quantity. In the case of labor, guaranteed employment (fixed quantity) in the presence of informational asymmetries may lead to problems of moral hazard in the choice of effort by workers or of adverse selection in the retention of high productivity workers.

It is not surprising, then, that incomplete contracting is the rule rather than the exception in many industries. It is not the purpose of this paper, however, to model the causes of incomplete contacting. Rather, we follow Paul Grout (1984) and others and examine the implications of bargaining under the assumption that contracts are incomplete. The advantage of assuming incompleteness is that it allows us to model bargaining under certainty. This not only makes for a more tractable model but it also enables us to isolate the purely strategic elements of a bargain. For example, Grout assumes that wage is bargained (contracted) but that the firm chooses both employment and capital expenditures. Our model is in the same spirit. In order to focus on the strategic aspects of flexibility, we consider a model under certainty where 1) the firm chooses a technology, 2) the firm and its input suppliers (and/or output purchasers) negotiate over price, and 3) the firm subsequently chooses input quantities. (The model developed herein builds on one developed by Stephen Marks, 1984, who studied the strategic implications of wage bargaining.)

The following simple thought experiment illustrates the basic approach. Consider two scenarios. In scenario I there is a fixed technology in place that uses one unit of labor. The firm and the labor union bargain over the pre-wage surplus, R. In scenario II the firm has a flexible technology in place with two modes. The first mode is identical to the fixed technology of scenario I. The second mode uses less labor. Suppose that it is profitable to switch to the second mode if wage is high. That is, the firm now has a threat that says to labor, "if you demand too high wages, we will employ fewer workers." Let us suppose that this flexibility is costless to install and that switching between modes is also costless. Finally, suppose that there is no uncertainty regarding the production process, future prices, or bargaining outcomes.

It is well established that such flexibility can confer a strategic advantage on the firm resulting in a lower input price. It is also well known that such flexibility has the potential for inefficiency. That is, it may lower joint profits. For example, Carliss Baldwin (1983) develops a model where building one efficient plant and one inefficient plant (rather than two efficient plants) produces a strategic advantage in wage bargaining since if wage is too high the firm will shut down the inefficient plant. The resultant restraint on wage bargaining allows the firm to capture profits in the efficient plant. The firm is better off but the result is socially inefficient. Another example is the case of an upstream monopolist forcing flexible downstream producers to shift to inefficient technologies. Flexibility makes the downstream firms better off but the result is socially inefficient.

A more striking result is that such flexibility may be detrimental to the firm itself. We develop a model that demonstrates how this may happen. We show that in some cases a mutually destructive (but incentive-compatible) threat may be exercised if in place. In these cases a rational firm will avoid flexibility even if it is technologically costless. Whether flexibility will be detrimental or beneficial (or whether it will have no value) depends on the exact parameters of the problem. We will show, however, that very similar parameters lead to very different results as to the value of flexibility.

I. The Model

Here we present the outline of the model. The formal propositions and proofs are given in Appendix I.

Consider a fixed technology which uses α units of input and generates revenues A. The price of the input, P, is negotiated after the technology is put into place. The value of this technology to the firm, V_A, is simply

$(A - \alpha P)$ if operated and zero if closed. (We ignore installation and fixed costs for now.) Another fixed technology uses β units of the input and produces a value, V_B, equal to $B - \beta P$ if operated and zero if closed. We can assume, without loss of generality, that $A \geq B$. The revenues not received by the firm are received by the input supplier. The input supplier is assumed to maximize net profits

$$(1) \qquad W = (P - C)Q,$$

where C is a unit opportunity cost and Q is quantity. We will assume for the exposition that $C = 0$ although this is unimportant. Q is determined by the firm after bargaining and can be zero, α, or β depending on the technology in place.

Now consider a flexible technology F which has as its two modes the fixed technologies A and B. The mode of operation of the flexible technology is chosen by the firm after P has been determined. Hence, its value, V_F, is given by $\max(A - \alpha P, B - \beta P)$ if operated and zero if closed. The flexible manufacturing technology will operate in mode A only if the profits in mode A are greater than the profits in mode B, that is, only if

$$A - \alpha P \geq B - \beta P$$

or, equivalently, if

$$(2) \qquad P \leq (A - B)/(\alpha - \beta) \equiv P_s,$$

where P_s is called the switching price for the flexible technology. Otherwise, it will operate in mode B. (Note that if there is equality we have assumed the firm will operate in mode A. Also, the firm may choose not to operate if profits are negative.)

A necessary condition for a positive switching price (given $A > B$) is that $\alpha > \beta$. (Note that if $\alpha \leq \beta$, the firm will choose mode A irrespective of price. In such a case, the flexible technology is not really flexible. That is, the alternative mode, B, is not a credible threat as it requires more of the input. In such cases, "flexibility" will have no value. We henceforth consider only cases where $\alpha > \beta$. However, as we will see, flexibility may have no value even if $\alpha > \beta$.) In Figure 1 we plot the firm's profit, V, against the input-supplier's revenues, W, for the three technologies.

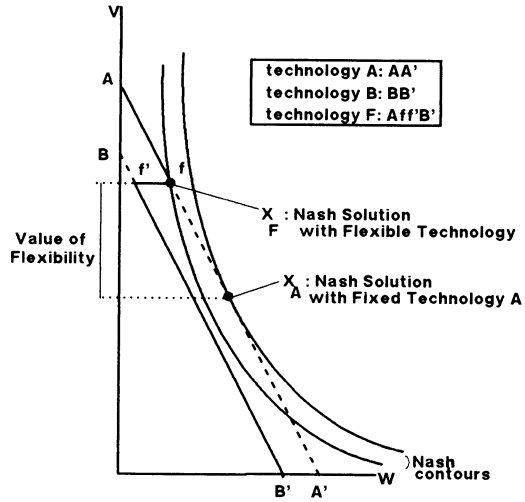

FIGURE 1. FLEXIBILITY IS BENEFICIAL TO THE FIRM

We now apply the Nash-bargaining solution to the set of feasible outcomes. The Nash solution is well known (see John Nash, 1950; Alvin Roth, 1979) and its use in labor-firm bargaining is not without precedent (see Grout, 1984). The Nash solution satisfies Pareto optimality, invariance with respect to linear utility transformations, independence from irrelevant alternatives and symmetry. Although the Nash solution is usually used with convex feasible sets, it is Pareto optimal even when the feasible set is not convex. Symmetry implies equal bargaining power. (We relax this assumption in Appendix I.) When applied to a constant surplus, the Nash solution splits the surplus. In our notation the Nash-bargaining solution is to choose a P that maximizes the product of $V(P)$ and $W(P)$. Nash contour lines are given by $V(P)W(P) = k$ for various values of k. In Figure 1, the Nash solution is the intersection of the highest Nash contour line and the feasible set. The Nash solution is X_A under the fixed technology A and X_F under the flexible technology. Clearly, the firm is better off under the flexible technology, that is, flexibility has value.

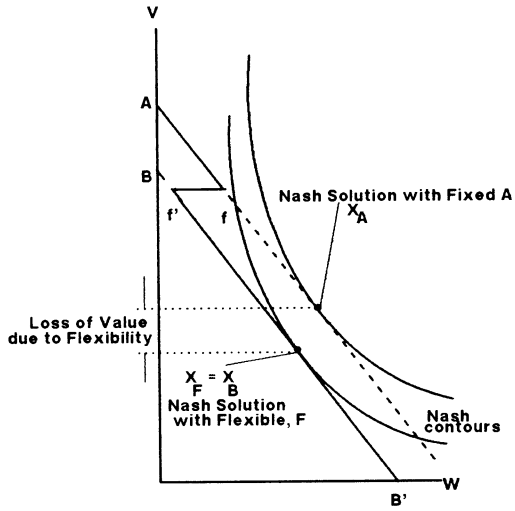

FIGURE 2. FLEXIBILITY IS DETRIMENTAL TO THE FIRM

Figure 2 depicts a situation with slightly different parameter values but a dramatically different result. The flexible technology leads to lower value to the firm. A rational firm will adopt a flexible technology under the parameter values of Figure 1 but a fixed (type A) technology under the parameters of Figure 2. That is flexibility can be detrimental to the firm even if it is costless. The formal propositions are presented in Appendix I.

Heuristically, the reason for these results is that the bargaining is over price but not quantity and flexibility removes from consideration a set of prices. In addition it alters the payoffs for another set of outcomes.

To see this recall that P_s is the price above which the firm will switch from mode A to mode B if the flexible technology is in place. Let $P' = P_s\alpha/\beta$. Now consider the interval (P_s, P'). Under the flexible technology any price in this interval is Pareto dominated by P_s. For the firm any price above P_s results in a worse outcome than P_s. For the input supplier, a price above P_s results in a greater unit return but a lower quantity. For prices below P', total revenues to the input supplier are lower than with P_s, that is,

$$\text{Revenue at Price } P \text{ in } (P_s, P') = P\beta < P'\beta = P_s\alpha = \text{Revenue at } P_s.$$

Thus in the interval (P_s, P') both parties are worse off than at P_s. If the bargaining outcome under the fixed technology falls in this interval then the removal of this "middle ground" through the adoption of the flexible technology means that the outcome must now fall to one side or the other of the interval. If the outcome falls to P_s or below, then the firm benefits; if it falls to P' or above, then the firm is hurt. Which will occur depends on the parameters of the problem.

In other words, the removal of this interval removes a region of possible compromise. In addition, outcomes in the interval (P', ∞) have been altered in a way that lowers the surplus over which the parties are bargaining. Again this makes compromise more difficult. Both these effects polarize bargaining by making it more of an "all or nothing" situation. The firm may benefit if it ends up with more ("all") or be hurt if it ends up with less ("nothing").

Note that the lost "middle ground" is independent of the bargaining rule. That is, the lost interval (P_s, P') can be determined without any reference to the bargaining rule. Thus, the results, particularly the result that flexibility can be detrimental, are robust to many different bargaining rules. (For example, instead of the Nash solution, we could have used an alternative bargaining rule suggested by Roth (1979, pp. 92–97) that maximizes the minimum of $V(P)$ and $W(P)$ after eliminating all Pareto-dominated outcomes.) In fact, we demonstrate in Appendix II that there need be no bargaining at all. In Appendix II we construct an example involving a monopolistic supplier and a price-taking downstream producer in which the adoption of flexibility by the downstream producer would be detrimental to it. Many different specifications of the objective functions led to the same basic conclusions, including those involving continuous quantities. In our example in Appendix II quantity can be any positive real number.

II. Concluding Comments

It should be noted that, in our model, both advantages and disadvantages of flexi-

bility depend on an incentive-compatible threat that the flexibility confers on the firm. If this threat can be negotiated away then flexibility has neither positive nor negative value. In our example, if both price and quantity can be negotiated then the feasible set of outcomes under the flexible technology F is identical to that under the nonflexible technology A. Thus, in the presence of complete contracts flexibility will have zero value. In practice, however, firms make decisions over many different variables that affect both the firm and the input supplier. Firms and input suppliers may bargain over some of these variables. As long as there are variables that affect the input supplier but are excluded from bargaining there will be a potential for beneficial or detrimental (to the firm) flexibility. That is, the input supplier and the firm may bargain over many dimensions but as long as they do not bargain over all dimensions the results presented herein apply. (It is easy but messy to construct examples in higher dimensions.) It is this incompleteness that makes detrimental flexibility possible even in the light of a bargaining rule (such as Nash) that otherwise would be Pareto optimal.

Finally, note that we developed our model in a world of certainty in order to isolate theoretically the strategic aspects of flexibility from the risk-reducing (option) aspects. In a more realistic setting (one involving risk) a complete contract would have to be a complete contingent contract. Such contracts simply do not exist because of the high information and transaction costs. In the absence of such contracts, flexibility would confer both a strategic value and a value in risk reduction. We have shown in this paper that the strategic value of flexibility can, under some conditions, be negative.

Appendix I. Formal Propositions

The model in the text is generalized and formalized below. We will use the generalized Nash solution to determine the outcome of bargaining. This involves maximizing $\phi = V^{1-\delta}W^{\delta}$ for each of the three different technologies where $\delta \in [0,1]$ is bargaining power of the input supplier. (See Roth, 1979, and Grout, 1984.) Note that

$$\text{(A3)}\quad \phi_A(P) = \begin{cases} (A-\alpha P)^{1-\delta}(\alpha P)^{\delta} & \text{if } 0 \le P \le A/\alpha \\ 0 & \text{otherwise} \end{cases}$$

$$\phi_B(P) = \begin{cases} (B-\beta P)^{1-\delta}(\beta P)^{\delta} & \text{if } 0 \le P \le B/\beta \\ 0 & \text{otherwise} \end{cases}$$

$$\phi_F(P) = \begin{cases} (A-\alpha P)^{1-\delta}(\alpha P)^{\delta} & \text{if } P > P_s \text{ and } 0 \le P \le A/\alpha \\ (B-\beta P)^{1-\delta}(\beta P)^{\delta} & \text{if } P > P_s \text{ and } 0 \le P < B/\beta \\ 0 & \text{otherwise} \end{cases}$$

The input prices under each of these technologies is thus

$$P_A = \operatorname{argmax} \phi_A(P)$$

$$P_B = \operatorname{argmax} \phi_B(P)$$

and $$P_F = \operatorname{argmax} \phi_F(P).$$

Then we can state the following propositions:

PROPOSITION 1: *If $P_s \ge P_A$, then $P_F = P_A$ and flexibility has no value.*

PROPOSITION 2: *If $P_s < P_A$, then either a) $P_F = P_s$ and flexibility is beneficial to the firm, or b) $P_F = P_B$ and flexibility is detrimental to the firm.*

The following simple results are used in the proofs of the propositions:

R1: $\phi_F(P) = \phi_A(P)$ if $P \in [0, P_s]$

R2: $\phi_F(P) = \phi_B(P)$ if $P \in (P_s, \infty)$

R3: $P_A = (\delta A)/\alpha$ uniquely maximizes $\phi_A(P)$

R4: $P_B = (\delta B)/\beta$ uniquely maximizes $\phi_B(P)$

R5: $\phi_A(P_A) > \phi_B(P_B)$

R6: $\phi_A(P)$ is strictly increasing for $P \in (0, P_A)$

R7: $\phi_B(P)$ is strictly decreasing for $P \in (P_B, B/\beta)$ and 0 for $P \le B/\beta$

R8: $\phi_A(P_s) > \phi_B(P_s)$

The proofs of these simple results are straightforward and are omitted.

Proof of Proposition 1. If $P_s \geq P_A$, then $\phi_F(P_A) = \phi_A(P_A)$. It then follows from R1, R2, R3, R4, and R5 that $P = P_A$ maximizes $\phi_F(P)$. Thus, $P_F = P_A$ and mode A will be used. The firm gains nothing since fixed technology A would lead to an identical result.

Proof of Proposition 2. There are four possibilities given $P_s < P_A$: *i*) $P_B \leq P_s$; *ii*) $P_B > P_s$ and $\phi_B(P_B) < \phi_A(P_s)$; *iii*) $P_B > P_s$ and $\phi_B(P_B) = \phi_A(P_s)$; and *iv*) $P_B > P_s$ and $\phi_B(P_B) > \phi_A(P_s)$.

In the interval $[0, P_s]$, ϕ_F is maximized at P_s (by R1, R6, and $P_s < P_A$). Now consider the interval (P_s, ∞). In Case (*i*) $\phi_F(P)$ is less than $\phi_B(P_s)$ for all P in (P_s, ∞) (by R2, R7, and $P_B \leq P_s$) and $\phi_B(P_s) < \phi_F(P_s)$ (by R1 and R8). Thus, ϕ_F is maximized at P_s or, in our notation, $P_F = P_s$. In Case (*ii*) P_B maximizes ϕ_F in the interval (P_s, ∞) (by R2, R4, and $P_B > P_s$), but $\phi_F(P_B) < \phi_F(P_s)$ (by R1, R2, $P_B > P_s$ and $\phi_B(P_B) < \phi_A(P_s)$). Thus again, $P_F = P_s$. In both these cases flexibility is beneficial since $P_s < P_A$ and

$$B - \beta P_s = A - \alpha P_s > A - \alpha P_A.$$

In Case *iii*) we get indeterminacy since $\phi_F(P_s) = \phi_F(P_A)$. This condition is a knife-edge that separates beneficial flexibility and detrimental flexibility.

In Case *iv*) P_B maximizes ϕ_F in the interval (P_s, ∞) (by R2, R4, and $P_B > P_s$) and $\phi_F(P_B) > \phi_F(P_s)$ (by R1, R2, $P_B > P_s$ and $\phi_B(P_B) > \phi_A(P_s)$). Thus, $P_F = P_B$. In this case the firm is worse off since at $P = P_B$, the firm will use mode B. This is worse than the outcome of adopting the nonflexible technology A since

$$A - \alpha P_A = A(1-\delta),$$

$$B - \beta P_B = B(1-\delta),$$

and $$A > B.$$

Appendix II. A Numerical Example in a Different Context of Detrimental Flexibility

Consider the case of an upstream monopolistic input supplier and a downstream price-taking producer. Suppose that the downstream firm has the choice of three technologies (two fixed, A and B, and one flexible, F), each of which use the input. Suppose also that the profits under the technologies, given the input price P, are as follows:

A. *Profit Functions of Downstream Firm*

Technology A: $\pi = 3.5 - P$

Technology B: $\pi = 3.65 - 1.1P$

Technology F: $\pi = \begin{bmatrix} 3.5 - P & \text{if } P \leq 1.5 \\ 3.65 - 1.1P & \text{if } P > 1.5 \end{bmatrix}$

Suppose the input demand of the downstream firm is given by the following demand functions:

B. *Input Demands of Downstream Firm*

Technology A: $Q = 4 - P$

Technology B: $Q = 2 - 0.5P$

Technology F: $Q = \begin{bmatrix} 4 - P & \text{if } P \leq 1.5 \\ 2 - 0.5P & \text{if } P > 1.5 \end{bmatrix}$

Finally suppose that the upstream monopolist has the following cost function.

C. *Cost Function of Upstream Monopolist*

$$\text{Total Cost} = (1/6)Q^3 - Q^2 + 3Q.$$

Simple profit-maximization results in the upstream monopolist's setting the following prices:

D. *Prices Set by the Monopolist*

Technology A: $P = 2.5858$

Technology B: $P = 3.1010$

Technology F: $P = 3.1010$

This yields the following profits to the downstream producer:

E. *Profits to the Downstream Firm*

Technology A: $\pi = 0.9428$

Technology B: $\pi = 0.2323$

Technology F: $\pi = -0.1042$

In this example it is clearly detrimental for the downstream firm to adopt a flexible manufacturing system, even if it is costless to install and to switch modes, and it is clear why this is so. The downstream producer's threat to switch to an input-conserving technology actually causes the input price to increase since demand is more inelastic in mode B.

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