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In Defense of Limited Manufacturing Cost Control: Disciplining Acquisition of Private Information by Suppliers

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ABSTRACT: When a firm's input supplier can acquire and misreport private information to gain an edge in negotiations, we show that the firm can blunt the supplier's informational advantage by permitting inefficiencies in its own internal production. Specifically, we establish that a modest increase in the cost of the input(s) a firm makes internally credibly commits it to be more aggressive in negotiations with a supplier for the input(s) the firm buys. Recognizing that its potential information rents will be limited, the supplier, in turn, becomes less aggressive in information acquisition. The paper fully characterizes the equilibrium—the firm's investments, the supplier's information acquisition and reporting decisions, and the terms of trade—to demonstrate that often-maligned internal bloat can be an endogenous facilitator of efficient outsourcing.

Keywords: cost control; information acquisition; optimal contracts; outsourcing.

I. INTRODUCTION

Make and buy decisions are familiar issues for accountants. Often, the problem is cast as a choice between either making or buying an input. While the "make versus buy" decision is indeed reflective of some circumstances, manufacturing firms often opt to both make and buy inputs. That is, firms purchase some inputs from external suppliers while relying on in-house production for others: they find areas of specialization and outsource those for which they have no discernable expertise. In this paper, we examine such sourcing circumstances and demonstrate that informational reasons can result in the costs of made inputs and the cost of outsourced inputs to interact. In particular, higher internal (make) costs credibly commit a firm to be tough in procurement negotiations with its external supplier. This, in turn, undercuts the supplier's incentive to acquire and misreport private information that would have given it an edge in negotiations. Broadly stated, internal production inefficiencies come with a silver lining for the firm by dissuading a supplier of outsourced inputs from gaining an information upper hand.

Formally, the paper models a firm that sells a product requiring two inputs. The firm makes one input, input *m,* internally and buys the other input, input *b,* from an external supplier. The firm can control the cost of input *m* by investing upfront in a new technology; the greater the firm's investment in the new technology, the lower its marginal cost of made inputs. The firm is also concerned with what it pays to procure input *b* from the supplier. Here, it confronts an informational problem: the supplier can install an information system (e.g., undertake an activity-based costing analysis) to provide it with more precise (private) information about input *b*'s cost. The precision of the information system is naturally tied to the supplier's spending on the system. When the supplier's information system proves ineffective and leaves it no better informed, buying inputs from it is

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straightforward for the firm. When the supplier is privately informed, the firm optimally offers a menu of contracts, each of which prescribes price and quantity of trade. The supplier selects from this menu via its self-reported cost. Following contract selection, the firm buys the contracted units of input b, makes an equal number of input m, and combines them to create an output. The focus of the model is on how the firm's cost-cutting investment in the new technology influences the supplier's information acquisition and reporting decisions and the terms of trade in light of adverse selection.

To provide intuition for the economic forces, we begin with a binary version of the model: the supplier's cost is low or high, and its information acquisition decision is a discrete one: whether to install a given information system. Moreover, the supplier's cost of installing the system and the firm's cost of investing in the new technology are each assumed to be arbitrarily small, ensuring that the information acquisition and investment decisions are driven solely by information-grounded incentive considerations. In this simplified setting, when the firm faces an informed supplier, the usual production-versus-rents trade-off leaves the firm with two options. It can offer a Slack contract (i.e., offer to pay a high price) that ensures the supplier will always agree to trade, but one that offers the supplier potential information rents. Alternatively, it can offer a Rationing contract (i.e., offer to buy only at a low price), under which the supplier agrees to trade only when its own cost is low, but which eliminates information rents. The absence of supplier rents with the Rationing contract means it provides the firm with an upside *ex ante:* it disincentivizes the supplier from acquiring private information, leaving the firm and its supplier on level information footing in negotiating trade terms.

Critically, the firm's threat to ration is only credible when its potential profits from the sale of the finished product are limited. After all, with high profits, forgoing trade is not optimal for the firm; recognizing this, the supplier will seek to acquire private information so as to secure information rents. By investing less in the new technology, i.e., ensuring higher marginal cost of made inputs, the firm can curtail product profitability sufficiently that Rationing is credible as the response to an informed supplier. Of course, when revenues are significant, this strategy imposes a substantial burden on the firm's make operation and, thus, would not be worthwhile. At the other extreme, when revenues are low, the commitment to Rationing is already natural without making in-house operations expensive. In short, the firm's investment decision is altered only for intermediate revenue values. For these values, a modestly higher marginal cost on the make side can commit the firm to aggressive trade terms, an action that stifles the supplier's incentives to acquire private information and, thus, secures more-than-offsetting gains for the firm on the buy side.

The fundamental trade-offs and interaction between the make and buy costs established in the binary setting applies in the more general continuous setting modeled in the paper. The equilibrium characterization and the accompanying comparative statics in the continuous case reiterate and reinforce the intuition. In particular, the more the firm's marginal cost of made inputs, (1) the stricter its buy offer to the informed supplier, and (2) the lower is the chosen precision of the supplier's information system due to the availability of lower information rents. As a consequence, the firm's equilibrium investment in cost-cutting technology is lower than if the supplier's information acquisition choice was taken as exogenous.

In the above analysis, we presume that the firm learns whether the supplier's information system is effective (i.e., whether the supplier is informed), although it is not privy to the specific cost information that the informed supplier obtains. This assumption permits us to focus squarely on the novel aspect of our model—supplier incentives for information acquisition—while employing familiar optimal contracts from the standard adverse selection literature (e.g., Harris, Kriebel, and Raviv 1982; Antle and Eppen 1985; Antle and Fellingham 1995; Rajan and Reichelstein 2004). However, we also demonstrate that the results are not sensitive to this assumption. Specifically, we extend the analysis to a setting where the firm does not even know whether the supplier it contracts with is uninformed or informed. While this "maybe informed" setting complicates the determination of the optimal contract (as in, e.g., Crémer and Khalil 1994; Crémer, Khalil, and Rochet 1998), we again identify the intermediate revenue values for which the firm's equilibrium make and buy costs interact in that the firm settles on a higher marginal cost of making in order to lower its expected payment for the outsourced input.

Finally, we devote a section to discuss some additional applications of the overall theme that internal weaknesses can put the firm in a position of external strength when negotiating with a potentially privately informed party. While our model incorporates internal weakness through inefficiencies in the cost of making an input, the implications of our model apply more generally to other forms of weaknesses that lower the product's unit margin, but not to others in which the firm simply "burns money" without affecting the product's unit margins. The key is whether the introduced inefficiency impacts the firm's marginal benefits of securing units when negotiating contract terms with the third party.

Our study builds on and adds to several streams of literature. In terms of incentive design in adverse selection models, Antle and Eppen (1985), applying the seminal Harris et al. (1982) framework to a capital budgeting and procurement setting, demonstrate that the production versus rents trade-off is captured by a simple "bang-bang" contract (the binary-type equivalent of which are the Slack and Rationing contracts). Subsequent papers have studied variants including, for example, the principal's design of information system (e.g., Antle and Fellingham 1995; Arya, Glover, and Sivaramakrishnan 1997), contracting over multiple periods (Antle and Fellingham 1990; Dutta and Reichelstein 2002), delegated contracting and the design of responsibility centers (e.g., Melumad, Mookherjee, and Reichelstein 1992; Mookherjee and Reichelstein 1997), transfer pricing (e.g., Vaysman 1996), and supplier relations (Lewis and Sappington 1991; Cachon and Lariviere 1999). For an excellent survey of this literature, see Rajan and Reichelstein (2004). These adverse selection models presume the agent is privately informed, and focus on the mechanism design problem to optimally extract the information from the agent. Our paper steps back and examines the agent's (i.e., supplier's) decision to become privately informed in the first place.

Studies that examine information acquisition decisions include Shavell (1994), Arya, Gong, and Ramanan (2014), and Dye (2017), who each demonstrate in different settings that discretion in disclosure can lead to excessive information acquisition. When disclosure is mandatory, Schneider and Scholze (2015) demonstrate that there can be under-acquisition of information when there is a concern with information falling into the wrong hands. In contrast to these studies that assume truthful reporting, we examine information acquisition in an adverse selection context in which the supplier can potentially pad and misreport cost information to the buyer. In this sense, our study is related to Crémer and Khalil (1994) and Crémer, Khalil, and Rochet (1998), who show how the optimal contract changes in light of information acquisition by a contracting party. Relative to these and the other adverse selection papers that have followed Baron and Myerson (1982), our paper adds that it may also be optimal to distort the firm's real actions (here, investment in cost cutting) in order to curb the agent's incentives to acquire private information and subsequently report it in self-interest. Moreover, the firm's distortion occurs on a front (the internally produced input) that is seemingly independent of the problem plagued by information concerns (the outsourced input).

Our study is also related to the literature on strategic outsourcing. Several papers discuss circumstances wherein a simple make-cost versus buy-cost comparison may be inadequate to capture the full impact of the outsourcing decision. Such considerations include predatory pricing by suppliers (Marx and Shaffer 1999), gains due to learning-by-doing (Chen 2005), revelation of proprietary information (Demski and Sappington 1993), outsourcing to a common supplier to avoid redundant fixed costs (Shy and Stenbacka 2003) or to disadvantage rivals (Salop and Scheffman 1987), and the reduction in investment incentives of independent suppliers when a firm has the option to source internally (Loertscher and Riordan 2019). Arya and Mittendorf (2007) show that higher internal transfer prices can reduce a decentralized firm's willingness to pay its supplier, leading the supplier to cut wholesale price. In Arya and Mittendorf (2007), there is no private information and the monopolist supplier has sole discretion over the price. In contrast, the acquisition and exploitation of private information by the supplier and the firm's offer of trade terms are the focus of the current paper.

The rest of this paper proceeds as follows. Section II models the problems of (1) the firm's investment in new technology that impacts the marginal cost of the input it makes in-house, (2) the supplier's acquisition of private cost information for the input the firm buys, and (3) the firm and the supplier's contract governing trade terms. Section III considers a binary version of the model and provides intuition for the economic forces by demonstrating how increasing the cost of the make-input can limit supplier rents. Section IV confirms this intuition more generally by deriving the equilibrium and key comparative statics for the primary setting. Section V extends the analysis to a more severe information problem in which the firm is not even aware of whether its supplier becomes privately informed. Section VI offers additional implications and interpretations of the model's findings. Section VII concludes.

II. MODEL

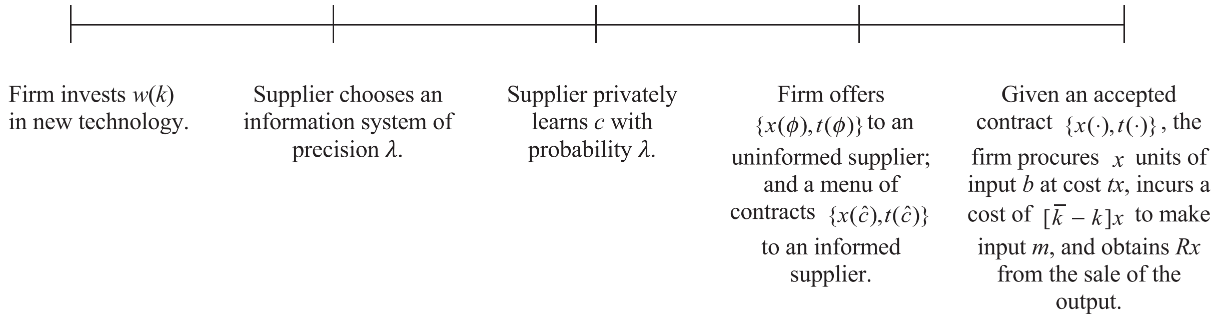
Firms often rely jointly on in-house manufacturing and outsourcing for key inputs. To model such dual sourcing paths simply, consider a (risk-neutral) firm that buys one input (input b) and makes another (input m). The firm then combines x units of each of these inputs, $x \in [0, X]$ to assemble x units of an output that generates revenue of R per unit. Here, X denotes the firm's production capacity, i.e., the maximum number of units the firm can assemble. This familiar upper-bound linear technology formulation, and the modeling of the ensuing adverse selection problem, was initiated in Antle and Eppen (1985) and subsequently employed by its many variants (e.g., Antle and Fellingham 1995).[1]

For the input it makes, the firm's default marginal cost of production is $\bar{k}$. However, the firm has the option to adopt a new technology to lower this cost. Specifically, by investing an upfront (fixed) cost $w(k)$ in this technology, the cost is lowered to $\bar{k} - k$ per unit, where $k \in [0, \bar{k}]$, $w'(k) > 0$, and $w''(k) \geq 0$.

For the input it buys, the firm is concerned with curtailing payments to a (risk-neutral) external supplier who may gain private information about its own costs (or, equivalently, its opportunity costs tied to next-best use of capacity). In particular, the supplier's uncertain unit cost of producing input b is given by the random variable $\tilde{c} \in [0, \bar{c}]$, with f and F representing the PDF and CDF, respectively, of the distribution of c. While the supplier initially does not know the precise production cost of b, it can try to learn c by installing an information system (e.g., investing in an activity-based costing analysis). The precision of the information system, i.e., the probability with which it reveals c, is denoted by λ, $\lambda \in [0, 1]$. The supplier's cost of installing

[1] The capacity constraint X ensures finite production quantities in the intuitive linear adverse selection model. In Appendix B, we derive the results without capacity constraints in a nonlinear framework (as in, say, the adverse selection model originally studied in Baron and Myerson [1982]).

FIGURE 1
Timeline



an information system of precision λ is given by $v(\lambda)$, with $v'(\lambda) > 0$ and $v''(\lambda) \geq 0$. Broadly viewed, the modeled uncertainty and information system design reflects the fact that the supplier may not be fully informed of a specific product's marginal costs, either because of the imprecision of the installed system or because the system may reveal the cost accurately only in aggregate across its operations and product lines; in the latter case, the splitting of costs into fixed and variable components and the issue of allocating shared costs introduces natural uncertainty in a particular product's true marginal cost.

While all parties observe whether the information system proves effective in determining the supplier's cost, it is only the supplier that is privy to the precise c-value that the effective system reveals (in Section V, we consider a more severe information problem in which the firm not only does not know the supplier's cost information, but does not even know if the supplier is privately informed). This private information then introduces the possibility of the supplier earning information rents by padding its cost reports. Specifically, when the supplier is uninformed, the firm offers a contract $\{x(\phi), t(\phi)\}$ to the supplier, i.e., the firm offers to buy $x(\phi)$ units of input b at $t(\phi)$ per unit. When facing an informed supplier, the optimal mechanism entails the firm offering a menu of contracts $\{x(\hat{c}), t(\hat{c})\}$, $\hat{c} \in [0, \bar{c}]$, from which the supplier selects one contract. Equivalently stated, the firm commits to quantity and payment terms contingent on the supplier's self-reported cost $\hat{c}$.

The sequence of events is as follows. First, the firm invests $w(k)$ to adopt a new technology. Second, the supplier incurs $v(\lambda)$ in information acquisition. Third, the firm and the supplier contract on trade terms. In the event of trade, x units of input b are procured by the firm at cost tx, and this input is combined with x units of input m at cost $[\bar{k} - k]x$ to create x units of the output that is sold in the market for Rx. Thus, the firm's profit is $\Pi_F = [R - (\bar{k} - k) - t]x - w(k)$ and the supplier's profit is $\Pi_S = [t - c]x - v(\lambda)$. To ensure production is optimal absent supplier private information and to ensure interior solution in the informed supplier setting, we assume that $Max\{E\{c\} + \bar{k}, \bar{c}\} < R < \bar{c} + H(\bar{c})$, where $H(c) = F(c)/f(c)$ is the hazard rate that satisfies the standard assumption $H'(c) > 0$. This monotone hazard rate condition is satisfied by several distributions, such as uniform, normal, logistic, Chi-squared, exponential, and Laplace. In adverse selection models, this assumption allows global incentive compatibility constraints to be replaced by their local counterparts (see, for example, Bagnoli and Bergstrom 2005; Laffont and Tirole 1994). Figure 1 summarizes the sequence of events.

III. INTUITION: THE BINARY SETTING

In order to provide intuition for the economic forces in play, this section examines a binary version of the model. In particular, let $c \in \{0, \bar{c}\}$ represent the supplier's uncertain cost, with p denoting the probability that $c = \bar{c}$. Also, let $\lambda \in \{0, \bar{\lambda}\}$, $\bar{\lambda} \leq 1$, with $v(0) = 0$ and $v(\bar{\lambda}) \to 0$. In effect, either the information system is (1) not installed, or (2) installed at an arbitrarily small cost to reveal c with probability $\bar{\lambda}$ to the supplier. This deliberate choice of an "almost costless" information system ensures that it is the incentives provided by the firm that are critical to the supplier's information acquisition decision. In similar spirit, we assume $w(k) \to 0$ for all $k \in [0, \bar{k}]$, ensuring that the only reason the firm will not minimize the cost of the input it makes is if the higher cost aids in providing appropriate incentives to the supplier.

Turning to the optimal contract, if the firm confronts an uninformed supplier, its offer is straightforward: $x(\phi) = X$ and $t(\phi) = E\{c\} = p\bar{c}$. Clearly, an uninformed supplier has no reason to decline this "production at expected cost" offer. When the firm contracts with an informed supplier, it has two options to optimally conduct the "production-versus-rents" trade-off typical in adverse selection settings.

One option is to offer the supplier a "Slack contract" wherein the firm sets $x(\hat{c}) = X$ and $t(\hat{c}) = \bar{c}$ for both the high-cost ($\hat{c} = \bar{c}$) and the low-cost supplier report ($\hat{c} = 0$). The supplier has no reason to decline this offer or to misreport; this offer ensures that X units are purchased from the supplier with certainty. Thus, under the Slack contract, the firm's payoff is $[R-(\bar{k}-k)-\bar{c}]X$.

The other option is for the firm to offer a "Rationing contract" wherein the firm trades if and only if the supplier submits a low-cost report $\hat{c}=0$, by offering the menu $x(\hat{c}=0)=X$, $t(\hat{c}=0)=0$ and $x(\hat{c}=\bar{c})=0$, $t(\hat{c}=\bar{c})=0$. In this case, a low-cost supplier does not benefit from padding its report and, thus, misreporting incentives are eliminated. On the one hand, this contract allows the firm to eliminate the supplier's information rents. On the other hand, the firm commits to forgoing production when the supplier's cost is high. That is, under Rationing, trade only occurs with probability $1-p$ (i.e., if $c=0$). In effect, under Rationing, with probability $1-p$, the firm is able to procure and sell X units, but with probability p, it makes no sale at all, for it is unable to procure input b. This "bang-bang" (no trade or full trade) nature of the Rationing contract ensures that the firm's expected payoff under this contract is $[1-p][R-(\bar{k}-k)]X$. As established in Appendix A, these two contracts capture the full range of possibilities in that the firm's optimal contract to an informed supplier in the binary setting is assured to be either Slack or Rationing. Comparing the Slack versus Rationing payoff expressions, the firm offers a Slack contract if and only if:

$$R>[\bar{k}-k]+\bar{c}/p. \tag{1}$$

Next, we turn to the supplier's incentive to become informed. Naturally, this decision is driven by the contract the supplier expects to be offered when informed. If it anticipates a Slack contract, then it invests in the information system to earn potential information rents. However, if it anticipates the Rationing contract, then its rents are guaranteed to be zero and, thus, it is unwilling to incur even the arbitrarily small cost to install the information system. In effect, since a Slack contract follows if and only if (1) is satisfied, the supplier acquires information only in that circumstance.

Now, consider the firm's investment $w(k)$ in the new technology that cuts its cost to make input m from $\bar{k}$ to $\bar{k}-k$. Since condition (1) dictates the supplier's information acquisition decision, the presence of "k" in (1) provides an avenue for the firm to affect the supplier's decision to become privately informed. Specifically, when make-costs are high enough that (1) is not satisfied (i.e., investment in the new technology is sufficiently low), the firm can credibly commit to being less generous in its buy-offer to the supplier. Formally, choosing lower cost-cutting investment has the downside of raising the cost of input m, but can have the upside of committing the firm to the Rationing contract when facing an informed supplier. After all, when Rationing is in the offing, the supplier will choose to remain uninformed, i.e., the firm does not even confront an adverse selection problem when $w(k)$ is low enough that the condition in (1) is violated.

In terms of the firm's optimal investment, suppose $R\leq\bar{c}/p$. In this case, even if the firm undertakes the maximum cost-cutting initiative $w(\bar{k})$, so $\bar{k}-k=0$, the condition in (1) is not satisfied. That is, for these low R-values, the firm can credibly commit to the Rationing contract when facing an informed supplier even while making its input efficiently. Given that the supplier is sure to receive a Rationing contract if informed, it prefers to not acquire private information. As a consequence, in equilibrium, the firm invests $w(\bar{k})$, confronts only an uninformed supplier, and guarantees trade of $x(\phi)=X$ units via the offer of $t(\phi)=p\bar{c}$, resulting in expected firm payoff of $[R-p\bar{c}]X$.

Now, suppose $R>\bar{c}/p$. In this case, the firm can follow one of two paths. It can incentivize the supplier to remain uninformed by threatening to offer a Rationing contract were the supplier to become informed. As noted earlier, this threat to ration is only credible if (1) is not satisfied. With $R>\bar{c}/p$, this requires that the firm not undertake the investment that maximally cuts the make cost, but rather choose $w(k)$ such that $k=\bar{k}-(R-\bar{c}/p)$, i.e., cut make-cost only to the extent that (1) holds as an equality. This arrangement results in the firm encountering an uninformed supplier, guaranteeing trade of $x(\phi)=X$ units via $t(\phi)=p\bar{c}$, and earning the firm expected profit of $[R-(\bar{k}-k)-p\bar{c}]X=[\bar{c}/p-p\bar{c}]X$.

Alternatively, the firm can engage in maximum cost-cutting for the input it makes, recognizing that it will result in the supplier investing in information acquisition. If the supplier is successful in learning its input cost, then the firm optimally offers the Slack contract, i.e., sets $x(\hat{c})=X$ and $t(\hat{c})=\bar{c}$ for $\hat{c}\in\{0,\bar{c}\}$; if the supplier is uninformed, then the firm sets $x(\phi)=X$ units and $t(\phi)=p\bar{c}$ per unit. In both instances, the offers are accepted and the firm is able to sell $x=X$ units. This approach provides the firm with the upside of minimizing the cost of the input it makes, but is accompanied with the downside of paying information rents to the supplier with probability $\bar{\lambda}$. This arrangement results in expected firm payoff of $[\bar{\lambda}(R-\bar{c})+(1-\bar{\lambda})(R-p\bar{c})]X$.

Comparing the firm's payoffs under the above two approaches, it follows that for the intermediate levels of R, $\bar{c}/p<R<\bar{c}/p+\bar{\lambda}(1-p)\bar{c}$, the firm prefers the former approach—to keep the cost of input m high in order to lower its payment to the supplier for input b. In contrast, for large R-values, $R>\bar{c}/p+\bar{\lambda}(1-p)\bar{c}$, the firm prefers the latter approach—to not distort its make cost, but instead bear a higher cost for the input it buys by offering the Slack contract. These outcomes lead directly to the following result. (Appendix A provides proofs of all results, with the proof of Proposition 1 providing a full and formal characterization of the optimal contracts and the described equilibrium.)

Proposition 1: For $\bar{c}/p<R<\bar{c}/p+\bar{\lambda}(1-p)\bar{c}$, the firm reduces its investment in the new cost-cutting technology to limit the supplier's incentives to acquire information. In particular, for these R-values, $k=\bar{k}-[R-\bar{c}/p]<\bar{k}$.

Proposition 1 establishes that for intermediate R-values, the firm underinvests in the new technology to credibly commit to Rationing when dealing with an informed supplier. In effect, "weakness" tied to higher internal make-costs puts the firm in a position of "strength" when dealing with the external supplier. When R is sufficiently small, voluntarily incurring higher make-costs is unnecessary for the firm—the low revenues automatically make Rationing a credible outcome. When R is sufficiently large, committing to Rationing is not worthwhile for the firm since it requires a substantial increase in make-costs. Consequently, distortion in cost-cutting investment is confined to the intermediate interval of revenue values identified in Proposition 1.

IV. ANALYSIS

The binary setting in the previous section highlights the paper's main theme: when accounting for supplier incentives to acquire private information, the firm's costs to make and buy inputs interact in subtle fashion. In particular, more expensive in-house operations permit the firm to credibly commit to being stricter in trade terms when dealing with an informed supplier. Recognizing that its ensuing information rents will be limited, the supplier is dissuaded from acquiring an information edge in the first place. This section demonstrates that the same economic forces continue to apply and the results generalize in our model, which permits continuous supplier production cost ($c \in [0, \bar{c}]$) and a continuum of information acquisition options ($\lambda \in [0, 1]$). We assume the functions $v(\lambda)$ and $w(k)$ are appropriately well-defined to ensure interior solutions for λ and k. This is true, for example, for the familiar quadratic cost formulation: $v(\lambda) = z_\lambda \lambda^2$ and $w(k) = z_k k^2$ with appropriately large z-coefficients.

The analysis is organized as follows. The first subsection, "Benchmarks," presents benchmark solutions corresponding to the case of a central planner making all decisions and the case wherein the supplier-buyer relationship is not subject to private information. The equilibrium for the main model with information asymmetry between self-interested buyer and supplier is derived via backward induction: the second subsection "The Firm's Optimal Contract," examines the firm's optimal contract offer to the supplier for buying input b. In particular, the contract specifies the quantity $x(\hat{c})$ and payment $t(\hat{c})$ as a function of the supplier's cost report $\hat{c}$. The third subsection, "The Supplier's Acquisition of Private Information," steps back to characterize λ, the supplier's information acquisition decision. The fourth subsection, "The Firm's Cost-Cutting Investment," details the firm's upfront cost-cutting investment in input m taking into account the impact of the decision on the ensuing λ, x, and t choices.[2]

Benchmarks

In our model, strategic interactions occur between a vertically separated buyer and supplier, and the relationship is plagued with concerns for private information. In this subsection, we present two pertinent benchmark results. The first benchmark details the outcome when all decisions are made by a central planner who owns and directs a vertically integrated supplier-buyer entity. In effect, in this case, there are no concerns with divergent goals or distributed information. The second benchmark reverts to an independent and self-interested buyer and supplier setting, but in the absence of private information in that any cost information learned by the supplier is also observed by the buyer.

Consider the decisions of the central planner of an integrated entity. In this case, given that the central planner controls both λ and k, he chooses k simply to maximize production efficiency. Further, he only acquires cost information if such information helps refine his production decision. Formally, the central planner's problem is as follows:

$$\underset{x(\cdot),\lambda,k}{Max}\ \lambda \int_0^{\bar{c}} [R - (\bar{k} - k) - c]x(c)f(c)dc + [1 - \lambda][R - (\bar{k} - k) - E\{c\}]x(\phi) - v(\lambda) - w(k).$$

The above problem reflects the fact that, absent cost information (an event that occurs with probability $1 - \lambda$), the central planner produces $x(\phi)$ units at expected cost, but when the planner obtains cost information, he makes cost-contingent production decisions $x(c)$. Lemma 1 presents the "central planner benchmark" by characterizing the solution to the above optimization problem. In denoting this solution, we define $\{\lambda^s, k^s\}$ as the $\{\lambda, k\}$-value that solves the following, and then define c^s as $R - (\bar{k} - k^s)$:

$$\frac{v'(\lambda)}{X} = \int\limits_{R-(\bar{k}-k)}^{\bar{c}} cf(c)dc - [1 - F(R - (\bar{k} - k))][R - (\bar{k} - k)],\ where\ \lambda = \frac{1 - w'(k)/X}{1 - F(R - (\bar{k} - k))}.$$

Lemma 1: With a central planner making decisions, the equilibrium is as follows.

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[2] The backward induction process identifies the unique subgame perfect Nash equilibrium in our sequential game. As a corollary, there is no (subgame perfect) mixed strategy equilibrium wherein the firm (supplier) randomizes its cost-cutting (information acquisition) investment.

(i) For $c^s < \bar{c}$: $k = k^s$, $\lambda = \lambda^s$, $x(\phi) = X$, $x(c) = X$ if $c \leq c^s$, and $x(c) = 0$ if $c > c^s$; and
(ii) For $c^s \geq \bar{c}$: k is the solution to $w'(k) = X$, $\lambda = 0$, $x(\phi) = X$, and $x(c) = X$ for all c.

The central planner finds the cost information helpful when its production decisions are cost contingent. In particular, when the downstream production cost c is below the threshold c^s, production is profitable and it is optimal to produce X units. When the same cost exceeds the said threshold, it is optimal to not produce at all. This "bang-bang" nature of production follows from linear cost and revenues. In part (i), the threshold value is interior ($c^s < \bar{c}$), and the production of X units corresponds to the planner opting for maximal production when the product's unit contribution margin is non-negative, i.e., the condition $c \leq c^s$ is equivalent to $R - (\bar{k} - k^s) - c \geq 0$. If the unit contribution margin is non-negative for all c-values, then the cost information is valueless for the central planner since he opts for the production of X units in all circumstances. This is the case in part (ii), so the solution is the boundary point $\lambda = 0$.

As a second intuitive benchmark, we consider a vertically separated supplier and buyer, so as to note the self-interested supplier's incentives for information acquisition when he does not have an information edge. In this no private information setting, the supplier does not acquire information for it derives no benefit from it—the firm will only reimburse the supplier the realized cost when trade takes place—but the supplier alone bears the cost of acquiring information. Thus, $\lambda = 0$. With both parties being uninformed, the firm pays the supplier its expected cost to purchase X units, i.e., $x(\phi) = X$ and $t(\phi) = E\{c\}$. The firm's cost-cutting initiative chooses investment in new technology to maximize $[R - (\bar{k} - k) - E\{c\}]X - w(k)$, yielding $w'(k) = X$. This "no private information benchmark," summarized in Lemma 2, is identical to the no information acquisition outcome in Lemma 1(ii).

Lemma 2: In the absence of private information, the equilibrium is as follows: the firm's investment in the new cost-cutting technology satisfies $w'(k) = X$; the supplier acquires no information, i.e., $\lambda = 0$; and the firm offers the contract $x(\phi) = X$ and $t(\phi) = E\{c\}$.

The main distinction of the no private information solution in Lemma 2, relative to the central planner solution in Lemma 1, is in the supplier's information acquisition incentive. Since the supplier does not internalize the buyer's benefit from the information, it never acquires information. Specifically, public information either leads to the supplier being reimbursed for production cost alone or to no transaction occurring. In effect, the supplier is subject to a holdup problem receiving no *ex post* payments for acquiring information.

In both the benchmarks presented, a common thread is that the cost-cutting investment decision $w(k)$ is chosen solely to maximize productive efficiency. However, as this paper will demonstrate, in the presence of supplier private information, the buyer is more strategic and judicious in its investment choice.

The Firm's Optimal Contract

Returning to our model, for a given k and λ, we first detail the firm's optimal contract offer to the supplier. Naturally, when the supplier is uninformed, the firm need not pay any information rents. Thus, as in the binary case, it is optimal for the firm to offer to buy $x^*(\phi) = X$ units at expected cost, i.e., $t^*(\phi) = E\{c\}$. (We use * to denote the equilibrium outcomes.) The supplier, of course, has no reason to decline this offer.

If the supplier is privately informed, the firm's optimal offer is obtained by solving the problem presented in Program 1 below. To elaborate, the firm offers a menu of contracts, $\{x(\hat{c}), t(\hat{c})\}$, $\hat{c} \in [0, \bar{c}]$, to maximize its expected profit subject to the individual rationality constraints (IR), the incentive compatibility constraints (IC), and the capacity constraints (CC), where the constraints hold for all c- and $\hat{c}$-values in $[0, \bar{c}]$.

Program 1

$$\underset{x(c),t(c)}{Max} \int_0^{\bar{c}} [R - (\bar{k} - k) - t(c)]x(c)f(c)dc$$

subject to:

$$[t(c) - c]x(c) \geq 0 \qquad \forall c \in [0, \bar{c}] \tag{IR}$$

$$[t(c) - c]x(c) \geq [t(\hat{c}) - c]x(\hat{c}) \qquad \forall c, \hat{c} \in [0, \bar{c}] \tag{IC}$$

$$0 \leq x(c) \leq X \qquad \forall c \in [0, \bar{c}] \tag{CC}$$

Relegating the technical derivation of Program 1's solution to Appendix A, we note the key process steps and the economics underlying the optimal contract. First, the highest-cost supplier earns no information rents, i.e., the (IR) constraint for $c = \bar{c}$ binds. Second, we establish that the incentive compatibility constraints (IC) can be replaced by their local counterparts: $[t(c) - c]x(c) = \int_{c}^{\bar{c}} x(\tilde{c})d\tilde{c}$. Notice that the right-hand side of the local incentive compatibility constraints represents the c-cost supplier's information rents. It follows that curtailing production for high c-values can then be a tool to use for reducing the supplier's rents, and the optimal contract indeed exhibits this feature.

In particular, given the linear cost and revenue functions, the optimal contract for the informed supplier prescribes "bang-bang" production: the firm sets $x^*(\hat{c}) = X$ for $\hat{c} \leq c^*$ and $x^*(\hat{c}) = 0$, otherwise. In terms of payment, for c-values below the c^*-hurdle value wherein production is prescribed, the firm pays the supplier $t^*(\hat{c}) = c^*$. This ensures that the supplier has no incentives to misreport its cost for any c-realization. Clearly, under this hurdle contract, the parties trade with probability $F(c^*)$, where c^* is the unique c-value that solves:

$$\underset{c}{Max}\, F(c)[R - (\bar{k} - k) - c]X. \tag{2}$$

Proposition 2 presents the optimal contract, and details how the cost of making one input is tied to the cost of buying the other input.

Proposition 2:

(i) When the supplier is uninformed, the firm's optimal contract is $x^*(\phi) = X$ and $t^*(\phi) = E\{c\}$;
(ii) When the supplier is informed, the firm's optimal contract is $x^*(\hat{c}) = X$ and $t^*(\hat{c}) = c^*(k)$ for $\hat{c} \in [0, c^*(k)]$, and $x^*(\hat{c}) = 0$ and $t(\hat{c}) = 0$ for $\hat{c} \in (c^*(k), \bar{c}]$, where: $c^*(k) + H(c^*(k)) = R - [\bar{k} - k]$; and
(iii) The more the firm invests to reduce the cost of the input it makes, the higher is its payment to the informed supplier when it procures the input, i.e., $\frac{dc^*(k)}{dk} = \frac{1}{1+H'(c^*(k))} > 0$.

Part (ii) of Proposition 2 establishes that the firm's offer to the informed supplier is conditional on the firm's upfront investment in reducing the cost of the input it makes. That is, while the firm's cost of making input m is independent of the supplier's cost of making input b, in light of private information, the make and buy problems interact. Specifically, part (iii) of Proposition 2 shows that $c^*(k)$ is an increasing function of the firm's cost-cutting investment.

Intuitively, the higher the firm's make cost, the greater its need to control the buy cost to optimize its profit. The reason for this is that once there is a significant internal cost of inputs, the opportunity cost of failing to produce a final good is smaller; this small opportunity cost of abandoning production translates into a small opportunity cost of limiting rents via rationing. Conversely, higher upfront investment in the new technology, i.e., lower marginal make costs, results in the firm subsequently becoming more generous in setting supplier trade terms. This effect suggests a silver lining to a firm incurring higher make costs: such a firm credibly signals to its supplier that attempts to extract information rents from the firm will be met with added resistance. This signal, in turn, impacts the supplier's enthusiasm for acquiring private information in the first place, the issue we next address.

The Supplier's Acquisition of Private Information

Using backward induction, and given the result in Proposition 2(i) and 2(ii), the supplier makes its information acquisition decision fully aware that, if informed and $c \leq c^*(k)$, it will supply the firm X units of input b at $c^*(k)$ per unit. By expending $v(\lambda)$, the supplier is informed of c with probability λ. When informed, and if $c \leq c^*(k)$, the supplier earns information rents of $c^*(k) - c$ per unit. In the other cases—whether the information system proves ineffective or reveals $c > c^*(k)$—the supplier earns no rents; in the former case, trade for X units occurs at expected cost, and in the latter case, trade does not occur. Thus, the supplier chooses the precision of its information system to maximize its expected rents, net of information acquisition cost, by solving:

$$\underset{\lambda}{Max}\, \lambda \int_0^{c^*(k)} [c^*(k) - c]Xf(c)dc - v(\lambda). \tag{3}$$

We denote the solution to (3), the supplier's optimal λ-value, by $\lambda^*(c^*(k))$; the next proposition presents this solution and details how it changes with investment in the new technology.

Proposition 3:

(i) The supplier chooses information system of precision $\lambda^*(c^*(k))$, where $\lambda^*(c^*(k))$ is the unique λ-value that satisfies $\int_0^{c^*(k)} H(c)f(c)dc = \frac{v'(\lambda)}{X}$; and

(ii) The more the firm invests in the new technology, the greater the precision of the supplier's information system, i.e., $\frac{d\lambda^*(c^*(k))}{dk} = \frac{XF(c^*(k))}{v''(\lambda^*)[1+H'(c^*(k))]} > 0$.

Proposition 3(i) prescribes the supplier's optimal $\lambda^*(c^*(k))$. Intuitively, the more generous the impending procurement contract when informed, the greater the potential information rents and, thus, the stronger the supplier's incentives to increase the precision of the information system. The dependence of λ^* on k is due to the fact that the firm's investment in the new technology impacts $c^*(k)$, the firm's offer to the informed supplier (as noted in Proposition 2(iii)). The offer, in turn, influences the supplier's expected information rents (as noted in (3)) and, hence, its desire to acquire information. Consistent with this linkage, and in line with intuition, the higher the firm's investment in new technology, the more generous its contract terms and, as a consequence, the greater the supplier's desire to acquire information. The comparative statics in Proposition 3(ii) capture this relationship.

To provide added intuition, consider the familiar quadratic cost function $v(\lambda) = z_\lambda \lambda^2$, with c drawn from the standard uniform distribution, i.e., $c \sim U[0, 1]$. In this case, $\lambda^* = X[R - (\bar{k} - k)]^2/16z_\lambda$. It follows that λ increases monotonically with k, as noted in part (ii) of the Proposition—the external supplier acquires private information more often as its buyer becomes more efficient. Additionally, as z_λ goes down, the supplier's λ-choice increases—as private information becomes less expensive for the supplier to acquire, it seeks to gain an information advantage more often.

The analysis highlights the conflicting dual roles of the firm's upfront investment $w(k)$. On the one hand, it lowers the firm's cost of making its input. On the other hand, it increases the likelihood of confronting an informationally advantaged supplier who will use that information to the detriment of the firm. In determining its optimal investment, the firm balances both effects, as shown next.

The Firm's Cost-Cutting Investment

Naturally, the firm would like to dissuade the supplier from becoming privately informed. But, as discussed thus far, doing so is costly for the firm—it has to bear a higher cost of making input m by making an inefficient investment in the new technology. Formally, the firm chooses k (i.e., invests $w(k)$) to maximize its *ex ante* expected profit as follows:

$$\underset{k}{Max}\, \lambda^*(c^*(k)) \cdot F(c^*(k))[R - (\bar{k} - k) - c^*(k)]X + [1 - \lambda^*(c^*(k))][R - (\bar{k} - k) - E\{c\}]X - w(k). \tag{4}$$

The first term in (4) is the firm's expected payoff from trade with an informed supplier; when trade occurs, the firm pays the supplier $c^*(k)$ for each of the X units of input b and incurs cost $\bar{k} - k$ to make each of X units of input m. The second term in (4) is the firm's expected payoff from trade with an uninformed supplier; in this case, trade occurs at expected cost for X units of input b and the firm incurs cost $\bar{k} - k$ to make each unit of input m. The last term is simply the cost of the firm's upfront investment in the new technology.

In order to better understand the role of the firm's cost-cutting initiative in (4) on the supplier's incentive to acquire information, we initially derive the firm's optimal investment absent such incentive. To this end, assume the supplier is informed of c with an *exogenous* probability $\hat{\lambda}$, i.e., λ is not a choice variable for the supplier, but is assumed "fixed." In this case, let $\hat{k}(\hat{\lambda})$ denote the firm's optimal reduction in cost. Formally stated, $\hat{k}(\hat{\lambda})$ is the solution to the problem in (4) wherein $\lambda^*(c^*(k))$ is simply replaced by $\hat{\lambda}$. Using the envelope theorem to account for the dependency of $c^*(k)$ on k, $\hat{k}(\hat{\lambda})$ is the unique k-value that satisfies the following first-order condition:

$$\left\{\hat{\lambda} \cdot F(c^*(k)) + [1 - \hat{\lambda}]\right\}X = w'(k). \tag{5}$$

The solution in (5) is intuitive. At one extreme, suppose the supplier was always uninformed. In this case, the firm would procure X units of input b at $E\{c\}$ and, thus, select its upfront investment to maximize$[R - (\bar{k} - k + E\{c\})]X - w(k)$. This yields the first-order condition $X = w'(k)$ in the uninformed supplier setting, and as in Lemma 2 for the no private information benchmark case. At the other extreme, suppose the supplier is always informed. In this case, the firm procures X units of input b at $c^*(k)$ with probability $F(c^*(k))$ and, thus, select its investment to maximize $F(c^*(k))[R - \{\bar{k} - k + c^*(k)\}]X - w(k)$. Using $dc^*(k)/dk$ from Proposition 2(iii), the first-order condition for this problem simplifies to $F(c^*(k))X = w'(k)$. Since the firm contracts with an uninformed (informed) supplier with probability $1 - \hat{\lambda}$ ($\hat{\lambda}$), the probability-weighted first-order conditions yield (5). Another way of viewing this is in relation to the central planner benchmark of Lemma 1, which specifies $\left\{\lambda^s \cdot F(R - (\bar{k} - k^s)) + [1 - \lambda^s]\right\}X = w'(k^s)$. That is, for a given λ, the firm's cost-cutting choice replicates the central planner's other than the reduction of investment brought by the rationing in production due to information rents in the first term (i.e., $c^*(k) < R - (\bar{k} - k)$).

Notice that the firm's cost-cutting investment is lowered due to the adverse selection problem compared to the benchmark solution in Lemma 2. This is reflected by the fact that the probability of trade in the left-hand side of (5) is "1" when dealing with an uninformed supplier, but "$F(c^*(\hat{k})) < 1$" when dealing with an informed supplier. Recall that (5) is derived for an exogenously chosen $\hat{\lambda}$. Endogenizing the supplier's information acquisition results in an "added marginal cost" to the firm's investment. In particular, the marginal cost to the firm of increasing investment is not just $w'(k)$, but also the cost associated with the increased likelihood of confronting an informed supplier. After all, a greater reduction in input m's cost conveys a greater willingness of the firm to pay for input b, boosting the supplier's desire to acquire information. The next proposition formalizes this result.

Proposition 4:

(i) The firm's investment in the new technology is $w(k^*)$, where k^* is the unique k-value that satisfies:

$$\{\lambda^*(c^*(k)) \cdot F(c^*(k)) + [1 - \lambda^*(c^*(k))]\}X =$$
$$w'(k) + \left[\int_0^{c^*(k)} H(c)Xf(c)dc + \int_{c^*(k)}^{\bar{c}} [R - (\bar{k} - k) - c]Xf(c)dc\right] \frac{d\lambda^*(c^*(k))}{dk};$$ and

(ii) The firm underinvests in the new technology to limit the supplier's incentives to acquire information, i.e., $k^* < \hat{k}(\lambda^*)$.

Formally, Proposition 4(i) presents the equilibrium investment undertaken by the firm. Compared to (5), the added (positive) term on the right-hand side of the equation captures the marginal impact of the firm's k-choice on the supplier's information acquisition and the ensuing adverse selection problem. Specifically, when trading with an uninformed supplier, the firm earns $\int_0^{\bar{c}} [R - (\bar{k} - k^*) - c]Xf(c)dc$ in profit. Relative to this "first best" profit level, with an informed supplier, the firm loses on two counts: (a) for $c \leq c^*(k)$, trade occurs, but the firm pays information rents of $\int_0^{c^*(k)} H(c)Xf(c)dc$, and (b) for $c > c^*(k)$, the firm forgoes profitable trade worth $\int_{c^*(k)}^{\bar{c}} [R - (\bar{k} - k^*) - c]Xf(c)dc$. The sum of the terms in (a) and (b) represents the total cost borne by the firm when an otherwise uninformed supplier acquires information and becomes informed. The increased likelihood of the supplier becoming informed due to a marginal decrease in the firm's make-cost is $d\lambda^*(c^*(k))/dk$, a positive term from Proposition 3(ii). Thus, the product of $d\lambda^*(c^*(k))/dk$ with the sum of losses in (a) and (b) captures the expected marginal cost of the firm due to supplier information acquisition tied to the firm's cost-cutting investment. Notice that this is precisely the term that is added to the right-hand side in Proposition 4(i) relative to the first-order condition in (5).

In summary, compared to the benchmark investment in the absence of private information noted in Lemma 2, the firm's equilibrium investment level is lowered on two counts. First, because of the adverse selection problem due to contracting with an informed supplier, the firm drops the investment down to $w(\hat{k})$. Second, the likelihood of contracting with an informed supplier is itself endogenous in the model since it is tied to the supplier's choice of the precision of the information system. In response to the supplier's information acquisition incentives, the firm further drops its investment, so $w(k^*) < w(\hat{k})$. Proposition 4(ii) confirms this intuition.

Taken together, Propositions 2, 3, and 4 also capture the frictions that arise relative to the central planner benchmark in Lemma 1: the firm engages in socially costly production rationing to counter the adverse selection problem with its self-interested supplier. The supplier, in turn, acquires information to maximize information rents rather than to promote production efficiency, as was the case with the central planner; this, too, results in socially suboptimal information acquisition. To dissuade such exploitation-driven learning, the firm, in turn, introduces cost inefficiencies. If these collective deviations cause substantial societal losses, one might expect regulatory (i.e., central planner) arrangements that prevent these frictions from arising in the first place. As an example, while allowing outsiders access to firms' internal data is often fraught with risk for an organization, mandatory audits of supplier cost and regulated cost-plus pricing, common practices in government contracts, can both reduce frictions and ensure that gains ensue to both supply chain participants. Further, our analysis in this setting provides impetus for regulators to more favorably view vertical integration, recognizing that the reduction in friction can offset the disadvantages due to reducing access of other buyers to the supplier's products. Elaborate contracts governing investments in information acquisition and transparency of acquired information, coupled with revenue sharing, can also serve as *de facto* means of approaching the integrated solution. Although the setting does not provide a determinative answer as to when regulatory intervention (or lack thereof) is necessary, identifying the relevant inefficiencies—both investment and production—driven by information concerns can help identify circumstances most ripe for intervention.

V. TRADING WITH A "MAYBE INFORMED" SUPPLIER

In the analysis thus far, it was assumed that when the firm offered a contract to the supplier, it knew whether the supplier was informed, although the information itself was privately known only to the supplier. This led to a familiar characterization of the optimal contract since the arrangement simply reflected standard adverse selection concerns. As a consequence, the analysis was able to focus on the novel economic force: how the firm's upfront investment in the new technology conveys its willingness to pay for an outsourced input, and the ensuing incentives for the supplier's private information acquisition. This subsection demonstrates that the results continue to apply in a framework where the information problem is more severe in that the firm confronts a "maybe informed" supplier. To succinctly examine the role of the firm's investment in this environment, we revert back to the binary setting in Section III with one change: when $\lambda = \bar{\lambda}$, at the time of offering the contract, the firm does not know whether it is dealing with an uninformed or an informed supplier, let alone the cost information the supplier may possess. In effect, the firm's observation is limited only to knowing whether the supplier installs the information system ($\lambda = \bar{\lambda}$) or does not install the system ($\lambda = 0$).

Analogous to Proposition 1, the next proposition notes that the firm again limits its cost-cutting investment in order to influence the supplier's acquisition of private information.

Proposition 5: The firm reduces its investment in the new technology to limit the supplier's incentives to acquire information it makes if:

(i) $\bar{\lambda} \leq \lambda^{\dagger}$ and $R^{\dagger} < R < R^{\dagger} + \frac{\bar{c}\bar{\lambda}^2[1-p]p^2}{[1-\bar{\lambda}][1-\bar{\lambda}p]}$; or
(ii) $\bar{\lambda} > \lambda^{\dagger}$ and $R^{\dagger} < R < R^{\dagger} + \bar{c}[1-p]$, where $\lambda^{\dagger} = \frac{1+p-\sqrt{(1-p)^2+4p^2}}{2p(1-p)}$ and $R^{\dagger} = Min\left\{\frac{\bar{c}p[1-\bar{\lambda}p]}{1-\bar{\lambda}}, \frac{\bar{c}}{1-\bar{\lambda}[1-p]}\right\}$.

In particular, for these parameter values, $k = \bar{k} - [R - R^{\dagger}] < \bar{k}$.

Proposition 5 identifies two cases of intermediate R-values wherein the firm underinvests, i.e., chooses $k < \bar{k}$, despite the fact that the investment in the new technology is essentially costless. To formally derive the parameters for these cases, note that if the supplier does not invest in the information system (i.e., chooses $\lambda = 0$), the firm buys $x(\phi) = X$ units from the supplier at $t(\phi) = p\bar{c}$ per unit and the firm's payoff is $[R - (\bar{k} - k) - p\bar{c}]X$. If the supplier invests in the information system (i.e., chooses $\lambda = \bar{\lambda}$), the firm has three options to deal with the "maybe informed" supplier:

(i) Rationing: Under this contract, $x(\hat{c} = 0) = X$, $t(\hat{c} = 0) = 0$, $x(\hat{c} = \bar{c}$ or $\hat{c} = \phi) = 0$, and $t(\hat{c} = \bar{c}$ or $\hat{c} = \phi) = 0$. Under Rationing, trade occurs with probability $\bar{\lambda}[1-p]$, i.e., if the supplier is informed and $c = 0$. The firm's payoff under Rationing is $\bar{\lambda}[1-p][R - (\bar{k} - k)]X$.
(ii) Partial Rationing: Under this contract, $x(\hat{c} = 0$ or $\hat{c} = \phi) = X$, $t(\hat{c} = 0$ or $\hat{c} = \phi) = p\bar{c}$, $x(\hat{c} = \bar{c}) = 0$, and $t(\hat{c} = \bar{c}) = 0$. Under Partial Rationing, trade occurs with probability $\bar{\lambda}[1-p] + 1 - \bar{\lambda}$, i.e., either if the supplier is informed and $c = 0$ or if the supplier is uninformed. The firm's payoff under Partial Rationing is $[\bar{\lambda}(1-p) + 1 - \bar{\lambda}][R - (\bar{k} - k) - p\bar{c}]X$.
(iii) Slack: Under this contract, $x(\hat{c}) = X$ and $t(\hat{c}) = \bar{c}$ for all cost reports, $\hat{c} = 0, \bar{c}, \phi$. Under Slack, trade always occurs since the contract attracts both the uninformed and the informed supplier. The firm's payoff under Slack is $[R - (\bar{k} - k) - \bar{c}]X$.

Comparing the profit expressions in (i) through (iii), the firm offers a Rationing contract to a supplier that has invested in the information system if and only if:

$$\bar{k} - k \geq R - Min\left\{\frac{\bar{c}p[1-\bar{\lambda}p]}{1-\bar{\lambda}}, \frac{\bar{c}}{1-\bar{\lambda}[1-p]}\right\}. \tag{6}$$

The lower bound on R in Proposition 5 implies that for low R-values (i.e., $R \leq R^{\dagger}$), condition (6) is satisfied even if the firm chooses the maximum investment, $w(\bar{k})$. That is, for these R-values, the firm can afford to make the maximum investment in the new technology, for it will still lead to the Rationing contract should the supplier choose to invest in the information system. Thus, for these R-values, the firm's investment is $w(\bar{k})$, the supplier does not install the information system, the firm seeks $x(\phi) = X$ units offering $t(\phi) = p\bar{c}$ per unit, and trade always occurs.

For $R > R^{\dagger}$, (6) is not satisfied for the choice of $k = \bar{k}$. Thus, for these R-values, the firm either has to distort its investment so that $k = \bar{k} - [R - R^{\dagger}] < \bar{k}$ and (6) is satisfied as an equality, or deal with a supplier who installs the information system. The upper bound on R in Proposition 5(i) is the R-value at which the firm is indifferent between (a) making the distorted investment decision such that $k = \bar{k} - \left(R - \frac{\bar{c}p[1-\bar{\lambda}p]}{1-\bar{\lambda}}\right)$, permitting commitment to the Rationing contract if $\lambda = \bar{\lambda}$, and (b) making the undistorted investment decision $w(\bar{k})$ and offering the Partial Rationing contract to the supplier who chooses $\lambda = \bar{\lambda}$. In akin fashion, the upper bound on R in Proposition 5(ii) is the R-value at which the firm is indifferent between (a) making the distorted investment decision such that $k = \bar{k} - \left(R - \frac{\bar{c}}{1-\bar{\lambda}[1-p]}\right)$, permitting commitment to the Rationing contract if $\lambda = \bar{\lambda}$, and (b) making the undistorted investment decision $w(\bar{k})$, and offering a Slack contract to the supplier who chooses $\lambda = \bar{\lambda}$.

The $\lambda^{\dagger}$ cutoff is the $\bar{\lambda}$-value at which the firm is indifferent between offering the Partial Rationing and the Slack contracts to a supplier who has chosen $\lambda = \bar{\lambda}$ when R is at the upper bound value in part (i). At this R-value, for $\bar{\lambda} \leq \lambda^{\dagger}$, the firm prefers Partial Rationing to Slack since giving up trade for the case $c = \bar{c}$ is acceptable if the event occurs with a small probability, $\bar{\lambda}p$.

Intuitively, for the firm to distort its upfront investment decision, R must be large enough that it is not credible for the firm to commit to curtailing the supplier's information rents at the offer stage without the distortion. At the same time, R must be small enough that the required distortion is not so severe that it overwhelms the benefit obtained from dissuading the supplier from acquiring information. In effect, the nature of the result—that the firm optimally distorts its make decision to curtail supplier information rents—is exactly the same as in the rest of the paper; the key difference in the "maybe informed" supplier setting is that it entails added algebraic computations to characterize the optimal contract needed to resolve the more severe information differential between the firm and the supplier.

VI. IMPLICATIONS AND ADDITIONAL INTERPRETATIONS

The primary result herein is couched in terms of limiting investment in cost-reducing technology. The main force is that a firm would willingly (and publicly) sidestep such investment so that it can credibly convey a willingness to ration purchases from a supplier. This signal to the supplier, in turn, convinces it not to invest in gaining an informational advantage as rents become less likely to ensue. Despite this focus on costs, an equally potent investment reduction would be on efforts to boost product demand, such as advertising, product improvements, market expansion, or research and development. In these cases, it is the marginal revenue that is sacrificed rather than marginal cost efficiencies, but the resulting lower margin will have a similar effect of dissuading supplier information acquisition.

Although this primary result is shown in a streamlined model, the key features point to when these considerations would prevail in practice: (1) a decision to willingly cut into profit margins in order to (2) address an inefficiency in the provision of inputs when (3) an input provider may gain private information to its own advantage. These features suggest some relevant empirical implications. In particular, all else equal, we would expect to see firm investments to be lower when they (a) rely more heavily on outside supply for inputs, (b) procure inputs in markets subject to inefficiencies, and (c) face potential information asymmetries upstream. These predicted determinants of firm investment levels can arise empirically as payments to primary suppliers representing a larger share of annual expenses (e.g., Chod, Lyandres, and Yang 2019; Chen, Di, Jiang, and Li 2020), the suppliers having a vested interest in the specific customer relationship in the form of high customer concentration (e.g., Patatoukas 2012; Hui, Liang, and Yeung 2019), and the relationships between those suppliers and firms being in early stages when potential information asymmetry is most pronounced (e.g., Irvine, Park, and Yildizhan 2016).

The results also point to a more nuanced explanation for the empirical connections between buyer-supplier relationships and buyer operating costs. A prevailing theme in empirical examinations of buyer-supplier relationships is that those characterized by more cooperative (more self-interested) behavior exhibit lower (higher) internal operating costs at the buyer level (see, e.g., Dahlstrom and Nygaard [1999] and Cannon and Homburg [2001] for early work in this arena). The natural inference drawn from this phenomenon is that cooperative suppliers can add value by helping lower buyers' costs even beyond the costs of the supplier's inputs. This paper presents a different interpretation—it is not that less cooperative suppliers undermine buyer operating costs, it is that buyers have reasons themselves to retain higher operating costs when dealing with self-interested suppliers. Future empirical work in this area, thus, could examine the extent to which information asymmetry is a determinant of the empirical relation between buyer-supplier interactions and buyer costs.

These specific implications for measures of firm investment notwithstanding, a willing decision to reduce unit margins is not limited to a decision not to invest, suggesting other implications. For example, many firms have been documented as willingly taking on socially responsible choices at the expense of rising marginal production costs. While this is typically viewed as a means of boosting product demand or as a defensive mechanism to dissuade regulation (see, e.g., Baron 2001; Bagnoli and Watts 2003; Orlitzky, Siegel, and Waldman 2011), our results suggest that upstream consequences also may play a role. In a similar vein, a firm may also willingly embed new costs as part of its sales strategy via a visible charitable act. The buy-one-give-one model popularized by TOMS and later adopted by Warby Parker, Bombas, and others is a prime example. These costly efforts are usually viewed through the lens of raising brand loyalty; the results here suggest an upstream consequence, in addition to the downstream one.

In terms of interpretations of the upstream relationship, we implicitly cast the provision of inputs as for tangible goods. The unique input provided by the supplier need not be a tangible product for the underlying forces to apply. For example, negotiations with potential labor providers also have the feature that weaker firm prospects can influence bargaining position (e.g., Bova 2013). Yet, there is varied evidence of the relationship between firm investment and union presence (see, e.g., Machin and Wadhwani 1991; Odgers and Betts 1997; Y. Chen and I. Chen 2013). The present analysis suggests that the relationship between investment levels and labor unions may also depend on the extent to which information asymmetry (or the potential for it) is a key piece of the negotiation. If the labor force in question can gain a leg up by gaining information or expertise that can boost negotiating leverage, then the firm's best response may be a reduction in investment as a signal that such leverage will not come to fruition.

Despite these potential applications, it should be stressed that there are circumstances in which the forces surely do not apply. Most importantly, for our result to hold, it must be that the seemingly inefficient investment reduces per-unit margins and is not simply a case of "burning money." That is, if the firm cuts investments in a way that reduced its overall bottom line without affecting the incremental benefits of additional production, such weakness would be counterproductive because it does not alter the firm's penchant for information-based rationing and thereby does not curb potential rents from supplier information acquisition. Similarly, limiting margins with cost-cutting investments can serve a productive role in cutting information rents only if it is seen as a credible signal by the supplier. If such investments are not externally observable in a timely fashion (e.g., negotiated contracts with executives that shift compensation terms) or can readily be reversed (e.g., just intentions to make charitable contributions), then they cannot serve the key role that limiting cost-cutting investments play here.

Some firm actions and decisions are naturally publicly observable, such as the adoption of a new technology considered in this paper. In other cases, public observability may require voluntary disclosures by the firm. Incorporating voluntary disclosures in our model—under the typical presumption that such disclosures are subject to audit and must be truthful—would yield full disclosure in our setting (e.g., Grossman 1981; Milgrom 1981), leaving the analysis unchanged. However, when disclosures are observed by multiple audiences, not just the supplier, the analysis is admittedly not so straightforward. For example, conveying high unit conversion costs to upstream suppliers rubs against the firm's incentives to disclose strength to deter downstream competitors or to meet capital market expectations. While beyond the scope of this paper, studying such offsetting tensions, and their consequences for the firm's investment, is an interesting problem for future work.

VII. CONCLUSION

Manufacturing processes in firms often entail in-house production of some inputs and reliance on outsourcing for other inputs. This paper examines investment and information issues that arise naturally in such situations. In particular, the firm is concerned with initiatives it can undertake to curtail the cost of the input it makes, as well as with contract terms it can offer to reduce payment for the input it buys. The firm's decisions are inextricably tied to the supplier's decision to acquire private information that allows it to potentially earn information rents for the input it sells to the firm. The paper derives the equilibrium that reveals an interaction between the firm's seemingly independent make and buy costs: a higher make cost for the firm serves to dampen the supplier's aggressiveness in information acquisition and reduces the firm's buy cost.

To elaborate, if the firm's in-house operations become more expensive on a per-unit basis, then the firm can credibly commit to being less generous in its trade terms with the supplier. Formally, when confronting a privately informed supplier, the firm balances "production and rents" by forgoing trade (i.e., engaging in rationing) on some occasions in order to reduce what it pays when trade does occur. The higher make-cost of the firm shifts this trade-off in favor of rationing, further limiting the supplier's information rents. As a corollary, the supplier has weakened incentives to acquire private information, resulting in the firm and the supplier being on a more level information footing when negotiating trade terms. To focus on this novel make-and-buy interaction, we establish the key result in a linear technology setting and one wherein the firm knows whether its supplier is informed, but not what the informed supplier knows. Subsequently, we also demonstrate that the interaction persists in the "maybe informed" supplier case, wherein the information problem is more severe in that the firm does not even know whether its supplier is informed.

Broadly stated, our analysis demonstrates that the firm's decision to procure from an external party has implications for internal efficiency for the firm. While the internal implications in this paper pertain to the firm's make decision, it is certainly not the only critical internal decision that can be so impacted. Future work may wish to study the implications of suppliers' private information acquisition on other aspects of a firm's accounting system, including its corporate governance mechanisms and internal control systems.

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APPENDIX A

Proofs

Proof of Proposition 1

When confronting an informed supplier, the firm's optimal offer is obtained by solving the program below. In particular, the firm offers a menu of contracts, $\{x(\hat{c}), t(\hat{c})\}$, $\hat{c} \in \{0, \bar{c}\}$, to maximize its expected profit subject to the following constraints: (i) the individual rationality constraints (IR_L) and (IR_H) ensure that the low-cost $(c = 0)$ and the high-cost $(c = \bar{c})$ suppliers each have incentives to accept its prescribed contract, (ii) invoking the Revelation Principle (Myerson 1979), the incentive compatibility constraints (IC_L) and (IC_H) ensure that the supplier has incentives to report its cost truthfully, i.e., set $\hat{c} = c$, and (iii) the firm's production capacity constraints are reflected by (CC_L) and (CC_H).

$$\underset{x(0),t(0),x(\bar{c}),t(\bar{c})}{Max}\ p[R-(\bar{k}-k)-t(\bar{c})]x(\bar{c})+[1-p][R-(\bar{k}-k)-t(0)]x(0)-w(k)\ subject\ to:$$

$$[t(0)-0]x(0) \geq 0 \tag{IR$_\mathrm{L}$}$$

$$[t(\bar{c})-\bar{c}]x(\bar{c}) \geq 0 \tag{IR$_\mathrm{H}$}$$

$$[t(0)-0]x(0) \geq [t(\bar{c})-0]x(\bar{c}) \tag{IC$_\mathrm{L}$}$$

$$[t(\bar{c})-\bar{c}]x(\bar{c}) \geq [t(0)-\bar{c}]x(0) \tag{IC$_\mathrm{H}$}$$

$$0 \leq x(0) \leq X \tag{CC$_\mathrm{L}$}$$

$$0 \leq x(\bar{c}) \leq X \tag{CC$_\mathrm{H}$}$$

Denoting $x(\hat{c}) \cdot t(\hat{c})$ by $T(\hat{c})$, and $R-(\bar{k}-k)$ by R^a (R adjusted for the make costs), the above program can be written as Program P (the primal program):

Program P

$$\underset{x(0),T(0),x(\bar{c}),T(\bar{c})}{Max} p[R^a x(\bar{c}) - T(\bar{c})] + [1-p][R^a x(0) - T(0)] \textit{ subject to}:$$

$$\bar{c}x(\bar{c}) - T(\bar{c}) \leq 0 \tag{IR$_H$}$$

$$T(\bar{c}) - T(0) \leq 0 \tag{IC$_L$}$$

$$T(0) - T(\bar{c}) - \bar{c}[x(0) - x(\bar{c})] \leq 0 \tag{IC$_H$}$$

$$x(0) \leq X \tag{CC$_L$}$$

$$x(\bar{c}) \leq X \tag{CC$_H$}$$

$$x(0), x(\bar{c}), T(0), T(\bar{c}) \geq 0$$

Denoting the dual variables associated with the five constraints of Program P by $w_1, ..., w_5$, Program D is the dual of the primal Program P:

Program D

$$\underset{w_1,w_2,w_3,w_4,w_5}{Min} [w_4 + w_5]X \textit{ subject to}:$$

$$-w_2 + w_3 \geq -[1-p]$$

$$-w_1 + w_2 - w_3 \geq -p$$

$$-\bar{c}w_3 + w_4 \geq [1-p]R^a$$

$$\bar{c}w_1 + \bar{c}w_3 + w_5 \geq pR^a$$

$$w_1, w_2, w_3, w_4, w_5 \geq 0$$

Within the specified region of the parameters, the table below presents a solution that is feasible in the primal program (Program P) and in the dual program (Program D). Moreover, at this solution, the primal and dual objective function values are equal. Hence, from the Duality Theorem of Linear Programming, the solution is optimal (e.g., Luenberger 1989, 89).

	$R^a \leq c/p$	$R^a > c/p$
$x(0)$	X	X
$T(0)$	0	$\bar{c}X$
$x(\bar{c})$	0	X
$T(\bar{c})$	0	$\bar{c}X$
w_1	$pR^a/\bar{c}$	1
w_2	$1-p$	$1-p$
w_3	0	0
w_4	$[1-p]R^a$	$[1-p]R^a$
w_5	0	$pR^a - \bar{c}$

Given the optimality of offering Rationing when $R^a \leq \bar{c}/p$ and Slack when $R^a > \bar{c}/p$ to an informed supplier, the equilibrium outcomes—the firm's investment, the supplier's information acquisition decision, per-unit payment, and quantity sold—are summarized below (alongside the firm's expected payoff), and complete the proof:

R-values	**k**	**λ**	**t**	**x**	**E{Π_F}**
$R \leq \frac{\bar{c}}{p}$	$\bar{k}$	0	$t(\phi) = p\bar{c}$	$x(\phi) = X$	$[R - p\bar{c}]X$
$\frac{\bar{c}}{p} < R < \frac{\bar{c}}{p} + \bar{\lambda}(1-p)\bar{c}$	$\bar{k} - [R - \frac{\bar{c}}{p}]$	0	$t(\phi) = p\bar{c}$	$x(\phi) = X$	$[\frac{\bar{c}}{p} - p\bar{c}]X$
$R \geq \frac{\bar{c}}{p} + \bar{\lambda}(1-p)\bar{c}$	$\bar{k}$	$\bar{\lambda}$	$t(\phi) = p\bar{c}$ $t(0) = \bar{c}$ $t(\bar{c}) = \bar{c}$	$x(\phi) = X$ $x(0) = X$ $x(\bar{c}) = X$	$[R - \bar{\lambda}\bar{c}-$ $(1-\bar{\lambda})p\bar{c}]X$

Proof of Lemma 1

The central planner's problem is presented in the "Benchmarks" subsection. Noting that $x(\phi) = X$ and $x(c) = X$ for $c \leq c^s = R - (\bar{k} - k)$ and $x(c) = 0$ for $c > c^s$, the problem is:

$$\underset{x,k}{Max}\ \lambda \int_0^{Min\{c^s,\bar{c}\}} [R - (\bar{k} - k) - c]Xf(c)dc + [1-\lambda][R - (\bar{k} - k) - E\{c\}]X - v(\lambda) - w(k).$$

The optimal k and λ values follow from solving the above, with the two cases corresponding to whether the upper bound of the integral is the interior c^s (as in part (i)) or the boundary $\bar{c}$ (as in part (ii)).

Proof of Lemma 2

The supplier gets reimbursed only for its expected production cost. In effect, it does not derive any benefit from acquiring cost information, but has to bear the cost. Hence $\lambda = 0$. With both parties being uninformed, the firm pays the supplier its expected cost to purchase X units, i.e., $x(\phi) = X$ and $t(\phi) = E\{c\}$. As a consequence, the firm's cost-cutting initiative is selected to maximize $[R - (\bar{k} - k) - E\{c\}]X - w(k)$, yielding $w'(k^B) = X$.

Proof of Proposition 2

When the supplier is uninformed, it accepts an offer $t(\phi)$ if $t(\phi)$ weakly exceeds its expected unit cost $E\{c\}$. Thus, from the assumption $R > E\{c\} + \bar{k}$, it follows that the firm maximizes its expected payoff by seeking $x^*(\phi) = X$ units at $t(\phi) = E\{c\}$, proving part (i). Turning to part (ii), in Program 1, replace $t(c) \cdot x(c)$ by $T(c)$ and $R - (\bar{k} - k)$ by R^a. We first prove that the (IC) constraint is equivalent to (I) and (II), where (I) is $T(c) = cx(c) + \int_c^{\bar{c}} x(\tilde{c})d\tilde{c} + [T(\bar{c}) - \bar{c}x(\bar{c})]$ and (II) is $x'(c) \leq 0$.

To show that (IC) implies (I) and (II), consider $c_1, c_2 \in [0, \bar{c}]$ with $c_2 \geq c_1$. The (IC) constraint $T(c_1) - c_1x(c_1) \geq T(c_2) - c_1x(c_2)$ can be equivalently rewritten as:

$$x(c_2) \leq \frac{[T(c_1) - c_1x(c_1)] - [T(c_2) - c_2x(c_2)]}{c_2 - c_1}. \tag{A1}$$

In likewise fashion, the (IC) constraint $T(c_2) - c_2x(c_2) \geq T(c_1) - c_2x(c_1)$ implies:

$$x(c_1) \geq \frac{[T(c_1) - c_1x(c_1)] - [T(c_2) - c_2x(c_2)]}{c_2 - c_1}. \tag{A2}$$

From (A1) and (A2) $x(c_1) \geq x(c_2)$, establishing (II). Also, using (A1) and (A2), and taking limits as $c_2 \to c_1$, yields $d[T(c_1) - c_1x(c_1)]/dc_1 = -x(c_1)$. Integrating both sides between c_1 values from 0 to $\bar{c}$, yields (I).

To show that (I) and (II) imply (IC), consider $c_1, c_2 \in [0, \bar{c}]$ with $c_2 \geq c_1$. From (I),

$$\begin{aligned} T(c_1) - c_1x(c_1) &= T(c_2) - c_2x(c_1) + \int_{c_1}^{c_2} x(\tilde{c})d\tilde{c} \\ &\geq T(c_2) - c_2x(c_2) + \int_{c_1}^{c_2} x(c_2)d\tilde{c} \text{ (from (II))} \\ &= T(c_2) - c_2x(c_2) + [c_2 - c_1]x(c_2) \geq T(c_2) - c_1x(c_2). \end{aligned} \tag{A3}$$

That is, truthful reporting is preferred to overreporting of cost. To prove that truthful reporting is preferred to underreporting, follow the same steps as in (A3) except that, using (II), $x(\tilde{c})$ is replaced by its largest value $x(c_1)$. Thus, (I) and (II) imply that the (IC) constraint is satisfied. Program 1 can, thus, be rewritten as:

$$\underset{x(c),T(\bar{c})}{Max} \int_0^{\bar{c}} \left[R^a x(c) - cx(c) - \int_c^{\bar{c}} x(\tilde{c}) d\tilde{c} \right] f(c)dc - [T(\bar{c}) - \bar{c}x(\bar{c})]$$

subject to:

$$T(\bar{c}) - \bar{c}x(\bar{c}) \geq 0$$

$$x'(c) \leq 0$$

$$0 \leq x(c) \leq X \qquad \forall c \in [0, \bar{c}]$$

It follows that the first constraint holds as an equality, i.e., $T(\bar{c}) = \bar{c}x(\bar{c})$.
Also note that $\int_0^{\bar{c}} \left[\int_c^{\bar{c}} x(\tilde{c}) d\tilde{c} \right] f(c)dc = \int_0^{\bar{c}} H(c)x(c)f(c)dc$. Hence, the above program simplifies to:

$$\underset{x(c)}{Max} \int_0^{\bar{c}} [R^a - c - H(c)]x(c)f(c)dc$$

subject to:

$$x'(c) \leq 0$$

$$0 \leq x(c) \leq X \qquad \forall c \in [0, \bar{c}]$$

The integrand in the objective function is linear in $x(c)$, with $R^a - c - H(c)$ being positive at $c = 0$, negative at $c = \bar{c}$, and decreasing in c since $H'(c) > 0$. Thus, ignoring the $x'(c) \leq 0$ constraint, it follows that there exists a $c^*(k)$ such that $R^a - c^*(k) - H(c^*(k)) = 0$, with $x^*(\hat{c}) = X$ for $\hat{c} \leq c^*(k)$ and $x^*(\hat{c}) = 0$ for $\hat{c} > c^*(k)$. Since this solution satisfies the $x'(c) \leq 0$ constraint, this is also the solution to the fully constrained problem. The $t^*(\hat{c})$ payment follows from the local incentive compatibility constraint in (I). Finally, differentiating $c^*(k) + H(c^*(k)) = R - [\bar{k} - k]$ in part (ii) with respect to k yields the result in part (iii).

Proof of Proposition 3

The first-order condition of (3) with respect to λ yields $\int_0^{c^*(k)} [c^*(k) - c]Xf(c)dc - v'(\lambda) = 0$. Integrating by parts, $\int_0^{c^*(k)} H(c)Xf(c)dc = v'(\lambda)$. Dividing both sides by X then completes the proof of part (i). Differentiating the equation in Proposition 3(i) with respect to k, and using Leibniz's rule, yields $\frac{dc^*(k)}{dk} F(c^*(k)) = \frac{v''(\lambda)}{X} \frac{d\lambda}{dk}$. Substituting $\frac{dc^*(k)}{dk} = \frac{1}{1+H'(c^*(k))}$ from part (iii) of Proposition 2 yields the result in part (ii).

Proof of Proposition 4

(i) The firm's optimal choice of k is the solution to (4). The first-order condition of (4), after noting from Proposition 2 (ii) that $H(c^*(k)) = [R - (\bar{k} - k) - c^*(k)]$, yields:

$$\begin{aligned} &\lambda^*(c^*(k))X \frac{d}{dk}[F(c^*(k))H(c^*(k))] + F(c^*(k))H(c^*(k))X \frac{d\lambda^*(c^*(k))}{dk} + [1 - \lambda^*(c^*(k))]X \\ &- [R - (\bar{k} - k) - E\{c\}] \frac{d\lambda^*(c^*(k))}{dk} \\ &= w'(k). \end{aligned} \tag{A4}$$

From Proposition 2(ii), $\frac{dH(c^*(k))}{dk} = 1 - \frac{dc^*(k)}{dk}$. Using this,

$$\begin{aligned} \frac{d}{dk}[F(c^*(k))H(c^*(k))] &= f(c^*(k))H(c^*(k)) \frac{dc^*(k)}{dk} + F(c^*(k)) \left\{ 1 - \frac{dc^*(k)}{dk} \right\} \\ &= F(c^*(k)) \frac{dc^*(k)}{dk} + F(c^*(k)) \left\{ 1 - \frac{dc^*(k)}{dk} \right\} = F(c^*(k)). \end{aligned} \tag{A5}$$

Substituting (A5) in (A4), and rearranging, yields:

$$\{\lambda^*(c^*(k))F(c^*(k)) + 1 - \lambda^*(c^*(k))\}X = w'(k) + [R - (\bar{k} - k) - E\{c\} - F(c^*(k))H(c^*(k))]X\frac{d\lambda^*(c^*(k))}{dk}. \tag{A6}$$

Notice $[R - (\bar{k} - k) - E\{c\} - F(c^*(k))H(c^*(k))]X$ can be written as the sum of the supplier's information rents and lost production, i.e., $\int_0^{c^*(k)} H(c)Xf(c)dc + \int_{c^*(k)}^{\bar{c}} [R - (\bar{k} - k) - c]Xf(c)dc$. Substituting this in (A6), and denoting the optimal k-value by k^*, completes the proof.

(ii) Consider the function $g(k)$, $g(k) = \{\lambda^*(c^*(k)) \cdot F(c^*(k)) + [1 - \lambda^*(c^*(k))]\}X - w'(k)$. It follows that $g(\hat{k}(\lambda^*)) = 0$ while, from Proposition 4(i), $g(k^*) > 0$; the latter follows since each of the terms $w'(k^*)$, $\int_0^{c^*(k^*)} H(c)f(c)dc$, $\int_{c^*(k^*)}^{\bar{c}} [R - (\bar{k} - k^*) - c]f(c)dc$, and $\frac{d\lambda^*(c^*(k))}{dk}$ is positive. Thus, $k^* < \hat{k}(\lambda^*)$, proving the result in part (ii).

Proof of Proposition 5

The proof follows the same lines as the proof of Proposition 1 except for the fact that, when $\lambda = \bar{\lambda}$, the firm also has the option to offer the Partial Rationing contract presented in Section V.

For $\lambda \le \lambda^\dagger$:

***R*-values**	***k***	***λ***	$t(\hat{c})$	$x(\hat{c})$	$E\{\Pi_F\}$
$R \le R^\dagger$	$\bar{k}$	0	$t(\phi) = p\bar{c}$	$x(\phi) = X$	$[R - p\bar{c}]X$
$R^\dagger < R < R^\dagger + \frac{\bar{c}\bar{\lambda}[1-p]p^2}{[1-\bar{\lambda}][1-\bar{\lambda}p]}$	$\bar{k} - [R - R^\dagger]$	0	$t(\phi) = p\bar{c}$	$x(\phi) = X$	$[R^\dagger - p\bar{c}]X$
$R^\dagger + \frac{\bar{c}\bar{\lambda}[1-p]p^2}{[1-\bar{\lambda}][1-\bar{\lambda}p]} \le R \le \frac{\bar{c}[1-p(1-\bar{\lambda}p)]}{\bar{\lambda}p}$	$\bar{k}$	$\bar{\lambda}$	$t(\phi) = p\bar{c}$ $t(0) = p\bar{c}$ $t(\bar{c}) = 0$	$x(\phi) = X$ $x(0) = X$ $x(\bar{c}) = 0$	$[\bar{\lambda}(1-p) + 1 - \bar{\lambda}]$ $[R - p\bar{c}]X$
$R > \frac{\bar{c}[1-p(1-\bar{\lambda}p)]}{\bar{\lambda}p}$	$\bar{k}$	$\bar{\lambda}$	$t(\phi) = \bar{c}$ $t(0) = \bar{c}$ $t(\bar{c}) = \bar{c}$	$x(\phi) = X$ $x(0) = X$ $x(\bar{c}) = X$	$[R - \bar{c}]X$

For $\lambda > \lambda^\dagger$:

***R*-values**	***k***	***λ***	$t(\hat{c})$	$x(\hat{c})$	$E\{\Pi_F\}$
$R \le R^\dagger$	$\bar{k}$	0	$t(\phi) = p\bar{c}$	$x(\phi) = X$	$[R - p\bar{c}]X$
$R^\dagger < R < R^\dagger + \bar{c}[1-p]$	$\bar{k} - [R - R^\dagger]$	0	$t(\phi) = p\bar{c}$	$x(\phi) = X$	$[R^\dagger - p\bar{c}]X$
$R > R^\dagger + \bar{c}[1-p]$	$\bar{k}$	$\bar{\lambda}$	$t(\phi) = \bar{c}$ $t(0) = \bar{c}$ $t(\bar{c}) = \bar{c}$	$x(\phi) = X$ $x(0) = X$ $x(\bar{c}) = X$	$[R - \bar{c}]X$

Proposition 5 follows immediately from the equilibrium above.

APPENDIX B

Nonlinear Production Technology

Appendix B provides details of how the economic forces modeled in the paper also apply in a nonlinear production framework. The main analysis, following Harris et al. (1982) and Antle and Eppen (1985), and many subsequent variants, utilizes a linear cost and revenue technology with a capacity constraint to model the adverse selection problem.[3] The linear formulation permits a crisp characterization of the optimal contract since it prescribes either full production or no production. In contrast, with nonlinear technology absent capacity constraints, the solution is no longer "bang-bang," but the key results hold.

To demonstrate the generalizability of our results on the interaction between the make and buy problems, assume the supplier's cost for producing x units is convex, denoted $cD(x)$, where $D'(x) > 0$ and $D''(x) > 0$, with $c \in [\underline{c}, \bar{c}]$, $0 < \underline{c} < \bar{c}$. In this setting, when the firm confronts an uninformed supplier, the supplier receives the expected cost for supplying x units of input b and, accounting for this payment, the firm sets x to equate its marginal revenue with the marginal cost to buy and make the inputs. In particular, the optimal contract $\{x^*(\phi), t^*(\phi)\}$ satisfies the following (with a slight abuse of notation, we use * to

[3] See Rajan and Reichelstein (2004)—written to discuss the seminal Harris et al. (1982) article and in celebration of the 50th anniversary of *Management Science*—for an excellent overview of such models.

denote the optimal outcome in the nonlinear technology case, as well).

$$D'(x^*(\phi)) = \frac{R - [\bar{k} - k]}{E\{c\}} \text{ and } t^*(\phi)x^*(\phi) = E\{c\}D(x^*(\phi)).$$

When facing an informed supplier, the optimal menu of contracts is determined in analogous fashion to Program 1. The difference is that the supplier's cost is convex, not linear as it was in Program 1, and there are no capacity constraints. In particular, the optimal menu of contracts in the nonlinear setting solves:

$$\underset{x(c),t(c)}{Max} \int_0^{\bar{c}} [R - (\bar{k} - k) - t(c)]x(c)f(c)dc$$

subject to:

$$t(c)x(c) - cD(x(c)) \geq 0 \qquad \forall c \in [0, \bar{c}] \tag{IR}$$

$$t(c)x(c) - cD(x(c)) \geq t(\hat{c})x(\hat{c}) - cD(x(\hat{c})) \qquad \forall c, \hat{c} \in [\underline{c}, \bar{c}] \tag{IC}$$

Again, it is easy to establish that the global (IC) constraints can be replaced by their local counterparts; the (IR) constraint for the highest cost holds as an equality; and the program can be solved via pointwise optimization. This yields the following optimal contract when the firm confronts an informed supplier who reports $\hat{c}$.

$$D'(x^*(\hat{c})) = \frac{R - [\bar{k} - k]}{\hat{c} + H(\hat{c})} \text{ and } t^*(\hat{c})x^*(\hat{c}) = \hat{c}D(x^*(\hat{c})) + \int_{\hat{c}}^{\bar{c}} D(x^*(\tilde{c}))d\tilde{c}. \tag{B1}$$

As in Baron and Myerson (1982), a feature of this screening mechanism is that the quantity traded is a decreasing function of the supplier's cost report, and the firm's marginal cost for procuring input b incorporates both the supplier's production cost and the supplier's information rents (via the added $H(\hat{c})$ term in $D'(x^*(\hat{c}))$). The expected information rents follow from the payment $t^*(\hat{c})$ in (B1). In particular, the supplier's expected rents equal $\int_{\underline{c}}^{\bar{c}} \left[\int_{c}^{\bar{c}} D(x^*(\tilde{c}))d\tilde{c} \right] f(c)dc,$ which can be equivalently written as $\int_{\underline{c}}^{\bar{c}} H(c)D(x^*(c))f(c)dc.$

The supplier's information acquisition strategy λ then maximizes the expected rents net of the acquisition cost, and the firm's investment k in the new technology is chosen not just with a singular focus on reducing its make costs, but also with an eye toward buy costs by curbing the supplier's incentives to acquire and exploit private information. The equilibrium outcomes are summarized as follows.

Result

(i) The firm's optimal contract is as follows: (a) when the supplier is uninformed, $D'(x^*(\phi)) = \frac{R-[\bar{k}-k]}{E\{c\}}$ and $t^*(\phi) = [E\{c\}D(x(\phi))]/x^*(\phi)$, and (b) when the supplier is informed, $D'(x^*(\hat{c})) = \frac{R-[\bar{k}-k]}{\hat{c}+H(\hat{c})}$ and $t^*(\hat{c}) = [\hat{c}D(x^*(\hat{c})) + \int_{\hat{c}}^{\bar{c}} D(x^*(\tilde{c}))d\tilde{c}]/x^*(\hat{c})$.

(ii) The supplier chooses information system of precision λ^*, where $\int_{\underline{c}}^{\bar{c}} H(c)D(x^*(c))f(c)dc = v'(\lambda^*)$; and the more the firm invests in the new technology, the greater the precision of the supplier's information system, i.e., $\frac{d\lambda^*}{dk} = \frac{1}{v''(\lambda^*)} \int_{\underline{c}}^{\bar{c}} \frac{D'(x^*(c))F(c)}{D''(x^*(c))[c+H(c)]} dc > 0.$

(iii) The firm's investment in the new technology is k^*, where k^* is the unique k-value that satisfies:

$$\lambda^* \int_{\underline{c}}^{\bar{c}} \left\{ x^*(c) + \frac{R - (\bar{k} - k) - cD'(x^*(c)) - H(c)D'(x^*(c))}{D''(x^*(c))[c + H(c)]} \right\} f(c)dc$$
$$+ [1 - \lambda^*] \left\{ x^*(\phi) + \frac{R - (\bar{k} - k) - E\{c\}D'(x^*(\phi))}{D''(x^*(\phi))E\{c\}} \right\}$$
$$= w'(k) + \left\{ \int_{\underline{c}}^{\bar{c}} [R - (\bar{k} - k) - t^*(c)]x^*(c)f(c)dc - [R - (\bar{k} - k) - t^*(\phi)]x^*(\phi) \right\} \frac{d\lambda^*}{dk}.$$

(iv) $k^* < \hat{k}(\lambda^*)$, where $\hat{k}(\lambda^*)$ is the optimal investment by the firm when the supplier's information system precision is exogenous and fixed at λ^*.

The above results parallel those in Propositions 2, 3, and 4, and while the optimal contract is more complicated, the economic forces are robust with both the linear and nonlinear technological formulation. In particular, the firm intentionally invests less in the new technology, raising its make-cost in order to curtail its buy-costs. Formally, part (i) of the Result presents the optimal contract; part (ii) presents the supplier's rents and its information acquisition decision; as in Proposition 3, part (ii) implies that $d\lambda^*/dk > 0$, leading the firm to underinvest in the new technology and reduce the supplier's information precision λ^*, as noted in parts (iii) and (iv).