Revisiting the Make-or-Buy Decision: Conveying Information by Outsourcing to Rivals

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Abstract

The textbook make-or-buy decision is typically described as choosing the cheaper of the two sourcing options. However, research in accounting has consistently demonstrated that strategic and informational considerations often complicate such seemingly straightforward criteria. In a similar vein, this paper shows that when a firm will become privy to accounting information pertaining to its profitability, its sourcing choice has powerful informational reverberations. This is because input procurement from an outsider serves to convey internal information that is both stochastic and strategic in nature. *Stochastic information conveyance* refers to the fact that the size of the input order provides the supplier a credible signal of the firm's internal accounting information and, thus, its relative ability to compete in the marketplace. *Strategic information conveyance* refers to the fact that the upfront placement of the input order also informs the supplier of the firm's chosen strategic posture in the marketplace. We demonstrate that both sources of information conveyance together can point to a firm preferring to buy inputs from a retail rival even when it can make them internally at a lower cost. This penchant for outsourcing to a rival is more pronounced the more accurate the firm's accounting system.

1. Introduction

The make-or-buy choice is typically viewed as one that amounts to contrasting the external market price for an input with a firm's estimate of the cost of producing that input. It is well known that accounting plays a key role in this comparison – a precise estimate of the relevant costs of input production can sharpen a firm's decision making, particularly when such estimates are adequately adjusted to reflect opportunity costs (Balakrishnan et al. 2009; Horngren et al. 2009). In this paper, we demonstrate a more nuanced role for accounting information in the make-or-buy decision: not only can production cost estimates stand to affect the make-or-buy choice, but so can revenue estimates. In particular, when a firm's accounting system provides it relevant information about the demand for its products, a firm's external input procurement level can indirectly convey this information upstream. As a result, the firm's information and competitive environment is notably different when it outsources input production to an upstream supplier who is also a downstream rival than when it establishes its own input production capacity.

To elaborate, the paper demonstrates that when a firm opts to outsource input production rather than make inputs internally, any order it places serves to (credibly) convey information to its input supplier. Such information transmission has both stochastic and strategic elements, each of which plays a crucial role in the firm's initial procurement choice. Stochastic information conveyance refers to the fact that the size of the firm's order with its supplier depends on its estimates of profitability of the products it will create with the input; as such, the supplier learns about potential demand for the firm's products from the order it receives. Strategic information conveyance refers to the fact that the firm's order with its supplier also reveals its impending strategic posture in the output market.

While the information conveyance effect of order quantities is innocuous when the supplier is an uninterested observer of output market proceedings, this is not the case with a supplier who also has a stake in the output market. As a result, a firm may opt to eschew opportunities to establish its own production capacity and instead rely on an output market rival for inputs, even when the rival's stated input price exceeds the firm's own cost of making the input.

The reasoning behind the result that information conveyance points to more outsourcing, specifically outsourcing to a rival, is roughly as follows. Take first stochastic information conveyance. When rivals in the output market are unaware of the demand for a firm's product, they must rely on expectations when choosing their own quantities. When the firm places an order that conveys such demand information, a rival can condition competitive response on it – when the firm's demand (and, thus, its input order) is high, the rival backs away in competition and when the firm faces low demand (and places a minimal input order), the rival is able to be more aggressive in competition. The net result is that the average level of competition is lower: the rival cedes power some of the time (when the firm is most profitable) and the firm cedes power other times (when the firm is less profitable).

Next, consider the effect of strategic information conveyance. When a firm opts to outsource and places an input quantity order with a rival, the rival naturally learns the ensuing output quantity. As such, the firm gets a Stackelberg-like first mover advantage over its rival. Two features complicate this Stackelberg-like effect: (i) only one of the firm's rivals, the input supplier, knows the quantity; and (ii) as the supplier, the rival must willingly hand over this first-move advantage. In terms of (i), the first-mover advantage would seemingly only affect the rival from whom the firm purchases. Consistent with this, the more rivals faced by the firm, the more muted its first-mover advantage is since it is only directly conveyed to one of the rivals. That said, the remaining rivals realize that the firm has this advantage over one of them and accounts for the firm's incentive for added aggressiveness accordingly. As such, despite the fact that only one rival observes the firm's order, the late-mover disadvantage is also borne by the other rivals. This nuance leads to the justification for (ii). Though the firm, of course, relishes the first-mover advantage that outsourcing gives it, the surprising part is that the rival can benefit from being the late mover. Though the supplying rival suffers in the output realm by being a late mover, its buyer's newfound competitive strength translates into a greater willingness to pay for inputs and, thus, greater input market profits for the rival. Further, while the supplying rival exclusively gains this input market benefit, the output market downside of being a late mover is spread among all rivals (as discussed in (i)). As a result, the rival may be eager to sell inputs to the firm, precisely because doing so puts it in a late-mover position.

Given these forces, the question is when the information conveyance role of purchases will lead to an equilibrium wherein not only the firm is a willing buyer but also the rival is a willing supplier. As discussed above, stochastic information conveyance is particularly useful when a firm's purchases communicate pertinent information. Consistent with this, we demonstrate that the firm opts to outsource if and only if its information advantage is sufficiently large. This means that greater uncertainty and more precise internal accounting each point towards increased outsourcing. Further, as also discussed above, strategic information conveyance is particularly appealing when a firm encounters several rivals. Consistent with this, we demonstrate that the firm opts to outsource when the output market is sufficiently competitive.

While perhaps surprising at first blush, the result herein that a firm may opt to outsource to its own competitor for strategic reasons is more than just a modeling novelty. In fact, the practice of relying on competitors for inputs is quite common, albeit not fully understood. Outsourcing to competitors has been documented in many arenas, including the aircraft, automobile, computer, glass, household appliances, telecommunications, and trucking industries (e.g., Arrunada and Vazquez 2006; Baake et al. 1999; Chen et al. 2011; Spiegel 1993). Some recent examples are worth noting: Apple buys chips for the iPhone and iPad from a key rival, Samsung; Dell and HP use Microsoft operating systems for their tablets while facing impending competition from Microsoft's own Surface tablet; Ferrari has agreed to supply engines to be used in Maserati and Alfa Romeo cars; and Olympus and Nikon each rely on Sony for key sensors in their latest cameras. Besides being high profile, these examples represent circumstances where brand-specific demand is highly uncertain and firms have diligently sought means of gathering market data. Our results suggest this is not a coincidence. In fact, the results predict that markets characterized by more volatile demand and/or greater competition, and firms with more precise internal accounting data point to buying inputs from rivals. These empirical predictions provide a useful contrast to the view that outsourcing to competitors is just an option of last resort in the face of technological constraints.

To elaborate on the implications for accounting precision in particular, two key features are noteworthy. First, the results indicate that not only does greater accounting precision favor buying inputs from rivals, but they also indicate that buying from rivals boosts incentives to invest in greater accounting precision. That is, the connection between internal accounting effectiveness and outsourcing propensity is a complementary two-way interaction. Second, the important feature underpinning the results is not that the information is about demand per se, but that it conveys some firm-specific knowledge. Thus, when the information pertains to a firm's costs of converting inputs into outputs, the results can also speak to a complementary relationship between cost accounting precision and the tendency to outsource.

The existing literature in accounting, economics, and operations also discusses other factors that work both for and against outsourcing. Long-term dynamics of supplier-buyer interactions (Anderson et al. 2000; Demski 1997), institutional pressures to keep particular inputs in-house (Balakrishnan et al. 2010), and the importance of learning-by-doing (Anderson and Parker 2002; Chen 2005) are key considerations. In terms of strategic effects in outsourcing, the noted downsides include concerns of misappropriation of innovation by suppliers (Baiman and Rajan 2002) and technology spillovers that benefit rivals (Van Long 2005), while the benefits include exploiting differential cost structures, avoiding redundant fixed costs, influencing rivals' wholesale prices when reliant on a common supplier, and fostering retail price collusion under decreasing returns to scale (Arya et al. 2008; Baake et al. 1999; Buehler and Haucap 2006; Shy and Stenbacka 2003; Spiegel 1993).

In this paper, the extant reasons for outsourcing (as briefly summarized above) are intentionally excluded in order to highlight the novel role played by information. In particular, the desire to convey both stochastic and strategic information to a rival may point to outsourcing despite the fact that the outsourced price exceeds the cost of making the input internally. The desire to convey stochastic information identified here fits more broadly with the notion that, depending on the type and behavior of the uncertain information, a firm may wish to disclose information to competitors (see, e.g., Darrough 1993; Bagnoli and Watts 2011). Such findings also necessitate discussion of whether the information can be credibly communicated without a costly audit (e.g., Bagnoli and Watts 2010). This question of whether a firm can credibly convey information to others whose priorities are not the same as its own also forms a long stream of literature (e.g., Newman and Sansing 1993; Gigler 1994; Stocken 2000; Fischer and Stocken 2002). A unique feature of outsourcing as a means of signaling information in our setting is that credible communication is a non-issue. Informational pooling and misrepresentation do not arise, since the external supplier is not interested in the underlying information itself, but only the implications of that information for the firm's retail quantity decision. In other words, the usual communication concerns between a firm and its rival pertain to distortions in both the mapping from private information to the transmitted information, and the mapping from the transmission to the firm's retail choice. These concerns are naturally alleviated under outsourcing since the order size conveys the firm's retail choice directly and credibly.

In terms of the desire to convey strategic information via outsourcing, our result is broadly related to Chen et al. (2011), which notes that quantity pre-orders can promote a first-mover (Stackelberg) advantage. In that setting, with no uncertainty and a simple duopoly, however, it is concluded that the specter of such strategic effects leads a supplier to withhold inputs from its retail competitor, thereby forcing the firm to buy from another source. In contrast, we demonstrate that a rival may willingly cede retail leadership by selling inputs to a firm, thereby endogenizing outsourcing to a rival. This stark reversal from Chen et al. (2011) arises due to the presence of uncertainty and/or multiple retail rivals that accentuate the mutual benefits of outsourcing. Importantly, with more than one rival in place, the leadership gained by the outsourcing firm (and that ceded by the supplying rival) is not equivalent to a Stackelberg advantage, but is nonetheless important in adding to the firm's aggressiveness. And, since the supplying rival shares the costs of handing over such leadership with other rivals but is the sole beneficiary of wholesale gains from doing so, it becomes a willing participant in the process.

The remainder of this paper proceeds as follows. Section 2 presents the basic model. Section 3 presents the results: 3.1 examines the equilibrium when the firm establishes internal capacity (make); 3.2 examines the outcome under outsourcing to a rival (buy); 3.3 presents the main results by deriving the precise conditions under which the firm opts to outsource input production; 3.4 provides discussion of additional practical considerations. Section 4 concludes.

2. Model

A firm, denoted firm 0, is deciding whether to make or buy a critical input that has uncertain value in the output (retail) market. The firm from which it can buy the input, denoted *R*, is also a retail rival. To eliminate standard reasons to make vs. buy inputs, we assume each party can produce the input at the same unit cost; we normalize this production cost to zero. Denoting the per-unit input (wholesale) price set by *R* as w, firm 0's choice is thus to make at cost zero or procure from a rival at cost w.[1]

Subsequent to its procurement choice, firm 0 faces (Cournot) competition in the retail market. As noted, firm *R* represents one source of such competition; that said, we allow for the possibility that there can be other retail competitors as well (with costs also normalized to zero). Say firm 0 faces *n* rivals in total, and denote the set of rivals by N.

The retail demand for firm 0 is given by the standard linear (inverse) demand function $p_0 = a + \delta - q_0 - k\sum_{i \in N} q_i$, and retail demand for rival i, $i \in N$, is $p_i = a - q_i - k\left[\sum_{j \in N_{-i}} q_j + q_0\right]$. In the demand functions, p_i and q_i reflect the retail price and quantity for firm i, a reflects industry-wide demand, δ reflects uncertain firm-specific demand for firm 0, k, $0 < k \leq 1$, reflects the degree of product differentiation, and N_{-i} denotes the set *N* less element *i*. As is standard, throughout the analysis we assume a is sufficiently large to ensure nonnegative quantities and prices.

The focus of this paper is on how firm 0's decision to outsource input production to a retail rival can hinge on its ability to subsequently convey pertinent accounting information. To capture this consideration, say firm 0's uncertain demand component is mean zero with variance σ^2, and consists of *T* elements: $\delta = \sum_{i=1}^{T} \delta^i$, where each δ^i is an *iid* mean-zero noise term with variance σ^2 / T. Prior to retail competition, firm 0's accounting system gives it an advance, but perhaps imperfect, read of uncertain demand. In particular, the accounting system reveals $t \leq T$ components of δ; without loss of generality, the information revealed by the system is captured by the signal $s = \sum_{i=1}^{t} \delta^i$. With this formulation, the precision of the accounting system is reflected by $\omega = t / T$ ($\omega = 0$ reflects an uninformative system, while $\omega = 1$ reflects a perfect signal).

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1 In this setting, it is readily confirmed that firm 0 would prefer making to buying from an outside supplier who is not a retail rival.

In the analysis that follows, we examine subgame perfect equilibria by working backwards in the game to determine outcomes. The timeline of events for the setting is summarized in Figure 1.

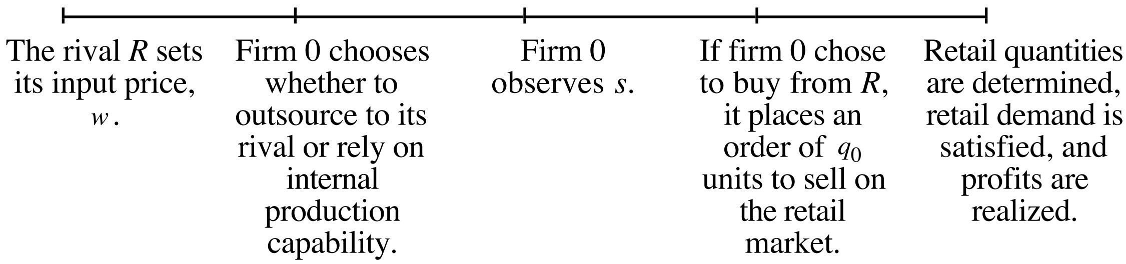


Figure 1: Timeline

3. Results

To determine firm 0's sourcing choice, we derive the subgame equilibrium in each case. The equilibrium sourcing decision requires evaluating the maximum amount firm 0 is willing to pay to procure, and then stepping back and asking whether firm *R* is willing to sell at such prices. We begin with deriving the outcome when firm 0 opts to install capacity to produce inputs internally.

3.1. Equilibrium when Making

A firm that makes its own inputs at the same unit cost as its competitors places itself on level competitive footing as far as production costs are concerned. On the revenue side, the firm retains its private accounting signal about firm-specific demand. In particular, firm 0 can condition its production choices on s, its signal of demand, whereas its competitors are left with less informed estimates of the firm's competitive position. In particular, denoting firm 0's conjecture of firm i's equilibrium quantity by $\tilde{q}_i,\ i \in N$, upon observing s, firm 0 chooses $q_0(s)$ to solve (1):

$$\underset{q_0(s)}{Max}\ E_{\delta|s}\left\{\left[a + \delta - q_0(s) - k \sum_{i \in N} \tilde{q}_i\right] q_0(s)\right\}. \tag{1}$$

Uninformed of s, firm i chooses q_i to maximize its expected profit, as in (2). In (2), $\tilde{q}_0(s)$ denotes firm i's conjecture of firm 0's equilibrium quantity as a function of s, and $\tilde{q}_j$, $j \in N_{-i}$, denotes firm i's conjecture of firm j's equilibrium quantity.

$$\underset{q_i}{Max} \;\; E_s\left\{E_{\delta|s}\left\{\left[a - q_i - k\tilde{q}_0(s) - k\sum_{j \in N_{-i}} \tilde{q}_j\right]q_i\right\}\right\},\; i \in N. \tag{2}$$

Jointly solving the first-order conditions of (1) and (2), and noting conjectures are correct in equilibrium, reveals the following proposition in which the superscript "M" denotes the make regime (complete proofs of all propositions are provided in the appendix).

PROPOSITION 1. When firm 0 opts to make, the equilibrium entails

(i) $q_0^M(s) = \dfrac{a}{2+kn} + \dfrac{s}{2}$; and

(ii) $q_i^M = \dfrac{a}{2+kn}$, $i \in N$.

The proposition reflects the standard Cournot quantities adjusted for firm 0's private information. In particular, each firm chooses a baseline quantity of $\dfrac{a}{2+kn}$, reflecting that greater demand (a) and/or lower competitive intensity (k or n) each lead a firm to produce more. Having private information about its own demand, firm 0 is able to condition its production on it, as reflected in $s/2$; the others rely only on their conjecture of firm 0's demand in assessing its competitive stance (recall, $E\{s\} = 0$). The net result is that each firm's expected profits are again the standard Cournot profits, with the exception that firm 0 gains from its ability to condition production on its accounting signal of firm-specific demand: the more the initial uncertainty and the more precise the accounting signal, the more such conditioning is useful. Formally, substituting quantities from Proposition 1 in (1) and (2), expected profits in the make regime for firm 0 and firm i, $i \in N$ equal:

$$\Pi_0^M = \left[\frac{a}{2+kn}\right]^2 + \frac{\omega\sigma^2}{4} \quad \text{and} \quad \Pi_i^M = \left[\frac{a}{2+kn}\right]^2,\; i \in N. \tag{3}$$

Though we will discuss the role of accounting precision more fully soon, note from (3) that greater precision (ω) stands to benefit the firm. This is because the early read of demand, if precise, affords the firm the opportunity to condition its production choice on the demand. Thus, the more uncertain the firm's demand (σ^2) and the more the accounting system can resolve this uncertainty (ω), the greater the firm's expected profit.

Following the previous logic, if the firm were to instead outsource to an independent third party, the equilibrium outcome would be the same, except the degree of demand (a) would be offset by the supplier price. Since any rational supplier would not set price less than cost (here, zero), making is preferred to seeking out an independent supplier. Buying from a rival, however, presents a different circumstance, one we consider next.

3.2. EQUILIBRIUM WHEN BUYING

When buying from a rival in the output market, firm 0's problem is similar to before except that it realizes its procurement order reveals its competitive posture to its rival. The rival (R), in turn, can condition its own production choice on its observation of firm 0's input order size. In particular, given its chosen wholesale price, w, and firm 0's input order, $q_0(s)$, and its conjectures of the quantities of the other firms, $\tilde{q}_j$, $j \in N_{-R}$, firm R chooses q_R to solve:

$$\underset{q_R}{Max}\ E_{\delta|s}\left\{\left[a - q_R - kq_0(s) - k\sum_{j\in N_{-R}}\tilde{q}_j\right]q_R + wq_0(s)\right\}. \tag{4}$$

Taking the first-order condition of (4) reveals firm R's reaction function to firm 0's input order:

$$q_R(q_0(s), \tilde{q}_j, j \in N_{-R}) = \frac{1}{2}\left[a - kq_0(s) - k\sum_{j\in N_{-R}}\tilde{q}_j\right]. \tag{5}$$

As can be expected, in (5) a greater order from firm 0 translates into a softened stance by R, i.e., $\partial q_R(q_0(s), \tilde{q}_j, j \in N_{-R})\big/\partial q_0(s) = -k/2 < 0$. This feature reflects the consequence of *strategic* information conveyed by firm 0's purchase: a higher quantity purchased by firm 0 reduces the marginal revenues of *R* and, thus, reduces its propensity to produce its own outputs. Given this response, and its conjectures of the quantities of the other firms, $\tilde{q}_j$, $j \in N_{-R}$, firm 0 chooses $q_0(s)$ to solve:

$$\underset{q_0(s)}{Max}\ E_{\delta|s}\left\{\left[a+\delta-q_0(s)-kq_R(q_0(s),\tilde{q}_j,j\in N_{-R})-k\sum_{j\in N_{-R}}\tilde{q}_j\right]q_0(s)-wq_0(s)\right\}. \quad (6)$$

The problem in (6) is as in (1) for the make case, except that (i) firm 0 pays to outsource the input, and (ii) the strategic information conveyance effect is in place, as q_R reflects not a conjecture but the strategic response function. In effect, by placing its input order upfront, firm 0 enjoys a pseudo-Stackelberg position; thus, in choosing its quantity it also accounts for the fact that the choice will change *R*'s response, now the de facto late mover. We say pseudo-Stackelberg, because the order only tells one rival of its quantities. The remaining competitors, though they remain in the dark about firm 0's purchases, are well-aware that firm 0 holds a leader position over *R*. That is, they form conjectures about firm 0's purchases and, given these conjectures, recognize how *R* would respond to those purchases, i.e., they use (5) with conjecture $\tilde{q}_0(s)$. Continuing with the same notation for said conjectures, firm *i*, $i \in N_{-R}$ chooses its quantity to solve:

$$\underset{q_i}{Max}\ E_s\left\{E_{\delta|s}\left\{\left[a-q_i-k\tilde{q}_0(s)-kq_R(\tilde{q}_0(s),\tilde{q}_j,j\in N_{-R})-k\sum_{j\in N_{-\{R,i\}}}\tilde{q}_j\right]q_i\right\}\right\}. \quad (7)$$

The second informational consequence of purchasing from *R* is now apparent. Unlike its competitors, *R* becomes aware of $q_0(s)$ and, as a result, indirectly conditions its quantities on s (see (5)). Thus, while the other firms ($i \in N_{-R}$) choose quantities in expectation of *s* (see (7)), *R*'s quantities reflect *s* (see (4)). Jointly solving the first-order conditions of (6) and (7), and the condition that all conjectures are correct in equilibrium yields the equilibrium in when firm 0 procures its inputs from *R*, as summarized in the following proposition.

PROPOSITION 2. When firm 0 opts to buy, the equilibrium entails

(i) $q_0^B(w;s) = \dfrac{2[(a-w)(2-k)-knw]}{8+k[4-k^2][n-1]-2k^2[n+1]} + \dfrac{s}{2-k^2}$;

(ii) $q_R^B(w;s) = \dfrac{a[4-2k-k^2]+2kw}{8+k[4-k^2][n-1]-2k^2[n+1]} - \dfrac{sk}{2[2-k^2]}$; and

(iii) $q_i^B(w) = \dfrac{a[4-2k-k^2]+2kw}{8+k[4-k^2][n-1]-2k^2[n+1]},\ i \in N_{-R}$.

From the proposition, three key features emerge. To see them most succinctly, say $w = 0$ (procurement from R is at cost), $n = 1$ (R is the only rival), and $k = 1$ (competition is intense). In this case, relative to the case of making the input, firm 0's expected quantity is greater when it buys ($a/2$ vs. $a/3$) due to its pseudo-Stackelberg advantage. Similarly, R's expected quantity is lower as the follower ($a/4$ vs. $a/3$). This reflects the first feature: strategic information conveyance.

The second critical feature, stochastic information sharing, is reflected in the fact that R's quantity is now implicitly a function of s; for this case, $q_R^B(0;s) = a/4 - s/2$, reflecting that when firm 0's information indicates it is more (less) profitable, R backs away (becomes more aggressive) in competition. Of course, though the information is stochastic in nature, it too has strategic repercussions. Since firm 0 can convince R to back away when s is higher, it will take advantage by increasing quantities even more. In this case, $q_0^B(0;s) = a/2 + s$, whereas $q_0^M(s) = a/3 + s/2$, reflecting that buying makes the firm's retail quantities more sensitive to its information. Thus, the second key feature too has a notable strategic consequence.

A final crucial feature of the equilibrium arises when there is more than one rival. When $n > 1$, not only are firms 0 and R affected by the procurement choice but so too are the "innocent" bystanders. That is, firm 0's buying gives itself a pseudo-Stackelberg advantage – only one firm is aware of its quantity, yet all are at least aware of the fact that firm 0's order influences firm R and firm 0 will thus be more aggressive in its quantity choice. Being aware of this extra aggressiveness means that the remaining firms unwittingly are followers as well. In fact, firm 0's added aggressiveness is not borne just by firm R but is actually shared among firm 0's rivals. The only difference between firm R and the other rivals is that $q_R^B(w;s)$ is contingent on s, whereas $q_i^B(w)$ is not, i.e., from Proposition 2, $E\left\{q_R^B(w;s)\right\} = q_i^B(w),\ i \in N_{-R}$.

Importantly, for all n, buying from a rival gives firm 0 a leadership advantage relative to standard Cournot competition. Continuing with the $w = 0$ and $k = 1$ case, under Cournot competition, firm 0's expected quantities can be easily derived and written as $E\left\{q_0^B(0;s)\right\} - \dfrac{a[1+n]}{6+5n+n^2}$, clearly less than $E\left\{q_0^B(0;s)\right\}$. At the same time, firm 0's strength that accompanies buying is not as strong as Stackelberg leadership since only one rival directly observes the firm's chosen quantities. Consistent with this, a pure Stackelberg equilibrium yields expected firm 0 quantities of $E\left\{q_0^B(0;s)\right\} + \dfrac{a[n-1]}{2[3+n]} > E\left\{q_0^B(0;s)\right\}$ for all $n > 1$. In short, buying from a rival does provide a clear leadership advantage for firm 0 but it is less pronounced than the routine Stackelberg advantage.

As we will shortly see, the above three features together form the basis for determining the equilibrium procurement option. To demonstrate this formally, using the outcomes in Proposition 2 in the profit expressions of firms 0 and R and taking expectations, the expected profits of each are presented in (8).

$$\Pi_0^B(w) = 2\left(2-k^2\right)\left(\frac{[(a-w)(2-k)-knw]}{8+k[4-k^2][n-1]-2k^2[n+1]}\right)^2 + \frac{\omega\sigma^2}{2[2-k^2]}\text{; and}$$

$$\Pi_R^B(w) = \left(\frac{a[4-2k-k^2]+2kw}{8+k[4-k^2][n-1]-2k^2[n+1]}\right)^2 + \frac{2w[(a-w)(2-k)-knw]}{8+k[4-k^2][n-1]-2k^2[n+1]} + \frac{\omega\sigma^2k^2}{4[2-k^2]^2}. \tag{8}$$

Using expected profit expressions in (3) and (8), we next derive the equilibrium procurement policy.

3.3. THE DECISION TO BUY FROM A RIVAL

Recall from the previous discussion that buying from a rival has both strategic and stochastic information effects. As far as the strategic information effect, the first-mover advantage it provides to firm 0 has clear benefits for the firm. As far as the stochastic effect, this too works in favor of outsourcing. To elaborate, with stochastic information conveyance, when the firm's demand is high, buying substantial quantities of inputs convinces its rival to reduce its own quantities; when the firm's demand turns out to be below average, the low input procurement informs the rival that it can dominate the market. The net effect is that average competition is lower, and firm 0 reaps the benefits of lower competition precisely when its demand (i.e., potential profit) is greatest. Both information effects together translate into firm 0's willingness to pay for inputs from its rival being above its own cost. In particular, comparing Π_0^M and $\Pi_0^B(w)$, firm 0 is willing to pay up to $\overline{w} > 0$ in order to buy, where

$$\overline{w} = \frac{a[2-k]}{2+k[n-1]} - \frac{[(2-k)^2(2+k)+kn(4-k(2+k))]\sqrt{4a^2(2-k^2)-k^2(2+kn)^2\omega\sigma^2}}{2\sqrt{2}[2-k^2][2+k(n-1)][2+kn]}. \quad (9)$$

Of course, since firm 0 buying from R puts the seller at a strategic disadvantage as a late mover, it is reasonable to presume that R does not want to sell to firm 0 and will thus price it out of the market. Before addressing this specifically, consider the broader question of what R would like to charge firm 0 for inputs if it were guaranteed to have firm 0 as a customer. That is, what is the value of w that maximizes $\Pi_R^B(w)$? When it comes to competitive positioning, higher w is better. However, even if firm 0 has no ability to make the input, R still wants it to be a nontrivial participant in the output market since it gleans input market (wholesale) profit from firm 0. If w is too high, then, R risks winning gaining substantial retail power but foregoing too much wholesale profit in the process. Due to the desire to balance retail and wholesale profits, R's preferred input price is interior in nature even if buying is guaranteed. In particular, setting $\partial\Pi_R^B(w)\big/\partial w = 0$ reveals R's preferred price is $\tilde{w}$, where

$$\tilde{w} = \frac{a[16 - 2k^2(4n - k + 2) + k(8 + k^3)(n-1)]}{2[16 + 16k(n-1) - k^4(n-1)^2 - 2k^2(1 + 6n - 2n^2) - 2k^3(n^2 + n - 2)]}. \qquad (10)$$

Taken together, (9) and (10) determine the equilibrium input price in the event firm 0 is induced to buy. That is, firm 0 is willing to pay up to $\overline{w}$ to buy from *R*. If *R* wants to sell to firm 0, it must charge no more than this. It can, however, charge less should it wish to. So, if $\tilde{w} < \overline{w}$, *R* would charge $\tilde{w}$. This result on the equilibrium input price in the event of buying is summarized in the Lemma.

LEMMA. If the equilibrium outcome entails firm 0 buying, the wholesale price is $w^* = Min\{\tilde{w}, \overline{w}\}$.

The question that remains is whether *R* would, in fact, choose a price so as to entice firm 0 into buying or would it prefer to let firm 0 make its inputs? Recall, though firm 0 would be happy to buy at zero cost since doing so gives it a first-mover advantage over *R*, one would presume that *R* would not be a willing participant. Even though firm 0 is willing to pay a premium for this advantage, it does not mean the premium will be enough for *R* to willingly cede competitive advantage. To get a feel for this, take first the limiting case of $\sigma^2 = 0$ and $n = 1$. For $\sigma^2 = 0$, stochastic information conveyance is absent. With $n = 1$, *R* bears the entire downside of strategic information conveyance, bearing the brunt of late mover status. In this event, it is also readily confirmed that $w^* = \overline{w}$, i.e., R's preferred price is more than the maximum firm 0 is willing to pay. To *R*, the benefit of selling at $w^* = \overline{w} > 0$ is that it gains non-zero wholesale (input) profit; the downside is the loss of retail (output) profit. Comparing $\Pi_R^B(\overline{w})$ and Π_R^M at $\sigma^2 = 0$ and $n = 1$ reveals that the downside is more pronounced. Thus, for $\sigma^2 = 0$ and $n = 1$, the equilibrium entails firm *R* pricing in order to entice firm 0 to make in equilibrium. This limiting case is consistent with Chen et al. (2011), which notes that a rival would be unwilling to sell inputs to a firm since doing so may provide too much strategic advantage to the buyer.

The limiting case of $\sigma^2 = 0$ and $n = 1$ excludes two of the key features discussed previously, stochastic information conveyance and the reverberations of strategic information conveyance on other rivals. It turns out that each of these effects is critical in establishing equilibrium outsourcing to a rival. Consider the consequence of $\sigma^2 > 0$. This introduces the possibility of stochastic information conveyance. As discussed before, the potential for stochastic information conveyance makes buying from a rival more attractive for firm 0, as manifest in its willingness to pay: $\partial \overline{w} / \partial \sigma^2 \geq 0$. This increased willingness to pay bodes well for the willingness of *R* to sell. Also, recall the reason firm 0 benefits from stochastic information conveyance – it reduces competition and gives it an edge precisely when it is most profitable. The same too goes for *R*: with information conveyance: *R* cedes market share precisely when it is (relatively) less profitable and grabs market share when it is more profitable. Thus, not only does stochastic information conveyance increase firm 0's willingness to pay, it also reduces the price *R* would require in order to sell. The end result is that the more pronounced this effect, i.e., the greater σ^2, the more attractive is outsourcing. The next proposition states this formally.

PROPOSITION 3. There exists $\hat{\sigma}^2$ such that the equilibrium outcome entails firm 0 buying from the rival if and only if $\sigma^2 \geq \hat{\sigma}^2$.

It is important to note from the proposition that the intuition provided above, ostensibly for the case of $n = 1$, applies for all n. In fact, $n > 1$ brings the second key effect, strategic information conveyance, to the fore. In particular, as discussed previously, strategic information conveyance under outsourcing has repercussions for other rivals (those not providing inputs to firm 0). Recall, from *R*'s perspective, the late-mover status it takes on when selling is costly. And, even though firm 0 will pay more to be a leader, it is not enough to justify the distinct disadvantage of effectively moving last. This reasoning applies to the case of $n = 1$, but not for $n > 1$, due to the added subtle effect on other rivals.

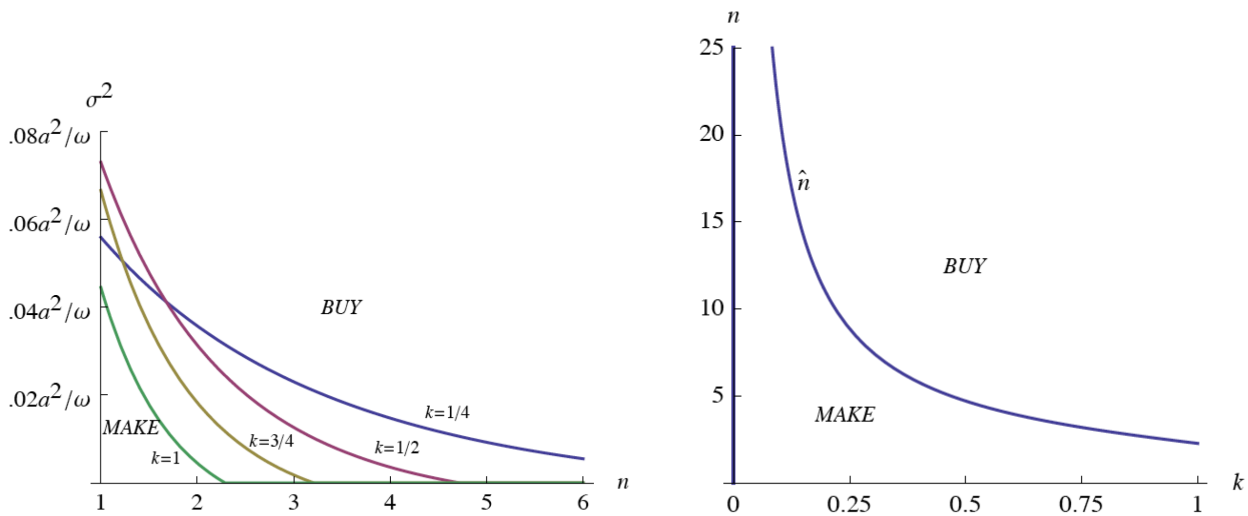
Though not privy to the strategic information conveyed by firm 0's purchases, the other rivals are aware that such purchases are being made and, as such, find themselves acting as de facto late movers too. From *R*'s perspective, this means that the disadvantage of being a late mover is both less pronounced and shared among the *n* rivals, whereas the advantage of firm 0's increased willingness to pay is its own to reap. As a result, the more rivals to share the cost of being at a competitive disadvantage, the more attractive is the added wholesale profit. This feature suggests that greater *n* favors buying from a rival (Proposition 4(i)). Taking the thinking even further, as long as competition is sufficiently intense (greater *n*), buying from a rival can be preferred even absent any stochastic effect. In other words, if $\sigma^2 = 0$, the strategic effect alone can favor buying from a rival for sufficiently large *n* (Proposition 4 (ii)).

PROPOSITION 4.

(i) Greater retail competition promotes buying from a rival, i.e., $\hat{\sigma}^2$ is decreasing in n.

(ii) There exists $\hat{n}$ such that $\hat{\sigma}^2 = 0$ if and only if $n \geq \hat{n}$. Thus, when firm 0 faces enough competitors, the equilibrium entails firm 0 buying the input even under demand certainty.

Figure 2 provides a pictorial depiction of the joint presence of the stochastic and strategic information effects. Panel A plots the equilibrium make vs. buy choice as a function of σ^2 (the stochastic effect) and *n* (the strategic effect). Panel B highlights that the strategic information effect alone can point toward buying from rivals by considering the certainty ($\sigma^2 = 0$) case and plotting the make vs. buy choice as a function of *k* and *n*.



Panel A. Choice as σ^2 and n vary. Panel B: Choice for $\sigma^2 = 0$ as n and k vary.

Figure 2. Equilibrium Make vs. Buy Choice

With the information effects of buying from a rival delineated, we now ask what the implications are for the firm's accounting system. First, how does the precision of the accounting system affect the make vs. buy decision? Recall that one feature pushing toward buying from a rival is the ability of purchase quantities to credibly convey the firm's knowledge of the demand for its brand. The extent of this knowledge and, thus, the degree of the benefit is rooted in the precision of the accounting system. Since greater information conveyance favors buying from a rival, then, a more precise accounting system does the same as well (Proposition 5(i)).

A second question is to reverse the causality of the previous question to ask how the make vs. buy decision affects the firm's accounting system. That is, what if the precision of the accounting system were itself an endogenous choice. When a firm makes inputs, there are clear advantages to more accounting precision, since such precision helps inform production and sales choices. When a firm buys from a rival, these advantages remain, but an additional one also comes into play. More accounting precision means the firm's input order conveys more information and, as such, helps reduce (expected) competitive pressures. As a result, the decision to buy inputs from a rival encourages a firm to undertake investments for better (more precise) internal accounting (Proposition 5(ii)).

PROPOSITION 5.

(i) A more precise accounting system promotes buying from a rival, i.e., $\hat{\sigma}^2$ is decreasing in ω.

(ii) Buying from a rival promotes a more precise accounting system, i.e., the benefit of increasing ω is greater when the firm buys from its rival than when it makes.

Proposition 5 highlights the interaction between accounting and operational choices. Further, the proposition lends itself to a natural empirical test: firms with better (weaker) internal accounting are more (less) likely to rely on outsourcing of inputs. As can also be gleaned from the proof of the proposition, not only is greater accounting precision more valuable when buying from a rival, but the value is also greater the more intense the competition with the rival (higher k). Importantly, the critical feature underpinning these connections is not that the accounting information is about demand, but that it represents firm-specific knowledge. More broadly, the results indicate that outsourcing to a rival may be fully rational for both the firm and the rival, solely on informational grounds.

3.4. DISCUSSION

In this section, motivated by some practical issues, we discuss model variants. Besides shedding some light on when considerations identified in this paper are most likely to be pressing, the variants also point to the robustness of the basic idea of information conveyance via outsourcing.

Input Sales by Multiple Rivals

The first thing worth noting is that the main setup presumes only one rival has the ability to sell inputs to firm 0. The discussion surrounding the strategic information effects of buying from a rival suggests that the only losers in the firm's decision to outsource are the remaining rivals who do not reap benefits from selling to firm 0 but have to realize some of the costs. This suggests the other rivals may too wish to get in the input selling business. Even if this possibility were included in the setting, the equilibrium procurement choices identified herein persist as equilibria, although firm 0's added bargaining power may shift more profits its way. That is, consider an equilibrium in which none of the n firms are willing to offer a price low enough that firm 0 would buy from them. In that case, the analysis above confirms that for $\sigma^2 < \hat{\sigma}^2$, none would be willing to deviate and offer a price to ensure buying by firm 0 (by symmetry, if R does not want to coax buying, neither would any other want to unilaterally do so). Similarly, for $\sigma^2 > \hat{\sigma}^2$ it is in R's best interest to set a price so as to ensure firm 0 would buy from it provided no other rivals choose to do so. Of course, given this, another rival may offer an even lower price to ensure that if buying occurs, at least wholesale profits go to them. As a result, the prevailing input price would be lower than identified here but the equilibrium make vs. buy choice is the same – for $\sigma^2 > \hat{\sigma}^2$, firm 0 opts to buy from one of its rivals.

A related question is whether the firm would want to buy not from one rival exclusively but instead agree to buy from several of its rivals. While firms who buy from rivals often do so in the form of exclusive dealing arrangements (e.g., the Ferrari, Samsung, and Microsoft examples previously discussed), multiple sourcing is also common. For example, after having to shut down production following supply disruption, Toyota initiated a policy of relying on at least two suppliers for each critical input. Interestingly, the reasons for multiple sourcing are typically tied to uncertainty – when capacity and/or demand are uncertain, a firm may seek multiple supply outlets to diversify risks of input shortage.

To get a feel for how multiple vs. single sourcing would affect the issues in our setting, consider the possibility of buying non trivial amounts from each rival. If such a buying arrangement were in place, note the stochastic benefits of buying can become more pronounced, since the information conveyed by purchases is conveyed to a larger set of rivals. On the other hand, multiple sourcing threatens to undermine strategic benefits of buying, since each supplier learns not firm 0's output quantity but only a lower bound of that quantity (the amount purchased directly from it). This means that the first-mover advantage that comes from placing an order with a rival that exceeds the standard Cournot quantities can be realized only if either there only few rivals that can supply inputs or if the firm can credibly commit to purchasing quantities proportionally so that an order from one conveys the full order. In short, then, multiple sourcing heightens the stochastic information benefits of buying from rivals but can undermine the strategic information benefits.

The Incentive to Carry Inventory

In the one-shot setting considered here, all units procured are sold, which means the input seller knows about output quantities based on the input order. If the setting were expanded to multi-period interactions, the issue of inventory may come into play. That is, if a firm carries inventory (and inventory levels are unknown to the input seller), there may no longer be a direct correspondence between input purchase and output sale volumes. Such a correspondence is often ensured by the supplier itself stocking retail shelves (take, for instance, grocery stores). But the question remains, what happens when the supplier provides inputs but is not assured that all inputs are placed for sale on the retail market?

To best capture the realm of possible costs and benefits of retaining inventory, say the cost of producing each input is $c \geq 0$, the cost of carrying a unit forward in inventory is

$h \geq 0$, and the value of an item held in inventory (be it present value of future sale; salvage; etc.) is $s \geq 0$. Given the natural condition $w > s - h$ (else the firm would seek infinite units of inventory), it is readily shown that in equilibrium the firm does not intentionally carry inventory. This, however, does not guarantee the same outcome as in the one-shot game. Yet, the buyer's potential aggressiveness associated with outsourcing still persists yielding similar insights.

To elaborate, having already purchased inputs from *R*, firm 0 treats the purchase price as sunk and so internalizes a zero incremental cost for each unit sold at the retail level. Knowing this, the supplier realizes that firm 0 will be more aggressive in selling than he would have been under make (where the incremental cost is *c*). Provided *c* is sufficiently large, this more aggressive posture translates into the precise equilibrium outcome identified in the main setup, despite the fact that the one-to-one mapping from purchases to sales is not mechanical. Even if *c* is not that large, a similar, albeit more muted, leadership effect emerges. Buying from firm 0 does not commit the firm to selling a specific number of units in the output market, but does convey a more aggressive posture (due to the sunk input cost), thereby getting the rival to cede market share. In this sense, even with multiple periods and the threat of inventory carry forward, though the precise equilibria may differ, the feature that buying from a rival can be useful both for strategic and stochastic information consequences persists.

Commitment to the Procurement Decision

Another consideration in terms of commitment is whether firm 0 is able to commit to its procurement source. Note that the presumption in the main setup is that the firm decides up front whether to make internally or buy externally. This presumption clearly has some practical underpinnings, since firms who wish to establish their own production capability need to do so well before actually producing. That is, our setting reflects the inherent lead time associated with the make or buy decision. And, since the information that later arrives (reflecting demand for outputs) has no bearing on the costs or benefits of the different input sources, little is lost in presuming the decision is made prior to uncertainty being resolved. This is in stark contrast to circumstances where information arrives (say about cost or quality) that can provide guidance to the firm about which input source is better.

All that said, we should also note the presumed pre-commitment to sourcing is not consequential: even if firm 0 could make a last minute change to either make or buy inputs, the equilibrium identified herein persists. To get a feel for why this is the case, consider the case in which the firm opts to buy. If firm 0, upon observing unusually low demand, were to reconsider the choice of conveying such information through its purchase order, its decision to "change its mind" would itself convey information. That is, if the temptation is to make when demand is low, the decision to make would convey such low demand, thereby making the temptation itself moot. Formally, for an equilibrium in which the firm buys inputs from its rival, the off-equilibrium beliefs about s in the event of making are set low enough that the temptation is avoided. In effect, the firm's upfront make or buy decision is also ex post sustainable. Thus, not only do practical considerations warrant the presumed precommitment to the make vs. buy choice, the results are unaffected even when the presumption is dropped.

<u>*Observing the Procurement Decision*</u>

As a final consideration, note that the setting presumes that not only do firms 0 and R learn of firm 0's sourcing choice, but so do the other rivals. That is, one feature supporting the fact that buying from a rival gives firm 0 a leadership advantage over all rivals is that even though the other rivals do not observe purchase quantities, they are at least aware of the chosen input source. This presumption too has roots in practice, since firms often disclose their decision to source from rivals (from previous examples, Apple, Dell, and Ferrari are cases in point). The presumption also naturally fits the model, since firm 0 has a clear incentive to inform its rivals of its sourcing choice, since doing so magnifies its leadership advantage (*R*'s ability to disagree with such claims provides a natural veracity check as well). That being said, even if firm 0 were unable to credibly convey its sourcing choice to others, the key forces at work are muted but not eliminated. Since the stochastic information sharing that comes with buying from a rival occurs whether or not the other rivals observe the choice, it remains relevant regardless of who observes the procurement choice. The strategic information effect, on the other hand, is clearly dampened if other rivals do not observe the procurement choice. In that event, the other rivals are unaware of whether firm 0 will have a leadership advantage over *R* and, thus, whether it will be more aggressive in competition. However, *R* does observe the procurement choice and, thus, the strategic effect persists with respect to *R*. Thus, as in the other modeling variations discussed in this section, the presumed observability of the procurement choice is not critical to the insights: in its absence, the strategic effect of buying may be less pronounced but persists nonetheless.

4. Conclusion

A firm's make-or-buy choice is a well documented management problem that has attracted the attention of academics and practitioners from diverse fields. The accountant's role in this choice also has a storied past, one rooted in the desire to develop accurate in-house production cost estimates to compare to external prices. The simple textbook explanation of the role of accounting information is quite staid, despite the fact that the information age has brought about a much more nuanced and strategic role of accounting in most other decisions a firm makes. In this paper, we revisit the role of information in the make-or-buy decision in light of the fact that firm decisions, and the information conveyed therein, often have notable strategic repercussions. In particular, we note that a firm's internal estimates of production cost are not the only estimates that prove crucial to the make-or-buy choice. A firm's internal estimate of demand too can influence the decision of whether or not to outsource, even when the demand itself is not affected by the sourcing decision.

The reason for this result is that the information gathered about demand by a firm is inevitably conveyed to a supplier by input quantities purchased by a firm. In particular, with outsourcing, a supplier gleans information about both the firm's belief about its demand and its intended strategic posturing from its input orders. While not all suppliers care about this information, we show that the fact that such information is on the horizon means a firm may prefer to buy from an input supplier who has "skin in the game" via a presence in the output market.

By conveying information on its profitability to its supplier through its purchasing decisions, a firm can soften competition with its supplier's output market arm. And, by conveying information about its output market quantity choices through its input orders, a firm can gain a first-mover advantage of sorts over its supplier (and even other rivals). Both effects point to a strategic role of outsourcing, one rooted in information conveyance and supportive of procurement from rivals. Admittedly, this point was made in a model that excludes other traditional considerations in the make-or-buy choice (e.g., low balling, investment incentives, quality concerns etc.) to highlight the novelty of the result. Future work could layer in these other factors to better parse the critical features that promote outsourcing as well as the determinants of who to outsource from and when to initiate outsourcing.

APPENDIX

Proof of Proposition 1. If firm 0 opts to make, the firms engage in Cournot competition, with only firm 0 being able to condition its quantity on s, its private information. In particular, given observation s, and Cournot conjecture of firm i's quantity, denoted $\tilde{q}_i,\ i \in N$, firm 0 chooses quantity to maximize its profit in (1). Since $E_{\delta|s}\{\delta\} = s$, the first-order condition of (1) yields:

$$q_0(\tilde{q}_i, i \in N; s) = \frac{1}{2}\left[a + s - k \sum_{i \in N} \tilde{q}_i\right]. \tag{A1}$$

Similarly, given firm i's, $i \in N$, conjecture of the quantities of its rivals, denoted $\tilde{q}_0(s)$ and $\tilde{q}_j,\ j \in N_{-i}$, firm i solves (2). The first-order condition of (1) yields:

$$q_i(\tilde{q}_0(s), \tilde{q}_j, j \in N_{-i}) = \frac{1}{2}\left[a - kE_s\left\{\tilde{q}_0(s)\right\} - k \sum_{j \in N_{-i}} \tilde{q}_j\right],\ i \in N. \tag{A2}$$

Jointly solving the $n+1$ linear equations in (A1) and (A2), along with the $n+1$ equilibrium conditions, $q_0(s) = \tilde{q}_0(s)$ and $q_i = \tilde{q}_i,\ i \in N$, yields the quantities in (A3), where the superscript "M" denotes the make regime:

$$q_0^M(s) = \frac{a}{2+kn} + \frac{s}{2} \quad \text{and} \quad q_i^M = \frac{a}{2+kn},\ i \in N. \tag{A3}$$

Since $E\{s\} = 0$ and $E\{s^2\} = E\left\{\left(\sum_{i=1}^{t} \delta^i\right)^2\right\} = \sum_{i=1}^{t} E\left\{(\delta^i)^2\right\} = t\sigma^2 / T = \omega\sigma^2$, substituting (A3) into (1), and taking expectation with respect to s, yields Π_0^M, expected profit of firm 0; using (A3) in (2) yields $\Pi_i^M,\ i \in N$, expected profit of firm i:

$$\Pi_0^M = \left[\frac{a}{2+kn}\right]^2 + \frac{\omega\sigma^2}{4} \quad \text{and} \quad \Pi_i^M = \left[\frac{a}{2+kn}\right]^2,\ i \in N. \tag{A4}$$

This completes the proof of Proposition 1. ■

Proof of Proposition 2. If firm 0 opts to buy from its rival, firm R, its placement of order puts it in the position of a Stackelberg leader vis-a-vis R. Thus, in this case, we begin with the quantity choice of R. Given wholesale price w, order $q_0(s)$ from firm 0, and conjecture $\tilde{q}_j$ of the quantity of firm j, $j \in N_{-R}$, firm *R* chooses quantity to solve (4). The first-order condition of (4) yields:

$$q_R(q_0(s), \tilde{q}_j, j \in N_{-R}) = \frac{1}{2}\left[a - kq_0(s) - k \sum_{j \in N_{-R}} \tilde{q}_j\right]. \tag{A5}$$

Anticipating the response in (A5), and given wholesale price *w* and conjecture $\tilde{q}_j$ for firm j's quantity, $j \in N_{-R}$, firm 0 solves (6). The first-order condition of (6) yields:

$$q_0(w, \tilde{q}_j, j \in N_{-R}; s) = \frac{a[2-k] - 2w - [2-k]k \sum_{j \in N_{-R}} \tilde{q}_j}{2[2-k^2]} + \frac{s}{2-k^2}. \tag{A6}$$

Finally, firm *i*, given its conjectures $\tilde{q}_0(s)$ and $\tilde{q}_j$, $j \in N_{-\{R,i\}}$, and the response in (A5), chooses its quantity to solve (7). The first-order conditions of (7) is as follows:

$$q_i(\tilde{q}_0(s), \tilde{q}_j, j \in N_{-\{R,i\}}) =$$
$$\frac{1}{2}\left[a - kE_s\left\{\tilde{q}_0(s)\right\} - kE_s\left\{q_R(\tilde{q}_0(s), \tilde{q}_j, j \in N_{-R})\right\} - k \sum_{j \in N_{-\{R,i\}}} \tilde{q}_j\right],\ i \in N_{-R}. \tag{A7}$$

Jointly solving the first-order conditions in (A5), (A6), and (A7), along with the equilibrium conditions, $q_0(s) = \tilde{q}_0(s)$, $q_i = \tilde{q}_i$, $i \in N_{-R}$, yields the quantities in (A8), where the superscript "*B*" denotes buying from the rival firm *R*:

$$q_0^B(w;s) = \frac{2[(a-w)(2-k) - knw]}{8 + k[4-k^2][n-1] - 2k^2[n+1]} + \frac{s}{2-k^2};$$

$$q_R^B(w;s) = \frac{a[4-2k-k^2] + 2kw}{8 + k[4-k^2][n-1] - 2k^2[n+1]} - \frac{sk}{2[2-k^2]};\ \text{and}$$

$$q_i^B(w) = \frac{a[4-2k-k^2] + 2kw}{8 + k[4-k^2][n-1] - 2k^2[n+1]},\ i \in N_{-R}. \tag{A8}$$

Substituting (A8) in (4) and (6), and taking expectation with respect to *s*, yields $\Pi_0^B(w)$ and $\Pi_R^B(w)$, expected profit of firm 0 and firm *R* in the buy regime:

$$\Pi_0^B(w) = 2\left(2-k^2\right)\left(\frac{[(a-w)(2-k) - knw]}{8 + k[4-k^2][n-1] - 2k^2[n+1]}\right)^2 + \frac{\omega\sigma^2}{2[2-k^2]};\ \text{and}$$

$$\Pi_R^B(w) = \left(\frac{a[4-2k-k^2] + 2kw}{8 + k[4-k^2][n-1] - 2k^2[n+1]}\right)^2 +$$

$$\frac{2w[(a-w)(2-k)-knw]}{8+k[4-k^2][n-1]-2k^2[n+1]}+\frac{\omega\sigma^2k^2}{4[2-k^2]^2}. \tag{A9}$$

This completes the proof of Proposition 2. ■

Proof of the Lemma. Suppose firm 0 is induced to buy from firm R. In this case, the wholesale price is firm R's preferred price (denoted $\tilde{w}$) assuming firm 0 is willing to procure at this price rather than make inputs. However, if $\tilde{w}$ is excessive in that firm 0 prefers to make, then firm R is restricted to charging the maximum price firm 0 is willing to pay (denoted $\overline{w}$). In other words, $w^* = Min\{\tilde{w},\overline{w}\}$.

The wholesale price $\tilde{w}$ is the w-value that maximizes $\Pi_R^B(w)$ in (A9). The first-order condition of (A9) yields:

$$\tilde{w}=\frac{a[16-2k^2(4n-k+2)+k(8+k^3)(n-1)]}{2[16+16k(n-1)-k^4(n-1)^2-2k^2(1+6n-2n^2)-2k^3(n^2+n-2)]}. \tag{A10}$$

Using (A4) and (A9), the wholesale price $\overline{w}$ is the w-value that solves $\Pi_0^B(w)-\Pi_0^M=0$. Thus, $\overline{w}$ equals:

$$\overline{w}=\frac{a[2-k]}{2+k[n-1]}-\frac{[(2-k)^2(2+k)+kn(4-k(2+k))]\sqrt{4a^2(2-k^2)-k^2(2+kn)^2\omega\sigma^2}}{2\sqrt{2}[2-k^2][2+k(n-1)][2+kn]}. \tag{A11}$$

This completes the proof of the Lemma. ■

Proof of Proposition 3. From $w^* = Min\{\tilde{w},\overline{w}\}$, (A4), and (A9), Π_R^M is free of σ^2 while $\Pi_R^B(w^*)$ is increasing in σ^2. Thus, there exists a variance cut-off, $\hat{\sigma}^2$, above which firm R induces firm 0 to buy and, below which, firm 0 is induced to make. For now, assume that at $\sigma^2=\hat{\sigma}^2$, $w^* = Min\{\tilde{w},\overline{w}\}=\overline{w}$, a claim we will confirm subsequently. Using (A4) and (A9), firm 0 is induced to buy by firm R if and only if:

$$\Pi_R^B(\overline{w})-\Pi_R^M \geq 0 \Leftrightarrow \sigma^2 \geq \frac{2a^2[4-2k^2-A^2(k,n)]}{k^2[2+kn]^2\omega}, \text{ where}$$

$$A(k,n)=\frac{[2-k^2][4+k(-6-k(n-1)+2n)][2+kn]+[2+k(n-1)]\sqrt{B(k,n)}}{20-k[20+k-4k^2+k^3-2(2-k)(5-k-k^2)n-k(5-k(2+k))n^2]} \text{ and}$$

$$B(k,n) = [2-k^2][72 - k(24 - 72n + k(22 + 2k(4-k)(2-k^2) + 36n + 4k(5-k^3)n + (-18 + k(12 + (2-k)^2 k))n^2))]. \tag{A12}$$

From (A12), if $4 - 2k^2 - A^2(k,n) < 0$, then $\Pi_R^B(\overline{w}) - \Pi_R^M > 0$ for all $\sigma^2 \geq 0$. Thus, the equilibrium outcome entails firm 0 buying the input if and only if:

$$\sigma^2 \geq \hat{\sigma}^2 = Max\left\{\frac{2a^2[4 - 2k^2 - A^2(k,n)]}{k^2[2+kn]^2\omega}, 0\right\}. \tag{A13}$$

Finally, from (A10) and (A11), note that $\tilde{w} - \overline{w}$ is decreasing in σ^2. Some tedious algebra verifies that $\tilde{w} - \overline{w}\big|_{\sigma^2=0} > 0$ and $\tilde{w} - \overline{w}\big|_{\sigma^2 = \frac{2a^2[4-2k^2-A^2(k,n)]}{k^2[2+kn]^2\omega}} > 0$. That is, $\tilde{w} - \overline{w} > 0$ at $\sigma^2 = \hat{\sigma}^2$ verifying our initial claim that $w^* = Min\{\tilde{w}, \overline{w}\} = \overline{w}$ at the variance cutoff. This completes the proof of Proposition 3. ■

Proof of Proposition 4. (i) Using (A13), the proof follows from the fact that $\frac{d\hat{\sigma}^2}{dn} < 0$ for $\hat{\sigma}^2 > 0$. (ii) From (A13), $\hat{\sigma}^2 = 0$ if and only if $4 - 2k^2 - A^2(k,n) \leq 0$. Using the expression for $A(k,n)$ noted in (A12):

$$\hat{\sigma}^2 = 0 \Leftrightarrow 4 - 2k^2 - A^2(k,n) \leq 0 \Leftrightarrow n \geq \hat{n}(k), \text{ where}$$

$$\hat{n}(k) = \frac{\sqrt{4-2k^2} - 2[1-k]}{2k} + \frac{\sqrt{[4+k][4-3k]\left[4 - k^2 - 2\sqrt{4-2k^2}\right]}}{\sqrt{2}\left[(2-k)\sqrt{4-2k^2} + k(2+k) - 4\right]}. \tag{A14}$$

This completes the proof of Proposition 4. ■

Proof of Proposition 5. Using (A13), the proof of part (i) follows from the fact that $\frac{d\hat{\sigma}^2}{d\omega} < 0$ for $\hat{\sigma}^2 > 0$. Part (ii) follows from ranking the derivative of (A4) and (A9) (evaluated at $w = w^*$), with respect to ω as follows:

$$\frac{d\Pi_0^M}{d\omega} = \frac{\sigma^2}{4} = \frac{d\Pi_0^B(\overline{w})}{d\omega} < \frac{d\Pi_0^B(\tilde{w})}{d\omega} = \frac{\sigma^2}{2[2-k^2]}. \tag{A15}$$

Thus, $\frac{d\Pi_0^M}{d\omega} \leq \frac{d\Pi_0^B(w^*)}{d\omega}$, with the inequality strict when $w^* = \tilde{w}$ (or, alternatively, when σ^2 is sufficiently large). This completes the proof of Proposition 5. ■

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