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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 becomes 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 both profitability information and strategic positioning. *Conveying profitability information* 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. *Conveying strategic positioning* refers to the fact that the upfront placement of the input order also informs the supplier about the firm's chosen strategic choices 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.

Keywords: *competition*; *information conveyance*; *make-versus-buy*; *supply chains*.

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I. INTRODUCTION

The make-or-buy choice is typically viewed as one that compares 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, Sivaramakrishnan, and Sprinkle 2009; Horngren, Datar, and Rajan 2009). This paper demonstrates a more nuanced role for accounting information in the make-or-buy decision: not only can production cost estimates affect the make-or-buy choice, but so can revenue estimates. In particular, when a firm's accounting system provides relevant information about the demand for its products, the 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 that is also a downstream rival than when it establishes its own input production capacity.

Information conveyance associated with outsourcing has both profitability and strategic positioning components, each of which plays a crucial role in the firm's initial procurement choice. Profitability information conveyance refers to the fact that the size of the firm's order to 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. Conveyance of strategic positioning refers to the fact that the firm's order with its supplier also reveals its strategic choices in the output market.

While the information conveyance effects of order quantities are innocuous when the supplier is an uninterested observer of output market proceedings, this is not the case with a supplier that also has a stake in the output market. As a result, a firm may rely on an output market rival for inputs rather than on its own production capacity, 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 as follows. First, with respect to conveying profitability information, 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 its competitive response on the demand information. When the firm's demand and its input order are high, the rival backs away in competition; when the firm faces low demand and places a smaller input order, the rival competes more aggressively. The net result is that the average level of competition is lower. The rival cedes power when the firm is more profitable and the firm cedes power when it is less profitable.

Second, with respect to conveying strategic positioning, 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: (1) only one of the firm's rivals, the input supplier, knows the quantity; and (2) as the supplier, the rival must willingly hand over this first-move advantage. In terms of (1), the first-mover advantage would seemingly only affect the rival from whom the firm purchases. Consistent with this, the more rivals the firm faces, the more muted is its first-mover advantage. However, the remaining rivals recognize the firm's advantage over one of them and anticipate the firm's 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 (2). Although the firm exploits the first-mover advantage, the rival can also benefit from being the late mover. The 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 disadvantage from being a late mover is spread among all rivals. As a result, under such circumstances, the rival will be willing 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 in which not only the firm is a willing buyer, but also the rival is a willing supplier. As discussed above, conveying profitability information 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 demand uncertainty and more precise internal accounting each point toward increased outsourcing. Further, conveying strategic positioning becomes more likely when a firm faces several rivals. Consistent with this, we demonstrate that the firm opts to outsource when the output market is sufficiently competitive.

The result that a firm may outsource to its own competitor for strategic reasons is more than just a modeling novelty. Firms frequently rely on competitors for inputs, including the aircraft, automobile, computer, glass, household appliances, telecommunications, and trucking industries (e.g., Arrunada and Vazquez 2006; Baake, Oechssler, and Schenk 1999; Chen, Dubey, and Sen 2011; Spiegel 1993). Significant recent examples include Apple buying chips for the iPhone and iPad from a key rival, Samsung; Dell and HP using Microsoft operating systems for their tablets while facing competition from Microsoft's own Surface tablet; Ferrari agreeing to supply engines for Maserati and Alfa Romeo cars; and Olympus and Nikon relying on Sony for key sensors in their latest cameras. These high-profile examples represent circumstances in which brand-specific demand is highly uncertain and firms have diligently sought means of gathering market data. Our results suggest that buying inputs from rivals will be associated with markets characterized by more volatile demand and/or greater competition as well as with purchasing firms that have more precise internal accounting data. 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.

Two key features concerning the implications for accounting precision are noteworthy. First, the results not only indicate that greater accounting precision favors buying inputs from rivals, but also 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 prominent feature 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, Glenn, and Sedatole 2000; Demski 1997), institutional pressures to keep particular inputs in-house (Balakrishnan, Eldenburg, Krishnan, and Soderstrom 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). The corresponding 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, Mittendorf, and Sappington 2008; Baake et al. 1999; Buehler and Haucap 2006; Shy and Stenbacka 2003; Spiegel 1993).

We exclude such additional reasons for outsourcing to highlight the novel role played by information. In particular, the desire to convey both profitability information and strategic positioning to a rival may point to outsourcing even when the outsourced price exceeds the cost of making the input internally. The desire to convey firm-specific profitability information is consistent with the notion that, depending on the type and behavior of the uncertain information, a firm may wish to disclose information to competitors (Darrough 1993; Bagnoli and Watts 2011). Such findings also necessitate discussion of whether the information can be credibly communicated without a costly audit (Newman and Sansing 1993; Gigler 1994; Stocken 2000; Fischer and Stocken 2002; Bagnoli and Watts 2010). 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), who note that quantity pre-orders can promote a first-mover Stackelberg advantage. In their setting with no uncertainty and a simple duopoly, however, the potential strategic effects lead a supplier to withhold inputs from its retail competitor, forcing the competitor 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. The reversal of results relative to Chen et al. (2011) arises from uncertainty and/or multiple retail rivals accentuating the mutual benefits of outsourcing. With multiple rivals, the leadership gained by the outsourcing firm is less than a full Stackelberg advantage, but it is nonetheless important in adding to the firm's aggressiveness. Because the supplying rival shares the follower costs with other rivals but is the sole beneficiary of the corresponding wholesale gains, the supplying rival is a willing participant in the process.

II. MODEL

A firm, denoted firm 0, must either make or buy a critical input that has uncertain value in the (retail) output market. The firm from which it can buy the input, denoted R, is also a retail rival. To eliminate standard reasons to make-versus-buy inputs, we assume each party can produce the input at the same unit cost, which we normalize to zero. Denoting the per-unit wholesale input 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.

Subsequent to its procurement choice, firm 0 faces Cournot competition in the retail market. Aside from firm R, there are also other retail competitors with costs also normalized to zero such that 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 $p_i = a - q_i - k[\sum_{j \in N_{-i}} q_j + q_0]$. 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. Throughout the analysis we assume a is sufficiently large to ensure nonnegative quantities and prices.

We focus 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, let firm 0's uncertain demand component have mean zero with variance σ^2, and be comprised of T elements, where $\delta = \sum_{i=1}^{T} \delta^i$, and each δ^i is an *iid* mean-zero noise term with variance σ^2/T. Prior to retail competition, firm 0's accounting system reveals $t \leq T$ components of δ. Without loss of generality, the information revealed by the system is captured by the signal $s = \sum_{i=1}^{t} \delta^i$. As a predictor of profitability, the accounting signal may reflect information pertinent to inherent customer demand and/or the relative cost of selling outputs. As examples, the signal could be an accounting of profits in test markets or limited product rollouts, budget forecasts from sales staff, or even past segment-level sales indicating the consumer preferences of different geographic areas.

FIGURE 1
Timeline

The rival R sets its input price, w.	Firm 0 chooses whether to outsource to its rival or rely on internal production capability.	Firm 0 observes s.	If firm 0 chose to buy from R, it places an order of q_0 units to sell on the retail market.	Retail quantities are determined, retail demand is satisfied, and profits are realized.

The informativeness of the signal provided by the accounting system is reflected by $\omega = t/T$, where $\omega = 0$ reflects an uninformative system and $\omega = 1$ reflects a perfect signal.

We examine subgame perfect equilibria by working backward in the game to determine outcomes. The timeline of events for the setting is summarized in Figure 1. In the timeline, it is presumed that firm 0's make-or-buy decision is made prior to its observing s. This reflects the practical consideration that a decision to make often entails substantial "set up" time. However, since the information is about product demand that is realized regardless of the sourcing choice, it is also without loss of generality even absent any set-up requirements (more on this later).

III. RESULTS

To determine firm 0's sourcing choice, we derive the subgame equilibrium in each case. The equilibrium sourcing decision requires comparing the maximum amount firm 0 is willing to pay versus the price at which firm R is willing to sell. We begin with the outcome when firm 0 installs capacity to produce inputs internally.

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. 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):

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

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), where conjectures are correct in equilibrium leads to Proposition 1 in which the superscript "M" denotes the make regime. (Proofs are in Appendix A.)

Proposition 1: When firm 0 opts to make, the equilibrium entails:

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

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

The proposition reflects the standard Cournot quantities adjusted for firm 0's private information. Each firm chooses a baseline quantity of $\frac{a}{2+kn}$, reflecting that greater demand (a) and/or lower competitive intensity (k or n) each lead a firm to produce more. Firm 0 conditions its production on its own demand, as reflected in $s/2$; competitors rely on their conjecture of firm 0's demand, where $E_s\{s\} = 0$. 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:

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

The expression in (3) indicates that greater precision (ω) stands to benefit the firm because the firm's demand signal enables it 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 its cost of zero, making is preferred to seeking out an independent supplier. We next consider buying from a rival.

Equilibrium when Buying

When buying from a rival in the output market, firm 0's problem is similar except that now its procurement order reveals its competitive positioning to its rival. In turn, the rival (R) can condition its production choice on firm 0's input order size. Given its 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:

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

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

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

From (5), a greater order from firm 0 translates into a softened stance by R, i.e.:

$$\partial q_R\left(q_0(s),\; \tilde{q}_j,\; j \in N_{-R}\right)/\partial q_0(s) = -k/2 < 0.$$

This feature reflects the consequence of information conveyed about strategic positioning by firm 0's purchase. A higher quantity purchased by firm 0 reduces R's marginal revenues and thus its output. 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:

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

The problem in (6) differs from (1) in that (i) firm 0 pays to outsource the input, and (ii) by the strategic information conveyance effect q_R is now a strategic response function rather than a conjecture. In effect, by placing its input order up-front, firm 0 enjoys a pseudo-Stackelberg position in which its quantity choice will change R's response, now the *de facto* late mover. The term pseudo-Stackelberg reflects the fact that the order only informs R, not the remaining competitors. However, the other rivals realize that firm 0 holds a leader position over R. 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, firm i, $i\in N_{-R}$ chooses its quantity to solve:

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

The second informational consequence of purchasing from R is that R becomes aware of $q_0(s)$, and 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) together with the condition that all conjectures are correct in equilibrium yields the equilibrium in Proposition 2.

Proposition 2: When firm 0 opts to buy, the equilibrium entails:

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

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

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

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

The second critical feature, conveying profitability information, is reflected in the fact that R's quantity is now implicitly a function of s. For the present case, $q_R^B(0;s)=a/4-s/2$, reflecting that when firm 0's information indicates it is more (less) profitable, R becomes less (more) aggressive in competition. At the same time, the information also has strategic repercussions. Since firm 0 can convince R to compete less aggressively 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 also has an important strategic consequence.

The third key feature is that when there is more than one rival, not only are firms 0 and R affected by the procurement choice, but so are the other rivals. That is, firm 0's buying gives itself a pseudo-Stackelberg advantage—only one firm is aware of its quantity, yet all are 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 are also followers. 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, $E_s\{q_R^B(w;s)\} = q_i^B(w),\ \ i \in N_{-R}$.

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 quantity is $E_s\{q_0^B(0;s)\} - \frac{a[1+n]}{6+5n+n^2}$, which is clearly less than $E_s\{q_0^B(0;s)\}$. At the same time, firm 0's strength that accompanies buying is not as strong as Stackelberg leadership because only one rival directly observes the firm's chosen quantities. Consistent with this, a pure Stackelberg equilibrium yields expected firm 0 quantities of $E_s\{q_0^B(0;s)\} + \frac{a[n-1]}{2[3+n]} > E_s\{q_0^B(0;s)\}$ for all $n > 1$. Buying from a rival provides a clear leadership advantage for firm 0 but less than the full Stackelberg advantage.

The above three features together form the basis for determining the equilibrium procurement option. Using the outcomes in Proposition 2 in the profit expressions of firms 0 and R and taking expectations yields the expected profits in (8):

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

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

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

The Decision to Buy from a Rival

The previous analysis describes how buying from a rival conveys both profitability information and strategic positioning. For the strategic positioning effect, the first-mover advantage outsourcing provided to firm 0 has clear benefits for the firm. The profitability information effect also favors outsourcing. With profitability information conveyance, when the firm's demand is high, buying substantial quantities of inputs convinces its rival to reduce its own quantities; conversely, when the firm's demand is low, 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 and profit potential are greatest. Both information effects together translate into firm 0's willingness to pay for inputs from its rival at prices above its own cost. In particular, comparing Π_0^M and $\Pi_0^B(w)$, firm 0 is willing to pay up to $\bar{w} > 0$ to buy, where:

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

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 firm 0 to be a nontrivial participant in the output market since R gleans input market profit from firm 0. If w is too high, then

R risks gaining substantial retail power, but forgoing too much wholesale profit in the process. To balance retail and wholesale profits, R's preferred input price is interior even if buying is guaranteed. In particular, setting $\partial \Pi_R^B(w)/\partial w = 0$ reveals R's preferred price is $\tilde{w}$, where:

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

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 $\bar{w}$ to buy from R. If R wants to sell to firm 0, it must charge no more than $\bar{w}$ but it can charge less, so if $\tilde{w} < \bar{w}$, R would charge $\tilde{w}$, as summarized in the Lemma.

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

We now consider when R would choose a price to entice firm 0 into buying versus letting firm 0 make its inputs. Although firm 0 would buy at zero cost since doing so gives it a first-mover advantage over R, R would not be interested in choosing $w = 0$. To get a feel for when the premium that firm 0 is willing to pay is sufficient for R to willingly cede competitive advantage, consider the limiting case of $\sigma^2 = 0$ and $n = 1$. For $\sigma^2 = 0$, profitability information conveyance is absent. With $n = 1$, R bears the entire downside of strategic information conveyance, bearing the brunt of late-mover status. Further, $w^* = \bar{w}$, i.e., R's preferred price is more than the maximum firm 0 is willing to pay. The benefit to R of selling at $w^* = \bar{w} > 0$ is that it gains non-zero wholesale (input) profit; the downside is the loss of retail (output) profit. Comparing $\Pi_R^B(\bar{w})$ 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 to entice firm 0 to produce itself (make) in equilibrium. This limiting case is consistent with Chen et al. (2011), who note 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: profitability information conveyance and strategic positioning conveyance effects on other rivals. Each of these effects is critical in establishing equilibrium outsourcing to a rival. Assuming $\sigma^2 > 0$ introduces the possibility of conveying relevant profitability information. As discussed before, the potential for profitability information conveyance makes buying from a rival more attractive for firm 0, which is reflected in its willingness to pay: $\partial \bar{w}/\partial \sigma^2 \geq 0$. This increased willingness of firm 0 to pay makes it more likely that R will be willing to sell. Firm 0 benefits from profitability information conveyance because it reduces competition and gives firm 0 an edge precisely when it is most profitable. Similarly, 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 information conveyance increase firm 0's willingness to pay, but it also reduces the price R would require 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 $\sigma^2 \geq \hat{\sigma}^2$.

From Proposition 3, the intuition developed above for the case of $n = 1$ also applies for all n. Further, when $n > 1$ information conveyance about strategic positioning becomes more prominent. Strategic information conveyance under outsourcing also has repercussions for rivals not providing inputs to firm 0. Recall, from R's perspective, the late-mover status it takes on when selling is costly. Although firm 0 will pay more to be a leader, when $n = 1$ it is alone not enough to justify the distinct disadvantage of the seller effectively moving last. However for $n > 1$, due to the added subtle effect on other rivals, the late-mover status can actually be worthwhile.

Although 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 also acting as *de facto* late movers. 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 R alone gains the advantage of firm 0's increased willingness to pay. As a result, the more rivals are available 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)). Further, as long as competition is sufficiently intense (greater n), buying from a rival can be preferred even absent any profitability information conveyance. 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 illustrates the joint presence of the profitability information and strategic positioning effects. Panel A plots the equilibrium make-versus-buy choice as a function of σ^2, the profitability information 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 case of $\sigma^2 = 0$ and plotting the make-versus-buy choice as a function of k and n.

Given the information effects of buying from a rival, we now consider the implications for the firm's accounting system. First, how does the precision of the accounting system affect the make-versus-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, depend on the precision of the accounting system. Since greater information conveyance favors buying from a rival, a more precise accounting system does the same as well (Proposition 5(i)).

Next, we reverse the causality to allow the make-versus-buy decision to affect the firm's accounting system by allowing the precision of the accounting system to be 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 advantage also comes into play. More accounting precision means the firm's input order conveys more information, and thereby reduces the expected competitive pressures. As a result, Proposition 5 establishes that the decision to buy inputs from a rival encourages a firm to undertake investments for better (more precise) internal accounting.

Proposition 5:

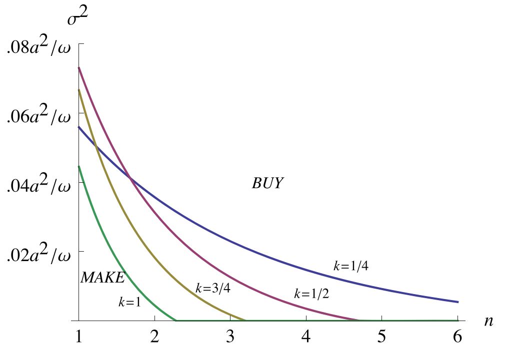
(i) A more precise accounting system promotes buying from a rival, i.e., $\hat{\sigma}^2$ is decreasing in ω.

(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.

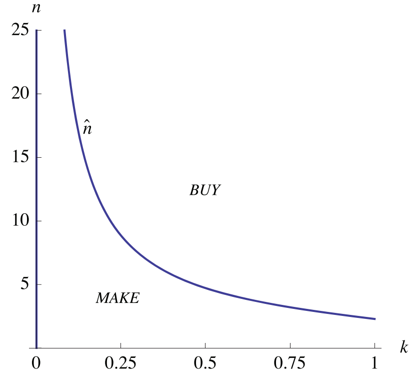
Proposition 5 highlights the interaction between accounting and operational choices. Further, the proposition lends itself to a natural empirical test of the prediction that firms with better (weaker) internal accounting are more (less) likely to rely on outsourcing of inputs. The proof shows that not 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). The critical feature driving these connections is not that the accounting information is about demand, but that it

FIGURE 2
Equilibrium Make versus Buy Choice

Panel A: Choice as σ^2 and n Vary



Panel B: Choice for $\sigma^2 = 0$ and n and k Vary



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.

Discussion

This section discusses model variants to reflect various practical considerations. 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

Our 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 that do not reap benefits from selling to firm 0 but have to realize some of the costs. This suggests the other rivals may compete in the input selling business. This possibility does not change the equilibrium procurement choices, but firm 0's added bargaining power may increase its profits. 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 firm. 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-versus-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 that buy from rivals often do so in the form of exclusive dealing arrangements, as in the Ferrari, Samsung, and Microsoft examples noted earlier, 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-versus-single sourcing would affect the issues in our setting, consider the possibility of buying nontrivial amounts from each rival. If such a buying arrangement were in place, the benefits of conveying profitability information by buying can become more pronounced because the information conveyed by purchases is conveyed to a larger set of rivals. On the other hand, multiple sourcing threatens to undermine strategic positioning benefits of buying, because each supplier learns only a lower bound of firm 0's output quantity, i.e., the amount it sells to firm 0. This means that the first-mover advantage from placing an order with a rival beyond 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. Multiple sourcing heightens the profitability information conveyance 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 as in grocery stores.

To best capture the realm of possible costs and benefits of retaining inventory, let the cost of producing each input be $c \geq 0$, the cost of carrying a unit forward in inventory be $h \geq 0$, and the value of an item held in inventory, reflecting the present value of future sale, salvage, etc., be $\lambda \geq 0$. Given the natural condition $w > \lambda - h$, in equilibrium the firm does not intentionally carry inventory. Although this does not guarantee the same outcome as in the one-shot game, the buyer's potential aggressiveness associated with outsourcing still persists.

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 when producing internally at cost 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 but 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, although the precise equilibria may differ, the benefits of buying from a rival due to both strategic and profitability information conveyance effects persist.

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 must decide up front whether to make internally or buy externally. This presumption reflects the need for firms using their own production capability to generate this capacity before actually producing. That is, our setting reflects the inherent lead time associated with the make-or-buy decision. Because the demand information that later arrives 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 fundamentally distinct from the arrival of cost or quality information that can provide guidance to the firm about which input source is better.

The presumed pre-commitment to sourcing is not consequential because even if firm 0 could make a last-minute change to either make or buy inputs, the equilibrium identified would persist. First, in the case in which the firm opts to buy, if firm 0 observed unusually low demand and reconsidered the choice of conveying such information through its purchase order, the 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-versus-buy choice, the results are unaffected even when the presumption is dropped.

Observing the Procurement Decision

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, as in previous examples involving Apple, Dell, and Ferrari. The presumption also naturally fits the model, because firm 0 has a clear incentive to inform its rivals of its sourcing choice, since doing so magnifies its leadership advantage and R's ability to disagree with such claims provides a natural veracity check. Even if firm 0 were unable to credibly convey its sourcing choice to others, the key forces at work are muted but not eliminated. Because the profitability 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 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, the presumed observability of the procurement choice is again not critical to the insights.

IV. 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 is rooted in the desire to develop accurate in-house production cost estimates to compare to external prices. The information age, which has brought about a more nuanced and strategic role of accounting in most firm decisions, can also enrich how we view the simple textbook explanations of the role of accounting in make-or-buy decisions.

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 can also influence the decision of whether to outsource, even when the demand itself is not affected by the sourcing decision.

This result reflects the fact 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 positioning 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 that a firm may prefer to buy from an input supplier that 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. Further, 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 as well as 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, including 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 whom to outsource from and when to initiate outsourcing.

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APPENDIX A

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 (2) yields:

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

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:

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

Since $E\{s\} = 0$ and:

$$E\{s^2\} = E\left\{\left(\sum_{i=1}^{t} \delta^i\right)^2\right\} = \sum_{i=1}^{t} E\left\{\left(\delta^i\right)^2\right\} = t\sigma^2/T = \omega\sigma^2,$$

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 Π_i^M, $i \in N$, expected profit of firm i:

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

This completes the proof of Proposition 1. ■

Proof of Proposition 2

If firm 0 opts to buy from its rival, firm R, its order placement puts it in the position of a Stackelberg leader *vis-à-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:

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

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) are as follows:

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

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:

$$\begin{aligned} q_0^B(w;s) &= \frac{2[(a-w)(2-k) - knw]}{8 + k[4-k^2][n-1] - 2k^2[n+1]} + \frac{s}{2-k^2} \\ q_R^B(w;s) &= \frac{a[4-2k-k^2] + 2kw}{8 + k[4-k^2][n-1] - 2k^2[n+1]} - \frac{sk}{2[2-k^2]}; \text{ and} \\ q_i^B(w) &= \frac{a[4-2k-k^2] + 2kw}{8 + k[4-k^2][n-1] - 2k^2[n+1]}, \ \ i \in N_{-R}. \end{aligned} \tag{A8}$$

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:

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

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

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 $\bar{w}$). In other words, $w^* = Min\{\tilde{w}, \bar{w}\}$.

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 $\bar{w}$ is the w-value that solves $\Pi_0^B(w) - \Pi_0^M = 0$. Thus, $\bar{w}$ equals:

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

This completes the proof of the Lemma. ■

Proof of Proposition 3

From $w^* = Min\{\tilde{w}, \bar{w}\}$, (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 $\sigma^2 = \hat{\sigma}^2$, $w^* = Min\{\tilde{w}, \bar{w}\} = \bar{w}$, a claim we will confirm subsequently. Using (A4) and (A9), firm 0 is induced to buy by firm R if and only if:

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

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

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

From (A12), if $4 - 2k^2 - A^2(k,n) < 0$, then $\Pi_R^B(\bar{w}) - \Pi_R^M > 0$ 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 $\tilde{w}-\bar{w}$ is decreasing in σ^2. Some tedious algebra verifies that $\tilde{w}-\bar{w}|_{\sigma^2=0}>0$ and $\tilde{w}-\bar{w}|_{\sigma^2=\frac{2a^2[4-2k^2-A^2(k,n)]}{k^2[2+kn]^2\omega}}>0$. That is, $\tilde{w}-\bar{w}>0$ at $\sigma^2=\hat{\sigma}^2$ verifying our initial claim that $w^*=Min\{\tilde{w},\bar{w}\}=\bar{w}$ 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):

$$\hat{\sigma}^2=0 \Leftrightarrow 4-2k^2-A^2(k,n)\leq 0 \Leftrightarrow n\geq \hat{n}(k), \text{ where}$$
$$\hat{n}(k)=\frac{\sqrt{4-2k^2}-2[1-k]}{2k}+\frac{\sqrt{[4+k][4-3k][4-k^2-2\sqrt{4-2k^2}]}}{\sqrt{2}[(2-k)\sqrt{4-2k^2}+k(2+k)-4]}. \tag{A14}$$

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:

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

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. ∎