Cost Uncertainty is Bliss:
The Effect of Competition on the Acquisition of
Cost Information
for Pricing New Products

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Abstract  
For competing firms, we examine the optimal acquisition of information about a common uncertain cost factor to price a new product and the implications of this acquisition for different parties. We show that findings for the acquisition of demand information or the acquisition of either cost or demand information for quantity decisions do not extend to this case. For cost information with price competition, the acquisition strategies are strategic substitutes even though the price decisions that are based on the information are strategic complements. Moreover, when the cost of information is low, identical firms acquire different amounts of cost information. Even when information is free, only one firm acquires perfect cost information. In fact, firms should accept (some) cost uncertainty because it acts like a ‘fog’ that lessens the destructive effect of price competition when products are close substitutes. Conversely, buyers have an incentive to help firms obtain better cost estimates because expected customer surplus is highest when competing firms are informed about their cost. Even though the expected value of cost information strictly decreases with competition, the optimal price for industry-specific cost information set by an information vendor increases with competition when the firms’ products are sufficiently substitutable.  

(Pricing, Cost Uncertainty, New Product Marketing, Information Acquisition, Information Pricing, Game Theory)
1. Introduction

New products and services must often be priced before they have been produced or even developed. For example, when in 2000 Airbus announced the ‘launch’ of the A380, a new aircraft that will seat 550 or more passengers, it had not yet built a production facility. Yet, Airbus needed to set a price to market the A380 to airlines for delivery starting in 2006.¹ In its bid to Amtrak to build a new high-speed train for the ‘North East Corridor’ in the US – the Acela Express – Bombardier included a ten-year service and maintenance guarantee for all delivered trains.² Components suppliers to OEMs like automobile manufacturers are often required to give price guarantees even when components have to be developed first. In all these cases, firms face substantial cost uncertainty when pricing a new product or service and need information to deal with this uncertainty. Interestingly, Bombardier did not assess in detail the cost implications of its service offer despite strong competition from Siemens and ABB while Airbus, which faced limited competition from Boeing’s 747X, invested heavily to more accurately estimate production cost. How much cost information should firms acquire and how does competition affect this decision?

A growing literature examines the acquisition of information for different conditions. However, existing studies focus primarily on the acquisition of demand information for quantity competition (e.g., Li et al. 1987; Hwang 1993, 1995). In this case, competition decreases the acquisition of information. This result also holds for cost information (Vives 1999).³ With price competition, the acquisition of demand information increases with competition (Raju and Roy 2000; Sasaki 2001) but the acquisition of cost information has not been fully analyzed (Vives 1999).

The objective of this paper is to close this gap in the literature and analyze the optimal acquisition of information about industry-specific (i.e., common) uncertain cost factors. Sasaki (1997) argues that the strategic interaction of information acquisition strategies follows the strategic interaction of the actions

¹ The “list” price for the A380 is about $230 million, but significant discounts were offered for launch orders. According to analysts, the production cost of the A380 is likely between $150 and $200 million (“Airbus A3XX: The Business Case for the Double Decker,” Dresdner, Kleinwort, Benson Aerospace and Defense Equity Report, May 8, 2000).
² The Acela Express turned out to be an embarrassment for both Amtrak and Bombardier, who have sued each other over the responsibility for the frequent breakdowns (see “Bombardier sues Amtrak for $200 million over high-speed train,” Washington Post, November 8, 2002).
³ Gal-Or (1988) examines a special case of cost uncertainty with Cournot competition, where firms acquire cost information through the production of a product (learning-by-doing). The accuracy of cost information increases with production volume, which creates a direct link between output and information acquisition decision. Such adaptive control models (Little 1966) are more appropriate for existing products.
for which the information is used. This ‘rule’ holds for the three cases analyzed in the literature and implies that the acquisition of cost information with price competition should be a strategic complement. We will show that this conjecture is incorrect.

A large, related literature examines the incentive of competitors to share private information. When uncertainty concerns a common parameter, the incentive to share information matches the effect of competition on the acquisition of information (Vives 1999). For price decisions, for example, firms prefer to share private demand information (Raith 1996) and competition increases the acquisition of demand information (Raju and Roy 2000). For quantity decisions, conversely, firms do not want to share either cost or demand information (Raith 1996) and competition decreases the acquisition of either information (Li et al. 1987). Based on her analysis of sharing firm-specific cost information, Gal-Or (1986) conjectures that for common cost uncertainty “sharing is a dominant strategy” (p. 91), which would imply that the acquisition of cost information increases with competition. Again, we will show that this conjecture is incorrect.

To examine the acquisition of cost information and the effect of competition, we use the same linear-quadratic framework as the existing literature (Vives 1999): In the first stage of the game, duopoly firms determine how much information to acquire about the stochastic marginal cost. The cost of information increases with its accuracy. The obtained private information is then used to update cost estimates in a Bayesian fashion and make the second-stage pricing decisions for a market with linear demand. We then examine i) whether buyers benefit or not when suppliers have more accurate cost estimates, and ii) if an information vendor could charge more or less for cost information when competition between client firms increases.

Our analysis yields four important results. First, we find that the acquisition strategies for cost information are strategic substitutes even though the price decisions are strategic complements. The equilibrium amount of cost information decreases with competition. Second, when the cost of information is sufficiently low, identical firms acquire different amounts of cost information and the expected value of cost information decreases with higher accuracy for the firm that acquires less

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4 Raith (1996) shows such inferences are not necessarily valid for the case of cost uncertainty with price competition because it differs structurally from cases with demand uncertainty or quantity competition.

5 A number of studies have examined the problem of pricing information (e.g., Admati and Pfleiderer 1986, 1990; Chang and Lee 1994; Sarvary and Parker 1997; Iyer and Soberman 2000), but they typically focus on demand information.
information. Even when information is free, only one firm acquires perfect information. Such firm heterogeneity is more likely when cost uncertainty is higher, buyers are more price sensitive, or competition is stronger. Third, buyers prefer perfectly informed suppliers and thus have an incentive to help them improve their cost estimates, especially when competition is high. However, suppliers would want exclusive help, which is not in the best interest of buyers. Finally, the optimal price set by a monopoly information vendor increases with competition when competition is high even though competition strictly reduces the expected value of cost information.

The negative effect of competition obtains for the following reason. When a competitor acquires more cost information, the firms have more similar cost estimates and price decisions become more correlated. This increases a firm’s profit when it learns that cost is higher than expected because a better informed competitor more likely obtains the same information and also raises its price. In contrast, when a firm learns that cost is lower than expected, it prefers an uninformed competitor because its profit is higher when the competitor does not reduce its price. A priori, each case is equally likely, but a signal indicating lower cost contributes more to the expected value of information because lower cost leads to higher profit. Said differently, a price adjustment after learning of lower cost is always more valuable compared to a price adjustment of equal magnitude after learning of higher cost. The marginal profit effect of the former price adjustment is greater when a competitor does not reduce its price, i.e., when it is uninformed. Hence, the effect of competition on the expected value of cost information is negative.

The negative effect of competition also reduces the expected value of more accurate information. More accurate information allows a firm to make a smaller pricing ‘error’ (direct effect), which always increases profit. It also allows a firm to better anticipate the competitor’s information and its price decision (strategic effect). But the same is true for the competitor. Hence, the strategic effect is negative because prices become more correlated the more accurate the acquired information. The strategic effect can dominate the direct effect, which causes the asymmetric equilibrium. Consider the extreme case with near perfect substitutes and free information. If both firms acquire perfect information, they do not make much profit because prices approach true marginal cost. The expected value of information is zero: the strategic effect offsets the positive direct effect. Now, if one firm acquires less than perfect information,

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6 A negative value of information in games with strategic interactions has also been shown for public information (e.g., Hirshleifer 1971), in zero-sum games (e.g., Ponssard 1976), and with sequential decisions (e.g., Gal-Or 1987).
the informed firm raises its price because it is possible that the uninformed firm overestimates cost and thus sets a higher price. Price decisions are strategic complements and the uninformed firm also raises its price, which leaves both firms better off. On the other hand, information acquisition strategies are strategic substitutes and the informed firm does not reduce its acquisition of cost information.

This study intends to offer the following contributions to the literatures on new product pricing, information marketing and firms’ information acquisition. First, it shows that firms should accept more cost uncertainty as competition increases when pricing a new product. Firms benefit if less cost information is acquired. Cost uncertainty works like a ‘fog’ that reduces the destructive effect of price competition when products are highly substitutable. Second, since price competition has the reverse effect on the acquisition of demand information (Raju and Roy 2000), this study shows that a market-orientation, i.e., learning about external market rather than internal cost factors, is more appropriate in more competitive markets (Kohli and Jaworski 1990). Third, an information vendor can increase its price for cost information as competition increases even though competition decreases the expected value of cost information because a higher information price helps firms maintain more cost uncertainty. Fourth, the study shows that information acquisition strategies can lead to firm differences, which contrasts with the argument that without prior firm differences (e.g., resource endowment), only chance can lead to differences in knowledge (Makadok and Barney 2001). Information differences play a key role in economics and strategy but research tends to focus more on examining the implications of such differences rather than the reasons for them to exist (Lamberton 1996). Finally, it not only confirms the argument that the case of cost uncertainty with price competition is different (Raith 1996) but specifically shows how it differs from cases with demand uncertainty or quantity competition.

The rest of the paper is organized as follows. Next, we introduce the model. In §3, we determine the equilibrium acquisition and provide comparative static and expected welfare results. In §4, we examine the information pricing problem for a monopoly vendor. We conclude with a discussion of various model extensions. All proofs are in a Technical Appendix that is available from the author.

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7 For demand information the reverse effects hold. Learning of higher demand contributes more to the expected value of information. Here firms can sustain higher prices when they are both informed. Hence, acquisition strategies for demand information are strategic complements, the strategic effect of accurate information is positive, and the equilibrium with identical firms is always symmetric (Raju and Roy 2000; Sasaki 2001).
2. Model

We follow the standard modeling framework used in the literature (Vives 1999). We assume a market with two risk neutral firms, a linear demand function \( q_i = a - b \cdot (p_i - \gamma \cdot p_j) \) and a constant marginal cost function \( m_i = c \) \((i, j = 1, 2, i \neq j)\). The parameter \( \gamma \) is equal to the ratio of cross-price to own-price effects and captures the degree of competition between the firms (Varian 1992). We focus on non-complementary products \((\gamma \geq 0)\). To ensure that total industry demand, \( q_1 + q_2 \), does not increase with prices, we assume \( \gamma < 1 \). The parameter, \( b \), indicates buyers’ price sensitivity.\(^8\)

The parameter \( c \) is stochastic and captures cost uncertainty. We want both firms to have the same prior knowledge. Consequently, we assume firms’ prior knowledge for \( c \) is distributed with finite mean \( \mu \) and finite variance \( u \). Firms acquire independent private signals (forecasts), \( x_i \), about the true value of \( c \). These signals are generated as \( x_i = c + \epsilon_i \), where the random noise \( \epsilon_i \) has zero mean and precision \( h_i \) and \( \text{cov}(c, \epsilon_i) = 0 \). The cost of information of precision \( h_i \) is \( \lambda \cdot h_i \). These assumptions are all common knowledge to both firms. The respective distributions of \( c \) and \( \epsilon_i \) are independent and such that Bayesian updating results in linear posterior expectations, i.e., \( E[c \mid x_i] = (1-w_i)\mu + w_i \cdot x_i \), where \( w_i = u/(u + 1/h_i) \).

The weight, \( w_i \), given to new information is a function of the firm’s initial confidence and the accuracy of the signal. From this also follows that \( E[x_j \mid x_i] = E[c \mid x_i] (i, j = 1, 2, i \neq j) \). The implied distributional assumption holds for the exponential family of conjugate distributions, which includes the normal, beta-binomial, and gamma-Poisson processes (Ericson 1969). The last two are especially appropriate for imposing a non-negativity constraint on the uncertain parameter.

The resulting game has two stages. In the first stage, firms simultaneously decide how much cost information they want to acquire. These decisions then become public knowledge. In the second stage, the firms simultaneously set prices of their new products conditional on their own private information, the competitor’s acquisition effort and all other common information. Consistent with previous studies (see Vives 1999), we directly consider \( w_i \) as the decision variables for the acquisition of cost information \((i = 1, 2)\).\(^9\) From \( w_i = u/(u + 1/h_i) \), follows that the amount of information, \( w_i \), for a given level of prior

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\(^8\) Such a demand system can be derived as the first-order condition of a representative buyer’s maximization of an appropriately defined concave utility function (Vives 1984). Given our focus on common (i.e., industry-specific) cost uncertainty, we ignore firm-specific cost factors.

\(^9\) This change is without loss of generality since \( w_i \) is a monotonically increasing function of \( h_i \) and \( 0 < u < \infty \). Referring to \( w_i \) as the “amount of information” implies that prior uncertainty, \( u \), is fixed.
uncertainty, $u$, costs $\kappa_i = \frac{\lambda \cdot w_i}{u \cdot (1 - w_i)}$. Information of zero precision ($w_i = 0$) is costless and perfect information ($w_i = 1$) is infinitely costly for $\lambda > 0$.

3. Analysis

The equilibrium concept we use is that of a perfect Bayesian equilibrium (Fudenberg and Tirole 1991). First, we derive the unique Bayesian-Nash equilibrium prices, $p_i^*$, for given amounts of acquired cost information, $w_i$ and $w_j$, and conditional on the realization of the private information, $x_i$. Second, we determine the equilibrium decisions, $w_i^*$, by assuming that the expected value of information is determined by equilibrium behavior for the second-stage price decision (sub-game perfection). Both firms are expected to adhere to this strategy.

3.1 Equilibrium Prices

The unique Bayesian-Nash equilibrium prices follow from the expected conditional profit $E[\pi_i \mid x_i] = E[q_i(p_i - c) \mid x_i]$, $i = 1, 2$. Since expectation, $E[c \mid x_i]$, is a linear function of new information, $x_i$, and price is a linear function of marginal cost, $c$, the equilibrium price, $p_i^*$, is also a linear function of the acquired information, $x_i$ (Vives 1999). Hence, $p_i^* = P + B_i(x_i - \mu)$, where

$$
P = \frac{a + b\mu}{b(2 - \gamma)}, \quad B_i = w_i \frac{2 + \gamma w_j}{4 - \xi} \quad \text{and} \quad \xi = \gamma^2 w_i w_j.
$$

The factor $P$ indicates the equilibrium price when no new information is acquired ($w_i = 0$). It is important to note that the equilibrium price, $p_i^*$, is more sensitive to new information when the competitor acquires more information (higher $w_j$) or competition, $\gamma$, is higher. These effects are the result of the strategic complementarity of price decisions. The magnitude of the price change for a signal $x_i$ does not depend on whether $x_i$ is larger or smaller than the prior expectation, $\mu$.

3.2 Equilibrium Acquisition of Cost Information

If the two firms follow their equilibrium price decisions (1), the expected value of information follows from $E_{x_i}[E[\pi_i \mid x_i]] = 1/b \cdot E_{x_i}[E[q_i(p_i^*, p_j^*) \mid x_i]^2]$, where expectations are first taken with respect to the uncertain parameter, $c$, conditional on the acquired information, $x_i$, and then over all possible sets of information. This expected value can be separated into the expected profit without additional information, $\Pi^0$, and the expected value of new cost information, $Z_i(w_i, w_j)$, $i, j = 1, 2$, $i \neq j$: 

\[ \Pi^0 = \frac{(a-b(1-\gamma))u}{b(2-\gamma)^2}, \text{ and } Z_i = \frac{ub}{w_i}(w_i - B_i)^2. \]  

To ensure that both firms acquire a positive amount of cost information, we assume that the unit cost of information is lower than the highest marginal value of information (when \( w_i = 0, i = 1, 2 \)): \( \lambda < \lambda_{\text{max}} = bu^2/4. \) This assumption makes the relevant payoff function, \( \Pi_i = Z_i - \kappa_i, \) ‘nicely’ behaved. We are now able to characterize the equilibrium acquisition of cost information:

**PROPOSITION 1.** With price competition, the acquisition of information about a common uncertain cost parameter is a strategic substitute.

**PROPOSITION 2.** The equilibrium acquisition of cost information is unique and symmetric, i.e., \( w_i^* = w_j^* = \omega \), only when \( \lambda > \Lambda \), where

\[ \Lambda = \frac{bu^2\gamma(1-\omega)^3(4-4\gamma\omega-\gamma^2\omega^2)}{(2-\gamma\omega)^3(2+\gamma\omega)^2}, \quad 0 \leq \Lambda < \lambda_{\text{max}}. \]  

When \( \lambda < \Lambda \), there exists a pair of asymmetric equilibria, i.e., \( w_i^* > w_j^* \) (\( i, j = 1, 2, i \neq j \)). The firm that acquires more cost information has higher expected profits. The likelihood of an asymmetric equilibrium increases with price sensitivity, \( b \), competition, \( \gamma \), and uncertainty, \( u \).

There always exists a symmetric solution to the first-order conditions (first- and second-order conditions are shown in the Technical Appendix). However, when condition (3) does not hold, it violates the stability condition and is thus not considered an equilibrium outcome of the game (Varian 1992). Propositions 1 and 2 confirm that a Bertrand market with cost uncertainty is structurally different than a Bertrand market with demand uncertainty or a Cournot market with either demand or cost uncertainty (Raith 1996). First, it is the only case where the strategic interaction for the information acquisition does not match the strategic interaction for the decisions which are based on the acquired information. Hence, one cannot necessarily infer the effect of competition on the acquisition of information from the type of competition (Sasaki 1997). Second, it is the only case where the equilibrium can be asymmetric with identical firms. Hence, information acquisition strategies can be a source of firm differences even without a priori different firms (Makadok and Barney 2001).

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[Sasaki (2001) discusses the possibility of an asymmetric equilibrium when information acquisition strategies are strategic substitutes. However, he conjectures that this could occur when information is more rather than less costly.](#)
Why is the acquisition of cost information with price competition a strategic substitute? Whether a competitor’s information acquisition increases or decreases a firm’s profit depends on the signal $x_i$. For product substitutes ($\gamma > 0$), an uninformed competitor is preferred when information leads to a price cut ($x_i < \mu$). An informed competitor would likely cut its price, which decreases the firm’s profit. An uninformed competitor is thus preferred. The opposite is true when information leads to a price increase ($x_i > \mu$). An informed competitor would likely raise its price, which increases a firm’s profit. A priori, both cases are equally likely but for the same deviation from expectations, $|x_i - \mu|$, learning lower cost leads to a larger increase in profit – independent of the competitor’s action – because profit increases nonlinearly with lower marginal cost. As a result, when taking expectations over all possible signals, $x_i$, the case where $x_i < \mu$ contribute more to the expected value of information than the case where $x_i > \mu$ and thus determines the effect of competition. The marginal expected value of cost information decreases as the competitor acquires more information and the slope of the best response functions is thus negative.

Why do identical firms acquire different amounts of cost information when information is inexpensive? More accurate information has two effects on a firm’s expected profit and thus the expected value of information. First, it leads to a more accurate cost forecast and thus a smaller pricing ‘error’ (direct effect), which always increases expected profit. Second, it leads to a more accurate anticipation of the competitor’s information and price decision (strategic effect). When a firm acquires more accurate information, it must assume the competitor does the same, which leads to more similar cost estimates and price decisions. Based on the previous discussion, the strategic effect is thus negative.

Moreover, the strategic effect can dictate equilibrium behavior when products are close substitutes. Consider (almost) perfectly substitutable products. As information becomes perfect, the expected value of information approaches zero. Prices approach marginal cost and profits go to zero. The strategic effect causes the marginal profit effect of more accurate information to turn negative and imperfect cost information can become more valuable than perfect cost information. The asymmetric equilibrium is then a consequence of the difference in strategic interactions between price decisions and information acquisition strategies. If a firm acquires less than perfect information, the (perfectly) informed firm will not reduce its information acquisition (information strategies are strategic substitutes) but will raise its price because it is possible that the uninformed firm overestimates the true cost, i.e., $E[c|x_j] > c$. In response, the uninformed firm will raise its price too (prices are strategic complements) and
both firms expect a positive profit. The informed firm has higher expected profit because it will never price below \( c \). Conversely, when an uninformed firm acquires more cost information, the informed competitor will lower its price, which causes the former firm to cut price as well, and so on. This competitive pressure can become so strong that the symmetric acquisition, \( w_i = w_j \), becomes unstable.\(^{11}\)

The effect of competition is illustrated in Figure 1a, which shows the best response functions for two levels of \( \lambda \). (For comparison, Figure 1b shows the best response functions for demand information for the same conditions.) When the cost of information \( \lambda \) is high, firms acquire little information and a firm’s optimal acquisition is relatively insensitive to the competitor’s acquisition of cost information. When \( \lambda \) is low however (bold lines in Figure 1), firms acquire a lot of cost information and the optimal amount becomes very sensitive to the competitor’s acquisition. This causes a sharp bend in the best response functions, which now also intersect off the dashed line (where \( w_i = w_j \)). The symmetric solution becomes unstable: a small deviation from it by either firm leads to an asymmetric outcome.\(^{12}\)

Cost uncertainty can alleviate the ‘destructive’ effect of price competition when products are close substitutes but firms are stuck in a Prisoner’s Dilemma. If firms cooperated for the acquisition of cost information (but continued to set their prices non-cooperatively), they would acquire less cost information or accept greater firm differences as shown in the following result:

**Proposition 3.** Cooperating firms acquire the same amount of cost information but less than competing firms, i.e., \( w_i^C = w_j^C = \nu < \omega \) when \( \lambda > \Lambda^C \), where

\[
\Lambda^C = \frac{bu^2\gamma(1-\nu)^3(8 - 2\gamma\nu - 5\gamma^2\nu^2)}{(2-\gamma\nu)^3(2+\gamma\nu)^2} > \Lambda. \tag{4}
\]

When \( \lambda < \Lambda^C \), one firm acquires no cost information and the other firm acquires more cost information than either firm in the competitive equilibrium, i.e., \( w_i^C = 0 \) and \( w_j^C > w_i^* \), \( w_j^* (i, j = 1, 2, i \neq j) \).

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\(^{11}\) When \( \gamma = 1 \) and \( w_i = w_j = 1 \), then \( B_i = w_i \) and thus \( Z_i = 0 \) (see (2)). When the cost of information is \( \lambda = 0 \), then the equilibrium is \( w_i^* = 1 \) and \( w_j^* < 1 \) for \( \gamma > 0.771 \), and \( w_i^* = w_j^* = 1 \) otherwise. For \( \gamma = 1 \), the optimal acquisition of cost information is \( w_i^* = 1 \) and \( w_j^* = 0.377 \) and both firms expect a positive profit. If firms maximized joint expected profits, the optimal acquisition for \( \lambda = 0 \) would be \( w_i = 1 \) and \( w_j = 0 \) when \( \gamma > 0.453 \).

\(^{12}\) For Cournot competition, the equilibrium is always symmetric for both cost and demand uncertainty even though information acquisition strategies are strategic substitutes (Li. et al. 1987). Compared to price competition, there is no escalation of production output because output decisions are also strategic substitutes. If a firm expects its competitor to increase output, it will reduce output, which stabilizes market prices.
3.3 Comparative Static Results

The comparative static results for the symmetric equilibrium are straightforward. The optimal amount of cost information increases with lower competition, $\gamma$, and all factors that increase the expected value of information (e.g., uncertainty, $u$, or price sensitivity, $b$) or reduce the cost of acquiring information. The results for the asymmetric equilibrium are less obvious as shown in the next proposition:

**Proposition 4.** When $\lambda > \Lambda$, the equilibrium amount of cost information, $\omega$, decreases with competition, $\gamma$, and the cost of information, $\lambda$, and increases with uncertainty, $u$, and price sensitivity, $b$. When $\lambda < \Lambda$, the equilibrium amount of cost information increases (decreases) with competition, $\gamma$, price sensitivity, $b$, and uncertainty, $u$, for the firm that acquires more (less) cost information.

When the equilibrium is asymmetric, parameter changes affect the optimal acquisition of cost information for the two firms in opposite directions. For the firm that acquires less cost information, this leads to the counterintuitive finding that changes which increase (decrease) the expected value of information decrease (increase) the acquisition of cost information. As a result, the demand function for cost information is upward sloping. This is illustrated in Figure 2, which shows demand curves for cost information for two different levels of competition, $\gamma$. 
3.4 Expected Consumer Surplus and Welfare Results

Since cost uncertainty reduces the competitive pressure on prices, buyers should prefer better informed firms (suppliers). Less obvious, however, is the effect of firms’ acquisition of cost information on expected welfare. Differentiated information acquisition strategies reduce expected competition but do they also decrease expected welfare? For Cournot competition, a reduction in competition can actually increase expected welfare from the acquisition of costly information (Hwang 1995).

To examine expected buyer surplus and welfare from the acquisition of cost information by firms that compete on prices, we follow the analysis by Hwang (1995) and assume that only the acquisition of information is coordinated to maximize welfare while prices continue to be determined by profit maximizing firms. Thus, equilibrium prices remain as shown in (1). Expected consumer surplus as a function of firms’ acquisition of cost information follows from \( \text{ECS} = 1/(2b)E[(q_1+q_2)^2] \) and expected welfare is the total surplus, i.e., \( \text{EW} = \text{ECS} + \Pi_1 + \Pi_2 \).

**Proposition 5.** Expected consumer surplus is a strictly increasing function of the amount of cost information, \( w_i \), the either firm acquires \( (i = 1, 2) \).

As expected, buyers benefit when both firms are better informed about cost. (With demand uncertainty, buyers prefer ‘demand ignorant’ suppliers (Vives 1999)). This implies that buyers have an incentive to help suppliers obtain more accurate cost estimates to determine a price (e.g., by paying for
firms’ cost research). A supplier in turn would insist on exclusive help, which is not in the best interest of buyers. They want suppliers to be equally informed to create more price pressure.

**Proposition 6.** When the cost of information is high, expected welfare is maximized when both firms acquire the same amount of cost information, $W$, which can be lower or higher than the equilibrium amount, $\omega$. When the cost of information is low, expected welfare is maximized when only one firm acquires information, i.e., $w_i^E > 0$ and $w_j^E = 0$. A sufficient condition for this outcome is $\lambda < \Lambda^E$, where

$$\Lambda^E = \frac{b u^2 (1 - W)^{\frac{1}{2}} (4 \gamma (6 - W) + 2 \gamma^2 (4 + W - 2 W^2) - \gamma^3 (8 + 3 W^2) - 2 \gamma^4 W (1 + W) - \gamma^5 W^2 - 8)}{2 (2 - \gamma W)^3 (2 + \gamma W)^2} > \Lambda. \quad (5)$$

Proposition 6 shows that a market with only one informed firm can be efficient. This can even be the case when information is free. The acquisition of perfect cost information by only one firm maximizes expected welfare when $\gamma > 0.653$. Compared to the competitive equilibrium (Proposition 2), welfare-maximizing differentiation is greater and occurs with less competition and higher cost of information. Moreover, it is interesting to note that when products are sufficiently close substitutes, the cooperative outcome (Proposition 3) can be closer to the welfare maximizing acquisition of cost information than the competitive equilibrium. The order of the three conditions for a differentiated information acquisition to be optimal – $\Lambda < \Lambda^E < \Lambda^C$ – shows that cost uncertainty cannot only increase firm profits but may also increase expected welfare of a market.

**4. Optimal Pricing of Cost Information**

Whether or not we observe an asymmetric equilibrium depends on the cost of information, $\lambda$. Our analysis so far has assumed that this cost is an exogenous factor. When the cost is set by an external information vendor that maximizes its profit, it is not obvious whether the resulting optimal price of cost information is low enough for an asymmetric equilibrium to occur. Given the negative effect of competition on the equilibrium amount of cost information, one would a priori expect the optimal price to decrease with competition. The negative competitive effect also raises the question whether it could be

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13 For demand information, expected welfare is always maximized when firms acquire the *same* amount of information (Vives 1999).
optimal for a vendor to sell cost information exclusively to one firm and create firm differences this way. For demand information, in contrast, one would expect a positive effect of competition since the expected value of demand information increases with competition (Raju and Roy 2000).

We next determine the optimal information price set by a monopoly information vendor. To compare the price for cost information with that for demand information, we conduct a similar analysis for information about a stochastic demand intercept, \( a \), based on existing results for the equilibrium acquisition of such information (Sasaki 2001). Without loss of generality, we assume the information vendor has zero marginal cost to produce information and maximizes revenues \( R = \lambda (w_1^* + w_2^*) \).

The first-order condition for the optimal price, \( \lambda^* \), is
\[
\frac{\partial R}{\partial \lambda} = (w_1^* + w_2^*) + \lambda \cdot \frac{\partial (w_1^* + w_2^*)}{\partial \lambda} = 0.14
\]

**PROPOSITION 7.** The optimal price for cost information decreases with competition when products are highly differentiated and increases when products are close substitutes. Both firms always acquire the same amount of cost information, i.e., \( \lambda^* > \Lambda \). The optimal price for demand information increases monotonically with competition.

The effect of competition on the optimal price of demand information is as expected. The result for cost information, however, is more intriguing. The finding that the optimal price can increase with competition is a direct consequence of the ‘benefit’ of cost uncertainty when competition between client firms is sufficiently high. A high price assures both firms that the competitor does not acquire too much cost information. In other words, by increasing the price of cost information as competition increases, the information vendor provides a ‘service’ to client firms: The higher price helps the firms get out of the Prisoner’s Dilemma in which they are stuck. This positive effect of competition also eliminates any incentive for the information vendor to sell cost information exclusively to one firm. As a result, whether the acquisition of cost information will result in firm differences depends on the way in which cost information is acquired. Consistent with other studies (e.g., Sarvary and Parker 1997; Iyer and Soberman 2000), this finding highlights the complex effect of competition on pricing information product.

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14 It is not possible to derive explicit information demand functions, \( w_i^* \), when products are not independent (\( \gamma \neq 0 \)). We thus use a numerical analysis to determine the profit-maximizing price of information, \( \lambda^* \). When products are independent (\( \gamma = 0 \)), the optimal price for cost information is \( \lambda^{CM} = bu^2/9 \) (and for demand information \( \lambda^{DM} = u^2/9b \)). From the numerical analysis, we find that the optimal information price is of the form \( \lambda^* = \lambda^N (1 + \sum \beta_n g^2) \), \( n = 1 \ldots 6 \). For cost information some \( \beta_n \) are negative. (For demand information all \( \beta_n \) are positive).
5. Discussion

In this paper, we have analyzed the optimal acquisition of information about a common uncertain cost parameter for pricing a new product by two competing firms. Existing studies that examine the acquisition of information in economics and marketing have so far largely ignored this particular case. Compared to demand uncertainty, cost uncertainty may be less important for pricing existing products, but it often constitutes a serious problem for pricing new products and services, especially in industrial markets and in bidding situations. With this study we close a gap in the existing literature and show that a number of conjectures in the literature regarding the acquisition of information in general and cost information with price competition in particular do not hold.

This study not only confirms that the case of cost uncertainty with price competition is different (Raith 1996; Vives 1999) but shows specifically how the results differ from findings for cases with demand information or quantity competition. Most importantly, the effect of competition on the acquisition of cost information is much stronger: In no other case do a priori identical firms acquire different amounts of information. This study also shows how the competitive equilibrium differs from a cooperative outcome and the welfare maximizing acquisition of cost information. Interestingly, cooperation for the acquisition of cost information can increase expected welfare.

Combining our results with the findings for demand information (Raju and Roy 2000; Sasaki 2001), indicates that competition increases the importance of demand information (market research) relative to cost information (internal research). This conclusion is consistent with the proposition that adopting a market orientation is more important in more competitive markets (Kohli and Jaworski 1990) but contradicts the argument that cost information plays a more significant role for setting prices when products are more substitutable (Porter 1980; Levitt 1983). To the contrary, firms should accept more cost uncertainty as competition increases. This could provide an explanation for the smaller effort of Bombardier to estimate the cost of its ‘product’ than Airbus did. Bombardier faced stronger competition from Siemens and ABB (more similar products) than Airbus did from Boeing.

In general, the focus on cost factors for price decisions is well documented (Noble and Gruca 1999). This raises the empirical question whether managers are too much concerned with the direct effect of accurate cost information to avoid pricing below cost compared to the strategic effect of cost information. Accepting more cost uncertainty requires accepting a (greater) chance of pricing below cost.
Loss aversion could thus lead to the acquisition of more cost information than is optimal according to the equilibrium results presented in this paper. Clearly, price differences between competing products matter more when they are more substitutable. When price differences arise because of different expectations, our findings suggest it is better to reduce differences in demand estimates than differences in cost estimates. This also suggests that firms do not want to share private information about a common cost parameter when products are close substitutes.

Our results are not only relevant for pricing new products. They also apply to the calculation of the expected net present value (NPV) of an R&D project to evaluate the profitability of an investment. In that case as well, a firm needs cost (and demand) forecasts and a price estimate. While for an NPV calculation a firm does not have to commit to a price, it does commit to develop a project based on its forecasts and price estimate. When information collection is time consuming, our results suggest that ‘rushing’ into a new product development with limited cost information may not only happen because of the quest for a first-mover advantage. While competition makes time-to-market more important, it also decreases the expected value of cost information, which makes waiting (for better information) less attractive.

There is always the question to what extent analytic findings are idiosyncratic to specific model assumptions. Our exposition has been limited to a duopoly market. The asymmetric outcome raises the question how a third competitor would behave. As shown in the Technical Appendix\(^\text{15}\), our findings extend to an oligopoly market with \(n\) firms. When the equilibrium is asymmetric, one firm acquires more cost information than all other firms, which in turn all acquire the same amount of cost information. In other words, the duopoly case can be viewed as a ‘reduced-form’ oligopoly case, where all \(n-1\) identical competitors are represented by a single “super” competitor.

Like other studies (e.g., Li et al. 1987; Raju and Roy 2000), we have used a linear demand specification. However, it is important to note that our findings are more a consequence of the strong effect of price competition and the ‘lure’ of learning about lower cost. We also assumed constant marginal cost. Although not shown here, our results extend to a linear marginal cost function. A linear marginal cost function also raises the question whether the results presented herein hold when the (common) slope parameter of the marginal cost function is uncertain. A slope parameter has a nonlinear effect on

\(^{15}\) Available from the author at http://.
equilibrium prices, which requires more restrictive distributional assumptions. A full analysis of this case goes beyond the scope of this paper. A preliminary analysis with a two-point distribution, similar to Malueg and Tsutsui (1996), indicates that our findings continue to hold, i.e., competition tends to lower the acquisition of cost information and the equilibrium can be asymmetric when products are sufficiently substitutable.

Raju and Roy (2000) also indicate the value of analyzing the implications of the order of price decisions. In a Stackelberg game, however, the follower can infer the private information from the price set by the leader. This adds a signaling component, which complicates the equilibrium acquisition of information. This analysis is left to future research. Another area of future research involves the extension to heterogeneous firms. We have limited our analysis to identical firms precisely to better highlight the result that firm differences can emerge as a result of purposeful differentiation rather than initial firm differences. Finally, it would be worthwhile to extend our analysis of optimal information pricing to a market with competing information providers (Sarvary and Parker 1997). In sum, investigating the acquisition and marketing of information that aids managers to cope with uncertainty will continue to be a fruitful area for future research.
References


Cost Uncertainty is Bliss:
The Effect of Competition on the Acquisition of Cost Information
for Pricing New Products

Technical Appendix

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Equilibrium Price Decisions

From the first-order condition, $a + bE[c \mid x_i] - 2bp_i + b\gamma E[p_j^* \mid x_i] = 0$, and the assumption that firm $j$ is expected to adhere to equilibrium decision (1), i.e., $E[p_j^* \mid x_i] = E[P_j + B_j(x_i - \mu) \mid x_i] = P_j + w_jB_j(x_i - \mu)$ follows the following set of four equations:

$$
P_i = \frac{a + \mu + b\gamma p_j}{2b} \quad \text{and} \quad B_i = w_i \frac{1 + \gamma B_j}{2}, \ i, j = 1, 2, i \neq j. \quad (A.1)$$

The solutions provided in (1) follow immediately by solving these four equations. For the uniqueness proof, we refer the reader to Basar and Ho (1974).

**Proposition 1: Slope of Reaction Functions**

The reaction functions for the acquisition of cost information follow from the following first-order and second-order conditions and the Lemma below:

$$
\frac{\partial \Pi_i}{\partial w_i} = Z_i \frac{8 - 4\gamma w_j - 10\xi - \gamma w_j \xi + \xi^2}{w_i (4 - \xi) (2 - \gamma w_j - \xi)} - \frac{\lambda}{u(1 - w_i)^2} = 0, \ i, j = 1, 2, i \neq j. \quad (A.2)
$$

$$
\frac{\partial^2 \Pi_i}{\partial w_i^2} = \frac{2Z_i \gamma^2 w_j (2 + \gamma w_j) (16 - 8\gamma w_j - 10\xi - \gamma w_j \xi)}{w_i (2 - \gamma w_j - \xi) (4 - \xi)^2} - \frac{2\lambda}{u(1 - w_i)^3} \quad \text{and} \quad (A.3)
$$

$$
\frac{\partial^2 \Pi_i}{\partial w_i \partial w_j} = -\frac{Z_iZ_j 4\gamma (16 - 16\xi - 3\xi^2 + 8\gamma (2w_i - w_j) - 2\gamma \xi (5w_i + 2w_j))}{w_i w_j (2 - \gamma w_i - \xi)^2 (2 - \gamma w_j - \xi)^2} i, j = 1, 2, i \neq j. \quad (A.4)
$$

**LEMMA.** The strategy space for the equilibrium acquisition of cost information when firms have some prior knowledge, i.e., $u < \infty$, is $w_i \in [0, W_{\max}]$, where

$$
W_{\max} = \min \left\{ 1, \frac{10 + \gamma w_j - \sqrt{68 + 36\gamma w_j + \gamma^2 w_j^2}}{2\gamma^2 w_j} \right\}, \ i, j = 1, 2, i \neq j. \quad (A.5)
$$

This Lemma restricts the strategy space for a firm’s acquisition of cost information, $w_i$, to less than one when $\gamma > 0.711$ and $w_j > 0.571$ (see Figure A.1).
Proof of Lemma

From the first-order conditions (A.2) follows that the marginal expected value of cost information, \( \partial Z_i / \partial w_i, \ i = 1, 2, \) becomes negative when \( 8 - 4\gamma w_j - 10\gamma^2 w_iw_j - \gamma^3 w_iw_j^2 + \gamma^4 w_i^2w_j^2 \leq 0. \) (A.5) follows immediately by solving this equation for \( w_i. \)

The second-order conditions can be positive for some values of \( w_i \) and \( w_j. \) The first-term of the second-order conditions (A.3) is only negative as long as \( 16 - 8\gamma w_j - 10\xi - \gamma w_j\xi > 0. \) Thus a sufficient condition for the second-order conditions to be negative is

\[
\frac{8(2 - \gamma w_j)}{\gamma^2 w_j(10 + \gamma w_j)}, \ i, j = 1, 2, i \neq j. \tag{A.6}
\]

Similarly, the cross partial effect (A.4) is negative only if

\[
w_i < \frac{4 - 4\gamma w_j - \gamma^2 w_j^2 + (2 + \gamma w_j)(4 + 2\gamma w_j + \gamma^2 w_j^2)}{\gamma^2 w_j(10 + 3\gamma w_j)}, \ i, j = 1, 2, i \neq j. \tag{A.7}
\]

However, conditions (A.6) and (A.7) are only violated for values \( w_i \) and \( w_j \) outside the strategy space as defined by the Lemma above, i.e., when the first-order conditions (A.2) do not hold (see Figure A1). We can thus conclude that the second-order conditions are always negative and thus the relevant payoff function, \( \Pi_i, \) is strictly quasi-concave in \( w_i. \) Similarly, the cross-partial effect is always negative implying that the best-response functions are downward sloping. ■

Figure A1

Strategy Space for Cost Information, \( w_i, \) and Conditions for Second-Order Partial to Have Negative Sign (for \( \gamma = 1 \))
Proposition 2: Equilibrium Acquisition of Cost Information

A sufficient and (almost) necessary condition for the equilibrium allocation, \( w_i^* = w_j^* \), to be locally stable is (Varian 1992):

\[
\begin{vmatrix}
\frac{\partial^2 \Pi_i}{\partial w_i^2} & \frac{\partial^2 \Pi_j}{\partial w_i \partial w_j} \\
\frac{\partial^2 \Pi_i}{\partial w_j \partial w_i} & \frac{\partial^2 \Pi_j}{\partial w_j^2}
\end{vmatrix} > 0, \ i, j = 1, 2, i \neq j.
\]

Due to the symmetry of the payoff function, \( \Pi_i \), this simplifies to \( \partial^2 \Pi_i/\partial w_i^2 - \partial^2 \Pi_i/\partial w_i \partial w_j < 0 \).

Condition (3) follows immediately from (A.3) and (A.4). Since we consider a duopoly model, the uniqueness of the symmetric equilibrium \( w_i^* = w_j^* \) when condition (3) holds, follows from supermodularity (Milgrom and Roberts 1990). When condition (3) does not hold, the best response functions have a slope that is steeper than \(|-1| \) for \( w_i = w_j \), which makes these decisions unstable. Since the best response functions \( r_i(w_j) \) are always defined in the interval \( w_j \in [0,1] \), there must be another crossing of the best response functions off the line \( w_i = w_j \) and the pair of asymmetric equilibria follows immediately. Moreover, this asymmetric crossing must be a stable equilibrium because the best response functions can only intersect again when their slopes again flatten and become less than \(|-1| \).

The changes in the likelihood of an asymmetric equilibrium provided in Proposition 2 follow directly from a comparative static analysis of condition (3) with respect to the different parameters.

Proposition 3: Cooperative Cost Acquisition

The first-order conditions for the joint expected profit maximum \( \Pi^C = \Pi_i + \Pi_j \), is for \( i, j = 1, 2, i \neq j \).

\[
\frac{\partial \Pi_i^C}{\partial w_i} = Z_i \frac{16 - 32 \gamma w_j + 24 \gamma w_j \xi - \xi^3 - 4 \gamma^2 w_j(5w_i + w_j) + \gamma^2 w_j \xi(12w_i + 5w_j)}{(4 - \xi)(2 - \gamma w_j - \xi)^2} - \frac{\lambda}{u(1 - w_i)^2} = 0. \tag{A.9}
\]

For the symmetric solution, \( w_i^C = w_j^C = w \), a comparison of (A.9) and (A.2) shows that the marginal benefit of more accurate information is always higher in the non-cooperative case while the marginal cost of information remains the same. More specifically,

\[
\frac{\partial \Pi_i}{\partial w} - \frac{\partial \Pi_i^C}{\partial w} = \frac{4bw(1 - \gamma w)}{(2 - \gamma w)^2(2 + \gamma w)} > 0.
\]

(A.10)
From (A.10) follows immediately that cooperating firms acquire less cost information than the non-cooperative equilibrium amount $\omega$.

The proof for the asymmetric cooperative acquisition is as follows. The second-order partials $\partial^2 \Pi_i / \partial w_i^2$ are always negative but the cross-partial $\partial^2 \Pi_i / \partial w_i \partial w_j$ can be even more negative for $w_i = w_j$ and $w_i = w_j$ is thus does not constitute an admissible profit maximum $(i, j = 1, 2, i \neq j)$. In other words, Hessian matrix may not be negative semidefinite. Condition (4) for a symmetric acquisition follows directly from $|\partial^2 \Pi_i / \partial w_i^2| - |\partial^2 \Pi_i / \partial w_i \partial w_j| = 0$.

If Condition (4) does not hold, the optimal acquisition of cost information has to be $w_i \neq w_j$. The expected joint profit function $\Pi_i$ contains the term $w_i(2 - \gamma w_j(1 + \gamma w_i)) + w_j(2 - \gamma w_i(1 + \gamma w_j))$, which is maximized when $w_i = w_j$ or when either $w_i = 0$ or $w_j = 0$. In other words, when the symmetric acquisition of cost information does not yield an admissible profit maximum, the profit maximum is achieved when one firm does not acquire cost information at all (corner solution).

**Proposition 4: Comparative Static Results**

The overall effect of a change in parameter, $x$, follows from

$$\left[ \frac{\partial^2 \Pi_i}{\partial w_i^2} + \frac{\partial^2 \Pi_i}{\partial w_i \partial w_j} * \frac{\partial w_j^*}{\partial w_i} \right] \frac{d w_i}{d x} + \left[ \frac{\partial^2 \Pi_i}{\partial w_i \partial x} + \frac{\partial^2 \Pi_i}{\partial w_i \partial w_j \partial x} \right] = 0, \ i, j = 1, 2, i \neq j. \quad (A.11)$$

When $w_i^* = w_j^*$, we $\partial w_j^*/\partial w_i = 1$. As a result of the stability condition (A.8), the first bracket is always negative. The sign of the total effect of a change in parameter $x$, $dw_i/dx$, is thus determined by the sign of the second bracket. The cross-partial $\partial^2 \Pi_i / \partial w_i \partial w_j$ is negative for cost information.

Since the proofs for the effects of price sensitivity, $b$, and uncertainty, $u$, are equivalent, we only show the proof for competition, $\gamma$. For competition, $\gamma$, the sign of the first part of the second bracket for market information is determined by

$$\frac{\partial^2 \Pi_i}{\partial w_i \partial \gamma} = -\frac{2 w_j Z_i 32 + 16 \gamma (4 w_i - w_j - 32 \xi - 18 \xi^2 - 8 \gamma \xi (5 w_i + 2 w_j - \gamma w_j \xi^2)}{(4 - \xi)^2 (2 - \gamma w_j - \xi)^2} < 0 \quad (A.12)$$

for $w_i \in [0, W_{\text{max}}]$. Since $\partial w_j^*/\partial \gamma < 0$ the second part is always negative and we have $dw_i/d\gamma < 0$. When condition (3) does not hold and the equilibrium is asymmetric, the competitive effect is greater than the direct effect. Thus any parameter change that increases the optimal amount of cost information for the
firm that acquires more cost information in equilibrium must have the opposite effect for the firm that acquires less cost information in equilibrium.

**Proposition 5: Expected Consumer Surplus**

Expected consumer surplus follows from $\text{ECS} = \frac{1}{2} b \text{E}[(q_1^2+q_2^2)]$, i.e.,

$$\text{ECS} = \frac{2(a-b(1-\gamma)^2)}{b} + \frac{b(1-\gamma)^2}{2} \left( \frac{B_1^2}{w_1} + \frac{B_2^2}{w_2} + 2B_1B_2 \right). \quad (A.13)$$

From this follows the following conditions to maximize expected consumer surplus:

$$\frac{\partial \text{ECS}}{\partial w_i} = \frac{bu(1-\gamma)^2(2+\gamma w_j)}{(4-\gamma^2 w_i w_j)} \left( 8 + 4w_j(4+3\gamma) + \gamma w_i w_j(16 + 6\gamma + \gamma^2(4+\gamma)w_j) \right) > 0, \quad (A.14)$$

with $i, j = 1, 2, i \neq j$. (A.14) is strictly greater than zero for all $1 \geq w_i, w_j > 0$. Hence expected consumer surplus is always maximized when both firms acquire perfect cost information, i.e., $w_i = w_j = 1$.

**Propositions 6: Expected Welfare**

We first provide an outline of this proof. To proof proposition 6, we start by showing that for free information (i.e., $\lambda = 0$) expected welfare is maximized when both firms acquire perfect information (i.e., $w_i = 1, i = 1, 2$) only when products are sufficiently differentiated. We then show that with an asymmetric acquisition of information a maximum is always achieved when one firm does not acquire cost information. From the first-order conditions for maximum expected welfare follows that for costly information, there is always an interior solution $w_i = w_j = W > 0$, as long as the cost of information is low enough, i.e., $\lambda < \lambda^w = ub/4 (3-2\gamma+\gamma^2)$. However, the second-order conditions indicate that this solution is not always a permissible maximum. When products are sufficiently substitutable, this maximum must be compared against the maximum obtained with only one firm acquiring information (corner solution).

Expected welfare from the acquisition of cost information follows from total surplus, i.e., $\text{EW} = \text{ECS} + \Pi_1 + \Pi_2$. When information is free (i.e., $\lambda = 0$), we need to check the corner solutions, i.e., $w_i = w_j = 1$ and $w_i = 1$ and $w_j = 0$. For these two cases expected welfare simplifies to

$$\text{EW}^s = \frac{4bu(1-\gamma)^2}{(2-\gamma)^2} \quad \text{and} \quad \text{EW}^w = \frac{bu(3-2\gamma+\gamma^2)}{8}, \quad (A.15)$$
where the superscripts $S$ and $A$ indicate, respectively, the symmetric and the asymmetric case. Equating the two expressions and solving for competition, $\gamma$, shows that $EW^A = EW^S$ when $\gamma = 0.653$. When $\gamma$ is larger, we have $EW^A > EW^S$. From the first-order condition $\partial EW/\partial w_j$ and the second-order condition $\partial^2 EW/\partial w_j^2$, evaluated at $w_i = 1$, follows that the expected welfare function has maxima only at the corners when $\lambda = 0$.

When information is costly, the first-order conditions, $\partial EW^S/\partial W = 0$, for a symmetric acquisition $w_i = w_j = W$ to be efficient follows from:

$$EW^S = W \frac{bu^2 (1 - W)(3 + W - 2\gamma(1 + 3W) + \gamma^2 (1 + W + 2W^2)) - 2\lambda(2 - \gamma W)^2}{u(1 - W)(2 - \gamma W)^2}.$$  \hspace{1cm} (A.16)

Condition (4) follows from the second-order conditions. While $\partial^2 EW^S/\partial w_i^2 < 0$, $i = 1, 2$, the Hessian matrix of second-order partials is not always negative semidefinite. Condition (5) follows by setting the determinant of this matrix to zero. However, this is not a necessary condition. An asymmetric outcome obtains for higher values of $\lambda$ than is implied by (5). There is no exact analytic expression for the necessary condition because it involves a comparison with a corner solution. The value $\gamma = 0.653$ for free information is a lower bound. This value increases with the cost of information, $\lambda$. Figure A.2 compares the numerically derived necessary condition with condition (5) and condition (3). It shows that a smaller degree of product substitutability $\gamma$ is needed for an asymmetric information acquisition to maximize expected welfare than for the equilibrium acquisition of cost information to be asymmetric. Moreover, it shows that condition (5) yields a value that is higher than the necessary condition for expected welfare to be maximized with one firm acquiring no information. When the efficient acquisition is symmetric, the efficient amount is higher than the equilibrium amount when product substitutability is low because the effect from expected consumer surplus matters more and the negative competitive effect is smaller. When product substitutability is high, the reverse effects hold and the efficient amount is lower than the equilibrium amount. ■
Figure A2

Conditions for Asymmetric Acquisition of Cost Information

Different curves are generated for $b = 2$ and $b = 20$.

**Bertrand Oligopoly**

To extend our analysis to a Bertrand oligopoly, we assume that demand for firm $i$ can be represented by the following linear function: $q_i = a - b(p_i - \gamma/(n-1)\sum_{j \neq i} p_j), i = 1...n$. All other model assumptions remain as outlined in §2. The general Bayesian-Nash equilibrium for the second-stage price decisions is again $p_i^* = P + B_i(x_i - \mu)$, where

$$P = \frac{a + b\mu}{b(2-\gamma)} \text{ and } B_i = \frac{w_i}{X_i}$$

with $X_i = 2(1 - D_j) - \gamma w_i D_j$ and $D_j = \gamma \sum_{j \neq i} \frac{w_j}{2 + \gamma w_j}$.  \hspace{1cm} (A.17)

The cost of information and the expected benefit of information remain as given for the duopoly. Thus, for the acquisition of cost information, the following first-order conditions obtain, which have the same structure as for the duopoly case.

$$\frac{\partial \Pi_i}{\partial w_i} = \frac{Z_i}{w_i X_i (1 - X_i)} \left(4(1 - D_j) - X_i (1 + X_i)\right) - \kappa_i \frac{1}{(1 - w_i)} = 0, i, j = 1, 2, i \neq j. \hspace{1cm} (A.18)$$
Again, due to the negative competitive effect, it is possible that the marginal expected value of cost information is zero for $w_i < 1$ when products are close substitutes (expression in parentheses in (A.18)). This limits the strategy space for the acquisition of cost information. Like for the duopoly case, it follows from the second-order conditions (available from the author) that (i) an interior solution exists and (ii) the best-response functions are always upward sloping for demand information and always downward sloping for cost information. The relevant condition that determines when the equilibrium for cost information turns asymmetric generalizes as follows:

**Proposition 2’.** There exists an interior equilibrium amount of cost information $w_i^*$, $i = 1 \ldots n$, which is determined by the first-order conditions (A.18). When $\lambda > \Lambda_n$, where

$$\Lambda_n = \frac{bu^2(1-\omega)^{1/2}(4(n-1)-4(2n-3)\gamma\omega\delta+4n-9)\omega^2}{(2-\gamma\omega)^{1/2}(2(n-1)+\gamma\omega)^2},$$

(A.19)

the equilibrium for cost information is unique and symmetric, i.e., $w_i^* = w_j^* = \omega$. When $\lambda < \Lambda_n$, there exist $n$ asymmetric interior equilibria, where $w_i^* > w_j^* = w^*$, $i \neq j$. The firm that acquires more cost information has higher expected profits than all other firms. The likelihood of an asymmetric equilibrium increases with the number of firms $n$.

Condition (A.19) follows from the same stability condition as condition (3).