INFORMATION ACQUISITION BY FIRMS: THE ROLE OF SPECIALIZATION, MOTIVATION AND ABILITY

by

M. CHRISTEN*

98/77/MKT
(Revised Version of 97/106/MKT)

* Assistant Professor of Marketing at INSEAD, Boulevard de Constance, 77305 Fontainebleau Cedex, France.

Information Acquisition by Firms:
The Role of Specialization, Motivation and Ability

Markus Christen

INSEAD

July 1, 1998

Markus Christen is Assistant Professor of Marketing at INSEAD, Boulevard de Constance, 77305 Fontainebleau-Cedex, France (tel: +33-1-60-72-44-38; fax: +33 1 60 74 55 34; email: markus.christen@insead.fr. The author would like to thank Bill Boulding and Rick Staelin for their invaluable help and input. He also thanks Reinhard Angelmar, Hubert Gatignon, Phil Parker, and David Soberman for their comments.

Information Acquisition by Firms:
The Role of Specialization, Motivation and Ability

Abstract

Today, firms have access to more timely and detailed data about all market aspects than ever before. However, they often lack resources and time to process all data into insights useful for decision making. Therefore, a critical step in the acquisition of information is the choice of data that should be processed. In this paper, we propose that the acquisition of information for decision making can be viewed as an allocation of limited managerial resources to process data about different market aspects. The optimal allocation must then consider two possible tradeoffs: (1) a tradeoff between breadth and depth of information, and (2) a tradeoff between motivation and ability to generate information. Given their limited data processing resources, firms must strike a balance between two extreme approaches to find the right degree of specialization. They can either diversify their resource allocation and process a limited amount of data about as many market factors as possible to acquire *broad* information or focus it on all available data about a single market factor to acquire *deep or detailed* information. In addition, when the various market aspects differ with respect to uncertainty, i.e., motivation to generate information, and ability to generate information, firms must decide whether to be more sensitive to higher uncertainty or better ability.

This paper develops a parsimonious game-theoretic model to examine these two tradeoffs in the acquisition of information. It consists of two Cournot competitors that face uncertainty about demand and cost conditions. We determine the perfect Bayesian equilibria of the two-stage game and then analyze the effects of uncertainty, degree of competition, availability of data and a firm's ability to process data on the acquisition of information.

Our analysis yields the following insights about the two tradeoffs. First, the optimal tradeoff between breadth and depth of information depends on the particular environment. When uncertainty is high, firms should acquire broad information, i.e., diversify their resource allocation. The incentives to specialize and acquire more detailed information increase with competition, the

availability of data and the firms' ability to generate information. Second, the optimal tradeoff between motivation and ability to generate information also depends on the environment. However in most situations, the optimal acquisition of information is more sensitive to the ability to generate information. Only when uncertainty is low and ability high or when the differences in uncertainty are very large, is the allocation more sensitive to uncertainty differences.

This paper is the first to analytically examine these two tradeoffs and makes a number of important contributions to our understanding of the acquisition of information by firms. First, it provides a framework grounded in economic theory to examine these tradeoffs. This framework can be extended to study other firm activities such as the resource allocation to process and product R&D. Second, it offers a normative explanation for why firms sometimes ignore data about market factors or stick to doing what they know best. The above results can be used to make predictions when these behaviors occur more likely. For example, early in the product life cycle, firms should more likely acquire broad information, while in mature markets they should more likely specialize and acquire detailed information. Third, it shows that identical Cournot duopolists may acquire different information. This occurs when the firms specialize since it allows them to reduce the effect of competition on expected profits, even though product substitutability remains unchanged. Thus, in markets with strong competition, limited uncertainty and good ability to process data, firms are more likely different. Fourth, the results show that when specialization is preferred to diversification, minor environmental changes can force firms to drastically change their information acquisition. Finally, the paper yields insights for data providers who need to assess the demand for different types and qualities of data products. For example, in stable, highly competitive markets, such as consumer packaged goods markets, firms more likely pay extra for highly accurate information.

(Information Acquisition, Specialization Vs. Diversification, Motivation Vs. Ability, Game Theory)

"The fox knows many little things, but the hedgehog knows one big thing."

Archiluchus, Greek Poet

1. Introduction

Imagine a firm that is developing a new generation of widgets. The new line of products is expected to broaden the target market. In addition, the production will be based on a new manufacturing process. The schedule for the new product introduction requires the firm to decide on the size of the production facility for the new widgets. Though the firm, i.e., its managers, can draw on prior experience, several factors of the market environment remain uncertain. They are uncertain about factors such as the market potential, the implications of the new production process, or competition for its new widgets. However, they have access to data, such as reports from numerous internal cost and external market studies, to better understand these various uncertain factors. Unfortunately, they lack time and resources to fully evaluate all available data. By using more time and postponing the decision, the firm risks falling behind its competitors. Increasing resources, e.g., hiring more managers to process the data, is not feasible in the short run. Consequently, the managers must decide which data to study at what level of detail. How should the widget manufacturer allocate its limited managerial resources to learn about its market environment? Should it acquire limited information about many market factors or acquire detailed information about few market factors? How does the level of competition affect this decision? What if the firm has better production engineers than market researchers, but is more uncertain about the market potential for its new widgets than the production costs? Should it take advantage of the greater expertise to process production data or address the greater need for information about the market potential?

Acquiring and managing information has become one of the most important strategic issues for firms. In a survey among European managers, 89% of the respondents indicated that information and knowledge is key to gain a competitive advantage and thus to long-term success (Murray and Myers 1997). Firms' information activities are typically conceptualized as consisting of a series of processes, namely acquisition, dissemination and utilization (Huber 1991). The focus of this paper is on managers' acquisition of information for decision making. We ignore dissemination issues and assume that acquired information is used optimally.

There is no universally accepted concept of information (Machlup and Mansfield 1983). In this paper, we follow the definition that is commonly used in the marketing literature and consider information as *data that have been interpreted into a form meaningful to users* (Blattberg et al. 1994). In other words, we make a clear distinction between data and information.[1] Data such as scanner data provide the raw material for information, but do not directly help managers make better decisions. Consequently, we regard the acquisition of information as learning, i.e., the process of *becoming aware of or understanding new market insights* (Day 1994). This requires the processing or "sensemaking" of available data (Thomas et al.1993).

As we will argue next, the information acquisition problem of the widget manufacturer is a representative description that applies to many firms. For example, as it integrated McDonnell Douglas, Boeing decided to stop two of the three projects for new passenger jets it inherited from McDonnell Douglas due to redundancy. The reason given for continuing the third project was uncertainty about the market demand and the production cost for the plane. A final go/no-go decision would be made in 1998 after having further studied the problem. Despite the strategic role of market knowledge and thus the acquisition of information, no theoretical research exists to provide answers to the widget manufacturer's questions or Boeing's problem as the issue is more complicated than simply determining how much information should be acquired. The objective of this paper is to provide answers by analyzing the acquisition of information by firms and determining the effect of different firm and market characteristics. In particular, we are interested in the effect of market uncertainty, competition, the availability of data and firms' capability to process data.

[1] Sometimes, the process by which data is brought from the external environment into the boundary of the firm is referred to as information acquisition (Kiesler and Sproull 1982). We consider this as the collection of data, a step that necessarily precedes the acquisition of information by managers.

1.1 Information Acquisition: Breadth Vs. Depth

The strategic value of information and with it the acquisition of information has been increasing for several reasons. First, firms have an increasing need for information to update their market knowledge (Day 1994; Murray and Myers 1997). The emergence of new markets and competitors, the increasing rate of changes in customer preferences, globalisation, and deregulation have all contributed to a dramatic reduction of the half-life of usable market knowledge. This list of trends illustrates that the need for information is not limited to a single market factor, but applies to most or all market factors. Second, advances in information technology offer more timely and detailed data about these different market factors. However, the amount of available data often overwhelms a firm's capacity to process all data. Technology advances in data generation and transmission far outpace advances in data processing, i.e., information generation. Moreover, firms often lack the ability to employ even existing technology to generate information (Blattberg et al. 1994). As a result, processing more data is not an answer to the firms' information acquisition problem, making the choice of data to be processed, i.e., what to learn, more and more important.

The introduction of scanners at the retail level with the associated emergence of point-of-sales data illustrates this dilemma. These data, particularly when combined with tools to identify individual households, have great potential to better understand consumer behavior and to increase profitability through more effective promotion and pricing strategies. Interestingly, the biggest change in retailing is the emergence of everyday low pricing (EDLP), a promotion and pricing strategy that requires comparatively less information. The problem with scanner data is not the quality, but the exploding quantity. According to IRI, a single category file contains about 50 million bits of information. It takes a human mind at peak attention more than 19 weeks of full-time effort to review the data (Kelly 1994). Although manufacturers are generally more sophisticated in analyzing market data, they face a similar challenge. A consumer packaged goods brand manager in the US is confronted with 2 million new numbers each week (McCann and Gallagher 1990).

Since learning about a market requires learning about its different factors, information about a market can be described along two dimensions – breadth and depth. *Breadth of information* refers to the number of different market factors covered by the information. Information that contains insights about many factors, such as customers, competitors or cost, is broad or diversified. *Depth of information* refers to the level of detail or accuracy of information about each market factor. In an ideal world, acquired information would be both broad and detailed. However, because of the inability to process all available data, firms must find a balance between breadth and depth of information.

This balance is somewhere between the following two extreme approaches. Firms can either process a limited amount of data about as many market factors as possible to acquire broad information or focus on all available data about a single market factor to acquire deep or detailed information. For example, Boeing could decide to focus on assessing the market potential and obtain a very accurate demand forecast, but in the process learn nothing new about production costs. Alternatively, it could decide to study both and learn the general level of market potential and production costs. In the former case, Boeing would acquire deep or detailed information, in the latter case broad information. Similarly, a retailer could focus on understanding consumers' sensitivity to promotions in detail at the store level for a few product categories or broadly study consumer responses for many different product categories at a more aggregate level.

The tradeoff between breadth and depth of information is a direct consequence of two basic premises underlying this paper: (i) firms need information about different market aspects to make decisions, and (ii) firms have insufficient resources to process all available data about them. Despite the importance of this tradeoff in the acquisition of information, it has been largely ignored in the literature. Though the acquisition of information is a key element of a market orientation, Kohli and Jaworski (1990) do not distinguish between information about different market factors nor address the tradeoff between breadth and depth of information. In contrast, Day and Nedungadi (1994) consider attention to both customer and competitor data necessary for a market orientation. They suggest that this orientation should generally be preferred to a selective focus. Said differently, in today's market environments firms should generally prefer broad information (see also Day 1994). Empirical evidence from studies that try to explain firm performance with information acquisition behavior tends to indicate an association rather than a causal link and does not yield insights about this tradeoff (e.g., Glazer et al. 1992; Narver and Slater 1990; Thomas et al.1993). In contrast, Eisenhardt (1989), in her study of strategic decision making in high-tech firms, found that how managers deal with this tradeoff depends on the particular environment. In slower paced industries, managers considered fewer alternatives at greater depth than managers who operated in high-velocity environments. In other words, managers favored depth over breadth when faced with less uncertainty.

In the economics literature, there are two different analytic research streams that examine the acquisition of information. One stream examines how much information a firm should acquire about a single uncertain market factor (e.g., Hwang 1993; Li et al. 1987) and whether it should share private information with its competitors (e.g., Gal-Or 1985; Malueg and Tsutsui 1996; Vives 1984). These models assume that costly information is available from an outside research firm. In contrast, adaptive control models assume that firms learn by observing market outcomes. Research based on such (dynamic) models examines how decisions (e.g., pricing) should be adjusted to simultaneously optimize learning and profits (e.g., Grossman et al. 1977; Harrington 1995; Little 1966).[2] However, neither stream considers what happens when firms face (i) limited resources to process data and (ii) multiple uncertain market factors. As a result, they cannot analyze the tradeoff between breadth and depth of information.

Cyert et al. (1993) explore learning about customer preferences *and* costs. Their study focuses on how learning changes over time. Information is obtained by observing market outcomes. The results suggest that firms should focus first on customer data. Over time, cost data grow in relative importance and should gradually receive more attention. Although it assumes multiple uncertain factors, the study does not explicitly examine the tradeoff between breadth and depth of information. The results are largely driven by higher initial uncertainty about customer preferences.

[2] Issues of information acquisition have also been addressed in the auction literature (e.g., Matthews 1984; Milgrom 1981) and the analyses of noisy rational expectations models of a financial market (e.g., Grossman and Stiglitz 1980; Verrecchia 1982).

1.2 Information Acquisition: Motivation Vs. Ability

Focusing on a few market factors may not only be optimal because of the value of specialization, but also because market factors may differ with respect to uncertainty, i.e., motivation to generate information, and ability to generate information. In fact, firms often have more data available about internal factors and are better capable to process them, but face more uncertainty about customers or competitors. For example, Drucker (1997) reports that 90% of the data available in a typical firm relate to internal processes. This contrasts with a great perceived need for customer information (Murray and Myers 1997). Thus, firms often face a tradeoff between addressing a greater need for (demand) information and taking advantage of a better ability to generate (cost) information.

Although these two prerequisites for information acquisition or variations of them play important roles in different research streams, no theoretical research exists about possible differences in sensitivity to them. For example, the Elaboration Likelihood Model (ELM) of attitude changes postulates different routes to message processing depending on the presence or absence of ability and motivation to process (Petty and Cacioppo 1986). Boulding and Staelin (1993; 1995) use the motivation-ability framework to study the effect of firm actions on performance. March (1991) described organizational learning as striking a balance between exploring the unknown and exploiting the known. He argued that firms have an incentive to overinvest in exploitation since it yields more positive and more certain returns in the near term. In contrast, the returns to exploration are generally lower and more remote in time. Yet, exploration offers a better chance to be successful in the long-run, in particular in markets with strong competition for relative position. Finding the right balance is important, but difficult. Thus, there is considerable value in gaining theoretical insights about the relative sensitivity of the expected value of information to these two factors.

1.3 Overview and Contributions

The basic premise of this paper is that the acquisition of information by firms can be viewed as an allocation of limited managerial resources to process data about different market aspects.[3] The

[3] The view of information acquisition as an allocation of resource other than money is consistent with the description of information acquisition as attention (Bettman 1979; Kahneman 1973) or awareness (Rogers 1983).

optimal allocation of these resources requires a tradeoff between breadth and depth of information, or *diversification* and *specialization*, and a tradeoff between *motivation* and *ability* to generate information. Given increasing competition, rapid changes in markets and advances in information technology, it is important for firms to process the "right" data. Therefore, there is considerable value in examining the widget firm's information acquisition problem – for academics to better understand firm behavior, for consultants to help firms with similar problems, and for data providers to better understand their customers' "product" needs.

There are three key insights from our analysis. First, the optimal tradeoff between breadth and depth of information depends on the particular environment. With high uncertainty, firms diversify and acquire broad information. The incentives to specialize and acquire more detailed information increase with competition and the ability to generate information. Second, specialization enables identical Cournot duopolists to reduce ex-ante competition for information by processing different data. Third, the optimal tradeoff between motivation and ability to generate information also depends on the environment. However in most situations, ability dominates motivation. Among other conclusions, these results provide an economic explanation why firms ignore available data or stick to doing what they know best and offer an indication to information sellers when firms may want a diverse set of information products or should be more willing to pay extra for highly accurate information.

In the next section, we formally develop a game-theoretic model that includes our assumptions underlying the acquisition of information and captures the two tradeoffs. In §3, we derive the analytic solutions of the two-stage game. This is followed by a detailed examination of the analytic results. In particular, we determine when competing firms should prefer broad to detailed information and when motivation outweighs ability to generate information, and vice versa. We conclude with a discussion of the implications and potential limitations of our research.

2. The Model

2.1 Model Description

The model we use is similar to those in previous studies of information acquisition (see Hwang 1993 or Li et al. 1987). We assume that the market consists of two identical, risk neutral firms that produce and sell a single product. In contrast to extant game-theoretic models, we assume that firms obtain information by using their *limited* management resources to process data that are available to the firm. Moreover, our model includes uncertainty about demand *and* cost conditions.

The two firms compete with each other by setting the production output for their products. While in marketing we often think of firms as competing on prices rather than quantities, Kreps and Scheinkman (1983) note that the outcome of the quantity-setting (Cournot) model is also the outcome when firms first choose capacities and then compete on a basis of price. Since Cournot models have relevance for many situations where firms make strategic decisions before pricing that can reduce price competition, it is appropriate given our interest in the acquisition of information for a specific strategic decision.

The game consists of two stages. In the first stage, firms generate private information by allocating their data processing resources to available data about demand and cost, respectively. We label these resources *management time*. A firm can allocate its management time equally to demand and cost data – a *balanced* allocation – or focus (more) on either demand or cost data – an *unbalanced* or *focused* allocation. A balanced allocation of resources means that a firm diversifies and acquires broad information. Similarly, an unbalanced allocation means that a firm specializes and acquires narrow but detailed information. In the second stage, each firm sets the production level of its product using the acquired information. We determine the pure strategy equilibria for the whole game and analyze the effect of firm and market factors on the equilibrium allocation of management time.

2.2 Model Specification

The market environment is described by a linear inverse demand function and a linear marginal cost function:

$$p_i = a - b \cdot q_i - d \cdot q_j, \quad a, b > 0, \quad 0 \le d \le b, \tag{1}$$

$$m_i = c + e \cdot q_i, \quad c > 0, \quad e \ge 0, \quad i, j = 1, 2, i \ne j. \tag{2}$$

Each firm determines its output, q_i, and the market place determines the market clearing price, p_i. The *degree of competition* is captured by the product substitutability, d. Competition is highest when the products are homogeneous, i.e., $d = b$, and lowest when they are independent, i.e., $d = 0$. Both firms are risk neutral and maximize expected profit $E\pi_i = q_i \cdot E(p_i - m_i)$, $i = 1, 2$. We do not include a cost of information acquisition since we assume that management time is a fixed firm resource whose cost does not vary with the allocation to available data. Therefore, we set this cost to zero, without loss of generality. The assumption that available data exceeds managers' capacities to process them is not only consistent with advances in information technology, but also with the observation that much of problem-oriented market research is not utilized (Deshpandé and Zaltman 1982).

The firms are uncertain about *shifts* in demand and marginal cost, i.e., the parameters a and c, respectively. The demand parameter a represents the market potential and the cost parameter c the level of costs for the firms' products. We make the following assumptions about the firms' prior uncertainty: (1) the two firms are equally uncertain; (2) the two parameters, a and c, are independent; and (3) uncertainty is captured by a continuous distribution, $f_I(\theta)$, with existing mean vector, $E[\theta] = [\mu_a \ \mu_c]^T$. Given these three assumptions, the covariance matrix of this distribution can be written as:

$$V[\theta] = \begin{bmatrix} u_a & 0 \\ 0 & u_c \end{bmatrix}, \quad \text{where } \theta = \begin{bmatrix} a \\ c \end{bmatrix}. \tag{3}$$

$E[\theta]$ represents the firms' *prior beliefs* and the variances u_a and u_c the level of *demand* and *cost uncertainty*, respectively. The distribution, $f_1(\theta)$, is common knowledge and all other demand and cost parameters, i.e., b, d, and e, are assumed to be known to both firms.

Processing available data yields two signals, one about demand, x_{ai}, and one about cost, x_{ci}, in the form of $x_i = \theta + \varepsilon_i$, where $\varepsilon_i = [\varepsilon_{ai}\ \varepsilon_{ci}]^T$ and $x_i = [x_{ai}\ x_{ci}]^T$.[4] The amount of management time employed to process data determines the error, ε_i, in these two signals. Because of the lack of sufficient management time, firms cannot obtain perfect information and the two signals will always contain some error. The effect of management time, τ, is captured by the function $\phi(\tau)$. In addition, we make the following assumptions about the error in the acquired information: (1) the error is described by a continuous distribution, $f_2(\varepsilon_i)$; (2) the information is unbiased, i.e., $E[\varepsilon_i] = 0$; (3) the error is independent of the true parameters, i.e., $Cov(\theta\varepsilon_i) = 0$; and (4) the error in demand information is independent of the error in cost information, i.e., $Cov(\varepsilon_{ai}\varepsilon_{ci}) = 0$ (i = 1, 2).

Since all data are potentially useful, available management time can be set to 1 without loss of generality.[5] As a result, if firm i allocates t_i of its management time to process demand data, it allocates the remaining fraction, $1-t_i$, to process cost data. Therefore, the covariance matrix for the error, ε_i can be written as follows:

$$V[\varepsilon_i] = \begin{bmatrix} \phi_a(t_i) & 0 \\ 0 & \phi_c(1-t_i) \end{bmatrix}, \quad 0 \le t_i \le 1; \quad i = 1, 2. \tag{4}$$

The variable t_i represents firm i's resource allocation. When $t_i = 0.5$, firm i allocates its management time equally to demand and cost data, respectively. Otherwise, the allocation is unbalanced and the firm processes either more demand ($t_i > 0.5$) or more cost information ($t_i < 0.5$). The functions ϕ_k are

[4] The information acquisition is not sequential and each firm generates only one set of information. The allocation of management time to process data is made prior to seeing any information and cannot be changed retroactively.

[5] This implies that (i) firms cannot be overloaded with information and (ii) no strategic advantage of ignorance exists. In contrast, Gal-Or (1988) shows that a firm benefits from ignorance about cost when the error in the acquired information is related to the production level. In our model, the error in information does not depend on the second-stage (production) decision. An advantage of ignorance can also arise when one firm can learn from the other by observing decisions. However, we assume simultaneous decision making, which eliminates this strategic consideration.

assumed to be continuous and twice differentiable. More management time always reduces error, i.e., $\phi_k' < 0$, but at a diminishing rate, i.e., $\phi_k'' > 0$. In other words, acquiring more detailed information requires more management time and becomes more and more difficult. Firms can have different data processing functions, ϕ_k, for demand and cost information (k = a, c).

The acquired information is used to update the beliefs, E[θ], about demand and cost. The distributions, $f_1(\theta)$ and $f_2(\varepsilon_i)$, are such that the Bayesian updating results in linear posterior expectations, i.e.,

$$E[a \mid x_i] = \mu_a + w_{ai}(x_{ai} - \mu_a) \quad \text{and} \quad E[c \mid x_i] = \mu_c + w_{ci}(x_{ci} - \mu_c),$$

$$\text{where} \quad w_{ai}(t_i) = \frac{u_a}{u_a + \phi_a(t_i)} \quad \text{and} \quad w_{ci}(t_i) = \frac{u_c}{u_c + \phi_c(1 - t_i)}. \tag{5}$$

From (5) also follows that $E[x_j \mid x_i] = E[\theta \mid x_i]$, i, j = 1, 2, i ≠ j. The distributional assumption underlying (5) 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 non-negativity constraints on the uncertain parameters. The updated beliefs about the market, $E[\theta \mid x_i]$, are a weighted average of the prior beliefs, E[θ], and the new information, x_i, where w_{ai} and w_{ci} are the respective weights given to demand and cost information.

One objective of this paper is to determine the effect of firm and market characteristics on a firm's optimal information acquisition. Two characteristics of interest are *uncertainty* and degree of *competition*, which are captured by the parameters u_k and d, respectively (k = a, c). Another important characteristic is the ability to generate information. This ability is determined by a firm's capacity and capability to process data (e.g., number and quality of managers) and the quality or diagnosticity of available data. To keep the model parsimonious, we capture these three different characteristics with one parameter. Changes in this ability lead to shifts in $\phi(\tau)$ for any τ. We measure these shifts at the point of the most accurate information obtainable about one factor by allocating all available management time to the same data. More specifically, we define it as the inverse of the error $\phi(1)$ and label it *effectiveness of management time*, η. In other words, a firm's effectiveness of management time to process demand data is $\eta_a = 1/\phi_a(1)$ and to process cost data $\eta_c = 1/\phi_c(1)$. Uncertainty and effectiveness of management time allow us to examine the tradeoff between motivation and the ability to generate information.

The model developed in this section is a parsimonious description of two firms with limited prior knowledge that compete with each other through setting production levels *and* acquiring information. It closely represents the problem of the widget manufacturer or Boeing and allows us to examine the two tradeoffs identified in the previous section. We next present the equilibrium analysis of this two-stage game.

3. Equilibrium Analysis

The equilibrium concept we use is that of a *perfect Bayesian equilibrium* (Fudenberg and Tirole 1991). The pure strategy equilibria of the game are found by proceeding backwards in two steps. First, the unique Bayesian-Nash equilibrium of the second stage of the game, $q^* = (q_i^*, q_j^*)$, is determined for given allocations $t = (t_i, t_j)$. The first-stage decision, i.e., the equilibrium allocation of management time, $t^* = (t_i^*, t_j^*)$, i, j = 1, 2, i $\neq$ j, is then found by assuming that the profits from the first stage decisions are determined by equilibrium behavior in the second stage of the game. Both firms are expected to adhere to this strategy.

Initially, we will focus our analysis on situations without differences between demand and cost, i.e., $u_a = u_c = u$, $\phi_a = \phi_c = \phi$, and $\eta_a = \eta_c = \eta$. This allows us to directly analyze the tradeoff between breadth and depth of information. To enhance the readability, we only show the analytic results in the text. Proofs are shown in Appendix A.

3.1 Equilibrium Output

Given the common knowledge of the distributions $f_1(\theta)$ and $f_2(\varepsilon_i)$ and the allocation of management time, $t = (t_i, t_j)$, chosen in the first stage, firm i determines its output, q_i^*, by maximizing expected profit conditional on its information, x_i, i.e., $\Pi_i = E[\pi_i \mid x_i] = q_i \cdot E[p_i - m_i \mid x_i]$, i = 1, 2.

PROPOSITION 1. *For any allocation of management time, $t = (t_i, t_j)$, there is a unique Bayesian equilibrium to the second-stage game, which is linear in the information, x_i. More specifically,*

$q_i^* = Q + K_{ai}(x_{ai} - \mu_a) + K_{ci}(x_{ci} - \mu_c)$, where for i, j = 1, 2, i ≠ j,

$$Q = \frac{\mu_a - \mu_c}{2\beta + d}, \quad K_{ai} = w_{ai}\frac{2\beta - d \cdot w_{aj}}{\xi_a}, \quad \text{and} \quad K_{ci} = -w_{ci}\frac{2\beta - d \cdot w_{cj}}{\xi_c},$$

$$\text{with} \quad \beta = b + e \quad \text{and} \quad \xi_k = 4\beta^2 - d^2 w_{ki} w_{kj}, \quad k = a, c. \tag{6}$$

The result in Proposition 1 is similar to that in Hwang (1993). The equilibrium output, q_i^*, is adjusted upward or downward from the ex-ante equilibrium quantity, Q, depending on the deviation of the information, x_i, from prior beliefs, E[θ]. The value of information is determined by its impact on expected profit through changes in the output decision, q_i^*, from Q. If a risk neutral firm does not expect information to change its decision, the information has no expected value. It is therefore important to understand the sensitivity of the output decision, q_i^*, to information x_i.

First, the sensitivity, K_{ai}, to demand information depends on the weight, w_{aj}, the competitor gives to demand information, which in turn depends on the competitor's allocation of management time, t_j. The quantity adjustment is larger, the less management time the competitor allocates to demand data and thus, the noisier its resulting information. If the error in the competitor's demand information is low, the firm's new insights about demand are more likely to be known to the competitor and thus, less useful to gain an advantage. This is consistent with the finding that Cournot competitors do not want to share private information (Vives 1984).

Second, K_{ai} increases as the error in the demand information, $\phi(t_i)$, for a given t_i decreases or uncertainty, u, increases. In both cases, the firm has more confidence in the demand information, x_{ai}, relative to its prior belief, μ_a (see (5)). The error, $\phi(t_i)$, decreases when more management time, t_i, is allocated or when the allocated management time is more effective, i.e., when η is higher.

Third, the more substitutable the products, i.e., the higher d, the smaller the quantity adjustment. Competition limits the potential for quantity adjustments and thus, the expected value of information. For the same reason, the marginal effect of information decreases with both b and e. Steeper inverse demand or marginal cost functions leave less "room" for quantity adjustments. To simplify the notation, we define $\beta = b + e$ without loss of generality.

Finally, these insights about K_{ai} also apply to the magnitude of the marginal effect of cost information, K_{ci}, although the quantity adjustment due to cost information, x_{ci}, is in the opposite direction ($K_{ci} < 0$). From the symmetry of (6) follows that the expected value of demand information is no different than the expected value of cost information – for a given amount of management time. A preference for either of them must be based on a preference for specialization over diversification.

3.2 Equilibrium Information Acquisition

If identical firms follow their output decisions (6) in the second stage of the game, the expected unconditional profit as a function of the firms' allocation of management time, $t = (t_i, t_j)$, is:

$$E[\Pi_i(t)] = \beta(\Pi_0 + Z_i(t)), \quad \text{with}$$

$$\Pi_0 = Q^2 \quad \text{and} \quad Z_i(t) = K_{ai}^2\left(u + \phi(t_i)\right) + K_{ci}^2\left(u + \phi(1 - t_i)\right), \tag{7}$$

where Π_0 represents the expected profit without information and $Z_i(t)$ the expected value of information.[6] The equilibrium allocation of management time $t^* = (t_i^*, t_j^*)$, can be determined from the payoff function $Z_i(t)$, which yields the following first-order conditions:

$$\frac{\partial Z_i(t)}{\partial t_i} = -K_{ai}^2 \frac{\zeta_a}{\xi_a} \phi'(t_i) + K_{ci}^2 \frac{\zeta_c}{\xi_c} \phi'(1 - t_i) = 0, \tag{8}$$

and second-order conditions:

---

[6] The result follows directly from $E[\Pi_i(t)] = \beta \cdot E_i[q_i^{*2}]$ and $E[q_i^{*2}] = E[q_i^*]^2 + V[q_i^*]$.

$$\frac{\partial^2 Z_i(t)}{\partial t_i^2} = \frac{K_{ai}^2}{\xi_a^2}\left[\frac{8\beta^2\phi'(t_i*)^2}{u+\phi(t_i*)}\left(\zeta_a + d^2 w_{ai} w_{aj}\right) - \xi_a\zeta_a\phi''(t_i*)\right]$$
$$+\frac{K_{ci}^2}{\xi_c^2}\left[\frac{8\beta^2\phi'(1-t_i*)^2}{u+\phi(1-t_i*)}\left(\zeta_c + d^2 w_{ci} w_{cj}\right) - \xi_c\zeta_c\phi''(1-t_i*)\right] < 0, \quad i = 1, 2, \qquad (9)$$

where $\zeta_k = 4\beta^2 + d^2 w_{ki} w_{kj}$, and ξ_k is as defined in (6) (k = a, c).

From (9) follows immediately that $\phi'' > 0$ is a necessary condition for an interior solution. If the returns to management time are non-diminishing, i.e., $\phi'' \leq 0$, the optimal allocation will always be a corner solution, i.e., $t_i = 0, 1$. Firms would always be completely specialized. We next describe the equilibrium of the full game.

PROPOSITION 2. *For identical firms, any equilibrium allocation of management time, t_i* and t_j*, $i \neq j$, must lie on the linear line*

$$t_j* = 1 - t_i*. \qquad (10)$$

Proposition 2 describes the potential equilibrium strategies of the game. Existence and uniqueness follow from the properties of the payoff and best response functions. The best response functions, $t_i = r_i(t_j)$, i, j = 1, 2, i ≠ j, are monotone decreasing (see Appendix A). However, since the equilibrium line (10) is also decreasing, neither the existence of an interior equilibrium nor its uniqueness is ensured since the best response curves could cross not at all or more than once. Thus, further conditions on the parameters are needed to establish the actual equilibrium allocation of management time. They follow from the properties of the best response and payoff functions.

PROPOSITION 3. *The necessary and sufficient condition for a* ***balanced*** *allocation of management time, i.e., $t_i* = 0.5$, to be the unique equilibrium of the game is $\phi'' > R_0$, where*

$$R_0 = \frac{2\phi'^2}{u+\phi}\cdot\frac{2\beta}{2\beta - d\cdot W} > 0, \quad \text{with } W = w_{ai}(0.5) = w_{ci}(0.5),\ i = 1, 2. \qquad (11)$$

When $\phi'' \leq R_0$, the equilibrium allocation of management time is ***unbalanced*** *and the game has two symmetric equilibria, i.e., $t_i* = 1 - t_j* \neq 0.5$, $i, j = 1, 2$, $i \neq j$.*

COROLLARY 4. *The second-order condition at $t_i = 0.5$ is not a sufficient condition for a balanced equilibrium allocation of management time for $d > 0$.*

COROLLARY 5. *When the equilibrium allocation of management time is unbalanced, i.e., $\phi'' \leq R_0$, identical firms acquire different information.*

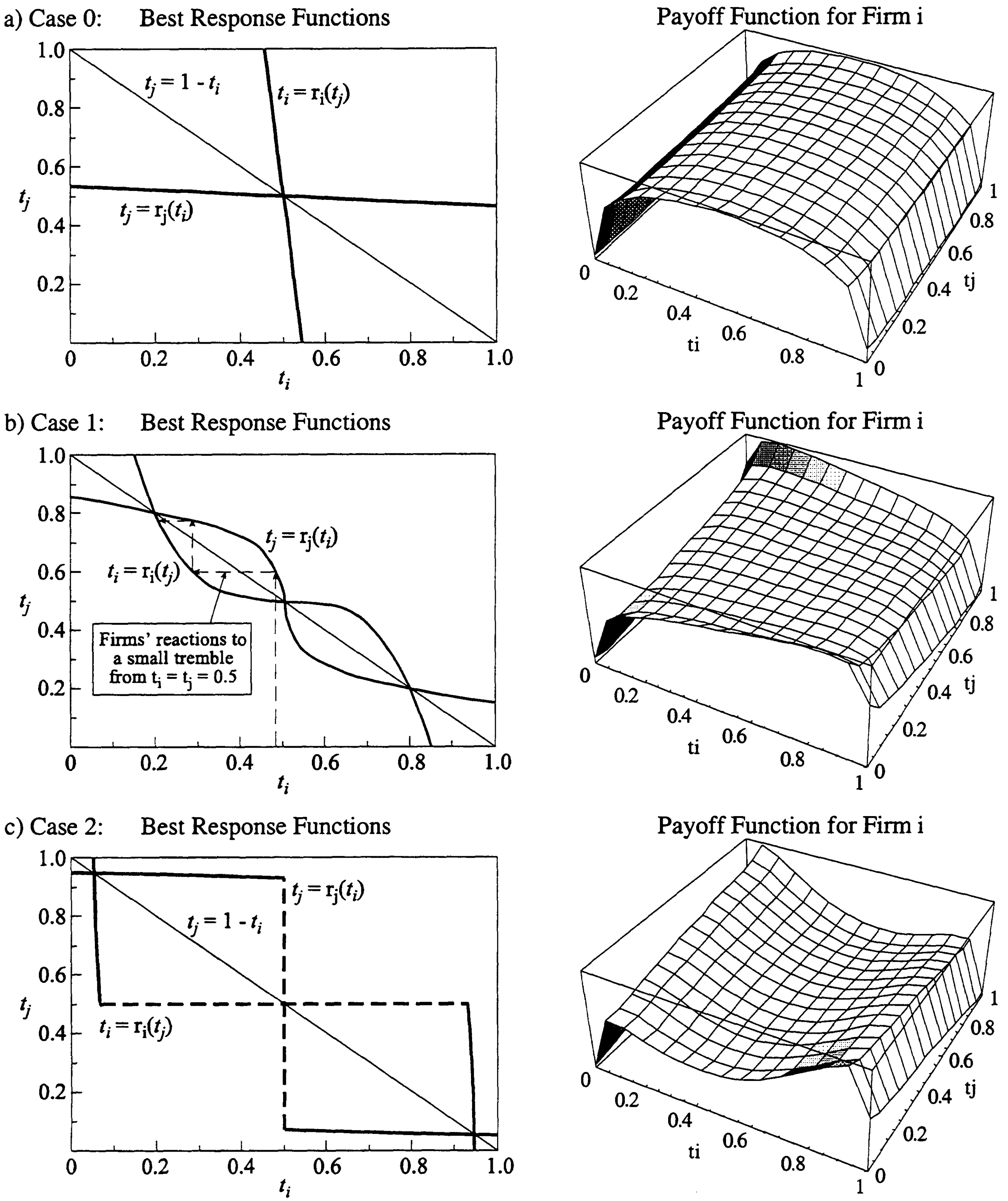
There are a number of comments in order about these results. First, condition (11) follows from the stability condition for the payoff function, $Z_i(t)$, to be bounded and concave. This together with the fact that the best response functions, $t_i = r_i(t_j)$, are monotone decreasing ensures existence and uniqueness of the equilibrium, $t_i^* = 0.5$, i = 1, 2 (Huang and Li 1990). It determines the degree of diminishing returns of management time required for a balanced allocation.

Second, $t_i = 0.5$, i = 1, 2, always satisfies the first-order conditions (8). However, this allocation can be a maximum or a minimum (see second-order conditions (9)). Moreover, according to Corollary 4, condition (11) is more restrictive than the second-order conditions for $t_i = 0.5$, i = 1, 2, which implies that not every profit maximum at $t_i = 0.5$, i = 1, 2, is also an equilibrium of the game. Therefore, there are three separate cases with different implications for the equilibrium allocation.

The best response and payoff functions associated with these three cases are illustrated in Figure 1. In case 0, condition (11) is satisfied and the payoff function, $Z_i(t)$, is nicely behaved (Figure 1a). In this case, firms should diversify their information acquisition, i.e., prefer broad over detailed information. In the other two cases, they should specialize and prefer either more demand or more cost information. In case 1, the allocation, $t_i = 0.5$, i = 1, 2, maximizes expected profits, but is not stable or trembling hand perfect. A small deviation or tremble from $t_i = 0.5$ leads to an unbalanced equilibrium allocation of management time (Figure 1b). In case 2, the second-order conditions for $t_i = 0.5$, i = 1, 2, do not hold and the payoff function $Z_i(t)$ has a minimum at $t_i = 0.5$, i = 1, 2 (Figure 1c).

Figure 1[a]

Three Cases of Best Response $r_i(t_j)$ and Payoff Functions $Z_i(t)$



[a]) These figures were created in Mathematica assuming $\phi(\tau) = s - r\tau^k$.

Third, when condition (11) does not hold, there is a pair of symmetric equilibria and the (identical) firms acquire different information. When one firm acquires more demand information, the other firm acquires more cost information, and vice versa. The equilibrium may or may not be an interior solution. In other words, it is possible that firms completely ignore demand or cost data.

Fourth, due to the symmetry between demand and cost, any preference for acquiring more information about either of them reflects a preference for specialization. Thus, the tradeoff between breadth and depth of information, i.e., between diversification and specialization, exists and depends on the particular environment. We next discuss the forces that lead to these results and determine the effect of firm and market characteristics on the optimal acquisition of information.

4. Discussion of Analytic Results

4.1 Diversification vs. Specialization

A closer examination of the analytic results shows that the expected payoff from allocating management time to demand and cost data is largely determined by three factors. First, there is the direct effect of the resources needed to acquire information, i.e., the effect of management time, τ, on the error of information, $\phi(\tau)$. This effect is diminishing by assumption, i.e., $\phi'' > 0$, which favors a balanced allocation or diversification.

However, a firm's objective is not to minimize the total error in the acquired information, i.e., $\phi(\tau) + \phi(1-\tau)$, but to maximize expected profits. Therefore, a second (indirect) effect is the expected impact of the acquired information on the updated beliefs about the market place and subsequently on the firm's production decision. This is captured by the effect of the respective weights given to demand information and cost information on the expected value of information. The expected value of information (7) is a quadratic function of K_{ai} and K_{ci} and thus of the weights w_{ai} and w_{ci}, respectively. In other words, it increases at an increasing rate, which favors a focused allocation or specialization. This is a direct consequence of our assumptions about $f_1(\theta)$ and $f_2(\varepsilon_i)$ and the use of Bayesian updating (see (5)). The distributional assumptions about uncertainty and accuracy of information are not very restrictive, as discussed earlier, and the use of Bayesian updating is a well accepted normative learning process.

The second-order conditions (9) indicate which of the two factors dominates. When the second factor dominates, the situation is as illustrated in case 2 (Figure 1c) and firms should specialize and focus their resources. There is an additional implication of this result. If we accept that the level of a firm's knowledge about different market parameters can be measured by the accuracy of beliefs, it can be represented by a covariance matrix. A focused allocation of resources to acquire information implies that the total error of the acquired information is not necessarily minimized. As a result, when firms have limited resources to learn about a market, it is not always best to aim at becoming the most "knowledgeable" firm.

So far, we have examined two of the three factors, namely the effect of the resources on the accuracy of information and the effect of the accuracy of information on its expected value. The third important factor is competition between the firms. From the discussion in §3.1 and the slope of the best response functions follows that information is a strategic substitute (Vives 1984). Said differently, as one firm acquires more demand information, its competitor acquires less demand information. Specialization and acquiring detailed information allows the firms to differentiate themselves and thereby reduce the negative effect of competition on expected profits, even though product substitutability remains unchanged. As a result, the second-order conditions (9) are not sufficient for firms to prefer broad over detailed information. Firm interactions when learning about a market as important implications. Differences in resource allocation lead to different information and thus to different output decisions. In other words, studying firms' information acquisition behavior is not only important for understanding how they should cope with uncertainty, but also how overall competition between the firms could evolve.

4.2 Effects of Firm and Market Characteristics

Though competition plays an important role in determining the equilibrium allocation, the two most important determinants of the optimal acquisition of information are the level of prior uncertainty, u, and the effectiveness of management time, η. Without any prior knowledge, i.e., $u \to \infty$, firms should always diversify and acquire broad information, regardless of the other parameters. Although the weight given to new information is high, firms should not expect to be competitive when being completely ignorant about either demand or cost.

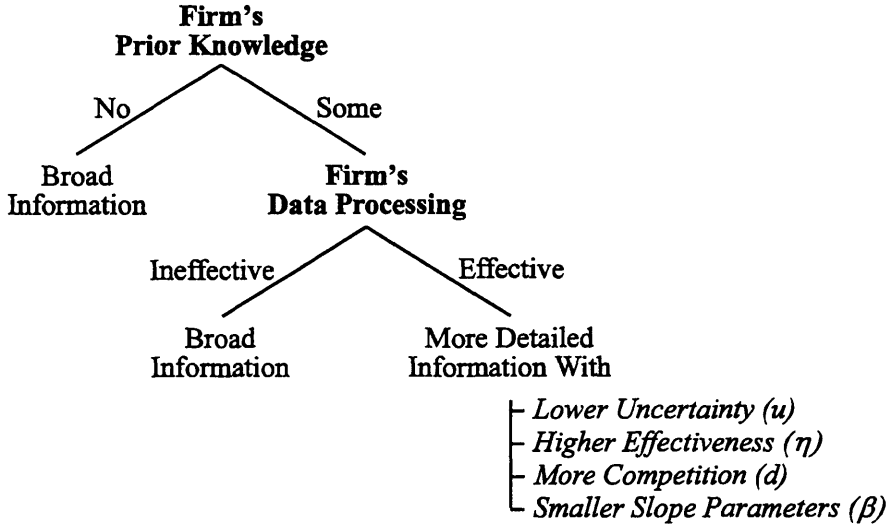
When firms have some prior knowledge and the effectiveness of management time, η, is low, a firm should also diversify and acquire broad information. In this situation, the effect of new information on the subsequent decision remains low and the diminishing returns to management time dominate the allocation. This can occur when firms lack the capacity or capability to process available data or when available data are of poor quality. Therefore, advances in information technology generally increase the incentives to specialize and acquire detailed information. Better data processing software generally increases a firm's capability, while improvements in data collection, e.g., the combination of scanner data with a loyalty program increases the quality of available data. Business schools can also influence managers' capability to process data and thus the preference for broad or detailed information.

When firms have some prior knowledge and management time is somewhat effective, the degree of specialization depends on the firm and market characteristics, as captured by the model parameters. Higher uncertainty increases the expected value of diversification, i.e., of broad information. This result is consistent with the empirical finding about management behavior reported in Eisenhardt (1989) that under high uncertainty managers consider more alternatives at less detail, i.e., prefer breath to depth. More intense competition increases the expected value of specialization, i.e., detailed information, driven by the possibility of differentiation. Higher effectiveness of management time also increases the expected value of specialization, but driven by the prospect of obtaining very accurate information. Steeper slopes of the inverse demand and cost functions, captured by β, increase the expected value of diversification, i.e., of broad information. However, this effect is of smaller magnitude.

These results follow directly from (11) and are summarized in Figure 2. The analysis of condition (11) determines the effect of parameter changes on the equilibrium allocation of

Figure 2

Preference for Broad or Detailed Information as a Function of Environment



management time when the equilibrium allocation is balanced, i.e., $t_i^* = 0.5$, i = 1, 2. When $t_i^* \neq 0.5$, the effect of parameter changes is determined by a comparative static analysis. The findings are exactly the same (see Appendix A).

Firms process data because they expect the resulting information to improve their decisions. The basic premise that firms have insufficient resources to process all available data implies that firms cannot acquire information until its marginal cost is equal to its marginal benefit. It is thus interesting to examine whether parameter changes have the same effect on the expected value of information and the equilibrium allocation.

Table 1 shows this comparison. It indicates that there is no direct correspondence between the two. For example, the expected value of information increases with both uncertainty, u, and the effectiveness of management time, η. However, the two parameters have opposite effects on the equilibrium resource allocation, partly because of the competitive interaction when acquiring information. This has important implications for data sellers. For example, as uncertainty increases, firms should be willing to generally pay more for data, but not necessarily for more detailed data. Data sellers would be better off adding data about other market factors. On the other hand, when more powerful data processing software becomes available, firms not only should be willing to

Table 1

Relationship Between Changes in Expected Value of Information and Optimal Resource Allocation

Increase in Parameter...	Expected Value of Information	Equilibrium Resource Allocation
Uncertainty u	Increases	More Balanced
Effectiveness η	Increases	More Focused
Competition d	Decreases	More Focused
Slope Parameters β	Decreases	More Balanced

generally pay more for data, but also ask for more detailed data. The comparison also indicates that an analysis of the second-stage equilibrium decision to understand the acquisition of information is not necessarily sufficient.

4.3 Differences Between Demand and Cost: Motivation vs. Ability

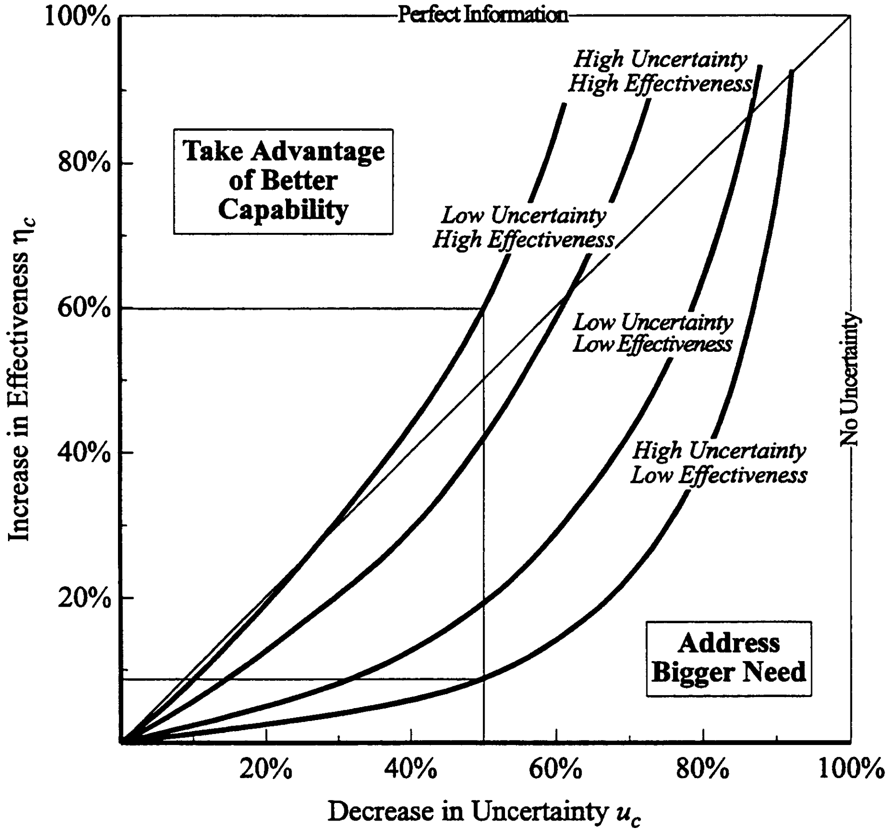
Until now we have focused on the tradeoff between diversification and specialization. When firms are no longer equally uncertain and equally able to generate information about demand and cost, they must likely consider a second tradeoff in their acquisition of information – the tradeoff between motivation and ability to generate information. We measure motivation to generate information with prior uncertainty, u_k, and ability to generate information with effectiveness of management time, η_k (k = a, c).

From the model as specified in §2 follows, as expected, that firms should acquire more information about the factor with higher uncertainty (u_a versus u_c) and take advantage of greater effectiveness of management time (η_a versus η_c), all else equal. The tradeoff between the two arises when, for example, a firm is more uncertain about demand ($u_a > u_c$) and more capable to generate cost information ($\eta_a < \eta_c$).[7]

[7] The examination of this tradeoff requires that two parameters are changed at the same time, which cannot be done with a comparative static analysis. Moreover, due to the complexity of the first-order and second-order conditions, we have to use numerical analyses to determine the sensitivity of the equilibrium allocation to these two parameters.

Figure 3[a]

Sensitivity of Information Acquisition to Changes in Uncertainty and Effectiveness of Management Time



[a]) This figure was created in Mathematica assuming $\phi(\tau) = s - r\tau^k$.

We start with the situation analyzed so far when firms are indifferent between demand and cost information. We then analyze how much the ability to generate cost (demand) information has to differ for a given difference in the motivation to generate cost (demand) information to maintain indifference. The difference in motivation is measured by the relative difference in uncertainty, $(u_a - u_c)/u_a$, the difference in ability by the shift in the data processing function, i.e., $(\phi_a(1) - \phi_c(1))/\phi_a(1)$, which is equivalent to the relative difference in the effectiveness of management time $(\eta_c - \eta_a)/\eta_c$.[8]

Figure 3 shows the resulting indifference curves for four different environments. On these indifference curves, the equilibrium continues to be $t_j^* = 1 - t_i^*$. The origin represents the situation

[8] We use a change in effectiveness of management time for this analysis rather than the change in error at the equilibrium allocation t, because the equilibrium itself can change due to the parameter changes.

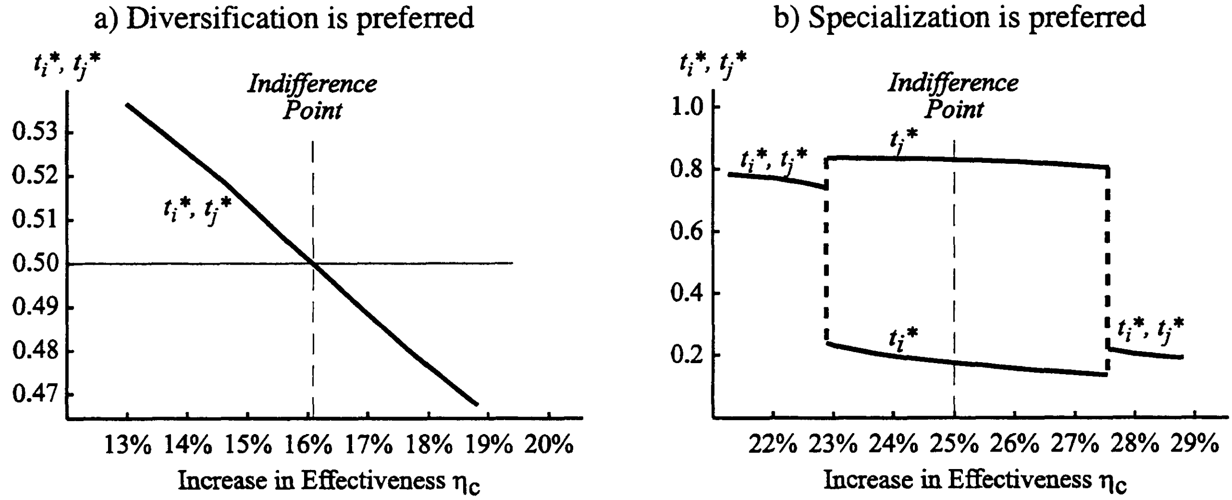
we have analyzed so far, i.e., $u_a = u_c$ and $\eta_a = \eta_c$. If cost uncertainty, u_c, is x% lower than demand uncertainty, u_a, the curves in Figure 3 indicate by how much the effectiveness of management time for acquiring cost information, η_c, must be higher for the firms to remain indifferent between acquiring demand and cost information. For example, when uncertainty is high and effectiveness low, a fifty percent lower cost uncertainty, u_c, relative to demand uncertainty, u_a, requires about a nine percent higher effectiveness of management time for cost data, η_c. When uncertainty is low and effectiveness high, the "break-even point" increases to about sixty percent. If the increase in effectiveness is much less than indicated by the indifference curve, both firms focus (more) on demand data. If the increase is much higher, they focus (more) on cost data. Other model parameters have only a minor effect. For example, competition, d, marginally increases the sensitivity to ability differences.

Overall, the curves indicate that in many situations the optimal acquisition of information is more sensitive to the difference in the effectiveness of management time, η_k, i.e., the ability to generate information, than to the difference in uncertainty, u_k, i.e., the motivation to generate information (k = a, c). The optimal acquisition of information is more sensitive to differences in uncertainty only (i) when uncertainty is low and effectiveness of management time high or (ii) when the differences in uncertainty about cost and demand are very large. Consequently, if firms are generally more uncertain about demand, but better able to obtain cost information, we should expect firms to focus more on cost data, all else equal.

This finding means that firms may have a tendency to favor exploitation not only because of higher short-term returns, organizational learning dynamics or incentives, as identified by March (1991). Even when the returns occur at the same time, exploitation often yields higher expected profits. This is particularly true in difficult environments, i.e., in situations when uncertainty is high and the ability to generate information to cope with uncertainty is low. In contrast, we should find that firms conduct relatively more exploration in stable environments. Note that this result is not driven by risk aversion. Our model assumes risk neutral firms.

Figure 4[a]

Changes in Equilibrium Allocation When Demand and Cost Conditions Are Different



[a]) This figure was created in Mathematica assuming $\phi(\tau) = s - r\tau^k$.

When specialization is preferred to diversification at the indifference point, a marginal change in uncertainty or effectiveness of management time for either demand or cost can lead to a discontinuous change in the equilibrium allocation. For example, if cost uncertainty is lower (e.g., by 25% as used for Figure 4), both firms process only or mostly demand data to cope with the larger uncertainty. As the effectiveness of management time to process cost data, η_c, increases, the equilibrium allocation moves marginally towards cost data.

At some point close to but below the indifference point, one firm switches to focus on cost data, since the benefits of differentiation outweigh the need to cope with the higher demand uncertainty. At some point above the indifference line, the second firm also switches to focus on cost data since now the benefits of the more effective management time outweigh the benefits of differentiation. In other words, a marginal change in the environment can lead to a discontinuous change in the optimal resource allocation. This discontinuity is illustrated in Figure 4b. When diversification is preferred, the equilibrium has no discontinuity (Figure 4a).

5. Concluding Remarks

5.1 Implications

The basic premises underlying our paper are that (i) learning about a market requires information about different market factors and (ii) firm resources to generate this information are insufficient to process all available data into information. As a result, the optimal acquisition of information involves two different tradeoffs. First, firms must decide whether they should prefer broad but less detailed information or detailed but narrower information. In other words, firms must decide to what extent they should diversify or specialize their resource allocation. Second, they must decide whether to focus on market factors with higher uncertainty or take advantage of the better ability to generate information about other market factors, which is a tradeoff between motivation and ability.

This paper is the first to examine the theoretical implications of these two tradeoffs for the acquisition of information. We do so by using a parsimonious game-theoretic model. The insights from our model make important contributions to our understanding of firms' information acquisition behavior. There are five points we want to highlight.

First, the effects of the firm and market factors examined in this paper indicate that today's general market trends do not yield a simple rule of thumb for the acquisition of information. The reduction in the half-life of market knowledge and its associated increase in uncertainty requires firms to acquire more diversified or broader information. In other words, they have to pay attention to many different market factors. On the other hand, increased competition and advances in information technology should induce firms to acquire more specialized or deeper information. In other words, it pays to focus on understanding few market factors and ignore others.

Second, although our model examines the acquisition of information, the same tradeoffs arise in other firm activities. For example, the marketing strategies can be grouped into specialization - differentiation, low cost - and diversification - playing the spread. R&D strategies can be grouped into specialization - process R&D, product R&D - and diversification - investing in both types of R&D. The model can be easily extended to examine these actions. For example, Thurow (1990) noted that R&D allocation varies for firms in different countries. Firms in the United States tend to favor product R&D and firms in Japan process R&D. Firms in Germany allocate R&D effort about equally to both. He criticized U.S. firms for what he considered an underinvestment in process R&D. Using our findings, the specialization observed in the U.S. and Japan could be caused by stronger competition in these two countries compared to Germany and does not necessarily indicate a biased allocation of R&D resources. (In the case of the US, the hypothesis that the R&D allocation is optimal could not be rejected (Boulding and Staelin 1995).)

Third, ignoring data about market factors, exploiting existing capabilities rather than exploring uncertain market factors, or drastically changing firm behavior are often believed to indicate some sort of "bias" or deviation from normative behavior. For example, IBM's downfall in the 80s is attributed to its focus on the mainframe market – exploiting an existing capability – and neglect of a new emerging market – exploring a new opportunity. Observed drastic changes are explained either by firms' lack of adjustment to market changes in the past (e.g. GM's failure to adapt to changes in competition and customer preferences in the 70s and 80s) or by discontinuous changes in the environment (e.g., airline deregulation). Our results show that *ex-ante* these three "biases" can indicate optimal firm behavior. For example, Emerson Electric has been well known for its strong focus on costs. Over the last two decades, the company has accumulated a tremendous success record. Recently, the company completely reversed its approach and is now focusing on customer needs with the same zeal (Fortune 1995). Neither drastic changes in its environment, changes in leadership nor performance problems explain this flip-flop. According to our results, the firm may have optimally responded to minor internal or external changes. For example, the potential to explore demand-side benefits may have finally reached a point so that exploiting cost reduction capabilities was no longer best. Although demand-side benefits have been increasing over time, the benefit of specializing could have always exceeded the benefits of adapting to the changes and become less specialized.

Fourth, our findings are indicators of customer buying behavior for data sellers. For example, when conditions are such that firms prefer broad information, competing firms have similar data needs. This offers data sellers less opportunity to segment a market and differentiate themselves. In addition, data sellers may be better off by adding data products about other market factors rather than increasing the level of detail for existing data. On the other hand, in stable, highly competitive markets – such as many packaged consumer goods markets – firms should be willing to pay extra for highly accurate information. At the same time, firms are also more likely to have different data needs, all else equal.

Finally, in the past firms often had to rely on intuition to make marketing decisions because of a lack of good information. Today, detailed data about many market factors are widely available. However, the processing of the "right" data requires that firms have knowledge of their uncertainty about different market factors. In our model, we assume that firms have that knowledge or at least unbiased beliefs. Yet, there is considerable evidence that ignorance is often denied or covered up (Zaltman and Staelin 1993). The importance of such information has been recognized by many managers. In a survey it was ranked as the most critical information, just after customer information and company performance information (Murray and Myers 1997). If information about uncertainty is difficult to obtain, there maybe a new role for intuition – the direction of firms' learning about their markets. Knowing what is not known may offer a greater potential for competitive advantages than knowing market facts.

5.2 Limitations and Future Research

This research represents a first step towards better understanding firms' acquisition of information in today's market environment. Obviously, it has several limitations, which offer opportunities for future research. Our objective was to examine the problem from a normative perspective. However, our results provide a basis for empirical research. In particular, they could be useful to researchers interested in the effect of market orientation, a construct that is based on information acquisition and use. The importance of the tradeoff between diversification and specialization provides support for using a multivariate construct of information acquisition in the definition of market orientation, as advocated by Day and Nedungadi (1994). In contrast, the measure used by Narver and Slater (1990) is of univariate nature.

Our model is a simultaneous one-shot game. This is justified in many situations, like the one-shot decision to set the capacity of a new production plant or to continue (or not) a product development project. Most information is acquired for problem related purposes (Deshpandé and Zaltman 1982). Often the prior commitments to data collection and processing are very strong and require a long lead time. For example, clients of IRI or AC Nielsen have to order data well in advance. The development of computer software also takes time. There are two possible directions to extend our model. First, assuming a leader-follower structure of competition leads to different competitive interactions since the leader has to take into account that its private information is "leaked" through its actions. Second, extending the model to a two-period game allows for further examination of the tradeoff between exploitation and exploration. In particular, it allows for the coupling of today's information acquisition with tomorrow's ability to generate information.

We have only considered situations with identical firms, which leaves open the question about the effect of firm differences. This is an important issue since we show that identical firms acquire different market information in some situations and thus, may not remain identical.

Finally, some assumptions were imposed for reasons of mathematical tractability. For example, we assume that demand and marginal cost functions are linear. Functional form assumptions are never really convincing, although our assumptions are consistent with a long stream of existing research on uncertainty and information acquisition. It also allows for less restrictive distributional assumptions. In addition, there is research suggesting that comparative static results derived from simpler models often hold more generally (Milgrom 1994).

References

Bettman, James R. (1979), *An Information Processing Theory of Consumer Choice.* Reading, MA: Addison Wesley.

Blattberg, Robert C., Rashi Glazer and John D. C. Little (1994), *The Marketing Information Revolution.* Boston. MA: HBS Press.

Boulding, William and Richard Staelin (1993), "A Look on the Cost Side: Market Share and Competitive Environment," *Marketing Science*, 12 (Spring), 144–166.

——— and ——— (1995), "Identifying Generalizable Effects of Strategic Actions on Firm Performance: The Case of Demand-Side Returns to R&D Spending," *Marketing Science*, 14 (3, Part 2), G222 –G236.

Cyert, Richard M., Praveen Kumar and Jeffrey R. Williams (1993), "Information, Market Imperfections and Strategy," *Strategic Management Journal*, 14 (Special Issue), 47–58.

Day, George S.(1994), "Continuous Learning About Markets," *California Management Review*, 36 (Summer), 9–31.

——— and Prakash Nedungadi (1994), "Managerial Representations of Competitive Advantage," *Journal of Marketing*, 58 (April), 31–44.

Deshpandé, Rohit and Gerald Zaltman (1982), "Factors Affecting the Use of Market Research Information: A Path Analysis," *Journal of Marketing Research*, 19 (February), 14–31.

Drucker, Peter F. (1997), "The Future that Has Already Happened," *Harvard Business Review*, September-Ocotober, 20–24.

Eisenhardt, Kathleen (1989), "Making Fast Strategic Decisions in High-Velocity Environments," *Academy of Management Journal*, 32, 543–576.

Ericson, William A. (1969), "A Note on the Posterior Mean of a Population Mean," *Journal of the Royal Statistical Society*, 31 (2), 332–334.

Fortune (1995), "Growing Your Company: Five Ways To Do It Right," November 25, 1995, 32–38.

Fudenberg, Drew and Jean Tirole (1991), *Game Theory.* Cambridge, MA: MIT Press.

Gal-Or, Esther (1985), "Information Sharing in Oligopoly," *Econometrica*, 53 (March), 329–343.

——— (1988), "The Advantages of Imprecise Information," *RAND Journal of Economics*, 19 (Summer), 266–275.

Glazer, Rashi, Joel Steckel and Russell Winer (1992), "Locally Rational Decision Making: The Distracting Effect of Information on Managerial Performance," *Management Science*, 38 (February), 212–226.

Grossman, Sanford J., Richard E. Kihlstrom and Leonard J. Mirman (1977), "A Bayesian Approach to the Production of Information and Learning By Doing," *Review of Economic Studies*, 44 (3), 533–547.

——— and Joseph E. Stiglitz (1980), "On the Impossibility of Informationally Efficient Markets," *American Economic Review*, 70, 393–408.

Harrington, Joseph E. Jr. (1995), "Experimentation and Learning in a Differentiated-Products Duopoly," *Journal of Economic Theory*, 66, 275–288.

Huang, Chi-Fu and Lode Li (1990), "Continuous Time Stopping Games With Monotone Reward Structures," *Mathematics of Operations Research*, 15 (August), 496–507.

Huber, George P. (1991), "Organizational Learning: The Contributing Processes and Literatures," *Organization Science*, 2 (February), 88–115.

Hwang, Hae-Shin (1993), "Optimal Information Acquisition for Heterogeneous Duopoly Firms," *Journal of Economic Theory*, 59, 385–402.

Kahneman, Daniel (1973), *Attention and Effort.* Englewood Cliffs, NJ: Prentice Hall.

Kelly, Paul J. (1994), "Still Waiting for the Information Age," *Marketing News*, 28 (12), 4–5.

Kiesler, Sara and Lee S. Sproull (1982), "Managerial Response to Changing Environments: Perspective on Problem Sensing from Social Cognition," *Administrative Science Quarterly*, 27 (December), 548–570.

Kohli, Ajay and Bernard Jaworski (1990), "Market Orientation: The Construct, Research Propositions, and Managerial Implications," *Journal of Marketing*, 54 (April), 1–18.

Kreps, David and John Scheinkman (1983), "Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes," *Bell Journal of Economics*, 14, 326–337.

Li, Lode, Richard D. McKelvey and Talbot Page (1987), "Optimal Research for Cournot Oligopolists," *Journal of Economic Theory*, 42, 140–166.

Little, John D. C. (1966), "A Model of Adaptive Control of Promotional Spending," *Operations Research* 14 (November-December), 1075–1097.

Machlup, F. and Una Mansfield (1983), *The Study of Information: Interdisciplinary Messages.* New York, NY: John Wiley & Sons, Inc.

Malueg, David A. and Shunichi O. Tsutsui (1996), "Duopoly Information Exchange: The Case of Uncertain Slope," *Journal of Industrial Organization*, 14 (1), 119–136.

Matthews, Steven (1984), "Information Acquisition in Discriminatory Auctions," in *Bayesian Models in Economic Theory* (Marcel Boyer and Richard E. Kihlstrom, Eds.), Amsterdam, NL: Elsevier, 181–207.

March, James G. (1991), "Exploration and Exploitation in Organizational Learning," *Organization Science*, 2, 71–87.

McCann, John H. and John P. Gallagher (1990), *Expert Systems for Scanner Data Environments: The Marketing Workbench Laboratory Experience*. Boston, MA: Kluwer Academic Publishers.

Milgrom, Paul (1981), "Rational Expectations, Information Acquisition, and Competitive Bidding," *Econometrica*, 49, 921–943.

——— (1994), "Comparing Optima: Do Simplifying Assumptions Affect Conclusions?" *Journal of Political Economy*, 102 (3), 607–615.

Murray, Peter and Andrew Myers (1997), "The Facts About Knowledge," *Information Strategy*, 1 (September), 29–33.

Narver, John C. and Stanley F. Slater (1990), "The Effect of a Market Orientation on Business Profitability," *Journal of Marketing*, 54 (October), 20–35.

Petty, Richard E. and John T. Cacioppo (1986), *Communication and Persuasion: Central and Peripheral Routes to Attitude Change*. New York, NY: Springer Verlag.

Rogers, Everett M. (1983), *Diffusion of Innovations*. New York, NY: The Free Press.

Thomas, James B., Shawn M. Clark and Dennis A. Gioia (1993), "Strategic Sensemaking and Organizational Performance: Linkages Among Scanning, Interpretation, Action and Outcomes," *Academy of Management Journal*, 36 (April), 239–270.

Thurow, Lester (1990), Speech given to the Corporate Leaders Forum, March.

Varian, Hal R. (1992), *Microeconomic Analysis*. New York, NY: W.W. Norton (5th edition).

Verrecchia, Richard E. (1982), "Information Acquisition in a Noisy Rational Expectations Economy," *Econometrica*, 50, 1415–1430.

Vives, Xavier (1984), "Duopoly Information Equilibrium: Cournot and Bertrand," *Journal of Economic Theory*, 34, 71–94.

Zaltman, Gerald and Richard Staelin (1993), "Ignorance, Knowledge, Wisdom and Questioning in the Development of Decision Maker's Theories," presentation at the conference *Understanding Competitive Decision Making*, Charleston S.C.

Appendix A

Proof of Proposition 1

Expected profit for the second-stage quantity decision is:

$$\mathrm{E}_i\left[\pi_i \middle| \mathrm{x}_i\right] = \mathrm{E}_i\left[a - c - d\cdot \mathrm{q}_j \middle| \mathrm{x}_i\right]\cdot \mathrm{q}_i - \beta\cdot \mathrm{q}_i^2, \quad \mathrm{i, j} = 1, 2, \mathrm{i} \neq \mathrm{j}. \tag{A.1}$$

Using the first-order condition, $\partial \mathrm{E}_i\pi_i/\partial \mathrm{q}_i = 0$, the quantity decision is:

$$\mathrm{q}_i{}^* = \frac{\mu_a + \mathrm{w}_{ai}(\mathrm{x}_{ai} - \mu_a) - \mu_c - \mathrm{w}_{ci}(\mathrm{x}_{ci} - \mu_c) - \mathrm{d}\cdot \mathrm{E}_i\left[\mathrm{q}_j{}^* \middle| \mathrm{x}_i\right]}{2\beta}. \tag{A.2}$$

In equilibrium, firm j is expected to adhere to the decision rule of Proposition 1. From (6) follows

$$\mathrm{E}_i\left[\mathrm{q}_j{}^* \middle| \mathrm{x}_i\right] = \mathrm{E}_i\left[\mathrm{Q} + \mathrm{K}_{aj}(\mathrm{x}_{aj} - \mu_a) + \mathrm{K}_{cj}(\mathrm{x}_{cj} - \mu_c) \middle| \mathrm{x}_i\right] = \mathrm{Q} + \mathrm{K}_{aj}\mathrm{w}_{ai}(\mathrm{x}_{ai} - \mu_a) + \mathrm{K}_{cj}\mathrm{w}_{ci}(\mathrm{x}_{ci} - \mu_c),$$

which results in the following five equations for i, j = 1, 2, i $\neq$ j:

$$\mathrm{Q} = \frac{\mu_a - \mu_c - d\cdot \mathrm{Q}}{2\beta}, \quad \mathrm{K}_{ai} = \mathrm{w}_{ai}\frac{1 - d\cdot \mathrm{K}_{aj}}{2\beta} \quad \text{and} \quad \mathrm{K}_{ci} = -\mathrm{w}_{ci}\frac{1 + d\cdot \mathrm{K}_{cj}}{2\beta}. \tag{A.3}$$

Proposition 1 follows immediately by solving these equations. Existence and uniqueness of this equilibrium have also be shown by Hwang (1993). ■

Proof of Proposition 2

Proposition 2 follows directly from the assumption that the two firms are identical, i.e., from the symmetry in the equilibrium output (6) and the payoff function, $\mathrm{Z}_i(t)$. From this symmetry follows that either $t_i^* = t_j^*$ or $t_i^* = 1 - t_j^*$. However, $\mathrm{Z}_i(t_i, t_i) < \mathrm{Z}_i(t_i, 1-t_i)$, $\forall\ t_i \neq 0.5$, i = 1, 2. ■

Best Response Functions

The properties of the best response functions $\mathrm{r}_i(t_j)$, i, j = 1, 2, i $\neq$ j follow from

$$\frac{\partial F_i}{\partial t_i}\mathrm{d}t_i + \frac{\partial F_i}{\partial t_j}\mathrm{d}t_j = 0, \tag{A.4}$$

where $F_i = \partial Z_i(t)/\partial t_i$ are the first-order conditions (8). First, the slope of the best response functions is determined by the cross partial derivatives, $\partial F_i(t)/\partial t_j$ i.e.,

$$\frac{\partial^2 Z_i(t)}{\partial t_i \partial t_j} = -\frac{K_{ai}}{\xi_a^3} 4\beta d w_{ai} w_{aj} \frac{\phi'(t_i)\phi'(t_j)}{u+\phi(t_j)}\left[8\beta^2(\beta - d w_{ai}) + d^2 w_{ai} w_{aj}(4\beta - d w_{ai})\right]$$
$$+\frac{K_{ci}}{\xi_c^3} 4\beta d w_{ci} w_{cj} \frac{\phi'(1-t_i)\phi'(1-t_j)}{u+\phi(1-t_j)}\left[8\beta^2(\beta - d w_{ci}) + d^2 w_{ci} w_{cj}(4\beta - d w_{ci})\right] < 0. \qquad \text{(A.5)}$$

The two brackets of (A.5) are always positive and the two leading factors always negative. The second factor is negative because $K_{ci} < 0$ (see (6)). Thus, the slope of the best response functions is always negative for $t_i \neq 0.5$, i = 1, 2.

The best response functions $r_i(t_j)$, i, j = 1, 2, i ≠ j can cross the equilibrium line (10) at most once for $0 \leq t_j < 0.5$ and once for $0.5 < t_j \leq 1$ since they are concave for $0 \leq t_j < 0.5$ and convex for $0.5 < t_j \leq 1$. This is illustrated in Figure 1b and follows from

$$\frac{d^2 t_i}{d t_j^2} = \frac{\partial^2 F_i}{\partial t_j^2} \Big/ \left(-\frac{\partial F_i}{\partial t_i}\right) + \frac{\partial F_i}{\partial t_j} \cdot \frac{\partial^2 F_i}{\partial t_i^2} \Big/ \left(-\frac{\partial F_i}{\partial t_i}\right)^2 . \qquad \text{(A.6)}$$

Both denominators are always positive since they contain the second-order condition. From (A.5) follows that $\partial F_i(t)/\partial t_j$ is always negative. It can be shown that for $0 \leq t_j < 0.5$ $\partial^2 F_i(t)/\partial t_j^2$ is positive and $\partial^2 F_i(t)/\partial t_i^2$ is negative. They yield similar expressions as (A.5). A sufficient condition for these signs to hold is $\phi''' < 0$. However, in many cases it is not needed at all. In other words, the conditions for ϕ are $\phi' < 0$, $\phi'' > 0$ and $\phi''' < 0$. As a result, (A.6) is positive for $0 \leq t_j < 0.5$ and the best response functions concave. For $t_j = 0.5$ (A.6) is 0 and for $0.5 < t_j \leq 1$ the signs of $\partial^2 F_i(t)/\partial t_j^2$ and $\partial^2 F_i(t)/\partial t_i^2$ reverse so that (A.6) becomes negative and the best response functions convex. ■

Proof of Proposition 3

A sufficient and (almost) necessary condition for the equilibrium allocation, $t_i^* = 0.5$, i = 1, 2, to be locally stable is (Varian 1992):

$$\begin{vmatrix} \dfrac{\partial^2 Z_i(t)}{\partial t_i^2} & \dfrac{\partial^2 Z_i(t)}{\partial t_i \partial t_j} \\ \dfrac{\partial^2 Z_j(t)}{\partial t_j \partial t_i} & \dfrac{\partial^2 Z_j(t)}{\partial t_j^2} \end{vmatrix} > 0 . \tag{A.7}$$

Due to the symmetry of the payoff function, $Z_i(t)$, at $t_i = 0.5$, i = 1, 2, this simplifies to $\partial^2 Z_i(t)/\partial t_i^2 - \partial^2 Z_i(t)/\partial t_i \partial t_j < 0$. Condition (11) follows immediately. The payoff function, $Z_i(t)$, is bounded and concave when condition (11) holds. This together with the fact that the best response functions, $t_i = r_i(t_j)$, are monotone decreasing ensures existence and uniqueness of the equilibrium, $t_i^* = 0.5$, i = 1, 2 (Huang and Li 1990).

Equivalently, (A.7) implies that the best response functions are flatter than the equilibrium line (9), i.e., they cut it from above at $t_i = 0.5$, i = 1, 2. Since the best response functions, $r_i(t_j)$, are strictly concave for $0 \le t_j < 0.5$ and strictly convex for $0.5 < t_j \le 1$, j = 1, 2, the allocation $t_i^* = 0.5$, i = 1, 2, is the unique perfect Bayesian equilibrium of the game. This is illustrated by the best response functions in Figure 1a.

When the stability condition (11) is not satisfied, the best response functions are stepper than the equilibrium line (10), i.e., they cut it from below at $t_i = 0.5$, i = 1, 2. The properties of the best response functions, as shown in the previous section, ensure that the pair of allocations $t_i^* = 1 - t_j^* \neq 0.5$, i, j = 1, 2, i ≠ j, are the unique symmetric perfect Bayesian equilibria of the game. If the best response functions, $r_i(t_j)$, cut the equilibrium line at $t_j \neq 0.5$, the equilibrium is an interior solution, i.e., $0 < t_i^* < 1$, i = 1, 2. This is illustrated in Figure 1b. If they do not cross, the equilibrium is a corner solution, i.e., $t_i^* = 0, 1$, i = 1, 2. ■

Proof of Corollary 4

From the second-order conditions (9) at $t_i^* = 0.5$, i = 1, 2, and condition (11) follows:

$$\frac{\text{Condition (11)}}{\text{SOC (9)}} = \frac{(4\beta^2 + d^2W^2)(2\beta + dW)}{4\beta(2\beta^2 + d^2W^2)} > 1 \quad \text{for } d > 0. \tag{A.8}$$

In other words, the stability condition is more restrictive than the second-order conditions as long as the products are not independent. ■

Comparative Static Analysis

The comparative static results are:

$$\frac{dt_i^*}{du}, \frac{dt_i^*}{d\beta} > 0 \quad \text{iff } t_i^* < 0.5 \quad \text{and} \quad \frac{dt_i^*}{du}, \frac{dt_i^*}{d\beta} < 0 \quad \text{iff } t_i^* > 0.5, \tag{A.9a}$$

$$\frac{dt_i^*}{d\eta}, \frac{dt_i^*}{dd} < 0 \quad \text{iff } t_i^* < 0.5 \quad \text{and} \quad \frac{dt_i^*}{d\eta}, \frac{dt_i^*}{dd} > 0 \quad \text{iff } t_i^* > 0.5. \tag{A.9b}$$

These results mean that the equilibrium allocation of management time moves towards a balanced allocation, i.e., towards 0.5, as u or β increase, and η and d decrease.

Since the proof of the effect of changes in η, d, β is similar, we present only the proof for the effect of u. The overall effect of changes in uncertainty, u, follows from

$$\left[\frac{\partial^2 Z_i(t)}{\partial t_i^2} + \frac{\partial^2 Z_i(t)}{\partial t_i \partial t_j}\frac{\partial t_j^*}{\partial t_i}\right]\frac{dt_i}{du} + \left[\frac{\partial^2 Z_i(t)}{\partial t_i \partial u} + \frac{\partial^2 Z_i(t)}{\partial t_i \partial t_j}\frac{\partial t_j^*}{\partial u}\right] = 0. \tag{A.10}$$

From the stability condition (A.7) and $\partial t_j^*/\partial t_i = -1$ (see (10)) follows that the first bracket is always negative. The sign of the total effect of a change in uncertainty u, dt_i/du, is determined by the sign of the second bracket. The sign of $\partial^2 Z_i(t)/\partial t_i \partial t_j$ is negative (see A.5). The sign of the first part of the second bracket is determined by

$$\frac{\partial^2 Z_i(t)}{\partial t_i \partial u} = -\frac{K_{ai}\phi'(t_i)}{\xi_a^2}\left[2\xi_a\zeta_a\frac{\partial K_{ai}}{\partial u} + 8\beta^2 d^2 K_{ai}\left(w_{ai}\frac{\partial w_{aj}}{\partial u} + w_{aj}\frac{\partial w_{ai}}{\partial u}\right)\right]$$
$$+\frac{K_{ci}\phi'(1-t_i)}{\xi_c^2}\left[2\xi_c\zeta_c\frac{\partial K_{ci}}{\partial u} + 8\beta^2 d^2 K_{ci}\left(w_{ci}\frac{\partial w_{cj}}{\partial u} + w_{cj}\frac{\partial w_{ci}}{\partial u}\right)\right]. \qquad \text{(A.11)}$$

When $t_i = t_j = 0.5$, the two parts are identical and $\partial^2 Z_i(t)/\partial t_i \partial u = 0$. The first part is positive and of larger magnitude when $t_i^* < 0.5$. The second part is negative and of larger magnitude when $t_i^* > 0.5$. Thus, $\partial^2 Z_i(t)/\partial t_i \partial u > 0$ when $t_i^* < 0.5$ and $\partial^2 Z_i(t)/\partial t_i \partial u < 0$ when $t_i^* > 0.5$. The sign for $\partial t_j^*/\partial u$ is found similarly. However, from Proposition 2 follows that when $t_i^* < 0.5$, then $t_j^* > 0.5$. In other words, in equilibrium when $\partial^2 Z_i(t)/\partial t_i \partial u > 0$, then $\partial t_j^*/\partial u < 0$, and vice versa. As a result, both parts of the second bracket of (A.11) are positive when $t_i^* < 0.5$, negative when $t_i^* > 0.5$, and zero when $t_i^* = 0.5$, yielding the result presented in (12a). In sum, as uncertainty, u, increases, the equilibrium allocations, t_i^*, i = 1, 2, become more balanced, i.e., move towards 0.5. ■