

# Unbalanced Information and the Interaction between Information Acquisition, Operating Activities, and Voluntary Disclosure

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**ABSTRACT:** As different activities cannot be measured or communicated with the same precision, accounting information is often only a partial and unbalanced reflection of the fundamental economics, emphasizing certain aspects of the underlying operations while disregarding others. We highlight this inherent imbalance in information as the source of an interaction between corporate operating and discretionary disclosure strategies, and thereby also as an important determinant of the information acquisition strategy. We demonstrate that information imbalance, via its distorting effect on operating activities, leads to a reduction in the propensity of managers to acquire information and provide voluntary disclosures.

**Keywords:** *financial accounting; asymmetric information; voluntary disclosure.*

## I. INTRODUCTION

In this paper, we investigate the interrelation between corporate discretionary disclosure and operating strategies, as well as their interaction with information acquisition activities, highlighting the information structure as a crucial source of these relationships. Our study is rooted in the notion that different activities cannot be measured or communicated with the same level of precision (and some activities cannot be measured or communicated at all). As a result, information produced and reported by a firm is often only a partial and unbalanced reflection of its fundamental economics, emphasizing some aspects

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We appreciate the helpful comments and suggestions of three anonymous referees, Gil Aharoni, Jonathan Glover, Madhav Rajan (the editor), Phillip Stocken, Varda Yaari, and participants in the 2005 European Accounting Association Annual Congress and the 2005 American Accounting Association Annual Meeting and in seminars at the Hebrew University, INSEAD, the Interdisciplinary Center Herzliya, Technion-Israel Institute of Technology, and Tel Aviv University. We thank Gerda Kessler for expert editorial assistance. Eti Einhorn also gratefully acknowledges financial support by the Joseph Kasierer Institute for Research in Accounting.

Editor's note: This paper was accepted by Madhav Rajan.

*Submitted December 2005*  
*Accepted March 2007*

of the firm's operations while disregarding others. The unbalanced structure of information has been identified by Holmstrom and Milgrom (1991) and subsequent papers (e.g., Feltham and Xie 1994; Zhang 2003; Hughes et al. 2005) as a cause of production inefficiencies under moral hazard settings with mandatory disclosure. Our primary contribution to this line of research is in exploring the suppressing impact of the inherent imbalance in information on the propensity of managers to acquire information and provide voluntary disclosures, via its well-known distorting effect on operating decisions.

Our analysis applies to a wide range of business processes where managerial operating decisions are unobservable to outsiders, but managers can acquire and credibly disclose useful, albeit noisy and unbalanced, measures of the resulting operating performance. The analysis pertains particularly to situations in which the information imbalance is salient and unobservable operating decisions significantly affect the information content. Firms with operations that are multifaceted in nature provide a natural point of reference. Diversity in the operating activities could take various forms. Firms may operate in several industries (conglomerates, financial institutions that provide both investments and insurance services), they may operate in several markets (public and private sectors, domestic and international), their operations may involve multi-task processes (aviation, oil—exploration, production and refining), and they may normally conduct both short-term and long-term projects (research and development in conjunction with production, products that require different aging—wine and liquor). In all these cases, performance measures are likely to be unbalanced as they are the aggregate of several operating activities that, due to differences in their economic nature, are subject to different measurement and reporting constraints. Aggregated performance measures, besides being unbalanced, are also sensitive to resource allocation decisions, such as the allocation of capital, equipment, and manpower.

We consider a model of a multi-divisional firm traded in a rational and risk-neutral market, whose manager makes three interrelated decisions: a resource allocation decision, an information acquisition decision, and a voluntary disclosure decision. To initiate the production process, the manager privately allocates the firm's limited resources among its operating divisions. While this operating decision is unobservable to investors, the manager can later acquire information that measures the operating performance of the firm, helps to augment it, and can be credibly communicated to investors. Such information is unbalanced in the sense that it is not equally informative about the performance of the firm's different operating divisions. Based on private knowledge regarding the cost of acquiring the information, the manager decides whether to acquire it. The information, if acquired, arrives after some stages of the production process have been completed, serving the manager in fine-tuning the remainder of the production process and enhancing the production output. Since the information can be credibly communicated, its acquisition also confronts the manager with the decision on whether to voluntarily disclose it to investors. The manager's resource allocation, information acquisition, and disclosure decisions are all made in light of their anticipated impact on the firm's future cash flows, as well as on the firm's current market price, which, in turn, is determined by the investors' rational expectations regarding the manager's strategies.

Recognizing the cost of acquiring information, the manager is capable of anticipating the future availability or lack of information. Upon anticipating the arrival of disclosable information that emphasizes the performance of one of the firm's divisions, the manager inevitably has the incentive to inefficiently bias the resource allocation toward that particular division. By doing so, the manager improves the expected content of the information, trying to manipulate the inference that will be drawn by investors in case of disclosure and thereby

boosting the firm's expected market price. This result is consistent with Holmstrom and Milgrom (1991), who show that managers cannot resist directing inefficient amounts of resources toward those tasks that have the greatest impact on observable performance measures. Unlike prior studies, however, the disclosure of the performance measure in our model is under the manager's discretion, and thus the suboptimal operating decision induced by the potential unbalanced disclosure has an additional backward effect on the disclosure decision. Disclosure resolves the investors' uncertainty regarding the manager's information endowment, and therefore reveals not only the operating advantage of information in improving the production process, but also the implied inefficiency in resource allocation, generating endogenous disclosure costs that diminish the manager's incentive to provide voluntary disclosure. Thus, in the presence of unbalanced information, a mutual dependence emerges between the firm's operating and disclosure activities, which leads to both production and disclosure distortions (Proposition 1).

Due to its distorting impact on the production and disclosure activities of the firm, the imbalance in information also affects the information acquisition activity. By creating an unavoidable production distortion, the imbalance reduces the advantage of information in improving the production process. Furthermore, by decreasing the disclosure intensity, the imbalance reduces the advantage of possessing information in manipulating the market's expectations about the firm via voluntary disclosures. Altogether, when information is unbalanced, it becomes less valuable to the manager from both the operating and the disclosure perspectives. The manager is thus less motivated to acquire information, and may not acquire value-enhancing information, even when its potential operating benefit exceeds its cost (Proposition 2). The less likely information acquisition becomes, the easier it is for the manager to hide behind the cover of not possessing information and avoid unfavorable disclosure, which still further reduces her propensity to provide voluntary disclosure. Information imbalance therefore endogenously evokes the two well-known triggers for suppressing disclosure: disclosure costs (Verrecchia 1983) and uncertainty regarding the information endowment (Dye 1985). By exploring the imbalance in information as a factor that impedes disclosure, our work joins the extensive research endeavor toward an understanding of why firms do not fully disclose their private information in capital markets with rational expectations, as suggested by the earlier studies of Grossman and Hart (1980), Grossman (1981), and Milgrom (1981).<sup>1</sup>

Other studies that analyze relationships between discretionary disclosure and operating decisions, though not their interplay with information acquisition decisions, include Lanen and Verrecchia (1987) and Pae (2002). Using different settings, both arrive at the conclusion that observable operating decisions might serve as noisy manageable substitutes for unfavorable disclosures, and might therefore be distorted in anticipation of the inferences of investors about the underlying withheld information. Our study explores other kinds of interactions between operating and disclosure activities that apply to a different class of frequent scenarios, in which the managerial operating decision is unobservable to investors and the information underlying the disclosure decision is a performance measure that arrives after the operating decision has been made rather than beforehand. In other words, while prior studies focus on interactions between operating and disclosure strategies that stem from the ability of investors to learn from an observable operating decision something about

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<sup>1</sup> For other factors that suppress voluntary disclosures, see Verrecchia (1983), Dye (1985, 1986), Nagar (1999), Einhorn (2007), and Suijs (2007). For surveys of the voluntary disclosure literature, see Dye (2001) and Verrecchia (2001).

the underlying withheld information, we explore interactions that arise due to the capability of disclosed information to provide investors with a clue about an unobservable operating decision.

The paper proceeds as follows. Section II provides a description of our model. Equilibrium is defined in Section III. It is analyzed for the operating and disclosure decisions in Section IV and for the information acquisition decision in Section V. Concluding remarks are offered in Section VI. Highlights of the proofs appear in the Appendix.

## II. MODEL

Our model depicts a public firm that first makes an operating decision that is unobservable to investors. Subsequently, the firm considers the acquisition of a noisy and unbalanced performance measure that can streamline production and can also be credibly disclosed. Our model thus involves three interrelated managerial decisions: an operating decision, an information acquisition decision, and a voluntary disclosure decision. These decisions are shaped by the manager's rational anticipation of their effect on the firm's future cash flows, as well as on its current market price, which, in turn, is determined based on the investors' rational expectations about the manager's decisions. The interaction between the three managerial decisions stems from the unbalanced structure of the information. Below we detail the model's ingredients, which are assumed to be commonly known to all players, unless otherwise indicated.

### Production Environment

The firm is comprised of two separate divisions, which produce and sell different products, while sharing a common resource.<sup>2</sup> We assume that the common resource is of limited capacity, which is normalized to one unit without loss of generality. The production technology in each division is stochastic and exhibits positive, but decreasing, expected returns to scale. The allocation of the common resource between the two divisions is under the manager's discretion (her operating decision) and is unobservable to the market. After allocating the common resource between the two divisions and completing some steps of the production process, but before it ends, the manager might privately observe information that measures the performance of both divisions.<sup>3</sup> The arrival of this private information enables the manager to refine the remainder of the production process and enhance production. Such refinements might include, for example, machinery tuning and adjustments, recycling of residue materials, or reassignment of employees.

We represent the production technology of each division  $j$  ( $j = 1, 2$ ) by the increasing and concave function  $f_j: \{inf, ui\} \times [0, 1] \rightarrow \mathfrak{R}^+$ , where  $inf(ui)$  stands for an informed (uninformed) manager. If information is not available, then the mean of the uncertain cash flows of the first division is  $f_1(ui, r)$  and that of the second division is  $f_2(ui, 1 - r)$ , given that  $r \in [0, 1]$  is the resource share allocated to the first division (and thus  $1 - r$  is the resource share allocated to the second division).<sup>4</sup> Conditioned on a future receipt of information, the expected cash flows of both divisions are improved and become  $f_1(inf, r) = (1 + \lambda_1)f_1(ui, r)$  and  $f_2(inf, 1 - r) = (1 + \lambda_2)f_2(ui, 1 - r)$ , respectively, where  $\lambda_1, \lambda_2 \geq 0$ . The parameters  $\lambda_1$  and  $\lambda_2$  represent the real value of the information in enhancing the expected production, and the special case of  $\lambda_1 = \lambda_2 = 0$  captures the possibility that information

<sup>2</sup> The model can be generalized to consider more than two divisions without qualitatively affecting the results.

<sup>3</sup> Below we expand on the process of information acquisition and disclosure, as well as on the information structure.

<sup>4</sup> Hereafter, we interchangeably use cash flow and output, implicitly normalizing all output prices to be 1.

has no such real value.<sup>5</sup> Given the manager's future information status,  $a \in \{inf, ui\}$ , and the resource share allocated to the first division,  $r \in [0, 1]$ , the divisions' uncertain cash flows are represented by the random variables  $CF_1(a, r)$  and  $CF_2(a, 1 - r)$ , which are assumed to be uncorrelated and normally distributed, with means  $f_1(a, r)$  and  $f_2(a, 1 - r)$ , and variances  $\sigma_1^2$  and  $\sigma_2^2$ , respectively. Accordingly, the random variable  $CF(a, r) = CF_1(a, r) + CF_2(a, 1 - r)$  is defined as the firm's total cash flows and is normally distributed with mean  $\mu(a, r) = f_1(a, r) + f_2(a, 1 - r)$  and variance  $\sigma^2 = \sigma_1^2 + \sigma_2^2$ .

### Information Environment

The manager can acquire information at a cost  $c$ .<sup>6</sup> Hence, given the manager's information status,  $a \in \{inf, ui\}$ , and the resource share allocated to the first division,  $0 \leq r \leq 1$ , the firm's net cash flows, denoted by  $NCF(a, r)$ , are  $NCF(inf, r) = CF(inf, r) - c$  if information is acquired and  $NCF(ui, r) = CF(ui, r)$  otherwise. Similarly to Pae (1999, 2004), while the manager knows the information acquisition cost, investors are uncertain and consider it a random variable,  $C$ , that is distributed over the interval  $[c, \bar{c}] \subseteq \mathbb{R}^+$  with a cumulative distribution function  $\Gamma$ .<sup>7</sup> That is, the manager's information superiority is two-fold. Prior to making the resource allocation decision, the manager privately observes the cost of acquiring information. After making the resource allocation decision, and conditioned on acquiring the information, the manager privately observes its content. We assume that the manager cannot credibly reveal to the market either the information acquisition cost or her information status. Upon receiving the information, however, the manager has to decide whether to make a credible disclosure of its content.<sup>8</sup>

We now detail the information structure. Consistent with Holmstrom and Milgrom (1991), our approach stems from the observation that, in general, different activities cannot be measured with the same degree of precision (and some activities cannot be measured at all).<sup>9</sup> Information that is reported to outsiders is subject to many constraints, apart from those relating to its measurement, as it must be available, timely, and verifiable, all at the same time. Therefore, it is often the case that different activities cannot be communicated with the same level of precision, even if they involve similar measurement restrictions. As a result, financial information produced and reported by a firm normally provides only a

<sup>5</sup> Though a real value of information is rarely assumed in the disclosure literature, we chose to incorporate it into our model in order to make it more representative of the real world. This feature of the model does not qualitatively affect the equilibrium outcomes, thus adding robustness to our results. However, as this is not the main focus of our analysis, for the sake of simplicity, we assume a constant real value of information that is independent of the information content. From a modeling perspective, this simplifying assumption is analogous to the standard assumption of constant disclosure costs that are independent of the disclosed content. In this context, see Einhorn (2005) for an analysis that demonstrates the robustness of equilibrium outcomes to information-dependent disclosure costs.

<sup>6</sup> Though we could have assumed an exogenous probability of information arrival (as in Dye 1985), we chose to incorporate an endogenous information acquisition decision into the model. This allows us to shed light not only on the nature of the interaction between operating and disclosure decisions, but also on their interplay with information acquisition decisions. Nevertheless, in Section IV, we also provide the analysis of a simplified version of the model with exogenous arrival of information.

<sup>7</sup> Uncertainty on the part of investors about the cost of acquiring information is used in the model as the source of uncertainty about the information endowment. Even if the cost of information is perfectly and commonly known, there could be other sources of uncertainty about the information endowment, such as uncertainty about the availability of information or uncertainty about its real value. While uncertainty about the information endowment plays a crucial role in our analysis, the specific way of modeling it does not affect the results.

<sup>8</sup> Credible disclosure is often assumed in the literature. It is usually justified by procedures (like audit or due diligence) that verify the manager's reported information or by the potential litigation and human capital erosion costs associated with misleading disclosure.

<sup>9</sup> Holmstrom and Milgrom (1991) provide several examples of imbalance in the ability to measure performance (e.g., for teachers, contractors, or franchisees).

partial and unbalanced picture of the firm's fundamental economics, giving emphasis to some aspects of the firm's operations and failing to capture others. In particular, measurement and reporting constraints are the reason for systematically applying different measurement rules to the different components that are aggregated into accounting measures, and thus aggregated measures are even more likely to be noisy and unbalanced. For example, imbalance is likely to occur in any accounting measure that aggregates earnings of divisions with different reliance on research and development, due to the special way that R&D activities are measured by accounting systems. Another example is imbalance in an aggregated earnings measure of divisions with reliance on similar equipment, due to differences in the timing of purchasing the equipment, which imply different acquisition costs and therefore also different depreciation expenses.<sup>10</sup>

To capture this typical characteristic of aggregated information, we model the manager's private information as a noisy unbalanced aggregated signal of the cash flows generated by the two operating divisions. Specifically, given the share of the resource allocated to the first division,  $0 \leq r \leq 1$ , we represent the manager's private signal by the random variable  $S(r)$  and assume that  $S(r) = CF_1(\text{inf}, r) + (1 - \omega)CF_2(\text{inf}, 1 - r) + \varepsilon$ , where  $\omega$  is a scalar and  $\varepsilon \sim N(0, \sigma_\varepsilon^2)$  is an independent random noise. That is,  $S(r)$  is a random variable that is normally distributed with mean  $\mu_s(r) = f_1(\text{inf}, r) + (1 - \omega)f_2(\text{inf}, 1 - r)$  and variance  $\sigma_s^2 = \sigma_1^2 + (1 - \omega)^2\sigma_2^2 + \sigma_\varepsilon^2$ . The parameter  $\omega$  represents the extent of imbalance in the manager's private signal,  $S(r)$ . Insofar as  $\omega \neq 0$ , the manager's private signal is not equally informative about the cash flows of the firm's two divisions.<sup>11</sup> Without loss of generality, we assume that the signal emphasizes the cash flows of the first division, that is,  $0 \leq \omega \leq 1$ . Two extreme cases deserve special attention. When  $\omega = 0$ , the manager's private signal is equally informative about the cash flows of the two divisions, describing balanced information. Later on, we benchmark our results against this case. The other extreme case,  $\omega = 1$ , depicts situations where the performance of one of the firm's divisions cannot be measured or communicated at all, so the manager's private signal pertains to only one division. The informational quality of the manager's private signal can be summarized by its correlation with the firm's cash flows, denoted  $\rho$ . Note that  $\rho$  is positive and decreasing in both the information imbalance,  $\omega$ , and the information noisiness,  $\sigma_\varepsilon$ .

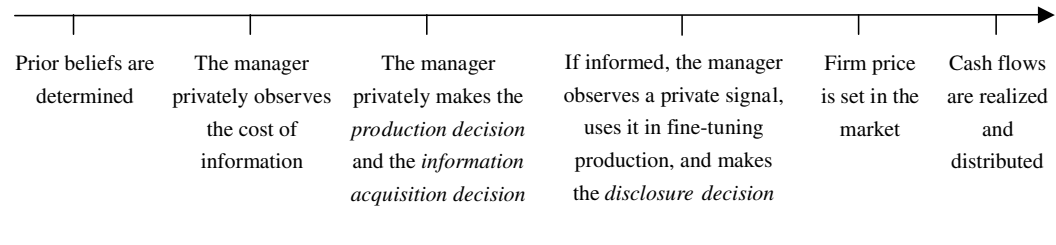
## Timeline

Figure 1 provides a timeline depicting the sequence of events in our model. At the beginning, prior beliefs of all players are determined. Then, the manager privately observes the cost  $c$  of acquiring the private signal and, accordingly, privately makes two decisions. She makes the resource allocation decision,  $r \in [0, 1]$ , and the common resource is allocated to the two divisions: a share of  $r$  to the first division and  $1 - r$  to the second division. She also makes the information acquisition decision,  $a \in \{\text{inf}, \text{ui}\}$ , choosing whether to acquire

<sup>10</sup> Other examples include aggregated accounting measures that are unbalanced due to differences in revenue recognition timing, differences in asset measurements (historical cost versus market value), differences in liability measurements (present value versus non-present value), differences in accounting estimates (discount rates, depreciation rates), and off balance sheet items (human capital, contingencies).

<sup>11</sup> The role of the parameter  $\omega$  can be demonstrated by considering two signals of the form  $S_1(r) = CF_1(\text{inf}, r) + \varepsilon_1$  and  $S_2(r) = CF_2(\text{inf}, 1 - r) + \varepsilon_2$ , where  $\varepsilon_1$  and  $\varepsilon_2$  are normally distributed noise terms with zero mean and variances  $\sigma_{\varepsilon_1}^2$  and  $\sigma_{\varepsilon_2}^2$ , respectively. As long as  $\varepsilon = \varepsilon_1 + (1 - \omega)\varepsilon_2$  and  $\omega = 1 - \sigma_2^2(\sigma_1^2 + \sigma_{\varepsilon_1}^2) / \sigma_1^2(\sigma_2^2 + \sigma_{\varepsilon_2}^2)$ , the information content of the aggregated signal  $S(r) = CF_1(\text{inf}, r) + (1 - \omega)CF_2(\text{inf}, 1 - r) + \varepsilon$  is equivalent from the investors' perspective to that of the two signals  $S_1(r)$  and  $S_2(r)$ , because  $E[CF(\text{inf}, r)|S(r)] = E[CF(\text{inf}, r)|S_1(r), S_2(r)]$ . Under these conditions, it also follows that  $\omega \neq 0$  is equivalent to  $\text{VAR}[CF(\text{inf}, r)|S_1(r)] \neq \text{VAR}[CF(\text{inf}, r)|S_2(r)]$ , implying that  $\omega \neq 0$  if and only if the two signals  $S_1(r)$  and  $S_2(r)$  are not equally informative about the future cash flow  $CF(\text{inf}, r)$ .

**FIGURE 1**  
**Timeline**



the forthcoming private signal ( $a = inf$ ) or not to acquire ( $a = ui$ ). Note that after observing the cost of the information, the manager can already anticipate her future information status. So, as long as the manager observes the cost of information in advance, it is immaterial which decision is made first—the information acquisition decision or the resource allocation decision. Hence, we can treat the two decisions as simultaneous. Conditioned on acquiring the information, however, there must be a time delay between allocating the resource and receiving the acquired information. Since the information is a performance measure of the operating divisions, it obviously arrives only after completing some stages of the production process (and, in particular, after the resource allocation decision is made). When the signal  $S(r)$  is received and privately observed by the manager, it allows her to generate production improvements by fine-tuning the remainder of the production process. Arrival of the signal  $S(r)$  is associated with the real value of multiplying the expected cash flows of each division  $j$  ( $j = 1, 2$ ) by a factor  $1 + \lambda_j$ . Also, based on the content of the signal, the manager makes her last decision—the disclosure decision,  $d \in \{dis, nd\}$ —and the signal is either disclosed ( $d = dis$ ) or not ( $d = nd$ ). Now, based on all the available public information, the firm's price is set in the market. Finally, at the end of the period, the firm's net cash flows  $NCF(a, r)$  are realized and distributed as a dividend to the shareholders.

### Players and Objective Functions

The manager chooses her resource allocation, information acquisition, and disclosure strategies based on the rationally anticipated effect on the firm's current market price and future cash flows. The assumption that the manager is interested in both the firm's current market price and its future cash flows is reasonable in a variety of prevalent situations. This is the case, for example, when the manager is compensated based on market price and at the same time is concerned about her future professional reputation, or when she is compensated based on cash flows but has ownership that she intends to liquidate at the market price. It is also the case when the firm acquires capital by issuing stocks (see, for example, Gigler 1994), or when there are different types of shareholders, some needing a quick liquidation (prior to the realization of cash flows) and others intending to hold their shares until cash is realized. Accordingly, we assume that the manager maximizes a linear combination that assigns a weight  $1 - \eta$  to the firm's price and a weight  $\eta$  to the net cash flows, where  $0 < \eta < 1$ .

The firm is traded in a rational and risk-neutral capital market. Its price is therefore determined in the market as its expected cash flows, conditioned on all the available public information, including the investors' rational expectations regarding the manager's resource allocation, information acquisition, and disclosure strategies. Conditioned on disclosure,

investors know that the manager was informed. In this case, using their expectations about how a manager who anticipates the future arrival of information would have allocated resources and based on the realization of the disclosed signal, investors update their beliefs about the firm's expected cash flows. On the other hand, if disclosure has not occurred, then investors predict the expected cash flows of the firm by updating their beliefs about the likelihood of acquiring the signal and its distribution (if acquired) based on their expectations regarding the manager's resource allocation, information acquisition, and disclosure strategies.

### III. EQUILIBRIUM DEFINITION AND PRELIMINARY RESULTS

Equilibrium consists of the manager's strategies and the investors' pricing rule. We use the functions  $A: [\underline{c}, \bar{c}] \rightarrow \{inf, ui\}$ ,  $R: \{inf, ui\} \rightarrow [0, 1]$  and  $D: \{inf, ui\} \times \mathfrak{R} \rightarrow \{dis, nd\}$  to describe the manager's information acquisition, resource allocation and disclosure strategies, respectively, whereas the investors' expectations about them are described by the functions  $\hat{A}: [\underline{c}, \bar{c}] \rightarrow \{inf, ui\}$ ,  $\hat{R}: \{inf, ui\} \rightarrow [0, 1]$  and  $\hat{D}: \{inf, ui\} \times \mathfrak{R} \rightarrow \{dis, nd\}$ , respectively. We also denote the investors' pricing rule by the function  $P: \{dis, nd\} \times \mathfrak{R} \rightarrow \mathfrak{R}$ , and the manager's expectations about it by the function  $\hat{P}: \{dis, nd\} \times \mathfrak{R} \rightarrow \mathfrak{R}$ . Explicitly,  $A(c)$ ,  $R(a)$  and  $D(a, s)$  are the manager's information acquisition, resource allocation, and disclosure decisions, respectively, given the cost  $c \in [\underline{c}, \bar{c}]$  of acquiring information, the information status  $a \in \{inf, ui\}$ , and the realization  $s \in \mathfrak{R}$  of the private signal (if acquired). Also,  $P(d, s)$  is the market price of the firm, where  $d \in \{dis, nd\}$  is the manager's disclosure decision and  $s \in \mathfrak{R}$  is the realization of her private signal (if acquired and disclosed).

We look for Bayesian equilibrium, formally defined as a vector of functions  $(A, \hat{A}: [\underline{c}, \bar{c}] \rightarrow \{inf, ui\}, R, \hat{R}: \{inf, ui\} \rightarrow [0, 1], D, \hat{D}: \{inf, ui\} \times \mathfrak{R} \rightarrow \{dis, nd\}, P, \hat{P}: \{dis, nd\} \times \mathfrak{R} \rightarrow \mathfrak{R})$  that simultaneously satisfies the following five conditions for any  $c \in [\underline{c}, \bar{c}]$ ,  $a \in \{inf, ui\}$ ,  $s \in \mathfrak{R}$ , and  $d \in \{dis, nd\}$ :

$$(1) A(c) \in \operatorname{argmax}_{a \in \{inf, ui\}} E[\eta NCF(a, R(a)) + (1 - \eta) \hat{P}(D(a, S(R(a))), S(R(a)))];$$

$$(2) R(a) \in \operatorname{argmax}_{r \in [0, 1]} E[\eta NCF(a, r) + (1 - \eta) \hat{P}(D(a, S(r)), S(r))];$$

$$(3) D(ui, s) = nd,$$

$$D(inf, s) \in \operatorname{argmax}_{d \in \{dis, nd\}} E[\eta NCF(inf, R(inf)) + (1 - \eta) \hat{P}(d, s)] = \operatorname{argmax}_{d \in \{dis, nd\}} \hat{P}(d, s);$$

$$(4) P(d, s) = \begin{cases} E[NCF(inf, \hat{R}(inf)) | S(\hat{R}(inf)) = s, \hat{A}(C) = inf] & \text{if } d = dis \\ E[NCF(\hat{A}(C), \hat{R}(\hat{A}(C))) | \hat{D}(\hat{A}(C), S(\hat{R}(\hat{A}(C)))) = nd] & \text{if } d = nd \end{cases}$$

$$(5) \hat{A}(c) = A(c), \hat{R}(a) = R(a), \hat{D}(a, s) = D(a, s), \hat{P}(d, s) = P(d, s).$$

The first equilibrium condition pertains to the information acquisition strategy,  $A$ , requiring that the manager's information acquisition decision maximizes her expected utility, given the cost of acquiring the information. Note that after acquiring the information, its cost becomes sunk, and thus is no longer relevant for the manager. The second equilibrium condition pertains to the resource allocation strategy,  $R$ , requiring that the manager's resource allocation decision maximizes her expected utility, given her information status. The third equilibrium condition, which relates to the disclosure strategy,  $D$ , implies that an uninformed manager obviously never provides disclosure, whereas the disclosure decision of an informed manager maximizes her expected utility, given the realization of her private signal. In particular, note that, in choosing her disclosure decision, the informed manager



can no longer affect the firm's cash flows, and therefore her objective is reduced to maximizing the expected market price of the firm. The fourth equilibrium condition relates to the pricing rule,  $P$ . The price condition requires investors to determine the firm's price as the expected cash flows of the firm conditioned on all the available public information. The fifth, and last, equilibrium condition implies that both the investors and the manager have rational expectations regarding each other's behavior.

We start the equilibrium analysis with some preliminary results that enable us to simplify the notation and condense the representation of the manager's strategies. Focusing first on the information acquisition decision, note that the manager makes a trade-off between the benefit from possessing information and the independent cost of acquiring it. Hence, consistent with Pae (1999), the information acquisition strategy must be lower-tailed in the cost of acquiring the information, so that information is acquired if and only if its cost is below some threshold level. Formally:

**Lemma 1:** The manager's equilibrium information acquisition strategy,  $A: [\underline{c}, \bar{c}] \rightarrow \{inf, ui\}$ , must be lower-tailed with a threshold  $c_0 \in [\underline{c}, \bar{c}]$ , such that for any  $c \in [\underline{c}, \bar{c}]$ :  $A(c) = \begin{cases} inf & \text{if } c \leq c_0 \\ ui & \text{otherwise.} \end{cases}$

Lemma 1 implies that the manager's information acquisition strategy is characterized by the threshold  $c_0$ , and thus it can be equivalently described by the *ex ante* (prior to observing the information cost) probability of acquiring information,  $\pi = \text{prob}[C \leq c_0] = \Gamma(c_0)$ . Hereafter, we refer to  $\pi$  as the information acquisition intensity and use it as a condensed representation of the information acquisition strategy,  $A$ .

We now consider the resource allocation strategy. Since each division has a commonly known production technology that exhibits positive and decreasing expected returns to scale, there is a unique allocation of the limited resource, known to the manager and dependent upon her information status, that maximizes the overall expected cash flows. When the manager is uninformed and knows there will be no disclosure, the firm's market price is independent of the resource allocation decision, and thus the manager maximizes the expected cash flows by choosing the first-best resource allocation. In contrast, the optimal resource allocation of an informed manager might deviate from the first-best allocation, due to its impact on the expected content of the disclosable information and thereby on the firm's expected market price. Formally:

**Lemma 2:** (i) Given the manager's information status,  $a \in \{inf, ui\}$ , there is a unique resource allocation,  $r^{FB}(a)$ , that maximizes the firm's expected cash flows, where  $f'_1(a, r^{FB}(a)) = f'_2(a, 1 - r^{FB}(a))$  and  $\mu(inf, r^{FB}(inf)) \geq \mu(ui, r^{FB}(ui))$ ; and  
(ii) The manager's equilibrium resource allocation strategy,  $R: \{inf, ui\} \rightarrow [0, 1]$ , must satisfy  $R(ui) = r^{FB}(ui)$ .

By Lemma 2, we can represent the resource allocation strategy by the incremental contribution of the information to the production process,  $\delta = \mu(inf, R(inf)) - \mu(ui, r^{FB}(ui))$ . Accordingly, we use  $\delta$  as a compacted representation of the resource allocation strategy,  $R$ , and refer to it as the operating value of information.

Finally, as the manager's private signal is positively correlated with the firm's cash flows, the disclosure strategy must be upper-tailed in the realization of the signal. That is,

consistent with extant results in the voluntary disclosure literature, including Verrecchia (1983) and Dye (1985), the manager chooses to disclose her private signal to investors if and only if its realization is sufficiently favorable, exceeding some threshold level. Formally:

**Lemma 3:** The manager's equilibrium disclosure strategy,  $D: \{inf, ui\} \times \mathfrak{R} \rightarrow \{dis, nd\}$ , must be upper-tailed with a threshold  $s_0 \in \mathfrak{R}$ , such that for any  $a \in \{inf, ui\}$  and  $s \in \mathfrak{R}$ :  $D(a, s) = \begin{cases} dis & \text{if } a = inf \text{ and } s \geq s_0 \\ nd & \text{otherwise} \end{cases}$ .

According to Lemma 3, the manager's disclosure strategy is characterized by the disclosure threshold  $s_0$ , and therefore it can be unequivocally represented by  $\tau = \text{prob}[S(R(inf)) \geq s_0]$ , which is the *ex ante* (prior to observing the realization of the signal) probability of disclosure occurrence *conditioned* on being informed. Hereafter, we refer to  $\tau$  as the disclosure intensity and use it to represent the disclosure strategy,  $D$ .

Having established the basic properties of the manager's strategies, we proceed to derive the equilibrium using backward induction. First, in Section IV, we assume a given information acquisition strategy and derive the operating and disclosure strategies. Then, in Section V, utilizing our results from Section IV, we move backward and derive the information acquisition strategy. Throughout the analysis, we pay special attention to the relationship between the manager's strategies and the information imbalance,  $\omega$ . To isolate the impact of a change in the extent of information imbalance, we neutralize its consequence on the informativeness of the manager's private signal. Specifically, we assume that any change in  $\omega$  is accompanied by an offsetting change in  $\sigma_e$ , such that the correlation between the signal and the firm's cash flows,  $\rho$ , remains intact. This assumption enables a comparison between equally informative signals that vary only in their degree of imbalance.

#### IV. ANALYSIS OF OPERATING AND DISCLOSURE STRATEGIES

In this section, we derive the operating and disclosure strategies in a sub-model where the information acquisition intensity,  $0 < \pi < 1$ , is given. This sub-model ignores the information acquisition decision, and can therefore be viewed as an extension of Dye's (1985) model involving mutually dependent disclosure and operating decisions. We explore the mutual dependence between the operating and disclosure strategies in two steps, first analyzing the operating strategy for any given disclosure strategy, and then analyzing the disclosure strategy for any given operating strategy. We benchmark the resulting operating and disclosure strategies against the case of balanced information,  $\omega = 0$ , where the two strategies are independent. We denote the benchmark case by the superscript  $B$ , so that  $\delta^B$  and  $\tau^B$  are the benchmark operating value of information and disclosure intensity, respectively.

Focusing first on the operating strategy, recall that being unable to affect the market price of the firm, an uninformed manager efficiently allocates resources between divisions, maximizing the firm's expected cash flows. In contrast, a manager who is about to be informed is aware that her resource allocation decision affects not only the firm's expected cash flows, but also the expected content of the disclosable information and thereby the expected market price of the firm. As the potentially disclosed signal is unbalanced, over-emphasizing the results of the first division, a manager who is about to be informed has the unavoidable incentive to inefficiently bias the resource allocation toward that division in order to increase the expected realization of the signal and in that way increase the expected market price of the firm. This bias in resource allocation is limited, because it

decreases the firm's expected cash flows and hence is costly to the manager. The more likely disclosure is, the larger are the bias and the implied production distortion, and the lower is the operating value of information.<sup>12</sup> In some cases, the production distortion is even larger than the contribution of the information to the production process, resulting in a negative operating value of information (i.e.,  $\delta < 0$ ). Lemma 4 formally characterizes the manager's resource allocation strategy for any exogenously given disclosure strategy:

**Lemma 4:** Suppose a given information acquisition intensity,  $\pi$ . Then, for any given disclosure intensity,  $\tau$ , there exists a unique operating value of information,  $\delta$ . When  $0 < \omega \leq 1$ ,  $\delta$  is decreasing in  $\tau$ , reaching a maximum of  $\delta^B = \mu(\text{inf}, r^{FB}(\text{inf})) - \mu(\text{ui}, r^{FB}(\text{ui})) \geq 0$  for  $\tau = 0$ , and can be negative for sufficiently high  $\tau$ . When  $\omega = 0$ ,  $\delta = \delta^B$  independently of  $\tau$ .

It follows from Lemma 4 that possession by the manager of unbalanced private information that can be credibly disclosed is a cause of production inefficiency.<sup>13</sup> This result is consistent with Holmstrom and Milgrom (1991), who show that managers cannot avoid the inefficient allocation of excessive amounts of resources to those tasks that have the greatest impact on observable performance measures. However, unlike Holmstrom and Milgrom (1991) and subsequent studies (e.g., Feltham and Xie 1994; Zhang 2003; Hughes et al. 2005), which analyze the adverse impact of information imbalance on production activities within moral hazard settings with mandatory disclosure, disclosure in our setting is under the manager's discretion.<sup>14</sup> Our setting, therefore, introduces an additional layer of analysis and yields further insights, exploring the impact of information imbalance on managerial discretionary disclosure strategies, via its already identified distorting effect on operating strategies. Described differently, in our model, not only does the disclosure strategy affect the resource allocation strategy, but also it is affected by that strategy. In the absence of disclosure, investors are unable to precisely identify the information status of the manager, so the firm's market price incorporates the operating value of information,  $\delta$ , only in expectations. On the other hand, when disclosure occurs, it unequivocally reveals the informed status of the manager and the implied production distortion, resulting in a market price that fully reflects the inferred operating value of information. Thus, as formally described in Lemma 5, the lower the operating value of information, the lower are the incentives for an informed manager to provide disclosure. This implies that by reducing the operating value of information, information imbalance endogenously generates disclosure costs that reduce the disclosure intensity.<sup>15</sup>

<sup>12</sup> The largest production distortion occurs when disclosure is always anticipated ( $\tau = 1$ ). This is the case, for example, when disclosure is mandatory or when the manager commits to disclose. On the other hand, if the manager never possesses private information ( $\pi = 0$ ), or if disclosure is prohibited ( $\tau = 0$ ), there will be no production distortions.

<sup>13</sup> While disclosure is the cause of production inefficiency in the circumstances depicted in our model, Lanen and Verrecchia (1987) and Pae (2002) demonstrate scenarios where the opposite could occur. There, an observable operating decision serves as a noisy manageable substitute for unfavorable disclosure, so that the absence of disclosure (rather than its presence) is the reason for making the inefficient operating decision in anticipating the inferences of investors about the withheld information.

<sup>14</sup> For a variety of other real effects of mandatory disclosure, see Kanodia (1980), Stein (1989), Kanodia and Mukherji (1996), Kanodia and Lee (1998), Melumad et al. (1999), Kanodia et al. (2000), and Kanodia et al. (2004).

<sup>15</sup> Note that disclosure costs arise only when  $0 < \pi < 1$ . If the manager never possesses private information ( $\pi = 0$ ), then there will be no disclosure and no production distortion. On the other hand, if the manager commits to acquiring information, and thus  $\pi = 1$ , then production distortion does occur, but it is in any case anticipated by the market, so disclosure is costless.

**Lemma 5:** Suppose a given information acquisition intensity,  $\pi$ . Then, for any given operating value of information,  $\delta$ , there exists a unique disclosure intensity,  $\tau$ . For any  $0 \leq \omega \leq 1$ ,  $\tau$  is increasing in  $\delta$ , reaching a maximum of  $\tau^B$  when  $\delta = \delta^B$ .

While Lemma 4 characterizes the manager's resource allocation strategy for any exogenously given disclosure strategy, Lemma 5 characterizes the manager's disclosure strategy for any exogenously given resource allocation strategy. Taken together, Lemmata 4 and 5 highlight the role that the imbalance in information plays in generating a mutual dependence between the resource allocation and disclosure decisions. Consistent with prior literature, Lemma 4 indicates that disclosure of unbalanced information is the cause of a production distortion that reduces the operating value of information. Lemma 5 implies that the reduction in the operating value of information makes disclosure more costly and thus leads to a reduction in the disclosure intensity as well. This interaction results in the unique equilibrium presented in Proposition 1.

**Proposition 1:** Suppose a given information acquisition intensity,  $\pi$ . Then, there exists a unique equilibrium. The equilibrium resource allocation of an uninformed manager is always efficient, while that of an informed manager is inefficient, unless  $\omega = 0$ , so that the operating value of information is  $\delta \leq \delta^B$ . The equilibrium disclosure strategy is upper-tailed with disclosure intensity  $\tau \leq \tau^B$ . Both  $\delta$  and  $\tau$  are decreasing in  $\omega$ , where an equilibrium of  $\delta = \delta^B$  and  $\tau = \tau^B$  is obtained if and only if  $\omega = 0$ .

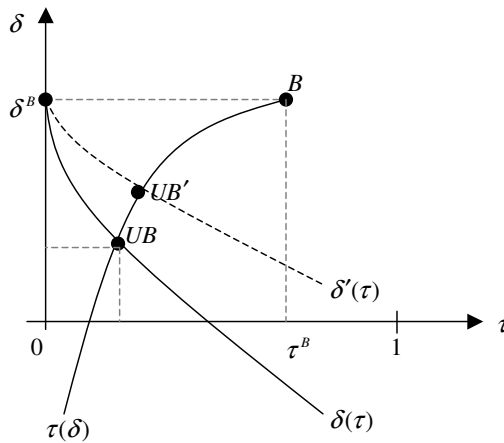
According to Proposition 1, in the presence of unbalanced information, the interaction between the operating and disclosure strategies results in a production distortion and a reduced disclosure intensity. The magnitude of both the production distortion and the reduction in the disclosure intensity is positively related to the extent of imbalance in the information. In particular, Proposition 1 yields the empirical prediction that firms with more diversity in their operations, which are usually prone to more information imbalance, are more likely to distort their resource allocation decisions and will consequently be reluctant to provide voluntary disclosure.

The results of Proposition 1 are illustrated in Figure 2. When information is unbalanced ( $\omega > 0$ ), the decreasing solid line, denoted by  $\delta(\tau)$ , describes the operating value of information for any given level of disclosure intensity, as implied by Lemma 4. The increasing line, denoted by  $\tau(\delta)$ , describes the disclosure intensity for any given level of operating value of information, as implied by Lemma 5.<sup>16</sup> Since the production line,  $\delta(\tau)$ , is strictly decreasing, whereas the disclosure line,  $\tau(\delta)$ , is strictly increasing, they intersect only once, and their intersection point,  $UB$ , represents the unique equilibrium.<sup>17</sup> As the information becomes more balanced (i.e.,  $\omega$  decreases), the operating value of information becomes less sensitive to the level of the disclosure intensity, as described by the dotted line  $\delta'(\tau)$ , whose slope is not as steep as that of the line  $\delta(\tau)$ . So, the resulting equilibrium point,  $UB'$ , involves

<sup>16</sup> We note that while the disclosure line,  $\tau(\delta)$ , depends upon the information acquisition intensity,  $\pi$ , the production line,  $\delta(\tau)$ , is independent of  $\pi$ . This observation plays an important role in the analysis of the following section where  $\pi$  is endogenous.

<sup>17</sup> We note that the operating value of information,  $\delta$ , at the equilibrium point,  $UB$ , can be either positive or negative.

**FIGURE 2**  
**Equilibrium Operating and Disclosure Strategies**



This figure illustrates the equilibrium operating and disclosure strategies for a given information acquisition intensity,  $\pi$ , in the space of all possible pairs of operating value of information ( $\delta$ ) and disclosure intensity ( $\tau$ ). When information is unbalanced ( $\omega > 0$ ), the decreasing solid line, denoted by  $\delta(\tau)$ , describes the operating value of information for any given level of disclosure intensity (Lemma 4). The increasing line, denoted by  $\tau(\delta)$ , describes the disclosure intensity for any given level of operating value of information (Lemma 5). The intersection point,  $UB$ , of these two lines describes the equilibrium in the case of unbalanced information (Proposition 1). As the information becomes more balanced (i.e.,  $\omega$  decreases), the operating value of information becomes less sensitive to the level of the disclosure intensity, as described by the decreasing dotted line  $\delta'(\tau)$ , whose slope is not so steep as that of the line  $\delta(\tau)$ . So, the resulting equilibrium point,  $UB'$ , involves a higher operating value of information and a higher disclosure intensity. Under the benchmark case of balanced information ( $\omega = 0$ ), the equivalent to the line  $\delta(\tau)$  is the horizontal line where  $\delta = \delta^B \geq 0$ . Therefore, the point  $B$  describes the equilibrium in the benchmark case of balanced information.

a higher operating value of information and a higher disclosure intensity. Under the benchmark case of balanced information ( $\omega = 0$ ), resource allocation is always efficient, so the production line  $\delta(\tau)$  coincides with the horizontal line  $\delta = \delta^B$ , and the equilibrium is obtained at the point  $B$ , where there is no production distortion and the disclosure intensity is maximal.

In analyzing the equilibrium, we put special emphasis on the impact of the information imbalance,  $\omega$ , showing that both the operating value of information,  $\delta$ , and the disclosure intensity,  $\tau$ , are negatively related to  $\omega$ . We now examine the relations between the equilibrium outcomes and the remaining parameters of the model. Most of these relations are clear-cut, as detailed in Corollary 1, but some of them are inconclusive due to the existence of multiple countervailing forces.

**Corollary 1:** The operating value of information,  $\delta$ , is decreasing in  $\pi$  and  $\sigma_2$ , and increasing in  $\eta$ ,  $\lambda_1$ ,  $\lambda_2$ , and  $\sigma_e$ . The disclosure intensity,  $\tau$ , is increasing in  $\pi$ ,  $\eta$ ,  $\lambda_1$ , and  $\lambda_2$ .

Consider first an increase in the probability  $\pi$  assigned by the market to the manager's endowment with private information. Consistent with Dye (1985) and Jung and Kwon

(1988), the disclosure intensity increases as investors are more convinced about the endowment of the manager with private information. The increase in the disclosure intensity intensifies the production distortion and therefore decreases the operating value of information. Consider now an increase in  $\eta$ , which suggests that the manager assigns a higher weight to the firm's cash flows and a lower weight to its market price. Examples of entities with a high value of  $\eta$  include private firms, firms that are held by institutional investors (e.g., private equity or hedge funds), and firms that do not use stock-based compensation. We predict, based on Corollary 1, that among such firms, both production and disclosure distortion will be less frequent or severe due to a reduced propensity to bias resource allocation. Similarly, an increase in either  $\lambda_1$  or  $\lambda_2$  obviously increases the operating value of information and thereby increases the disclosure intensity as well. Next, note that a decrease in the noisiness of the signal,  $\sigma_\varepsilon^2$ , or an increase in the variability of the second division's cash flow,  $\sigma_2^2$ , enhances the relevance of the manager's private signal. As a result, disclosure has a stronger impact on the firm's market price, so the propensity of the manager to bias resource allocation increases, reducing the operating value of information. The increase in the relevance of the signal increases the disclosure intensity, but the increased production distortion makes the disclosure of the signal more costly and thus has the opposite effect of decreasing the disclosure intensity. Consistent with the existing literature, in most of our numerical analyses the former force dominates, but we are also able to construct examples where the latter force dominates. The effect of an increase in the variability of the first division's cash flow,  $\sigma_1^2$ , is inconclusive not only with respect to the disclosure intensity, but also with respect to the operating value of information. This is because the relevance of the signal is not necessarily increasing in  $\sigma_1^2$  due to the reporting imbalance. Again, examples exist where the results can go both ways.

## V. ANALYSIS OF INFORMATION ACQUISITION STRATEGY

In this section, utilizing our results from the previous section, we move backward and derive the information acquisition strategy. In making the information acquisition decision, the manager faces a trade-off between the benefit from possessing information and the independent cost of acquiring it, so that the information is acquired if and only if its cost does not exceed some threshold  $c_0 \in [\underline{c}, \bar{c}]$ . Similarly to Pae (1999), we cannot rule out the existence of multiple equilibria. However, the analysis in this section sheds light on the properties of the threshold cost,  $c_0$ , within each equilibrium.

Observe that information benefits the manager in two ways. First, it can provide an operating advantage that enables her to augment production and increase the firm's expected cash flows. Second, it allows her to use voluntary disclosure to manipulate the investors' expectations about the firm and thereby increase the firm's market price. Therefore, the manager's benefit from possessing information is increasing in both the operating value of information,  $\delta$ , and the disclosure intensity,  $\tau$ . Recall now that according to Proposition 1, for any level of information acquisition intensity,  $\pi$ , both the operating value of information,  $\delta$ , and the disclosure intensity,  $\tau$ , are decreasing in the extent of imbalance in information. Hence, as shown in Lemma 6, the imbalance in the information decreases the benefit to the manager from possessing the information:

**Lemma 6:** For any given information acquisition intensity,  $\pi$ , the difference in the expected utility of an informed manager and an uninformed manager is decreasing in  $\omega$ .

It follows from Lemma 6 that imbalance in information decreases the benefit to the manager from possessing the information, and thus it also decreases the threshold cost,  $c_0$ , of acquiring the information. So, the equilibrium information acquisition intensity,  $\pi$ , is decreasing in the extent of imbalance in the information. As in the previous section, we benchmark our results against the case of balanced information,  $\omega = 0$ , denoted by the superscript  $B$ , where  $\pi^B$ ,  $\delta^B$ , and  $\tau^B$  are the benchmark information acquisition intensity, operating value of information, and disclosure intensity, respectively.<sup>18</sup> Since the equilibrium information acquisition intensity,  $\pi$ , is negatively related to  $\omega$ , it never exceeds the benchmark level,  $\pi^B$ . Combining this conclusion with the results presented in Section IV, we complete the characterization of the equilibrium. The equilibrium properties, as presented in Proposition 2, reflect the role that the inherent imbalance in information plays in suppressing the managerial propensity to acquire information and provide voluntary disclosures, via its distorting impact on operating activities.

**Proposition 2:** In equilibrium, the information acquisition strategy is lower-tailed with an information acquisition intensity  $\pi \leq \pi^B$ . The equilibrium resource allocation of an uninformed manager is always efficient, while that of an informed manager is inefficient, unless  $\omega = 0$ , so that the operating value of information is  $\delta \leq \delta^B$ . The equilibrium disclosure strategy is upper-tailed with disclosure intensity  $\tau \leq \tau^B$ . Also,  $\pi$  and  $\tau$  are decreasing in  $\omega$ , but  $\delta$  is not necessarily monotonic in  $\omega$ , where an equilibrium of  $\pi = \pi^B$ ,  $\delta = \delta^B$  and  $\tau = \tau^B$  is obtained if and only if  $\omega = 0$ .

Proposition 2 complements the results of Proposition 1 by demonstrating that the production and disclosure distortions caused by the information imbalance diminish the manager's incentives to acquire the information in the first place. By creating both production and disclosure distortions, the information imbalance reduces the operating advantage of the information and the value of the disclosure option. That is, when the information is unbalanced, it becomes less valuable to the manager and therefore less likely to be acquired. Supplementing the empirical predictions emanating from Proposition 1, we also predict that firms with more diversified operations will be less likely to join trade associations that serve to collect and share information among their members.

The suppressing effect of the information imbalance on the propensity to acquire information, via its impact on the operating and disclosure decisions, has implications for the operating and disclosure decisions. As information acquisition becomes less likely, the manager can better hide behind the cover of not possessing information in order to avoid unfavorable disclosure, and thus her propensity to provide voluntary disclosure is further reduced. In other words, when the information endowment is endogenously derived, information imbalance creates an environment where two effects combine to reduce the manager's incentives to provide voluntary disclosure. First, disclosure becomes costly, because it resolves the uncertainty about the information endowment and thereby reveals the implied production distortion. Second, the manager is better able to pretend to be uninformed, because of the lower likelihood of acquiring information. Unlike the first-mentioned effect

<sup>18</sup> While the information acquisition intensity is irrelevant for determining the benchmark operating value of information,  $\delta^B$ , it is an important determinant of the benchmark disclosure intensity,  $\tau^B$ . Hence, in this section we use the notation  $\tau^B$  to denote the benchmark disclosure intensity for an information acquisition intensity of  $\pi^B$ , whereas in the previous section the same notation serves to represent the benchmark disclosure intensity for the exogenously given information acquisition intensity  $\pi$ .

concerning disclosure, which has been already explored in the previous section, the second arises due to the endogenous derivation of the information acquisition decision. Hence, by endogenously deriving the information endowment, we are able to further reinforce the suppressing impact of the information imbalance on the manager's propensity to provide voluntary disclosure. However, this intensification in the disclosure distortion due to the endogenous information endowment has a moderating effect on the production distortion. Hence, while the reductions in both the information acquisition intensity and the disclosure intensity are positively related to the extent of imbalance in information, this is not necessarily the case with respect to the production distortion. Consistent with the intuition drawn from Holmstrom and Milgrom (1991) and subsequent papers, most of our numerical analyses show that the magnitude of the production distortion is positively related to the extent of the information imbalance, but we are also able to construct examples where this relationship is non-monotonic. To illustrate why our result here differs from that of the previous section, where  $\pi$  was exogenously given, we refer again to Figure 2. Since  $\pi$  is now endogenously derived and negatively related to the information imbalance, not only does the information imbalance shift the production line downward, but also it shifts the disclosure line to the left. Hence, unlike the analysis in the previous section, because of the shift to the left of the disclosure line, the magnitude of the production distortion is not necessarily monotonically increasing in the extent of imbalance in information. Nevertheless, the equilibrium must involve a lower operating value of information compared to the benchmark of balanced information.

The results of Proposition 2 are of particular interest when considering the special case of  $\delta^B \geq \bar{c}$ . In this case, information is value-enhancing in the sense that its expected operating advantage always exceeds its cost. Here, our benchmark of balanced information yields a unique equilibrium with first-best production ( $\delta = \delta^B$ ), full information acquisition ( $\pi^B = 1$ ), and full disclosure ( $\tau^B = 1$ ). However, imbalance in the information might lead to partial information acquisition accompanied by a partially revealing disclosure strategy and inefficient production. The imbalance in information, which leads to suboptimal production ( $\delta < \delta^B$ ), makes information less valuable and thereby reduces the propensity to acquire it. Consequently, there could be a deviation from the benchmark of full information acquisition to an equilibrium with partial information acquisition ( $\pi < \pi^B = 1$ ), implying that imbalance in information might create another kind of inefficiency by preventing the acquisition of value-enhancing information with a cost that is low relative to its potential benefit. This prediction is interesting in light of Pae's (1999) observation regarding the inevitable incentives of managers to acquire value-distorting information. Furthermore, when acquiring the information, the manager adopts a partial rather than a full disclosure strategy ( $\tau < \tau^B = 1$ ). This is because the uncertain information acquisition makes it possible for the manager to hide behind the cover of not possessing information and also confronts her with the disclosure-associated cost of revealing the production distortion. Information imbalance therefore endogenously generates an environment where investors are uncertain about the manager's information endowment (Dye 1985),  $\pi < \pi^B = 1$ , and disclosure is costly (Verrecchia 1983),  $\delta < \delta^B$ . By endogenously creating both uncertainty about the information endowment and disclosure costs, the imbalance in value-enhancing information acts as a trigger for a move from a fully revealing equilibrium to a partially revealing one.

We use a numerical example to demonstrate our results. Assume an identical Cobb-Douglas production function for the two divisions,  $f_1(ui, x) = f_2(ui, x) = (400x)^{0.8}$ , a uniformly distributed information acquisition cost over the support [ $\underline{c} = 0$ ,  $\bar{c} = 10$ ], and the following set of parameters:  $\lambda_1 = 0.05$ ,  $\lambda_2 = 0.1$ ,  $\eta = 0.4$ ,  $\rho = 0.6$ ,  $\sigma_1 = 5$  and  $\sigma_2 = 15$ .



We derive the manager's equilibrium strategies under two alternative assumptions about the information structure: balanced ( $\omega = 0$ ) and unbalanced ( $\omega = 0.8$ ) information. Under the benchmark case of balanced information, the resource allocation is always efficient, yielding a first-best expected output of about 138.6 when the manager is uninformed and a higher first-best of 149.2 when the manager is informed, so the benchmark operating value of information is  $\delta^B = 10.6$ . Since the cost of the information does not exceed its operating advantage ( $\bar{c} = 10 < \delta^B = 10.6$ ), it is always beneficial for the manager to acquire the information, so the benchmark information acquisition intensity is  $\pi^B = 1$ . As investors are certain about the information endowment and disclosure is costless, the benchmark also yields full disclosure and the benchmark disclosure intensity is  $\tau^B = 1$ . On the other hand, when the information is unbalanced ( $\omega = 0.8$ ), an informed manager over-allocates resources to the first division, yielding suboptimal expected output of about 137.4, which is below even the first-best of the uninformed manager (138.6). This implies a negative operating value of information,  $\delta = -1.2$ . As information becomes value-distorting, the propensity of the manager to acquire it decreases significantly. As a result, instead of full information acquisition, we get a much lower information acquisition intensity of  $\pi = 0.42$ , where information is acquired only if its cost is below the threshold of  $c_0 = 4.2$ . Therefore, with probability 0.58, there is an inefficiency of 3.5 because of not acquiring information that has the potential to contribute a value of  $\delta^B = 10.6$  to the expected production at an average cost of  $(c_0 + \bar{c})/2 = (4.2 + 10)/2 = 7.1$ . With probability 0.42, there is an inefficiency of  $\delta^B - \delta = 10.6 - (-1.2) = 11.8$  because of the production distortion in the case of acquiring the information. Averaging these two inefficiencies, the imbalance in information results in an average efficiency loss of  $0.58 \cdot 3.5 + 0.42 \cdot 11.8 = 7$  (about 5 percent of the first-best value). Furthermore, being able to pretend to be uninformed because information endowment is uncertain, and knowing that disclosure is costly as it reveals the production distortion, the informed manager is considerably less motivated to provide disclosure, resulting in a disclosure intensity of  $\tau = 0.48$  instead of full disclosure. That is, conditioned on acquiring the information, the imbalance in information dramatically reduces the probability of disclosure occurrence from 1 to 0.48. The reduction from 1 to  $0.42 \cdot 0.48 = 0.20$  in the unconditional probability of disclosure occurrence is even steeper.

Having discussed the sensitivity of the equilibrium outcomes to the central modeling parameter  $\omega$ , we complete the analysis by discussing the sensitivity of the equilibrium outcomes to changes in the other parameters of the model. It appears that some of the relationships between the parameters and the equilibrium outcomes are subject to countervailing economic forces and are thus inconclusive. Clear-cut results are obtained only when considering the impact of the parameters  $\eta$ ,  $\lambda_1$ , and  $\lambda_2$  on the information acquisition intensity and on the disclosure intensity. These results are presented in Corollary 2:

**Corollary 2:** The information acquisition intensity,  $\pi$ , and the disclosure intensity,  $\tau$ , are increasing in  $\eta$ ,  $\lambda_1$ , and  $\lambda_2$ .

To understand the results of Corollary 2, recall that according to Corollary 1, an increase in each of the parameters  $\eta$ ,  $\lambda_1$ , and  $\lambda_2$  results in an increase in both the operating value of information and the disclosure intensity, enhancing the benefit to the manager from possessing information (Lemma 6) and her propensity to acquire the costly information. The increase in the information acquisition intensity further increases the disclosure intensity, but has an opposite downward effect on the operating value of information, so the overall impact on the operating value of information is inconclusive. For all other parameters ( $\sigma_1, \sigma_2, \sigma_e$ ), recall our discussion in the previous section about the existence of multiple

forces, which leads here to an inconclusive impact on all three equilibrium outcomes where the results can go both ways.

## VI. CONCLUDING REMARKS

In this paper, we integrate voluntary disclosure into the overall corporate activities and strategies. Our study is based on the notion that there is an inherent variation in the precision with which different activities can be measured or communicated. As a result, information produced and reported by firms normally provides only a partial and unbalanced reflection of their economic fundamentals, putting different levels of emphasis on different aspects of their operating activities. We identify this embedded imbalance in information as the source of an interaction between operating and discretionary disclosure strategies, and thereby also as an important determinant of the information acquisition strategy. We show that the imbalance in information, via its distorting effect on production, reduces the managerial propensity to acquire information and provide voluntary disclosures of acquired information.

While our analysis applies to a wide range of business contexts, it pertains especially to firms with diversified operations, such as firms that operate in several industries or markets, firms with operations that involve a multiplicity of tasks, and firms engaged in projects with different time horizons. In such diversified business environments, information is most likely to be unbalanced and is also expected to be sensitive to resource allocations, and thus the distortions in production, information acquisition, and voluntary disclosure are expected to be more salient. Our discussion in Sections IV and V provides several empirical predictions along these lines.

Obviously, the relationships between discretionary disclosure decisions and other managerial decisions are much richer than those we were able to consider in our model. We believe that there is considerable potential for future research in exploring many other sources of such relationships within multi-decision settings. Extensions could involve settings with several different concurrent decisions, as in our current paper, or settings with repeated sequential decisions (e.g., Einhorn and Ziv 2007).

## APPENDIX HIGHLIGHTS OF THE PROOFS

Throughout the Appendix, let  $z$  and  $\Phi$  be the probability density function and the cumulative distribution function for a standard normal variable, respectively. Also, for any random variable  $V$  that is normally distributed with mean  $m$  and standard deviation  $s$ , let  $\hat{V}$  be the standard normal variable  $\frac{V - m}{s}$ . Similarly, given a realization  $v$  of the variable  $V$ , let  $\hat{v}$  be the realization  $\frac{v - m}{s}$  of the variable  $\hat{V}$ . Besides Lemmata 1–6, the proofs are based on an additional lemma that is stated and proved below.

**Lemma A:** (i) The function  $F(x) = x + \frac{z(x)}{\Phi(x)}$  is continuous and increasing in  $x \in \Re$ , where  $\lim_{x \rightarrow -\infty} F(x) = 0$  and  $\lim_{x \rightarrow \infty} F(x) = \infty$ ;

(ii) The function  $G(\pi, x) = \frac{\pi}{1 - \pi} (x\Phi(x) + z(x)) + x$  is continuous and increasing in  $x \in \Re$  and in  $\pi \in (0, 1)$ , where  $\lim_{x \rightarrow -\infty} G(\pi, x) = -\infty$  and

$\lim_{x \rightarrow \infty} G(\pi, x) = \infty$ ; and

(iii) The function  $H(x) = x\Phi(x) + z(x) - x$  is continuous and decreasing in  $x \in \mathfrak{R}$ .

**Proof of Lemma A**

Being a composition of continuous functions, the function  $F$  is obviously continuous. For the monotonicity, recall that  $z'(x) = -xz(x)$  and recall also Sampford (1953) who shows:

$$\forall x \in \mathfrak{R}: 0 < \frac{z(x)}{1 - \Phi(x)} \left( \frac{z(x)}{1 - \Phi(x)} - x \right) < 1.$$

Thus:

$$\begin{aligned} F'(x) &= 1 + \frac{z'(x)\Phi(x) - z(x)\Phi'(x)}{\Phi^2(x)} = 1 - \frac{z(x)}{\Phi(x)} \left( \frac{z(x)}{\Phi(x)} + x \right) \\ &= 1 - \frac{z(-x)}{1 - \Phi(-x)} \left( \frac{z(-x)}{1 - \Phi(-x)} - (-x) \right) > 0. \end{aligned}$$

Now, based on  $\lim_{x \rightarrow -\infty} z(x) = \lim_{x \rightarrow \infty} z(x) = \lim_{x \rightarrow -\infty} \Phi(x) = 0$  and  $\lim_{x \rightarrow \infty} \Phi(x) = 1$ , and using l'Hopital's

rule repeatedly,  $\lim_{x \rightarrow -\infty} x\Phi(x) = \lim_{x \rightarrow -\infty} \frac{\Phi(x)}{1/x} = \lim_{x \rightarrow -\infty} \frac{z(x)}{-(1/x^2)} = \lim_{x \rightarrow -\infty} \frac{x^2}{-(1/z(x))} = \lim_{x \rightarrow -\infty} \frac{2x}{z'(x)/z^2(x)} = \lim_{x \rightarrow -\infty} -2z(x) = 0$ ,  $\lim_{x \rightarrow -\infty} F(x) = \lim_{x \rightarrow -\infty} \frac{x\Phi(x) + z(x)}{\Phi(x)}$

$$\begin{aligned} &= \lim_{x \rightarrow -\infty} \frac{\Phi(x) + xz(x) + z'(x)}{z(x)} = \lim_{x \rightarrow -\infty} \frac{\Phi(x)}{z(x)} = \lim_{x \rightarrow -\infty} \frac{z(x)}{z'(x)} = \lim_{x \rightarrow -\infty} -\frac{1}{x} = 0, \lim_{x \rightarrow \infty} F(x) = \lim_{x \rightarrow \infty} x \\ &+ \frac{\lim_{x \rightarrow \infty} z(x)}{\lim_{x \rightarrow \infty} \Phi(x)} = \infty. \end{aligned}$$

Again, being a composition of continuous functions, the function  $G$  is obviously continuous. For the monotonicity, observe:

$$\begin{aligned} \frac{dG(\pi, x)}{dx} &= \frac{\pi}{1 - \pi} (xz(x) + \Phi(x) + z'(x)) + 1 \\ &= \frac{\pi}{1 - \pi} (xz(x) + \Phi(x) - xz(x)) + 1 = \frac{\pi}{1 - \pi} \Phi(x) + 1 > 0 \end{aligned}$$

and:

$$\frac{dG(\pi, x)}{d\pi} = \frac{1}{(1 - \pi)^2} (x\Phi(x) + z(x)) > 0.$$

Now, based on  $\lim_{x \rightarrow -\infty} z(x) = \lim_{x \rightarrow \infty} z(x) = \lim_{x \rightarrow -\infty} x\Phi(x) = 0$  and  $\lim_{x \rightarrow \infty} \Phi(x) = 1$ , we get  $\lim_{x \rightarrow -\infty} G(\pi, x) = -\infty$  and  $\lim_{x \rightarrow \infty} G(\pi, x) = \infty$ .

As before, the function  $H$  is continuous, because it is a composition of continuous functions. For the monotonicity, observe:

$$H'(x) = xz(x) + \Phi(x) + z'(x) - 1 = xz(x) + \Phi(x) - xz(x) - 1 = \Phi(x) - 1 < 0.$$

**Proof of Lemma 1**

The lower-tailed form of the information acquisition strategy follows from the fact that the benefit from being informed is independent of the cost of acquiring the information.

**Proof of Lemma 2**

For any information status,  $a \in \{inf, ui\}$ , the resource allocation  $r^{FB}(a)$  that maximizes the firm's expected cash flows,  $E[CF(a, r^{FB}(a))] = f_1(a, r^{FB}(a)) + f_2(a, 1 - r^{FB}(a))$ , must satisfy the first-order condition:  $\frac{f'_1(a, r^{FB}(a))}{f'_2(a, 1 - r^{FB}(a))} = 1$ . As the functions  $f_1$  and  $f_2$  are increasing and concave, there is a unique solution  $r^{FB}(a)$  to the first-order condition that represents the first-best resource allocation given the information status  $a$ . If  $a = ui$ , then the manager cannot affect the market price of the firm, so her objective is reduced to maximizing the firm's expected cash flows, implying that  $R(ui) = r^{FB}(ui)$ .

**Proof of Lemma 3**

The upper-tailed form of the disclosure strategy follows from the fact that the price under disclosure  $P(dis, s)$  is an increasing function of the signal's realization  $s$  (due to the positive correlation between the signal and the cash flows), while the price in the absence of disclosure  $P(nd, s)$  is constant and independent of  $s$ .

**Proof of Lemma 4**

According to Lemma 2, an uninformed manager chooses the first-best resource allocation,  $R(ui) = r^{FB}(ui)$ . Moving now to deriving the optimal resource allocation of an informed manager, recall that the joint distribution of the firm's cash flows and the signal is normal, so the firm price is a linear in the signal,  $P(dis, s) = \alpha + \beta s$  and  $P(nd, s) = \gamma$ , where  $\alpha, \beta, \gamma \in \Re$ . The positive correlation between the signal and the cash flows implies  $\beta > 0$ . Specifically,  $\beta = \frac{\sigma_1^2 + (1 - \omega)\sigma_2^2}{\sigma_s^2} = \frac{\sigma_p}{\sigma_s}$ . Recall also that according to Lemma 3, the disclosure strategy is upper-tailed with a threshold  $s_0$ . Thus, an informed manager chooses the resource allocation,  $r$ , to maximize  $(1 - \eta)(\tau(\alpha + \beta E[S(r)|S(r) \geq s_0]) + (1 - \tau)\gamma) + \eta E[CF(inf, r)]$ , where  $1 - \Phi(\hat{s}_0) = \tau$ . Using  $E[CF(inf, r)] = f_1(inf, r) + f_2(inf, 1 - r)$  and  $E[S(r)|S(r) \geq s_0] = f_1(inf, r) + (1 - \omega)f_2(inf, 1 - r) + \frac{z(\hat{s}_0)}{1 - \Phi(\hat{s}_0)} \sigma_s$ , the manager chooses  $r$  to maximize  $((1 - \eta)\tau\beta + \eta)f_1(inf, r) + ((1 - \eta)\tau\beta(1 - \omega) + \eta)f_2(inf, 1 - r)$ . The first-order condition is:

$$\frac{f'_1(inf, r)}{f'_2(inf, 1 - r)} = \frac{(1 - \eta)\tau\beta(1 - \omega) + \eta}{(1 - \eta)\tau\beta + \eta} \tag{1}$$

As  $0 < \eta < 1$  and  $\tau, \beta > 0$ , the right side of Equation (1) is less than 1 for any  $0 < \omega \leq 1$  and is exactly 1 for  $\omega = 0$ . This, together with Lemma 2, implies  $r \geq r^{FB}(inf)$  and  $\delta \leq \delta^B$ , where equality holds if and only if  $\omega = 0$ . Also, while the right side of Equation (1) is independent of  $\tau$  for  $\omega = 0$ , it is decreasing in  $\tau$  for any  $0 < \omega \leq 1$ . Thus, if  $\omega = 0$ ,

then  $\delta = \delta^B$  independently of  $\tau$ , and otherwise  $-\delta$  is decreasing in  $\tau$ . Regardless of  $\omega$ , as  $\tau$  converges to zero, the right side of Equation (1) converges to 1, so  $\lim_{\tau \rightarrow 0} r = r^{FB}(inf)$  and  $\lim_{\tau \rightarrow 0} \delta = \delta^B$ .

**Proof of Lemma 5**

According to Lemma 3, the manager’s disclosure strategy is upper-tailed. To derive the disclosure threshold level  $s_0$ , denote  $\widehat{c} = E[C|C \leq c_0]$ , where  $c_0$  is the threshold cost of acquiring information implied by  $\pi$ , and observe that:

$$P(dis,s) = E[CF(inf,R(inf))|S(R(inf)) = s] - \widehat{c} = \mu(inf,R(inf)) + \sigma\rho\delta - \widehat{c}$$

and:

$$\begin{aligned} P(nd,s) &= \frac{1 - \pi}{1 - \pi + \pi(1 - \tau)} E[CF(ui,R(ui))] \\ &\quad + \frac{\pi(1 - \tau)}{1 - \pi + \pi(1 - \tau)} (E[CF(inf,R(inf))|S(R(inf)) \leq s_0] - \widehat{c}) \\ &= \frac{1 - \pi}{1 - \pi + \pi\Phi(\hat{s}_0)} \mu(ui,R(ui)) \\ &\quad + \frac{\pi\Phi(\hat{s}_0)}{1 - \pi + \pi\Phi(\hat{s}_0)} \left( \mu(inf,R(inf)) - \sigma\rho \cdot \frac{z(\hat{s}_0)}{\Phi(\hat{s}_0)} - \widehat{c} \right) \\ &= \mu(inf,R(inf)) - \widehat{c} - \frac{1 - \pi}{1 - \pi + \pi\Phi(\hat{s}_0)} (\delta - \widehat{c}) - \sigma\rho \cdot \frac{\pi z(\hat{s}_0)}{1 - \pi + \pi\Phi(\hat{s}_0)}. \end{aligned}$$

Given  $P(dis,s_0) = P(nd,s_0)$ , we get  $\hat{s}_0 + \frac{\pi z(\hat{s}_0)}{1 - \pi + \pi\Phi(\hat{s}_0)} = -\frac{1 - \pi}{1 - \pi + \pi\Phi(\hat{s}_0)} \cdot \frac{\delta - \widehat{c}}{\sigma\rho}$ .

So, if  $\pi = 1$ , we get  $F(\hat{s}_0) = 0$ , which implies  $s_0 = -\infty$  and  $\tau = 1$  based on Lemma A. For any  $0 \leq \pi < 1$ , we get the equation:

$$G(\pi,\hat{s}_0) = -\frac{\delta - \widehat{c}}{\sigma\rho}. \tag{2}$$

By Lemma A, Equation (2) has a unique solution  $\hat{s}_0$ , which is decreasing in  $\delta$ . Accordingly,  $\tau = 1 - \Phi(\hat{s}_0)$  is increasing in  $\delta$ .

**Proof of Proposition 1**

Based on the proofs of Lemmata 4 and 5, in equilibrium,  $\delta$  and  $\tau$  must satisfy both Equation (1) and Equation (2). In the benchmark case of  $\omega = 0$ , the unique solution to both equations is  $\delta = \delta^B$  and  $\tau = \tau^B$ . Suppose now that  $\omega > 0$ . In this case, Equation (1) describes  $\delta$  as a strictly decreasing function of  $\tau$ , while Equation (2) describes  $\tau$  as a strictly increasing function of  $\delta$ . In particular, note that  $\tau = 0$  implies  $\delta = \delta^B$  according to Equation (1), but  $\delta = \delta^B$  implies  $\tau = \tau^B > 0$  according to Equation (2). Also,  $\tau = \tau^B > 0$  implies  $\delta < \delta^B$  according to Equation (1), but such  $\delta$  implies  $\tau < \tau^B$  according to Equation (2). Hence, the two functions described by Equations (1) and (2) must intersect in a unique pair

of  $\delta$  and  $\tau$  that constitutes the equilibrium. As  $\tau$  must be positive, Equation (1) implies that  $\delta < \delta^B$ . Now using Equation (2), it follows that  $\tau < \tau^B$ .

The right side of Equation (1) is decreasing in  $\omega$ , reaching a maximum of 1 at  $\omega = 0$ . Thus, the operating value of information,  $\delta$ , is decreasing in  $\omega$ , reaching a maximum of  $\delta^B$  at  $\omega = 0$ . Since the disclosure intensity,  $\tau$ , is increasing in  $\delta$ , it is also decreasing in  $\omega$ , reaching a maximum of  $\tau^B$  at  $\omega = 0$ .

### Proof of Corollary 1

The right side of Equation (1) is decreasing in  $\tau$ , increasing in  $\eta$ , independent of  $\pi$  and decreasing in  $\beta$ , which is decreasing in  $\sigma_\epsilon$  and increasing in  $\sigma_2$ , but could be either decreasing or increasing in  $\sigma_1$ . Thus,  $\delta$  is decreasing in  $\tau$ , increasing in  $\eta$ , independent of  $\pi$ , increasing in  $\sigma_\epsilon$  and decreasing in  $\sigma_2$ , but could be either decreasing or increasing in  $\sigma_1$ . Given the structure of the production technology,  $\delta$  is also increasing in  $\lambda_1$  and in  $\lambda_2$ .

By Lemma A, the solution  $\hat{s}_0$  of Equation (2) is decreasing in  $\delta$ , independent of  $\eta$ , independent of  $\lambda_1$ , independent of  $\lambda_2$ , decreasing in  $\pi$ , increasing in  $\sigma_\epsilon^2$  and decreasing in  $\sigma_2^2$ , but could be either increasing or decreasing in  $\sigma_1$ . Thus,  $\tau$  is increasing in  $\delta$ , independent of  $\eta$ , independent of  $\lambda_1$ , independent of  $\lambda_2$ , increasing in  $\pi$ , decreasing in  $\sigma_\epsilon^2$  and increasing in  $\sigma_2^2$ , but could be either increasing or decreasing in  $\sigma_1$ .

The proof now follows by considering the impact on Equation (1) and Equation (2) together.

### Proof of Lemma 6

Recall that the firm's market price in the absence of disclosure equals  $P(dis, s_0)$  in equilibrium. Accordingly, the manager's expected utility if information is not acquired is  $\eta\mu(ui, R(ui)) + (1 - \eta)P(dis, s_0)$ . The manager's expected utility if information is acquired is  $\eta(\mu(inf, R(inf)) - c) + (1 - \eta)(\tau E[P(dis, S)|S \geq s_0] + (1 - \tau)P(dis, s_0))$ . The difference in the expected utility of an informed manager and an uninformed manager is therefore  $\Delta = \eta(\delta - c) + (1 - \eta)\tau(E[P(dis, S)|S \geq s_0] - P(dis, s_0))$ , which equals  $\Delta = \eta(\delta - c) + (1 - \eta)(1 - \Phi(s_0))\rho\sigma \left( \frac{z(s_0)}{1 - \Phi(s_0)} - s_0 \right) = \eta(\delta - c) + (1 - \eta)\sigma\rho H(\hat{s}_0)$ . This difference is increasing in  $\delta$ . It is also decreasing in  $s_0$  by Lemma A, and thus increasing in  $\tau$ . Since  $\delta$  and  $\tau$  are both decreasing in  $\omega$  (Proposition 1), the difference  $\Delta$  is decreasing in  $\omega$ .

### Proof of Proposition 2

According to the proof of Lemma 6, the difference in the expected utility of an informed manager and an uninformed manager is  $\eta(\delta - c) + (1 - \eta)\sigma\rho H(\hat{s}_0)$ . This difference equals zero at the threshold cost  $c = c_0$ , implying that:

$$\eta c_0 = (1 - \eta)\sigma\rho H(\hat{s}_0) + \eta\delta. \quad (3)$$

It follows from Lemma 6 that  $c_0$  is decreasing in  $\omega$ , and thus  $\pi$  is also decreasing in  $\omega$  where  $\pi \leq \pi^B$ . Using Proposition 1, and the positive relationship between  $\tau$  and  $\pi$ ,  $\tau$  is also decreasing in  $\omega$ , where an equilibrium of  $\pi = \pi^B$ ,  $\delta = \delta^B$  and  $\tau = \tau^B$  is obtained if and only if  $\omega = 0$ . To demonstrate that  $\delta$  might be non-monotonic in  $\omega$ , consider the following example. Assume an identical Cobb-Douglas production function for the two divisions,  $f_1(ui, x) = f_2(ui, x) = (400x)^{0.8}$ , and the following set of parameters:  $\lambda_1 = 0.1$ ,  $\lambda_2 = 0.2$ ,  $\eta = 0.4$ ,  $\rho = 0.6$ ,  $\sigma_1 = 5$  and  $\sigma_2 = 15$ ,  $\underline{c} = 0$ ,  $\bar{c} = 20$ . When the parameter  $\omega$

increases from 0.755 to 0.760, the equilibrium operating value of information  $\delta$  also increases from 5.66 to 5.81. However, when  $\omega$  further increases from 0.760 to 0.765,  $\delta$  decreases from 5.81 to 5.77.

### Proof of Corollary 2

By Corollary 1, for any given  $\pi$ , both  $\delta$  and  $\tau$  are increasing in  $\eta$ ,  $\lambda_1$  and  $\lambda_2$ . Lemma 6 implies that  $\pi$  is increasing in  $\delta$  and  $\tau$ , and thus  $\pi$  is also increasing in  $\eta$ ,  $\lambda_1$  and  $\lambda_2$ . Based again on Corollary 1,  $\tau$  is increasing in  $\pi$ , and thus is increasing in  $\eta$ ,  $\lambda_1$  and  $\lambda_2$  even when  $\pi$  is endogenously derived.

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