

NBER WORKING PAPER SERIES

COMPETING FOR ATTENTION IN FINANCIAL MARKETS

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Working Paper 16085  
<http://www.nber.org/papers/w16085>

NATIONAL BUREAU OF ECONOMIC RESEARCH  
1050 Massachusetts Avenue  
Cambridge, MA 02138  
June 2010

We would like to thank Tony Bernardo, Murillo Campello, Doug Diamond, Mike Fishman, Simon Gervais, Vincent Glode, Rick Green, Mark Grinblatt, Jack Hughes, Francis Longstaff, David Robinson, Richard Roll, Avanidhar (Subra) Subrahmanyam, and Brett Trueman for their helpful insights and suggestions. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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Competing for Attention in Financial Markets

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NBER Working Paper No. 16085

June 2010

JEL No. D21,D53,G14,M41

**ABSTRACT**

Competition for positive attention in financial markets frequently resembles a tournament, where superior relative performance and greater visibility are rewarded with convex payoffs. We present a rational expectations model in which firms compete for such positive attention and show that higher competition for this prize makes discretionary disclosure less likely. In the limit when the market is perfectly competitive, transparency is minimized. We show that this effect persists when considering general prize structures, prizes that change in size as a result of competition, endogenous prizes, prizes granted on the basis of percentile, product market competition, and alternative game theoretic formulations. The analysis implies that competition is unreliable as a driver of market transparency and should not be viewed as a panacea that assures self-regulation in financial markets.

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# 1 Introduction

Competition for positive attention in financial markets frequently resembles a tournament, where superior relative performance is rewarded with convex payoffs.<sup>1</sup> In many settings, rankings drive remuneration (i.e., order statistics matter). For example, mutual funds that advertise better past performance or achieve greater visibility experience convex investor flows (e.g., Brown, Harlow, and Starks, 1996; Berk and Green, 2004; Del Guercio and Tkac, 2008).<sup>2</sup> Firms with higher status attract superior human capital, especially when labor is scarce (e.g., Gatewood, Gowan, and Lautenschlager, 1993).<sup>3</sup> CEO's who receive higher public praise are rewarded with positively skewed payoffs (e.g., Gibbs, 1994; Malmendier and Tate, 2009). Such convexity is also likely to exist when other scarce resources are allocated: supplies and supplier credit, venture capital (e.g., Hsu, 2004), and investor attention (e.g., Hendricks and Singhal, 1996). In short, there is a prize in the market for the parties that reveal more favorable information than others.

How then does competition for this prize affect each participants's incentives to reveal private information to the public? The answer to this question turns out to be non-obvious. Though it might seem intuitive that higher competition for such a prize should increase incentives to reveal private information, we find that this is often not the case. Thus, we cannot appeal to the Invisible Hand to make markets more transparent: while competition may drive prices down in product markets, it may have the opposite effect on transparency. Based on this, our analysis provides an important implication for the regulation of financial markets: competition should *not* be viewed as a panacea to assure information disclosure and self-regulation by participants in the market.<sup>4</sup>

Summarizing our base model makes it easy to appreciate the intuition for this result. We build on the model of Dye (1985), where incomplete disclosure results from investors' uncertainty as to whether or not management possesses relevant information. In our variant, a finite number of firms compete in the market. All firms experience a random shock that changes their fundamental value. Each firm may or may not observe the precise value of their shock. Firms that make an observation

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<sup>1</sup>As first pointed out by Rosen (1981), convex payoffs mean that small differences in performance at the high end of the spectrum become magnified in larger earnings differences or returns to effort.

<sup>2</sup>Capon, Fitzsimons, and Prince (1996) and Sirri and Tufano (1998) show that past performance is the crucial input in investors' choice of mutual fund. Brown, Harlow, and Starks (1996) are credited as being the first to point out the tournament-nature of mutual fund markets and the effects this has on managerial incentives. See Berk and Green (2004) for a theoretical model of convex performance incentives in mutual fund markets. See Gallaher, Kaniel, and Starks (2005), Gualtieri and Petrella (2005), Del Guercio and Tkac (2008), and Starks and Yates (2008) for the affects of visibility and reputation on mutual fund flows. See Nanda, Wang, and Zheng (2004) and Gaspar, Massa and Matos (2006) for the effect that past returns and visibility have on flows to other offerings in fund families.

<sup>3</sup>See also Chauvin and Guthrie (1994) and Turban and Greening (1996).

<sup>4</sup>This does not mean that competition can never promote disclosure. Even in our simplified model we find some exceptions.

then choose whether to announce it publicly, while firms with no new information have nothing to reveal. The firm with the best announcement gets a fixed prize from the market, which represents the rank-based convex remuneration previously described.

In the symmetric equilibrium of the game, each firm with new information applies a threshold in deciding whether or not to reveal its news. If the observed shock value is above this threshold, the firm announces it and competes for the prize. If the observed shock is lower, however, the firm conceals its information. The presence of uninformed firms lends plausible deniability to informed firms wishing to conceal a bad observation. Rational investors use Bayesian learning to adjust the market price of firms that do not release any news.

Because the probability of winning the prize drops when more firms compete, the benefit of making announcements decreases with competition. Therefore, increasing competition leads to decreased information revelation and lower market transparency. Our base model with a fixed prize shows this effect most simply and directly, but we show that this effect remains reasonably robust to other model variations: general reward systems, prizes that change in size as a result of competition, and product market competition.<sup>5</sup>

We consider more general reward systems in which multiple prizes are awarded, so that runners-up also receive compensation. Adding more prizes definitively increases the incentive to reveal information, *ceteris paribus*. However, holding any prize structure fixed, the equilibrium incentive to reveal private information still decreases with competition because the probability of winning or being one of the runners-up drops when more firms are in the market.

We then consider what happens when the size of the prize changes because of competition. When the size of the prize shrinks, our primary result is magnified. The incentive to reveal information drops because of two forces: competition for the prize is higher and the reward is lower. Such an effect is plausible under a number of economic scenarios. For example, as competition for human resources increases, labor's bargaining power grows and lowers the value (via higher wages) that the top firm gets when winning the competition. Interestingly, though, our results remain surprisingly robust even when the prize grows with firm entry. For example, if the prize scales linearly with the number of participating firms, competition still has a negative influence on information revelation when the number of competing firms exceeds a modest threshold. In fact, competition reduces disclosure unless the prize grows at least exponentially in the number of firms.

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<sup>5</sup>In Appendix B, we build on this and show that this consideration is robust when considering endogenous prizes, prizes awarded based on percentile, and a sequential disclosure game structure (instead of the simultaneous game modeled in the paper). There, we also consider the effect of volatility on the tendency for firms to disclose private information.

We then consider the effect of product market competition on the analysis. In our base model, all firms draw their shocks from a common distribution which does not change with the number of competing firms. That is, the entry of a new competitor reduces a firm's chance to win the prize, but does not reduce its earnings. To include this effect, we alter our model by scaling the value of firms and shocks to firm value downward with competition. This agnostic framework allows us to analyze how competition affects information revelation without limiting ourselves to any particular model of pricing and supply. We find this modification mitigates the tendency for competition to reduce information revelation when a very small number of firms compete. However, once the number of firms reaches a critical mass, further competition reduces information transmission as in the base model. We provide analytic proof and numerical examples to show that this critical mass of firms is very small, and conjecture that most industries are large enough that further competition generally reduces firms' incentives to reveal private information. Though according to the model, in the limit when the market becomes perfectly competitive, profits converge to zero but transparency is minimized.

The analysis yields novel and testable empirical predictions. Our model predicts that performance announcements, advertising, and discretionary disclosure should decline with competition, *ceteris paribus*. This implies, for example, that in the mutual fund industry where firms compete for Morningstar ratings (Del Guercio and Tkac, 2008), advertising expenditure and discretionary disclosure should be negatively correlated with Herfindahl Index. Such a prediction might be tested cross-sectionally or with a time series, while controlling for other fund characteristics. Our model also predicts that when asymmetric information increases, discretionary disclosure should increase in industries with low status-based prizes. However, in industries with high status rewards, discretionary disclosure should decline when information asymmetry increases. This prediction might also be tested in the mutual fund industry with a time-series that includes periods of high volatility.

This paper contributes to a large literature on information revelation and discretionary disclosure in financial markets. The paper that is closest to ours is Fishman and Hagerty (1989), which shows that firms compete for attention in financial markets because informed trading leads to price efficiency, which is valuable for firms making investment decisions. The prize in their paper is price efficiency. In fact, Fishman and Hagerty show that firms spend more on disclosure than is socially optimal when competing for the prize. Our paper adds to theirs in the following way: when more and more firms compete for this type of attention, each firm's ability to achieve price efficiency declines because traders have a fixed bandwidth when following firms. Decreasing marginal benefit to disclosure relative to its cost, makes disclosure less attractive. Therefore, applying our model to

the formulation in Fishman and Hagerty (1989), we would predict that their effect would diminish with more competition.

Early work on disclosure theory suggest that market forces are sufficient to induce full disclosure. Grossman and Hart (1980), Grossman (1981), and Milgrom (1981) suggest that in the absence of disclosure costs or asymmetric information, firms adhere to the Full Disclosure Principle. That is, when firms have private information about their prospects, adverse selection prompts high-valued firms to distinguish themselves from others by disclosing their information. In so doing, they reduce the expected prospects of the remaining non-disclosing firms. The effect cascades, finally resulting in full disclosure by all firms. Diamond (1985) shows that such disclosure is welfare-improving because of explicit information cost savings and improved risk sharing.

Subsequent work challenges these results: full disclosure may not occur because disclosure is costly (e.g. Verrecchia 1983; Fishman and Hagerty 1990), some market participants are unsophisticated (e.g., Fishman and Hagerty 2003), or the market is unsure whether firms have asymmetric information (Dye, 1985 and Jung and Kwon, 1988). We build our model on Dye (1985) and Jung and Kwon (1988), but we could just as well have used Verrecchia (1983) for our foundation. In either case the prospect of a prize increases the incentive to disclose, and growing competition reduces that incentive. While we use Dye's model as a matter of choice, our result generalizes to alternative models of discretionary disclosure.

Our work also adds to the literature on product market competition and discretionary disclosure. Again, this literature is split on whether product market competition increases or decreases disclosure. Stivers (2004) argues that product market competition increases disclosure, as firms might even make negative disclosures if doing so will hurt competitors more. In contrast, Wagenhofer (1989), Darrrough (1993), Clinch and Verrecchia (1997), and Board (2009) argue that firms may avoid disclosure to conceal private information from competitors. Similarly, Darrrough and Stoughton (1990), Feltham and Xie (1992), and Pae (2002) argue that firms may conceal such private information to prevent new entry into the market. Finally, Dye and Sridhar (1995) find that product market competition may increase or decrease disclosure depending on whether the information the firms receive is private or industry-related. In many of these papers, disclosure itself affects the nature of competition, which in turn affects the tendency to disclose. While we do not address these considerations specifically, we do add to this literature by considering product market competition simultaneously with competition for attention, finding again that increased competition often reduces management's tendency to reveal private information.

The rest of the paper is organized as follows. Section 2 introduces our base model, the action

set presented to firms, and the corresponding payoffs. Section 3 characterizes the equilibrium and explores key comparative statics. We show the results are robust to more generalized prize structures, and to changing sizes of the prize with competition. In Section 4, we add product market competition to the model. We show that competing for the same resources, customers, etc. can initially lead to an increase in information revelation, but once the number of firms reaches an economically reasonable level, additional competition leads to less disclosure. Section 5 offers some concluding remarks. Proofs of all propositions are deferred to Appendix A, as are some technical definitions and lemmas. In Appendix B, we show that our results remain robust when considering a sequential game set-up, volatility, endogenous prizes, and prizes awarded based on percentile.

## 2 Base Model

We consider a single period model in which a group of  $N$  risk-neutral firms, indexed by  $j \in \{1, \dots, N\}$ , compete in a game of discretionary “disclosure”.<sup>6</sup> Each firm experiences a random change in fundamental valuation,  $\tilde{x}_j \sim F$ . We assume  $\tilde{x}_j$  has a probability density function  $f(x) > 0$  for all  $x \in \mathbb{R}$ , and that  $E[\tilde{x}_j] = 0$ . Realizations are independent and identically distributed for each firm, and their distribution does not depend on the number of firms competing in the market, though we will relax this assumption in Section 4.

In each firm, a manager observes the true realization of  $\tilde{x}_j$  with probability  $p$ . With probability  $(1 - p)$ , the manager observes nothing. The parameter  $p$  measures the degree of asymmetric information in the market. When  $p$  is high, it is likely that firms have more information about their value than outsiders. When  $p$  is low, it is unlikely that firms have learned anything new. As such,  $p$  is also a measure of strong form market (in-)efficiency.

**Definition 1.** *The possible information events are*

$$I_j \equiv \text{firm } j \text{ is } \mathbf{informed} \text{ of } \tilde{x}_j$$

$$U_j \equiv \text{firm } j \text{ remains } \mathbf{uninformed} \text{ of } \tilde{x}_j.$$

Firms that observe  $\tilde{x}_j$  may either conceal its value, or may credibly reveal it to investors. Firms that do not observe a value are not permitted to fabricate one. Implicitly, we suppose that investors

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<sup>6</sup>Our use of quotes is purposeful here because what we have in mind is more general than solely accounting disclosure alone. Disclosure is meant to refer to any instance in which information might be revealed. Likewise, our use of “firm” here is meant to represent any party that competes in the market for attention, which includes individuals (e.g., CEO’s).

can freely verify and penalize false claims of  $\tilde{x}_j$ , but cannot determine whether a non-disclosing firm is in fact concealing information.<sup>7</sup>

**Definition 2.** *If firm  $j$  is informed, its available actions are  $\{D_j, C_j\}$ , where*

$$D_j \equiv \text{firm } j \text{ \textbf{discloses} its observation } x_j$$

$$C_j \equiv \text{firm } j \text{ \textbf{conceals} its observation } x_j.$$

*The event that firm  $j$  either conceals its observation or is legitimately uninformed is given by  $P_j$  (i.e., firm  $j$  pools).*

For the moment, we allow firms to choose non-deterministic strategies, although we will soon show deterministic strategies are dominant, almost surely. Formally, we describe each firm’s strategy by a “disclosure policy.”

**Definition 3.** *An informed firm  $j$  determines its action using a **disclosure policy**, a mapping  $\sigma_j : \mathbb{R} \rightarrow [0, 1]$ . Given any observation  $x \in \mathbb{R}$ , firm  $j$ , discloses with probability  $\sigma_j(x)$  and conceals with probability  $1 - \sigma_j(x)$ .*

All informed firms act simultaneously and without knowing which of their competitors are also informed. What we have in mind is that a market-wide event arises in which investors expect informed firms to make disclosures over a short time horizon.<sup>8</sup> We define  $\sigma \equiv \{\sigma_1, \dots, \sigma_N\}$  as the collection of strategies used by all firms in the market. After acting, each falls into one of three categories: uninformed firms, informed firms that reveal information, and informed firms that pool with the uninformed.

Investors are competitive, risk-neutral, and have rational expectations about firm behavior. If firm  $j$  pools (event  $P_j$ ), investors weigh the odds that it is uninformed against the odds that it is concealing a poor  $x_j$  and adjust its price by Bayesian inference. Firm utility is determined by these price changes, so this expectation is also the utility an informed firm obtains by concealing its information,

$$u_j^C \equiv E[\tilde{x}_j | P_j, \sigma, p].$$

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<sup>7</sup>As such, we follow the previous literature on discretionary disclosure and do not consider the firms’ tendency to make false statements here. To address this, an alternative set-up might include a cheap talk game (e.g., Crawford and Sobel, 1982), but we do not analyze this directly.

<sup>8</sup>However, in Appendix B we explore a sequential game of disclosure and show that the frequency of disclosure of private information is minimized as  $N \rightarrow \infty$ .

After all disclosures have been made, investors award a prize  $\phi$  to the firm with the highest disclosed value. This prize value represents the convex gain in value that accrue to the high-performing firm. We take this prize to be given exogenously, but consider what happens when this prize is endogenously determined in Appendix B. There we show that our primary result still holds.

Including this exogenous prize, firm  $j$ 's expected utility of revealing  $x$  is

$$u_j^D(x) \equiv x + \phi W_j(x),$$

where we define  $W_j(x)$  as the probability that firm  $j$  has the highest disclosure. This value depends on the probability  $p$  of competing firms being informed, and on the strategies  $\sigma_{-j}$  they employ.

Therefore, this model extends the Jung and Kwon (1988) refinement of the Dye (1985) model, in which uncertainty about a single firm's information induces an incomplete disclosure equilibrium. Dye's model corresponds to ours in the specific case where we have only one firm and no prize ( $N = 1$  and  $\phi = 0$ ).

### 3 Equilibrium Disclosure

With Lemmas 1, 2, and 3, we determine the game's unique subgame-perfect Nash equilibrium.

**Lemma 1.** *In any subgame-perfect Nash equilibrium, each firm acts according to a **disclosure threshold**  $t_j < 0$ ,*

$$\sigma_j(x_j) = \begin{cases} 1 & \text{for } x_j > t_j \\ 0 & \text{for } x_j < t_j. \end{cases}$$

*The threshold is implicitly defined by the condition that a firm observing  $x_j = t_j$  be indifferent between disclosing and concealing,*

$$u_j^D(t_j) = u_j^C.$$

According to Lemma 1, each informed firm simply compares the expected utility it can obtain by revealing information to what it obtains by pooling. If it conceals its signal, then the actual realization certainly cannot affect the valuation investors assign, so  $u_j^C$  is constant with respect to the observed value  $x_j$ . In contrast, the value obtained by revealing information is increasing in  $x_j$ . If the two utilities are equal when the firm observes its threshold value  $\tilde{x}_j = t_j$ , then the firm should reveal any observation greater than  $t_j$  and conceal any lesser observation.

Note that the threshold  $t_j$  is lower than the distribution mean, which we've assumed to be zero. The average  $\tilde{x}_j$  for an uninformed firm is simply the distribution mean, and because firms disclose their best observations, rational investors expect the average concealed observation to be negative.

The weighted average assigned to herding firms must therefore be below the distribution mean. Since disclosure yields strictly greater utility than the value disclosed, no firm will ever conceal an above-average observation. So if firm  $j$  is indifferent between revealing and concealing a value  $x_j = t_j$ , then  $t_j < 0$ .

**Lemma 2.** *Every firm uses the same disclosure threshold, defined as  $t^*$ .*

In other words, there cannot be an equilibrium in which some firms are more “honest” than others. This is not too surprising, since all firms draw the observations from identical and independent distributions. One can imagine an alternate model in which there was some endogenous benefit of being perceived as trustworthy, and such a model might induce a heterogeneous equilibrium. In our equilibrium, Lemma 2 ensures that any two firms will behave identically with any given observation.

This result justifies our description of the non-disclosing firms as a “pool.” Since they all have identical disclosure thresholds and distributions  $F$ , investors value all non-disclosing firms identically. In a hypothetical equilibrium where some firms are more honest, investors would assign a higher valuation to an honest non-disclosing firm than to a firm that has a reputation for concealing poor valuations. But when no firm distinguishes itself by its honesty, investors assign the same value  $u^C$  to every non-disclosing firm in the pool.

**Lemma 3.** *The common disclosure threshold  $t^*$  is unique.*

Not only does each individual firm have a unique optimal response to the other firms’ strategies, but there is only one viable choice for the entire group. So for given model parameter values, we can theoretically determine the unique disclosure threshold. This allows us to predict how disclosure behavior responds to exogenous parameter changes. Most importantly, we will demonstrate how equilibrium disclosure responds to an increase in the number of competing firms.

Taken together, Lemmas 1, 2, and 3 establish Proposition 1.

**Proposition 1.** *There exists a unique and non-trivial subgame-perfect Nash equilibrium, in which every firm discloses according to a common threshold  $t^*$  defined implicitly by*

$$t^* + \phi(1 - p + pF(t^*))^{N-1} = \frac{p}{1 - p + pF(t^*)} \int_{-\infty}^{t^*} xf(x) dx. \quad (1)$$

*Further, the threshold  $t^*$  lies below the unconditional mean of  $\tilde{x}_j$ , i.e.  $t^* < 0$ .*

The left side of (1) can be understood as the utility a firm that observes  $\tilde{x}_j = t^*$  expects if it reveals its information. The firm immediately receives its own value  $\tilde{x}_j = t^*$ , and can also win

the prize  $\phi$  if its disclosure is the highest. But since competing firms never reveal values below  $t^*$ , any other disclosing firm will have a higher value almost surely. Firm  $j$  can win, therefore, only if all other firms pool. Each competing firm pools if either it is uninformed or it is informed with an observation below the threshold. These events occur with probabilities  $(1 - p)$  and  $pF(t^*)$ , respectively. The left side therefore is the  $u_j^D(t^*)$  term from Lemma 1.

The right side is utility a firm obtains by concealing its observation, which equals the expected value change of a pooling firm. Such a firm could be uninformed and have a zero expected value for its observation, or could be hiding an observation lower than the threshold. The weighted average of these possibilities yields the right side of Equation 1.

### 3.1 Comparative Statics

Proposition 1 implicitly defines the equilibrium disclosure threshold  $t^*$ , so we could now proceed by using the Implicit Function Theorem to determine comparative statics on  $t^*$ . But the economic interpretation of  $t^*$  is not immediately obvious, and it is not clear what empirical predictions can be made from it. A more useful characterization is the frequency with which firms opt to reveal private information. That is, what is the ex ante probability that a firm, if it observes its value change, will choose to share its observation with investors?

**Definition 4.** We define the equilibrium ex ante probability of an informed firm disclosing by

$$\omega^* \equiv \Pr(D|I).$$

We refer to this probability as the equilibrium **disclosure frequency**. Since the equilibrium is symmetric, we omit firm-specific subscripts.

When firms follow threshold disclosure strategies, as described in Lemma 1, there is a one-to-one relationship between the disclosure threshold and the corresponding disclosure frequency,

$$\omega^* = \Pr(\tilde{x} > t^*) = 1 - F(t^*).$$

Note that disclosure threshold and frequency move in opposite directions. That is, if a firm lowers its threshold, it discloses more of its realized values, and vice-versa.

**Definition 5.** Let  $\hat{\omega}$  be the equilibrium disclosure frequency when  $\phi = 0$ , defined implicitly by

$$x(\hat{\omega}) = \frac{p \int_{\hat{\omega}}^1 x(\Omega) d\Omega}{1 - p\hat{\omega}}. \quad (2)$$

Let  $\hat{t}$  be the corresponding disclosure threshold, used in equilibrium when  $\phi = 0$ , so that

$$\hat{\omega} = 1 - F(\hat{t})$$

Dye (1985) and Jung & Kwon (1988) consider disclosure with no strategic interaction (i.e.,  $N = 1$ ) and no prize  $\phi$ . Their equilibrium condition is equivalent to Equation 2. The chance to win  $\phi > 0$  offers firms a greater incentive to disclose, so in equilibrium, we have

$$\omega^* \geq \hat{\omega} \quad \forall \phi \geq 0, \forall N < \infty.$$

That is,  $\hat{\omega}$  is a lower bound for  $\omega^*$  over all  $\phi$  and  $N$ . In fact, it is the largest possible lower bound. Note that  $\hat{t}$  is similarly an upper bound for  $t^*$ , which by Proposition 1 must lie below  $E[\tilde{x}] = 0$ . We therefore also have

$$t^* \leq \hat{t} < 0 \quad \forall \phi \geq 0, \forall N < \infty.$$

Because  $\omega^*$  and  $t^*$  are informationally equivalent, we may conduct our investigation using either variable. We therefore rewrite Proposition 1 in terms of disclosure frequency, instead of a disclosure threshold.

**Proposition 2.** *There exists a unique and non-trivial subgame-perfect Nash equilibrium, in which every firm discloses its highest observations with a common disclosure frequency  $\omega^*$  defined implicitly by*

$$F^{-1}(1 - \omega^*) + \phi(1 - p\omega^*)^{N-1} = \frac{p}{1 - p\omega^*} \int_{\omega^*}^1 F^{-1}(1 - \Omega) d\Omega. \quad (3)$$

Furthermore,  $\omega^* > \hat{\omega}$ .

Like Proposition 1, this proposition defines the equilibrium frequency  $\omega^*$  by an indifference between disclosure and non-disclosure for a firm that observes the threshold value,  $\tilde{x} = t(\omega^*)$ .

**Proposition 3.** *Equilibrium disclosure frequency is:*

- (i) *decreasing in the number of competing firms,  $N$ .*
- (ii) *increasing in the prize value,  $\phi$ .*

Further, as  $N \rightarrow \infty$ ,  $\omega^*$  converges to  $\hat{\omega}$ .

Proposition 3(i) is the simplest possible statement of our main result. When firms disclose competitively to win positive attention, increased competition reduces disclosure. This defies the general economic intuition that tightening competition drives firms to give up their small advantages

in the interest of providing a competitive product. Rather, increasing competition drives firms to hoard their informational advantage over investors. The result has immediate application in the financial sector, where disclosure is critical and where top-performing firms enjoy large rewards.

Mathematically, the cause of the competition effect is straightforward. As more firms enter the market, each firm's chance of making the highest disclosure diminishes. With it, their chances of receiving positive attention from their disclosure decreases. Since the disclosure decision is a trade-off between the desire to win the prize and the desire to conceal bad signals, additional firm entry tips the balance in favor of concealing. In the sections that follow, we will show this effect to be robust to more sophisticated model specifications.

Proposition 3(ii) states simply that firms will be more inclined to disclose when the prize they can win is large. Again, a larger prize tips the balance between the competing desires to pool and to compete openly for positive investor attention. This concept is also robust to our alternative model specifications.

Finally, according to Proposition 3, once the market for attention becomes perfectly competitive, equilibrium disclosure is minimized. Moreover, the frequency with which firms disclose their information approaches that when there is no prize in the market whatsoever. Therefore, perfect competition induces firms to retain the maximum degree of asymmetric information and market transparency is minimized.

The comparative statics in  $p$  turn out to be trickier. Jung and Kwon (1988) consider the special case where  $N = 1$  and  $\phi = 0$ , and find disclosure to be strictly increasing in  $p$ . We are able to confirm this result by computing our comparative statics with  $\phi = 0$ . But when there is a prize, the situation becomes more complicated.

Hypothetically, if  $p$  increases and firms fail to adjust their disclosure strategies, there would be two sources of change in firm utility. First, the increase in asymmetric information would increase the Bayesian probability of a firm having inside information. Rational investors would respond by reducing their assessment  $u^C$  of pooling firms. Second, the increase in  $p$  means competing firms are more likely to be informed. Since being informed is a prerequisite to disclosing, the increase in  $p$  makes any given disclosing firm less likely to win the prize by default. Mathematically, a higher  $p$  decreases  $W_j(x)$ , which implies a lower expected utility of disclosure.

These two effects of increased  $p$  work against each other. To determine whether  $\omega^*$  will increase or decrease, we need to know which of these effect impact firm utility more. If the reduction in  $u^C(\omega^*)$  is larger than the reduction in  $u^D(\omega^*)$ , then disclosure becomes more appealing. Firms will then respond to an increase in  $p$  by disclosing more frequently. Conversely, if the reduction in

$u^D(\omega^*)$  dominates, then firms respond with less frequent disclosure.

If the prize value  $\phi$  is small or zero, then the reduction in  $W_j(x)$  is unimportant, so the reduction in  $u^C(\omega^*)$  dominates, and equilibrium disclosure increases. This echoes the Jung and Kwon (1988) result. The same result follows when  $N$  is very large, in which case the probability of winning the prize is low from the outset. In contrast, when  $\phi$  is large and  $N$  is modest, the reduction in  $W_j(x)$  is critical. The second effect dominates, so overall the incentive to disclose is reduced more than the incentive to pool. Consequently, firms pool more often, reducing the equilibrium disclosure frequency.

## 3.2 Generalized Prize Structure

We now show that competition's effect of reducing disclosure is robust to alternative model specifications. Because the probability of winning  $\phi$  declines exponentially with firm entry, the effect tends to trump other simultaneous considerations, especially when  $N$  is large. Neither multiple prizes nor prizes that decrease with competition alter this result. Prizes that grow with  $N$  can change things, but only for small  $N$  or for prizes that (rather implausibly) grow exponentially ad infinitum.

### 3.2.1 Multiple Prizes

Allowing only a single firm to win the prize  $\phi$  has simplified our analysis, but it seems reasonable for the second-highest discloser to receive some positive investor attention as well. Perhaps the top ten firms all deserve some sort of status prize.

There are situations where having a single prize makes sense. In industries with natural monopoly, or where the government awards a single contract, firms like Microsoft and Raytheon might be entitled to such a winner-take-all prize. In such fields the runners-up receive little if any reward from their second-place, and a single-prize model is best.

But a more egalitarian prize structure is sensible if firms are limited by capacity or distribution constraints. A single grocery store cannot service the entire state, regardless of how acclaimed its fresh produce may be. In such cases, some prize should be reserved for the firms with slightly less impressive disclosures. In what follows, we consider that a finite number of prizes  $K$  are awarded to the top firms. In Appendix B we show that the analysis remains robust to considering prizes awarded by percentile.

**Definition 6.** *A disclosure game with a **progressive prize structure** is one in which the firms that make the  $K$  highest disclosures each win a prize. The firm that makes the  $k^{\text{th}}$  highest disclosure*

wins  $\phi_k$ . We require the prizes to be positive and strictly monotonic,

$$\phi_1 > \phi_2 > \dots > \phi_K > 0.$$

Compared to a model with a single prize of  $\phi = \phi_1$ , the addition of prizes for runners-up naturally induces greater disclosure. But although the change to a progressive prize structure may increase disclosure for any particular  $N$ , our central result remains unchanged:

**Proposition 4.** *Under any particular progressive prize structure, equilibrium disclosure frequency strictly decreases as competition increases. That is,  $\omega_{N+1}^* < \omega_N^*$  for any  $N$ .*

This result justifies our simplification in working with a single prize  $\phi$ . Although additional prizes may change the quantitative predictions of equilibrium disclosure, the qualitative comparative statics remain unchanged. The chance of winning a lesser prize decreases with competition just as the chance of winning a single prize does. Competition therefore reduces disclosure in this setup as well.

### 3.2.2 Increasing/Decreasing Prize Values

A further objection to our model might be that we constrain the prize value to remain constant. One reasonable alternative is to allow the prize value to vary with  $N$ . Indeed, a reasonable case might be made for either increasing or decreasing prize values.

Prize value might decrease when additional firms enter because investor attention is diluted over a larger population of firms. More commonly, though, the prize might shrink because of increasing competition for a scarce resource. For example, as competition for bank financing, supplier credit, or labor resources increases, the relative bargaining power of these residual claimants grows, thereby lowering the value that the top firm gets when winning the competition.

In response to this argument, we note simply that a prize that decreases in  $N$  only augments our result. If the addition of further competitors causes an exogenous reduction of prize value (i.e., lower  $\phi$ ), then equilibrium disclosure falls even faster than if the prize remained constant.

The argument that prizes should increase with competition is a more challenging one. Such a case can be made when disclosures are easy to compare, and when choosing the very best firm has high value to potential clients and investors. One might argue that investment funds fit this description. A single fund can accommodate large increases in the amount of money it manages, and there is very little reason to be content with the second best fund (net of fees, at least). If potential investors believe that the disclosed information is a strong predictor of future performance

(e.g., Berk and Green, 2004), then being the best in a large field of competitors may bring a larger prize than being the best in a small field.

We concede that a continuously increasing prize value can overcome the effect of competition, at least when  $N$  is small. But the following proposition shows that unless the prize grows exponentially by a factor of at least  $1/(1 - p\hat{\omega})$ , disclosure will eventually decrease once  $N$  reaches some critical value.

**Proposition 5.** *If, under the non-competitive model with a variable prize  $\phi_N$ ,*

$$\lim_{N \rightarrow \infty} \frac{\phi_{N+1}}{\phi_N} < \frac{1}{1 - p\hat{\omega}}, \quad (4)$$

*then there exists some  $\bar{N} \in \mathbb{R}$  such that  $N > \bar{N}$  implies that  $\omega_{N+1}^* < \omega_N^*$ .*

Specifically, consider the case in which prize value per firm remains constant:

$$\phi_N \equiv N\phi_1$$

In this case,

$$\lim_{N \rightarrow \infty} \frac{\phi_{N+1}}{\phi_N} = 1 < \frac{1}{1 - p\hat{\omega}},$$

so the condition in (4) is satisfied, and disclosure decreases with competition for large  $N$ .

Intuitively, the chance of winning the prize declines exponentially in  $N$ , so unless the prize grows forever at the same exponential rate, the expected winnings will eventually decline in  $N$ . One must ask, however, where a prize that increases exponentially with firm entry would come from. The value of high status may well increase exponentially as the number of competing firms increases from, say  $N = 1$  to  $N' = 10$ . But it is difficult to believe the same exponential increase could continue from  $N = 10$  to  $N' = 50$ . We conjecture that exponentially increasing status prizes are uncommon at best, and may never occur in industries with a large number of firms.

### 3.3 Implications for Regulation

In most markets, transparency and truthful disclosure increase welfare for several reasons. Disclosure improves explicit information cost savings and allows for better risk sharing (Diamond, 1985). Disclosure also improves the allocation and use of scarce resources because informed trading leads to price efficiency (Fishman and Hagerty, 1989). Finally, transparency and disclosure make tradable assets more liquid because of decreased adverse selection in the market (Diamond and Verrecchia, 1991).

From the results presented so far, it is easy to appreciate that competition for attention may make markets less transparent, which can lower welfare through these mechanisms. This is especially true in settings where such competition resembles a tournament. For example, our analysis predicts that in the mutual fund market, as more firms compete for recognition (e.g., Morningstar ratings), fewer funds will make discretionary disclosure and may even attempt to reduce the clarity of their fund attributes (e.g., Carlin, 2009). This may make it harder for retail investors to make optimal initial allocations or rebalance their investments, and may even lead to decreased market participation (Carlin and Manso, 2010).

It is important to note that our results here are not special because we build on the models of Dye (1985) and Jung and Kwon (1988). Indeed, other formulations could be used to generate similar findings. For example, consider the fixed cost of disclosing as in Verrecchia (1983). As the benefit to competing for the prize drops with competition, so would the incentive to disclose. That is, in a competitive market firms would be less willing to pay a cost to reveal private information. As such, we view our results with sufficient generality as they do not depend on the particular formulation we use.

Our results, then, should give policy makers pause when relying on competitive forces to induce market transparency. Especially, in settings that resemble a tournament, competition may make transparency worse, which may cause a decline in welfare. Clearly, while we do not wish to portray this finding as a tautology—indeed, there exist some settings in which competition does induce firms to reveal private information—it does suggest that market forces alone are often insufficient to maximize welfare in the market. This emphasizes the idea that regulation likely has a role in financial markets.

## 4 Disclosure Under Product Market Competition

Our base model is most appropriate for firms that compete for the prize only indirectly. That is, it models the competition for  $\phi$  between firms in different industries, such as Facebook and Google. Although such firms don't compete directly for customers or revenue, they both vie for the same status-based prize: being seen as the premiere internet destination. The base model is less appropriate when comparing, say, Microsoft and Apple, which compete directly in the product market, as well as for attention through their disclosures.

In this section, we present an alternative model that better characterizes the latter case. That is, we suppose that firms compete for customers as well as for positive attention from investors.

The fundamental aspect of competition relevant here is that firm revenue decreases with the entry of additional firms. Accordingly, signals that affect firm value have a smaller absolute impact, even if they alter firm value by the same fraction. For example, an internal audit that reveals an increase in efficiency has a greater absolute effect if it happens in a firm with high revenue and market value.

#### 4.1 Simple Product Market Competition

To capture this effect simply, we model product market competition by using a distribution of value signals that becomes compressed with the entry of additional firms. When  $N$  firms compete in the product market as well as for investor attention, we exchange the original distribution of signals  $x \sim F$  for a compressed distribution  $x_N \sim F_N$ . Specifically, whenever a firm would have drawn a signal  $x$  in the original model, they instead draw a scaled-down event  $x/N$  in the new model.

Formally, we write the new distribution as

$$F_N(x) \equiv F(Nx).$$

An increase in  $N$  has the effect of “squishing” the distribution of news events while leaving the support unchanged. If  $x = \$10k$  had been a 90<sup>th</sup>-percentile result with  $N = 5$ ,  $x = \$1k$  would be the new 90<sup>th</sup>-percentile with  $N = 50$ . Increasing  $N$  scales down expectations while preserving the concavity and any other peculiarities of the value distribution. We refer to this as “equal shares competition” for earnings.

We wish to stress that this is not intended as a realistic model of competition. A plethora of microeconomic papers have dealt with such issues before us, so we initially gloss over other aspects of pricing, capital, and entry costs. Our goal is simply to show how the value-scaling effect of competition affects disclosure, using the simplest model that captures the relevant effect. In Section 4.2, though, we consider more general models of competition, and show that our general result holds for most plausible models of competition and revenue.

We have already addressed the comparative statics of the base model in Section 2. There we found that as  $N$  increases, the incentive to disclose falls as the probability of winning the prize decreases. This reduces the incentive to disclose. With product market competition potential revenue declines as well. This reduces the incentive to pool. These two effects oppose one another. Which effect dominates depends upon the number of competing firms.

For what values of  $N$ , then, does competition reduce disclosure? If we were to find the necessary number of firms to be in the millions, for example, then our point here would only be academic

and not of practical import. To gain a sense of how many firms is “enough,” consider the following proposition.

**Proposition 1.** *If  $N > 1/(p\hat{\omega})$ , then  $\omega_{N+1}^* < \omega_N^*$ . Further, as  $N \rightarrow \infty$ ,*

*(i) Average per-firm earnings  $\pi_N$  converge to zero.*

*(ii) The equilibrium disclosure frequency  $\omega_N^*$  converges to  $\hat{\omega}$ .*

To appreciate Proposition 1, suppose the distribution  $\tilde{x} \sim F$  is symmetric, so the fact that  $\hat{t} < E[x]$  implies that

$$\hat{\omega} = 1 - F(\hat{t}) > 1 - F(E[x]) = 0.5. \quad (5)$$

Then the necessary condition becomes  $N > 2/p$ . If, for example, firm information arrives with probability 20%, then  $N = 2/(20\%) = 10$  firms is enough competition that further entry will only reduce disclosure. The higher  $p$  is, the fewer firms that are required to assure that further competition decreases disclosure. We conjecture that in many industries (e.g., financial sectors), there are already enough competitors present so that disclosure responds negatively to additional competition.

Proposition 1 also shows that  $\omega_N^*$  actually converges to  $\hat{\omega}$  under perfect competition, while industry profits converge to zero. In most Microeconomic models, as in ours, producer surplus falls to zero under perfect competition. Product prices generally converge to their lowest possible values, which maximizes social welfare. However, perfect competition in disclosure induces firm to retain their maximum degree of asymmetric information. Thus, while perfect competition drives product prices to their most socially efficient, it drives firm prices to their least informationally efficient. To better appreciate this, we provide the following example.

**Example 1.** *Consider the disclosure game where  $\tilde{x}$  is Gaussian with  $\mu = 0$ ,  $\sigma = 5$  and  $\phi = 1$ ,  $p = .3$  and product market competition characterized by  $F_N(x) = F(Nx)$ . Figure 1 shows how the equilibrium disclosure changes with the number of competing firms. Disclosure initially increases, then decreases asymptotically to the lower limit  $\hat{\omega} \approx .556$ .*

Although the above condition of  $N > 1/(p\hat{\omega})$  is mild enough, the condition is indeed only sufficient for competition to decrease disclosure, not necessary. Typically, an even smaller number of firms will suffice. We therefore derive the constraint on  $N$  that is both necessary and sufficient for further entry to reduce disclosure.

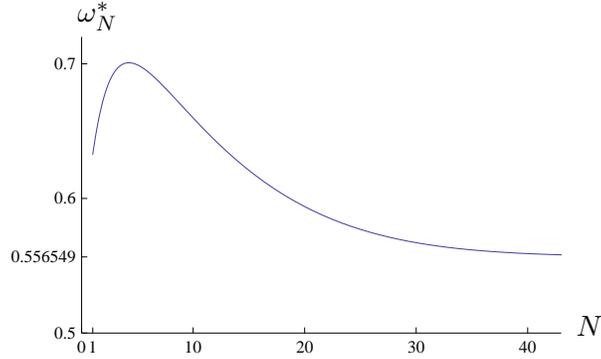


Figure 1: Disclosure game with product market competition. The random variable is  $\tilde{x} \sim N(0, 5)$  and  $\phi = 1$  and  $p = .3$ . The product market competition characterized by  $F_N(x) = F(Nx)$ . The curve shows how the equilibrium disclosure changes with the number of competing firms. Disclosure initially increases, then decreases asymptotically to the lower limit  $\hat{\omega} \approx .556$ .

Consider the position of a firm  $j$  that draws the threshold value,  $x_j = F^{-1}(1 - \omega^*)$ . With  $N$  firms competing for the prize, firm  $j$  is indifferent between disclosing and herding. If a  $(N + 1)^{th}$  competitor enters, and firm  $j$  observes the same  $x_j$ , how do the firm's prospects change? Should it disclose, the entry reduces its expected prize winnings by a factor of  $(1 - p\omega)$  because

$$\phi W(\omega; N) = \phi(1 - p\omega)^{N-1} \quad (6)$$

is exponentially decreasing in  $N$ . But the other terms,  $F_N^{-1}(1 - \omega)$  and  $u_N^C(\omega)$ , decline by a factor of  $N/(N + 1)$ , as demonstrated in Lemma A2 in the appendix. As  $N$  rises, then, this linear effect diminishes in significance compared to the exponential effect on the expected prize value. Intuitively it seems that there is a critical number of firms at which additional competition makes herding more attractive than competing for the prize.

**Proposition 6.** *Disclosure frequency decreases with firm entry if and only if the number of competing firms exceeds some threshold.:*

$$N > \frac{p\omega_N^*}{1 - p\omega_N^*} \equiv \bar{N} \iff \omega_{N+1}^* < \omega_N^*. \quad (7)$$

Because the ex-ante probability of a firm disclosing is  $P(D_j|N) = p\omega_N^*$ , we may equivalently write

$$N > \frac{P(D_j|N)}{P(P_j|N)} \iff \omega_{N+1}^* < \omega_N^*. \quad (8)$$

That is, if  $N$  exceeds the threshold specified by the relative probabilities of disclosing and pooling, then the exponential effect overwhelms the linear effect. So, the net effect of firm entry

is a reduction in the incentive to disclose, which results in  $\omega_{N+1}^* < \omega_N^*$ . Note, however, that the threshold for  $N$  established by Proposition 6 is changing with  $N$ . That is, as  $N$  increases,  $\omega_N^*$  varies, and so the probability ratio in Equation 8 may also increase. Therefore, although this proposition details the necessary and sufficient condition for  $N$ , it does not provide a tighter unconditional bound than Proposition 1.

## 4.2 Generalized Product Market Competition

Now let us consider more general models of competition. That is, consider a model in which firm entry reduces the value of competing firms in a more sophisticated way than the simple  $\frac{1}{N}$  rule used in the previous section. Instead of  $F_N(x) \equiv F(Nx)$ , we define the distribution as a function of  $N$  by

$$F_N(x) \equiv F\left(\frac{x}{\alpha_N}\right),$$

for some decreasing sequence  $\{\alpha_N\}$ . Note that if  $\alpha_N$  decreases rapidly, then firm entry has a dramatic effect on the revenue of competing firms. If  $\alpha_N$  decreases more slowly, then the effect is less pronounced.

**Proposition 7.** *If, under generalized competition with  $F_N(x) = F(\frac{x}{\alpha_N})$ ,*

$$\lim_{N \rightarrow \infty} \frac{\alpha_{N+1}}{\alpha_N} > 1 - p\hat{\omega},$$

*then there exists some  $\bar{N} \in \mathbb{R}$  such that  $N > \bar{N} \Rightarrow \omega_{N+1}^* < \omega_N^*$*

The proof follows nearly the same structure as the proof of Proposition 6. Note, however, that in this case, we need an additional restriction on the sequence  $\{\alpha_N\}$  in order to complete the proof. Roughly stated, the requirement above is that competition not reduce firm value too “quickly” as additional firms enter.

Thus, the question becomes one of whether the per-firm revenue can decrease ad-infinitum at such a rate with the entry of additional firms. Although one can posit such a model, exponentially decreasing revenue is not a common feature of microeconomic models of competition.

**Example 2.** *Consider a Cournot competition with linear pricing. In such a model, per-firm earnings (and hence firm value) declines as  $N$  grows:*

$$\pi_N = \frac{\pi_1}{N^2}. \quad \text{Therefore} \quad \alpha_N = \frac{1}{N^2}$$

*This sequence satisfies the criterion in Proposition 7 because*

$$\lim_{N \rightarrow \infty} \frac{\alpha_{N+1}}{\alpha_N} = \lim_{N \rightarrow \infty} \frac{N^2}{(N+1)^2} = 1 > 1 - p\hat{\omega},$$

*So under linear Cournot competition, disclosure does indeed decline with competition for large  $N$ .*

## 5 Concluding Remarks

The primary result in this paper is that increased competition for attention in financial markets reduces disclosure in well-populated industries. We show this both in a parsimonious model, as well as in more sophisticated extensions. The fundamental idea, that firm entry makes attaining top status more difficult, is straightforward. But the exponential relationship between the number of competing firms and the probability of winning the prize is mathematically powerful. The result is a robustness that makes our central result widely generalizable.

As our model shows, we cannot appeal to the Invisible Hand to make markets transparent. While competition in product markets often has a favorable effect on prices, driving firms to lower and more socially efficient prices, it can have the opposite effect on disclosure. Specifically, when a large part of the firm incentive to disclose is due to the prize value of high status, the entry of additional firms can reduce this incentive. In the asymptotic limit of perfect competition, prices converge to their most efficient values, but disclosure falls to its least efficient.

Our analysis in this paper can be applied to debates regarding disclosure that have evolved following the recent financial crisis. Indeed, terms like “sub-prime mortgage” and “collateralized debt obligation” became household language and massive devaluations made these “toxic assets” infamous in the eyes of the public. Investors and regulators were eager to know firms’ exposure to these assets, but many firms did not know their own positions. This maps well onto our model, since investors could not be certain which firms accurately knew the contents of their balance sheets. Informed firms could choose either to conceal their asset positions, or to disclose the gruesome details. Financial markets might have been able to right themselves more quickly had the position of insured and insuring firms been known to investors. A great deal of media and political attention has focused on the need to mitigate or avoid such problems in the future.

While past models have focused on the “Lemons Problem” of corporate disclosure, little attention has been paid to the exogenous benefits of positive investor attention. Essentially, existing disclosure theory casts disclosures from Wells Fargo in the same light as disclosures from a local grocer. But in financial sectors, where investor attention and high status make a large contribution

to firm value, the comparison is simply inappropriate. If firms do in fact take the benefits of status into account when considering discretionary disclosure, then we can make meaningful predictions about their actions. Understanding the incentives for disclosure allow meaningful predictions to be made about its comparative statics. When economic conditions can change rapidly, such an understanding is critical for investors, managers, and regulators alike. In a crisis, our model predicts that firms that compete for large prizes will be less inclined to disclose, owing to the increased asymmetric information. Further, while the increase in uncertainty will certainly affect disclosure, it is the specifics of the distribution of new information that determine whether a second-order stochastic shift will lead to greater or lesser transparency.

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# Appendix A

## Proof of Lemma 1

Suppose firm  $j$  observes the event  $x$ . In a subgame-perfect Nash equilibrium, the firm must disclose optimally given the value of  $x$ . That is, it discloses when  $u_j^D(x) > u_j^C$  and conceal  $x$  when  $u_j^C < u_j^D(x)$ .

If the firm discloses, then it is eligible to win the prize  $\phi$ . So its new market valuation is  $x$ , plus an additional  $\phi$  if no competing firm makes a higher disclosure,

$$u_j^D(x) = x + \phi W_j(x),$$

where  $W_j(x)$  is the probability that no competing firm discloses a higher value than  $x$ :

$$\begin{aligned} W_j(x) &= \prod_{k \neq j} (1 - P(I_k)P((x_k > x) \cap D_j)) \\ &= \prod_{k \neq j} \left( 1 - p \int_x^\infty \sigma_k(z) f(z) dz \right) \end{aligned} \quad (\text{A1})$$

Note that  $u_j^D(x)$  is differentiable, and therefore continuous. Furthermore, for any  $x$ ,

$$u_j^D(x) \leq x + \phi \quad \text{and} \quad x \leq u_j^D(x)$$

Evaluating at  $x = u_j^C - \phi$  and  $x = u_j^C$ , these inequalities yield

$$u_j^D(u_j^C - \phi) \leq u_j^C \quad \text{and} \quad u_j^C \leq u_j^D(u_j^C).$$

So if firm  $j$  observes  $x_j = u_j^C - \phi$ , then disclosure yields a lower expected utility than  $u_j^C$ ; and if it observes  $x_j = u_j^C$ , then disclosure yields a higher expected utility than  $u_j^C$ . Because  $u_j^D(x)$  is continuous, the Intermediate Value Theorem assures us there is a potential observation  $t_j \in [u_j^C - \phi, u_j^C]$  for which

$$u_j^D(t_j) = u_j^C. \quad (\text{A2})$$

This  $t_j$  is the disclosure threshold for firm  $j$ , where the firm is indifferent between disclosing and pooling. Since  $u_j^D(x)$  is strictly monotonic in  $x$ , we further obtain

$$\begin{aligned} x > t_j &\Rightarrow u_j^D(x) > u_j^C \\ x < t_j &\Rightarrow u_j^D(x) < u_j^C. \end{aligned}$$

The subgame-optimal response of firm  $j$  is therefore to disclose any values above the threshold  $t_j$  and to conceal any values below, as desired.

Now to show that  $t_j < 0$ , we derive the value  $u_j^C$  that investors assign if the firm conceals its observation. In a rational expectations equilibrium, the beliefs of the investors with respect to the strategy must be consistent with the strategy actually used,

$$\begin{aligned} u_j^C = E[x|P_j] &= \frac{P(U_j)E[x|U_j] + P(I_j \cap C_j)E[x|I_j \cap C_j]}{P(U_j) + P(I_j)P(C_j|I_j)} \\ &= \frac{(1-p) \cdot 0 + pP(x < t_j)E[x|x < t_j]}{(1-p) + pP(x < t_j)} \\ &= \frac{pF(t_j)}{1-p + pF(t_j)}E[x|x < t_j] \end{aligned} \quad (\text{A3})$$

$$\begin{aligned} &< \frac{pF(t_j)}{1-p + pF(t_j)}E[x] = 0. \\ \therefore u_j^C &< 0 < u_j^D(0). \end{aligned} \quad (\text{A4})$$

Because  $u_j^D(x)$  is monotonically increasing in  $x$ , the threshold  $t_j$  must be below zero. That is, all average or better values of  $x$  will be disclosed in equilibrium. ■

## Proof of Lemma 2

Write Equation (A3) as an integral, then apply integration by parts,

$$\begin{aligned} u_j^C &= \frac{p}{1-p + pF(t_j)} \int_{-\infty}^{t_j} xf(x) dx \\ &= \frac{p}{1-p + pF(t_j)} \left( [xF(x)]_{-\infty}^{t_j} - \int_{-\infty}^{t_j} F(x) dx \right) \\ &= \frac{p}{1-p + pF(t_j)} \left( t_j F(t_j) - \int_{-\infty}^{t_j} F(x) dx \right). \end{aligned} \quad (\text{A5})$$

Using this expression, some algebraic manipulation transforms  $u_j^D(t_j) = u_j^C$  into

$$\phi W_j(t_j)(1-p + pF(t_j)) = (1-p)(-t_j) - p \int_{-\infty}^{t_j} F(x) dx. \quad (\text{A6})$$

Now suppose for contradiction that a non-symmetric equilibrium exists. That is, suppose an equilibrium exists in which firms  $j$  and  $k$  use different thresholds. Without loss of generality, assume that  $t_k < t_j$ . Equation (A6) holds for firm  $k$  as well as for  $j$ . Subtracting these yields

$$\begin{aligned} &\phi \left( W_j(t_j)(1-p + pF(t_j)) - W_k(t_k)(1-p + pF(t_k)) \right) \\ &= (1-p)(-t_j + t_k) - p \int_{t_k}^{t_j} F(x) dx < 0. \\ \therefore W_j(t_j)(1-p + pF(t_j)) &< W_k(t_k)(1-p + pF(t_k)). \end{aligned} \quad (\text{A7})$$

But we can obtain a contradiction by deriving the opposite inequality. We simplify Equation (A1) with the assumption that all firms use threshold strategies, then evaluate at  $t_j$ :

$$\begin{aligned}
W_j(t_j) &= \prod_{i \neq j} \left( 1 - p \int_{t_j}^{\infty} \sigma_i(z) f(z) dz \right) \\
&= \prod_{i \neq j} \left( 1 - p + pF(\max(t_i, t_j)) \right) \\
&= \left( 1 - p + pF(\max(t_j, t_k)) \right) \prod_{i \neq j, k} \left( 1 - p + pF(\max(t_i, t_j)) \right).
\end{aligned} \tag{A8}$$

The same holds for firm  $k$ , so we obtain

$$W_k(t_k) = \left( 1 - p + pF(\max(t_j, t_k)) \right) \prod_{i \neq j, k} \left( 1 - p + pF(\max(t_i, t_k)) \right).$$

Since  $t_j > t_k$ , these equations show that  $W_j(t_j) > W_k(t_k)$ . Therefore,

$$W_j(t_j)(1 - p + pF(t_j)) > W_k(t_k)(1 - p + pF(t_k)).$$

This directly contradicts Equation (A7), so the hypothesized asymmetric equilibrium cannot exist. ■

### Proof of Lemma 3

Suppose for contradiction there exist two distinct equilibrium thresholds  $t^*$  and  $t^{**}$ . Without loss of generality, assume  $t^* < t^{**}$ . Equation (A6) holds at both thresholds. Subtracting, we obtain

$$\begin{aligned}
&\phi \left( W(t^*)(1 - p + pF(t^*)) - W(t^{**})(1 - p + pF(t^{**})) \right) \\
&\quad = (1 - p)(t^{**} - t^*) + p \int_{t^{**}}^{t^*} F(x) dx < 0. \\
\therefore \quad &W(t^*)(1 - p + pF(t^*)) < W(t^{**})(1 - p + pF(t^{**})).
\end{aligned} \tag{A9}$$

We now obtain a contraction by deriving the opposite inequality. Since strategies are symmetric,  $t_i = t_j$  in Equation (A8), so the equation simplifies to

$$W(t^*) = (1 - p + pF(t^*))^{N-1}. \tag{A10}$$

And the same holds for the other equilibrium threshold,

$$W(t^{**}) = (1 - p + pF(t^{**}))^{N-1}.$$

Because  $t^* > t^{**}$ , these equations show that  $W(t^*) > W(t^{**})$ . Therefore,

$$W(t^*)(1 - p + pF(t^*)) > W(t^{**})(1 - p + pF(t^{**})),$$

directly contradicting Equation (A9). By this contradiction, we conclude that a second distinct equilibrium threshold  $t^{**}$  cannot exist. ■

## Proof of Proposition 1

Taken together, Lemmas 1, 2 and 3 show that all firms use a common and unique disclosure threshold defined implicitly by

$$u_j^D(t^*) = u^C(t^*).$$

We expand this equivalence using  $u_j^D(t^*) = t^* + \phi W(t^*)$ , Equation (A10), and Equation (A5) to obtain the desired expression

$$t^* + \phi(1 - p + pF(t^*))^{N-1} = \frac{p}{1 - p + pF(t^*)} \int_{-\infty}^{t^*} xf(x) dx.$$

Finally, we find  $t^* < 0$  by the same argument that shows  $t_j < 0$  in Lemma 1. ■

## Proof of Proposition 2

Consider the integral in the right hand side of Equation (1). The substitution  $\Omega = 1 - F(x)$  yields

$$f(x) dx = -d\Omega, \quad x = F^{-1}(1 - \Omega) = t(\Omega).$$

Therefore,

$$\int_{-\infty}^{t^*} xf(x) dx = \int_{1-F(-\infty)}^{1-F(t^*)} F^{-1}(1 - \Omega)(-d\Omega) = - \int_1^{\omega^*} F^{-1}(1 - \Omega) d\Omega = \int_{\omega^*}^1 F^{-1}(1 - \Omega) d\Omega.$$

Equation (1) therefore becomes the desired expression,

$$F^{-1}(1 - \omega^*) + \phi(1 - p\omega^*)^{N-1} = \frac{p}{1 - p\omega^*} \int_{\omega^*}^1 F^{-1}(1 - \Omega) d\Omega.$$

■

**Definition A1.** For any disclosure frequency  $\omega$ , define the corresponding disclosure threshold by  $t(\omega)$ . That is,

$$t(\omega) \equiv F^{-1}(1 - \omega)$$

**Definition A2.** Define  $B(\omega)$  as the benefit of disclosing the threshold value relative to concealing, assuming that all firms disclose with frequency  $\omega$ ,

$$B(\omega) \equiv u^D(\omega) - u^C(\omega),$$

where

$$\begin{aligned} u^D(\omega) &\equiv E[u_j^D | x_j = t(\omega)] \\ u^C(\omega) &\equiv E[x_j | P_j, t_j = t(\omega)]. \end{aligned}$$

Note that this definition does not require that  $\omega$  be the equilibrium frequency, which we denote distinctly by  $\omega^*$ .

**Lemma A1.** *The equilibrium disclosure frequency is defined implicitly by*

$$B(\omega^*) = 0.$$

Further, for any  $\omega > \hat{\omega}$ ,

$$(i) \quad \frac{\partial B}{\partial \omega} < 0$$

$$(ii) \quad B(\omega) > 0 \Rightarrow \omega < \omega^*$$

$$(iii) \quad B(\omega) < 0 \Rightarrow \omega > \omega^*$$

### Proof of Lemma A1

Using Definitions A1 and A2, we can write  $B(\omega)$  as

$$B(\omega) = t(\omega) + \phi(1 - p\omega)^{N-1} - \frac{p}{1 - p\omega} \int_{\Omega}^1 t(\Omega) \, d\Omega.$$

Comparing this to Corollary 2 reveals that  $B(\omega^*) = 0$  is algebraically equivalent to Equation 3. So  $B(\omega^*)$  defines the equilibrium disclosure frequency, as desired.

(i) Note that

$$\frac{\partial}{\partial \omega} t(\omega) = \frac{\partial}{\partial \omega} F^{-1}(1 - \omega) = \frac{-1}{f(F^{-1}(1 - \omega))} < 0,$$

so the first term is decreasing in  $\omega$ . Clearly the second term is also decreasing in  $\omega$ . In the third term,

$$\frac{\partial}{\partial \omega} \left( -\frac{p \int_{\omega}^1 t(\Omega) \, d\Omega}{1 - p\omega} \right) = \frac{-p^2 \int_{\omega}^1 t(\Omega) \, d\Omega + pt(\omega)(1 - p\omega)}{(1 - p\omega)^2}$$

and the integrand  $t(\Omega)$  is decreasing in  $\Omega$ , so

$$\begin{aligned} \dots &< \frac{-p^2(1 - \omega)t(\omega) + pt(\omega)(1 - p\omega)}{(1 - p\omega)^2} \\ &= \frac{-p^2 + p^2\omega + p - p^2\omega}{(1 - p\omega)^2} t(\omega) \\ &= \frac{p(1 - p)}{(1 - p\omega)^2} t(\omega). \end{aligned}$$

By our assumption that  $\omega > \hat{\omega}$ , we know that  $t(\omega) < \hat{t} < E[\tilde{x}] = 0$ , and so the derivative of the third term is also negative. Thus,  $B(\omega)$  is strictly decreasing in  $\omega$  for all  $\omega > \hat{\omega}$ .

(ii) Since  $\omega^* > \hat{\omega}$ ,  $\partial B/\partial\omega < 0$ . So because  $B(\omega^*) = 0$ , we have

$$B(\omega) = B(\omega) - B(\omega^*) = \int_{\omega^*}^{\omega} \frac{\partial B(\Omega)}{\partial\Omega} d\Omega < 0.$$

The contrapositive of this statement is the desired expression,

$$B(\omega) > 0 \Rightarrow \omega < \omega^*.$$

(iii) Proven as in part (ii).

■

### Proof of Proposition 3

For clarity, let us write  $B(\omega) \equiv u^D(\omega) - u^C(\omega)$  explicitly in terms of the model parameters:

$$B(\omega, \phi, p, N) = t(\omega) + \phi(1 - p\omega)^{N-1} - \frac{p}{1 - p\omega} \int_{\omega}^1 t(\Omega) d\Omega.$$

For any set of parameter values  $(\phi, p, N)$ , the equilibrium disclosure frequency is uniquely defined by  $B(\omega^*, \phi, p, N) = 0$ . Because  $B$  is differentiable with respect to each of its parameters, the Implicit Function Theorem tells us how the equilibrium frequency changes with the parameter values. For each parameter  $\theta \in \{\phi, p, N\}$ , the IFT gives

$$\frac{\partial\omega^*}{\partial\theta} \equiv \left. \frac{\partial\omega}{\partial\theta} \right|_{B=0} = - \frac{\left. \frac{\partial B}{\partial\theta} \right|_{B=0}}{\left. \frac{\partial B}{\partial\omega} \right|_{B=0}}.$$

Lemma A1 tells us that  $\frac{\partial B}{\partial\omega} < 0$  for all  $\omega > \hat{\omega}$ . Differentiating with respect to the other model parameters yields

$$\begin{aligned} \frac{\partial B}{\partial\phi} &= (1 - p\omega)^{N-1} > 0 \\ \frac{\partial B}{\partial N} &= \phi(1 - p\omega)^{N-1} \ln(1 - p\omega) < 0 \\ \frac{\partial B}{\partial p} &= -\omega\phi(N - 1)(1 - p\omega)^{N-2} - \frac{1}{(1 - p\omega)^2} \int_{\omega}^1 t(\Omega) d\Omega. \end{aligned}$$

Note that  $\int_{\omega}^1 t(\Omega) d\Omega < 0$  is the expected value of  $x$  for a non-disclosing firm, which is negative. So the second term of  $\frac{\partial B}{\partial p}$  is positive, while the first is negative. Which term dominates depends on the parameter values.

Applying the Implicit Function Theorem yields the desired comparative statics:

$$\begin{aligned} \frac{\partial B}{\partial\phi} > 0 & \quad \text{so} \quad \frac{\partial\omega^*}{\partial\phi} = - \frac{\partial B/\partial\phi}{\partial B/\partial\omega} > 0, \\ \frac{\partial B}{\partial N} < 0 & \quad \text{so} \quad \frac{\partial\omega^*}{\partial N} = - \frac{\partial B/\partial N}{\partial B/\partial\omega} > 0. \end{aligned}$$

As shown already,  $\omega$  is decreasing in  $N$ . Since any monotonic bounded sequence of real numbers converges<sup>9</sup>, and since we know  $\omega_N^* > \hat{\omega}$  for all  $N$ ,  $\omega_N^*$  converges as  $N \rightarrow \infty$ . Let us refer to its limit as

$$\omega_\infty = \lim_{N \rightarrow \infty} \omega^* \quad (\text{A11})$$

The function  $B(\cdot)$  is continuous in  $\omega_N^*$  and  $N$ , and  $B_N(\omega_N^*) = 0$  for all  $N$ . The sequence  $\{B_N(\omega_N^*)\}$  therefore converges to zero as well:

$$0 = \lim_{N \rightarrow \infty} B_N(\omega_N^*) \quad (\text{A12})$$

$$= \lim_{N \rightarrow \infty} x(\omega_N^*) + \lim_{N \rightarrow \infty} \phi(1 - p\omega_N^*)^N - \lim_{N \rightarrow \infty} \frac{p \int_{\omega_N^*}^1 x(\Omega) \, d\Omega}{1 - p\omega_N^*} \quad (\text{A13})$$

$$= x(\omega_\infty) + 0 - \frac{p \int_{\omega_\infty}^1 x(\Omega) \, d\Omega}{1 - p\omega_\infty} \quad (\text{A14})$$

That is,

$$x(\omega_\infty) = \frac{p \int_{\omega_\infty}^1 x(\Omega) \, d\Omega}{1 - p\omega_\infty}, \quad (\text{A15})$$

and therefore  $\omega_\infty = \hat{\omega}$ . ■

## Proof of Proposition 4

Define a firm's "rank" according to the firm's place among realized disclosures by competing firms. That is, if there are  $k - 1$  higher disclosures, the firm has rank  $k$  and receives  $\phi_k$ . A disclosing firm's rank is therefore a stochastic function of its disclosed value. We define  $\tilde{r}(\omega)$  accordingly:

$$\tilde{r}(\omega) = \text{rank of a firm that discloses } x = F^{-1}(1 - \omega).$$

Using this notation, we would write the expected utility of disclosure in the base model as

$$\begin{aligned} u^D(\omega) &= t(\omega) + \phi W(\omega) \\ &= t(\omega) + \phi P(\tilde{r}(\omega) = 1). \end{aligned} \quad (\text{Single Prize } \phi)$$

With prizes for the top  $K$  firms, the expected payout becomes

$$u^D(\omega) = t(\omega) + \sum_{k=1}^K \phi_k P(\tilde{r}(\omega) = k). \quad (\text{Multiple Prizes } \{\phi_k\})$$

We wish to show that this value is decreasing in  $N$ . Unfortunately, we cannot claim that  $P(\tilde{r}(\omega) = k)$  is decreasing in  $N$  without some further restrictions. Although the chance of having *at least* the

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<sup>9</sup>Rudin, Theorem 3.14, "Principles of Mathematical Analysis."

$k^{\text{th}}$ -highest disclosure is strictly decreasing in  $N$ , the chance of having *exactly* the  $k^{\text{th}}$ -highest disclosure may be increasing in  $N$ , at least for certain parameter values. We therefore rearrange the sum in order to write it in terms we know to be unconditionally decreasing in  $N$ ,

$$\begin{aligned} u^D(\omega) &= t(\omega) + \sum_{k=1}^K \phi_k \left( P(\tilde{r}(\omega) \leq k) - P(\tilde{r}(\omega) \leq k-1) \right) \\ &= t(\omega) + \sum_{k=1}^K (\phi_k - \phi_{k+1}) P(\tilde{r}(\omega) \leq k). \end{aligned}$$

Note that  $P(\tilde{r}(\omega) \leq k)$ , the probability of having at least the  $k^{\text{th}}$ -highest disclosure, is strictly decreasing in  $N$ . Since prizes are strictly decreasing in rank, we also have  $(\phi_k - \phi_{k+1}) > 0$ . Therefore,  $u^D(\omega)$  is unconditionally decreasing in  $N$ . We conclude that disclosure frequency decreases in  $N$  under a progressive prize structure. ■

## Proof of Proposition 5

We consider the base model with prizes  $\phi_N$  that increase with  $N$  according to some sequence  $\{\phi_N\}$ . Then the benefit of disclosing relative to concealing is a function of  $N$ ,

$$B_N(\omega) = t(\omega) + \phi_N(1 - p\omega)^{N-1} - u^C(\omega).$$

The same holds for  $(N + 1)$  firms, so we can subtract the two equations to obtain

$$\begin{aligned} B_{N+1}(\omega) - B_N(\omega) &= \phi_{N+1}(1 - p\omega)^N - \phi_N(1 - p\omega)^{N-1} \\ &= \phi_N(1 - p\omega)^{N-1} \left( \frac{\phi_{N+1}}{\phi_N}(1 - p\omega) - 1 \right). \end{aligned} \quad (\text{A16})$$

Under our assumption that  $\lim_{N \rightarrow \infty} \frac{\phi_{N+1}}{\phi_N} < \frac{1}{1 - p\hat{\omega}}$ , there exists some  $\bar{N}$  such that

$$N > \bar{N} \Rightarrow \frac{\phi_{N+1}}{\phi_N} < \frac{1}{1 - p\hat{\omega}},$$

so evaluating Equation (A16) at  $\omega = \omega_N^*$  for any  $N > \bar{N}$  yields

$$B_{N+1}(\omega_N^*) - 0 < \phi_N(1 - p\omega_N^*)^{N-1} \left( \frac{\phi_{N+1}}{\phi_N}(1 - p\hat{\omega}) - 1 \right) < 0.$$

By Lemma A1, we obtain the desired  $\omega_{N+1}^* < \omega_N^*$ . ■

**Lemma A2.** *Under equal shares competition, the signal that corresponds to a given probability  $\omega$ , previously written as  $x(\omega)$  becomes*

$$t_N(\omega) = \frac{1}{N}x(\omega). \quad (\text{A17})$$

Similarly,

$$u_N^C(\omega) = \frac{1}{N}u^C(\omega) \quad (\text{A18})$$

$$u_N^D(\omega) = \frac{1}{N}x(\omega) + \phi(1 - p\omega)^{N-1}. \quad (\text{A19})$$

## Proof of Lemma A2

Under the definition,

$$F_N(x) = F(Nx),$$

we find, for any  $p \in [0, 1]$ , that

$$p = F_N\left(F_N^{-1}(p)\right) \equiv F\left(NF_N^{-1}(p)\right),$$

which can be rearranged to

$$F_N^{-1}(p) = \frac{1}{N}F^{-1}(p),$$

so for  $p = 1 - \omega$ , we have

$$\begin{aligned} F_N^{-1}(1 - \omega) &= \frac{1}{N}F^{-1}(1 - \omega). \\ \therefore t_N(\omega) &= \frac{1}{N}t(\omega). \end{aligned}$$

Using this first result, the others follow quickly

$$\begin{aligned} u_N^D(\omega) &\equiv t_N(\omega) + \phi(1 - p\omega)^{N-1} \\ &= \frac{1}{N}t(\omega) + \phi(1 - p\omega)^{N-1} \end{aligned}$$

$$\begin{aligned} u_N^C(\omega) &\equiv \frac{p}{1 - p\omega} \int_{\omega}^1 t_N(\Omega) \, d\Omega \\ &= \frac{p}{1 - p\omega} \int_{\omega}^1 \frac{t(\Omega)}{N} \, d\Omega \\ &= \frac{1}{N}u^C(\omega). \end{aligned}$$

- (i) This follows immediately from our definition  $F_N(x) \equiv F(Nx)$ . As  $N \rightarrow \infty$ ,  $F_N(x) \rightarrow F(0)$  for every  $x \in \mathbb{R}$ .

(ii) For any  $N > \frac{1}{p\hat{\omega}}$ , Proposition 1 tells us that  $\omega_N^*$  is decreasing in  $N$ . Since any monotonic bounded sequence of real numbers converges<sup>10</sup>, and since we know  $\omega_N^* > \hat{\omega}$  for all  $N$ ,  $\omega_N^*$  converges. Let us refer to its limit as

$$\omega_\infty = \lim_{N \rightarrow \infty} \omega_N^* \quad (\text{A20})$$

The function  $B(\cdot)$  is continuous in  $\omega_N^*$  and  $N$ , and  $B_N(\omega_N^*) = 0$  for all  $N$ . The sequence  $\{B_N(\omega_N^*)\}$  therefore converges to zero as well:

$$0 = \lim_{N \rightarrow \infty} B_N(\omega_N^*) \quad (\text{A21})$$

$$= \lim_{N \rightarrow \infty} x(\omega_N^*) + \lim_{N \rightarrow \infty} \phi(1 - p\omega_N^*)^N - \lim_{N \rightarrow \infty} \frac{p \int_{\omega_N^*}^1 x(\Omega) \, d\Omega}{1 - p\omega_N^*} \quad (\text{A22})$$

$$= x(\omega_\infty) + 0 - \frac{p \int_{\omega_\infty}^1 x(\Omega) \, d\Omega}{1 - p\omega_\infty} \quad (\text{A23})$$

That is,

$$x(\omega_\infty) = \frac{p \int_{\omega_\infty}^1 x(\Omega) \, d\Omega}{1 - p\omega_\infty}, \quad (\text{A24})$$

and therefore  $\omega_\infty = \hat{\omega}$ .

■

## Proof of Proposition 1

Note: This proof calls upon Proposition 6, which comes next in the appendix. Clearly  $P(P_j|N) < 1$ , so

$$NP(D_j|N) > 1 \quad \Rightarrow \quad NP(D_j|N) > P(P_j|N),$$

which implies  $\omega_{N+1}^* < \omega_N^*$  by Proposition 6. We can achieve this inequality by a sufficient assumption,

$$N > \frac{1}{p\hat{\omega}} \quad \Rightarrow \quad NP(D_j|N) > 1.$$

■

## Proof of Proposition 6

Applying Proposition A2 to the definition of  $B(\omega)$  under equal shares competition yields

$$\begin{aligned} B_N(\omega) &= u_N^D(\omega) - u_N^C(\omega) \\ &= \frac{1}{N}t(\omega) + \phi(1 - p\omega)^{N-1} - \frac{1}{N}u^C(\omega). \\ \therefore \quad NB_N(\omega) &= t(\omega) + N\phi(1 - p\omega)^{N-1} - u^C(\omega). \end{aligned} \quad (\text{A25})$$

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<sup>10</sup>Rudin, Theorem 3.14, "Principles of Mathematical Analysis."

The same holds for  $N + 1$ . That is,

$$(N + 1)B_{N+1}(\omega) = t(\omega) + (N + 1)\phi(1 - p\omega)^N - u^C(\omega). \quad (\text{A26})$$

Subtracting Equation (A25) from Equation (A26) yields

$$\begin{aligned} (N + 1)B_{N+1}(\omega) - NB_N(\omega) &= (N + 1)\phi(1 - p\omega)^N - N\phi(1 - p\omega)^{N-1} \\ &= \phi(1 - p\omega)^{N-1}((N + 1)(1 - p\omega) - N) \\ &= \phi(1 - p\omega)^{N-1}(N + 1 - Np\omega - p\omega - N) \\ &= \phi(1 - p\omega)^{N-1}((1 - p\omega) - Np\omega). \end{aligned} \quad (\text{A27})$$

If we at  $\omega = \omega_N^*$ , then  $B_N(\omega_N^*) = 0$ , so Equation (A27) reduces to

$$B_{N+1}(\omega_N^*) = \frac{\phi(1 - p\omega_N^*)^{N-1}}{N + 1} \left( (1 - p\omega_N^*) - Np\omega_N^* \right).$$

Focusing on the sign of the term in parenthesis, we find

$$N > \frac{1 - p\omega_N^*}{p\omega_N^*} \quad \Rightarrow \quad B_{N+1}(\omega_N^*) < 0 \quad \Rightarrow \quad \omega_{N+1}^* < \omega_N^*, \quad (\text{A28})$$

where the second implication is due to Lemma A1. That is, disclosure at the frequency  $\omega_N^*$  gives  $B < 0$ , so the marginal disclosure loses value. The equilibrium frequency  $\omega_{N+1}^*$  must be lower.

This shows that the entry of the  $(N + 1)^{th}$  firm reduces disclosure when  $N$  is large. When  $N$  is smaller than the threshold, the inequalities in Equation (A28) are reversed, as shown by the same logic. This completes the equivalence.

Finally, note that the ex ante probability of a firm  $j$  disclosing is the joint probability that it observes  $x_j$  and that  $x_j$  exceeds its threshold. Given the number of competing firms, this means

$$P(D_j|N) = p\omega_N^* \quad \text{and} \quad P(P_j|N) = 1 - p\omega_N^*,$$

so the same equivalency holds using the threshold  $N > \frac{P(P_j|N)}{P(D_j|N)}$ , as desired. ■

## Proof of Proposition 7

Under generalized competition with  $N$  firms, we have

$$\begin{aligned} B_N(\omega) &= t_N(\omega) + \phi(1 - p\omega)^{N-1} - u_N^C(\omega) \\ &= \alpha_N t(\omega) + \phi(1 - p\omega)^{N-1} - \alpha_N u^C(\omega). \end{aligned}$$

$$\therefore \quad \frac{1}{\alpha_N} B_N(\omega) = t(\omega) + \frac{1}{\alpha_N} \phi(1 - p\omega)^{N-1} - u^C(\omega).$$

The same holds for  $N + 1$ , so we can subtract the two equations to obtain

$$\begin{aligned} \frac{1}{\alpha_{N+1}}B_{N+1}(\omega) - \frac{1}{\alpha_N}B_N(\omega) &= \frac{1}{\alpha_{N+1}}\phi(1-p\omega)^N - \frac{1}{\alpha_N}\phi(1-p\omega)^{N-1} \\ &= \frac{1}{\alpha_{N+1}}\phi(1-p\omega)^{N-1} \left( (1-p\omega) - \frac{\alpha_{N+1}}{\alpha_N} \right). \end{aligned}$$

Evaluating at  $\omega_N^*$  and rearranging terms yields

$$B_{N+1}(\omega_N^*) = (1-p\omega_N^*)^{N-1} \phi \left( (1-p\omega_N^*) - \frac{\alpha_{N+1}}{\alpha_N} \right).$$

Under our assumption that  $\lim_{N \rightarrow \infty} \frac{\alpha_{N+1}}{\alpha_N} > 1 - p\hat{\omega}$ , there exists some  $\bar{N}$  such that

$$N > \bar{N} \Rightarrow \frac{\alpha_{N+1}}{\alpha_N} > 1 - p\hat{\omega}.$$

So for  $N > \bar{N}$ , we obtain

$$\begin{aligned} B_{N+1}(\omega_N^*) &= (1-p\omega_N^*)^{N-1} \phi \left( (1-p\omega_N^*) - \frac{\alpha_{N+1}}{\alpha_N} \right) \\ &< (1-p\omega_N^*)^{N-1} \phi \left( (1-p\omega_N^*) - (1-p\hat{\omega}) \right) \\ &= (1-p\omega_N^*)^{N-1} \phi(\hat{\omega} - \omega_N^*). \end{aligned}$$

$$\therefore B_{N+1}(\omega_N^*) < 0.$$

By Lemma A1, we conclude that  $\omega_{N+1}^* < \omega_N^*$ , as desired. ■

## Appendix B

In this appendix, we present several extensions and alternative model formulations to further show the robustness of our results under perfect competition. First, we consider endogenous prizes and prizes that are based on firm percentile. Following that, we explore a sequential disclosure model in which firms take turns making disclosures, based on what others have done previously. Finally, we conclude the appendix with a numerical analysis of the effect of volatility on disclosure.

### B.1 Endogenous Prizes

Our analysis in the body of the paper assumes that the prize is given exogenously. One might ask whether the analysis is robust to considering that residual claimants (e.g., lenders, suppliers, or labor) set an industry prize optimally to maximize profits. While a full treatment of this is outside the scope of this paper, we present the following two-stage game to show that perfect competition still leads to decreased disclosure when endogenous prizes are awarded.

Let us consider that the residual claimant's goal in awarding the prize is to efficiently allocate a scarce resource (e.g., loans, supplies, labor). Specifically, we consider that the residual claimant can do business with at most  $j < N$  firms and wishes to screen potential trading partners via the disclosure process. For any firm that exceeds a threshold  $\underline{x}$ , the firm is said to be sufficiently solid to be a trading partner. Note that in equilibrium,  $\underline{x} < t$  or vice versa.

We denote the benefit to paying a cost  $\phi$  in screening business partners as  $B(\phi, N)$ , which also depends on the number of firms in the market. The game takes place in two stages. At  $T = 1$ , the residual claimant solves the following problem

$$\max_{\phi \in [0, \bar{\phi}]} B(\phi, N) - \phi, \tag{B1}$$

which is equivalent to maximizing their economic welfare subject to some bound on the magnitude of the prize they can award (e.g., cost of funds, cost of supplies, reservation wage). At  $T = 2$ , the rest of the disclosure game takes place as in Section 2 of the paper.

The following proposition characterizes the solution to this problem under perfect competition.

**Proposition B1.** *As  $N \rightarrow \infty$ ,  $\omega^* \rightarrow \hat{\omega}$ .*

*Proof.* Consider that the residual claimant wishes to screen firms according to a particular  $\underline{x} < 0$ . By construction, the probability that  $\tilde{x} > 0$  for a particular firm is  $\underline{\omega}$ . Define the  $M_j$  to be the probability that at least  $j$  firms out of the total  $N$  draw a value of at least  $\tilde{x} = 0$ . As  $N \rightarrow \infty$ ,  $M_j \rightarrow 1$ . This implies that  $B(\phi, N) \rightarrow 0$  as  $N \rightarrow \infty$ . This, in turn, implies that when the residual

claimant solves (B1),  $\phi^* \rightarrow 0$  as  $N \rightarrow \infty$ . Hence, as  $N \rightarrow \infty$ ,  $\omega_N^* \rightarrow \hat{\omega}$ . Finally, the same logic holds for  $\underline{x} > 0$ . ■

The intuition for Proposition B1 is as follows. As the number of firms rises to a large number, the probability that the residual claimant can identify  $j$  firms that exceed any particular threshold  $\underline{x}$  approaches one. In particular, the probability that the residual claimant can identify  $j$  firms whose disclosure exceeds  $x = 0$  approaches one. Therefore, the need for a prize decreases when there are more firms present in the market. That is, since  $B(\phi, N)$  becomes small for large  $N$ , the solution to (B1)  $\phi^*$  diminishes in size. According to our previous analysis in Proposition 3, this implies that disclosure frequency is minimized (i.e.,  $\omega^* \rightarrow \hat{\omega}$ ).

It is fair to point out that this result does depend on the absence of product market competition, which we analyzed in Section 4. It also depends on the assumption that there is a representative residual claimant (as opposed to a strategic interaction among claimants). Notwithstanding this, though, it is clear that our primary result can remain robust even when considering at least one reasonable setting in which the prize is set optimally and endogenously.

## B.2 Prizes based on percentiles

Rather than awarding a fixed number of prizes, we can instead use a firm's relative ranking. For example, each firm in the top 20% of the  $N$  firms could be awarded a prize. That is, the  $N/5$  highest disclosures each receive an additional  $\phi$ . We again find that disclosure decreases to its minimum possible frequency in the limit of perfect competition.

This variation introduces some complications that prevent us from showing the claim from the main model, "equilibrium disclosure  $\omega_N^*$  is strictly decreasing in  $N$ ." Because the number of prizes is discrete, it cannot increase in exact proportion with  $N$ . When 20% of the firms receive a prize, for example, a single prize is awarded when  $N = 5, 6, 7, 8, 9$ , and we numerically find that  $\omega_5^* > \omega_6^* > \dots > \omega_9^*$ . But for  $N = 10$  we suddenly award a second prize, which can mean that  $\omega_9^* < \omega_{10}^*$ . We must therefore content ourselves with the perfect competition limit result below.

**Proposition B2.** *Suppose that for any  $N$ , a fixed fraction  $\lambda$  of the competing firms win the prize  $\phi$ . Further, suppose that  $\lambda \leq p\hat{\omega}$ . Then disclosure converges to its lower bound in the perfectly competitive limit:*

$$\omega_N^* \longrightarrow \hat{\omega} \text{ as } N \rightarrow \infty.$$

*Proof.* Let  $t_N^*$  be the equilibrium disclosure threshold with  $N$  firms. Suppose that a firm  $j$  observes and discloses exactly  $x_j = t_N^*$ . Then the probability  $q$  that any other given opponent observes a

higher value is given by

$$q \equiv p(1 - F(t_N^*)) = p\omega_N^*.$$

Any such realization above the threshold will certainly be disclosed, so the number of firms who disclose values higher than  $t_N^*$  is a binomial random variable  $\tilde{S} \sim B(N, q)$ . The probability that firm  $j$  wins a prize is bounded by the probability that fewer than  $\lambda N$  other firms disclose values higher than  $\hat{t}$ . That is,

$$W_j(t_N^*) \leq P(\tilde{S} \leq \lambda N - 1).$$

This probability is the weight of a left tail of the binomial distribution of  $\tilde{S}$ . We may bound it using Hoeffding's inequality (Hoeffding, 1963), which states that the sum  $\tilde{s}$ , of any  $N$  random variables, has the probabilistic bound

$$P(|\tilde{s} - E[\tilde{s}]| \geq c) \leq 2 \exp\left(\frac{-2c^2}{\sum_{i=1}^N (b_i - a_i)^2}\right) \quad (\text{B2})$$

where the  $i^{\text{th}}$  random variable is contained by the interval  $[a_i, b_i]$ . In our application,  $\tilde{S}$  is the sum of  $(N - 1)$  identically-distributed Bernoulli trials with success probability  $q$ , so

$$a_i = 0, \quad b_i = 1, \quad E[\tilde{S}] = q(N - 1).$$

We first transform our probability into the same form as Hoeffding's inequality,

$$\begin{aligned} W_j(t_N^*) &= P(\tilde{S} \leq \lambda N - 1) \\ &= P(\tilde{S} - E[\tilde{S}] \leq \lambda N - 1 - q(N - 1)) \\ &\leq P(|\tilde{S} - E[\tilde{S}]| \geq (q - \lambda)N - q + 1). \end{aligned}$$

We then can apply the (B2) with  $c = (q - \lambda)N - q + 1$  to obtain

$$W_j(t_N^*) \leq 2 \exp\left(-\frac{2((q - \lambda)N - q + 1)^2}{N}\right). \quad (\text{B3})$$

Note that firms will always disclose values above  $\hat{t}$ , so any equilibrium threshold  $t_N^*$  must be below  $\hat{t}$ . We therefore have

$$q = p(1 - F(t_N^*)) > p(1 - F(\hat{t})) = p\hat{\omega} > \lambda.$$

This ensures that as  $N \rightarrow \infty$ , the exponential in (B3) goes to  $-\infty$  and the right hand side goes to zero for any sequence of thresholds  $\{t_N^*\}$ . Since firms optimally respond to  $W = 0$  by concealing all realizations below  $\hat{t}$ , the disclosure frequency converges to  $\hat{\omega}$ , as desired. ■

According to Proposition B2, as the market becomes perfectly competitive, disclosure is minimized. It should be noted that the condition that  $\lambda < p\hat{\omega}$  is weak in the sense that it allows for a large number of firms to receive prizes. If  $\lambda = p\hat{\omega}$  when  $N \rightarrow \infty$ , this would mean that all firms that observed a value above  $\hat{t}$  would receive a prize. Therefore, we limit the fraction of prizes ( $\lambda < p\hat{\omega}$ ) to keep the analysis realistic and economically interesting.

### B.3 Sequential Disclosure

As a further robustness check, consider an alternate model specification in which firms act sequentially instead of simultaneously. Firms are randomly ordered, and each in turn observes its shock value  $\tilde{x}$  with probability  $p$ , then chooses whether to disclose.

Since each firm makes a unique, history-dependent decision, we no longer have a single symmetric, deterministic disclosure threshold. Rather, each firm will have a random disclosure threshold that depends upon the disclosures of the preceding firms and on the number of firms remaining to act. Let  $\nu_j$  be the ex ante probability that the  $j^{\text{th}}$  firm to act will disclose if they are informed. The average of these probabilities is the analogue of the disclosure frequency in the main model,

$$\bar{\nu}_N = \frac{1}{N} \sum_{j=1}^N \nu_j.$$

In the perfectly-competitive limit, we can show that every individual  $j^{\text{th}}$  firm discloses with frequency  $\hat{\omega}$ , the minimum possible. We can also show the slightly stronger claim that the average frequency of disclosure over all  $N$  firms converges to the minimum  $\hat{\omega}$ .

**Proposition B3.** *In sequential equilibrium with  $N$  firms,*

- (i) *The ex ante probability that the  $j^{\text{th}}$  firm discloses converges to the minimum with perfect competition:*

$$\lim_{N \rightarrow \infty} \nu_j = \hat{\omega}.$$

- (ii) *The ex ante probability that a randomly selected informed firm discloses also converges to the minimum with perfect competition:*

$$\lim_{N \rightarrow \infty} \bar{\nu}_N = \hat{\omega}.$$

*Proof.* By our definition of  $\hat{t}$ , any firm with a realization  $x_j > \hat{t}$  discloses even if they have no chance of winning the prize. This establishes a lower bound for both limits:

$$\lim_{N \rightarrow \infty} \nu_j \geq \hat{\omega} \quad \text{and} \quad \lim_{N \rightarrow \infty} \bar{\nu}_N \geq \hat{\omega}. \quad (\text{B4})$$

- (i) Suppose firm  $j$  discloses a lower value,  $x_j < \hat{t}$ . If any of the  $N - j$  firms yet to act observes a value above  $\hat{t}$ , they will certainly disclose it. The probability that firm  $j$  wins the prize is therefore bounded above by

$$W_j(x_j) \leq W_j(\hat{t}) = \left(1 - p(1 - F(\hat{t}))\right)^{N-j} = (1 - p\hat{\omega})^{N-j}.$$

So as  $N \rightarrow \infty$ , the probability of winning the prize converges to zero. In this limit, so firm  $j$  will optimally conceal any values below  $\hat{t}$ , disclosing no more frequently than  $\hat{\omega}$ . Together with (B4), this establishes the desired result.

- (ii) Again, note that a firm that realizes  $x_j < \hat{t}$  will not disclose unless it has a positive probability of winning the prize. Specifically, it will not disclose if any preceding firm has already disclosed a value above  $\hat{t}$ . That is, the probability of disclosing a value below  $\hat{t}$  cannot possibly be larger than the probability that no preceding firm  $i$  has disclosed  $x_i > \hat{t}$ . This allows us to place a very loose upper bound on  $\nu_j$ :

$$\begin{aligned} \nu_j &= P(\tilde{x}_j < \hat{t}) \cdot P(D_j | x_j < \hat{t}) + P(D_j | x_j > \hat{t}) \cdot P(\tilde{x}_j > \hat{t}) \\ &\leq (1 - \hat{\omega}) \cdot \prod_{i=1}^{j-1} P(U_i \text{ or } x_i < \hat{t}) + \hat{\omega} \cdot 1 \\ &= (1 - \hat{\omega})(1 - p\hat{\omega})^{j-1} + \hat{\omega}. \end{aligned}$$

Averaging over all  $j$  yields

$$\begin{aligned} \bar{\nu}_N &\leq \frac{1}{N} \sum_{j=1}^N ((1 - \hat{\omega})(1 - p\hat{\omega})^{j-1} + \hat{\omega}) \\ &= (1 - \hat{\omega}) \frac{1}{N} \left( \frac{1 - (1 - p\hat{\omega})^N}{1 - (1 - p\hat{\omega})} \right) + \hat{\omega} \\ &= \frac{1 - \hat{\omega}}{p\hat{\omega}} \left( \frac{1 - (1 - p\hat{\omega})^N}{N} \right) + \hat{\omega}. \end{aligned}$$

As  $N \rightarrow \infty$ , the first term vanishes, so  $\lim_{N \rightarrow \infty} \bar{\nu}_N \leq \hat{\omega}$ . Together with (B4), this yields the desired result.

■

## B.4 Volatility and Disclosure

We now consider the effect of an exogenous distribution change on disclosure, specifically an increase in volatility. When volatility suddenly increases, inside information becomes more significant as larger deviations from past beliefs become possible, and larger swings in firm prices may result.

We incorporate an increase in volatility into our analysis by examining the effect of a noisier, or second-order stochastically dominated distribution. Firms and investors realize that they do not know the relevant facts as precisely as they had believed, so new information acquisitions take on a greater significance, and larger surprises become more likely. We assume that investors are aware of the regime change, although the signals firms receive will still be private.

We consider a shift from the prior distribution  $\tilde{x} \sim F$  to a new distribution  $\tilde{x} \sim G$ , where  $F$  stochastically dominates  $G$  in second order. Intuitively, the shift from  $F$  to  $G$  makes rare events more likely. This increases the informational advantage of firms, since the events they observe are likely to be more significant, due to the new distribution's increased variance.

As we have noted before, Jung and Kwon (1988) refine the Dye (1985) model, which is similar to our model, except that they enforce  $N = 1$  and  $\phi = 0$ , and they allow a non-zero mean of information events  $E[x] \neq 0$ . In their setting, they show that if  $F$  stochastically dominates  $G$  in second order, then  $t_G^* > t_F^*$ . That is, a noisier distribution induces a higher threshold. We show, however, that this increase in  $t^*$  need not imply an increase in  $\omega^*$ . That is, because the distribution itself has changed, the higher disclosure threshold may nevertheless yield a lower disclosure frequency.

Since finding a closed-form solution for the disclosure frequency ranges from difficult to impossible, we offer proof of this assertion in the form of the following numerical examples.

### Example 1: More Volatility: Less disclosure

Compare two distributions:

$$F(x) = \frac{1}{1 + e^{-1000x}}$$

$$G(x) = \frac{-\sin(2\pi x)}{2\pi} + x + 0.5.$$

Distribution  $F(x)$  has nearly all of its density located around zero. A realization around the mean is almost a sure bet and firms with that or anything above are quick to disclose. Firms that do not disclose are those that receive the rare realizations in the left tail.

In a time of increased uncertainty, the distribution could become  $G(x)$  instead. This is an increase in volatility in which the density at the mean shifts to the tails. Note that this distribution has the same mean signal  $x$ , but much greater variance. We say that the distribution  $F$  stochastically dominates  $G$  in second order.

We determine disclosure behavior numerically for the sample parameter values below. Since the situations we describe above could occur with or without a prize  $\phi$ , we present the results in both cases:

Investors know there are few intermediate realizations under  $G(x)$ , i.e. that the majority of the realizations are in the tails. Firms with this knowledge find non-disclosure ideal for low realiza-

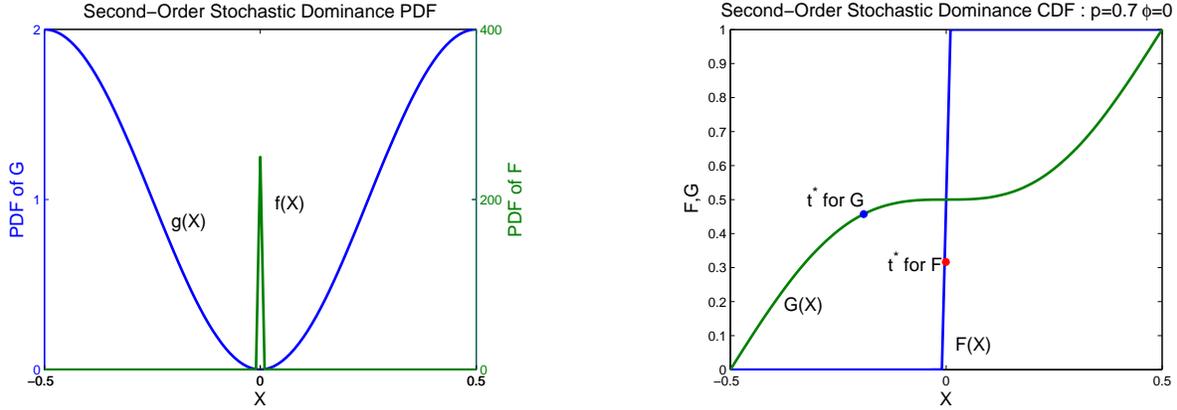


Table 1: More Volatility; Less Disclosure

Distribution	$p$	$\phi$	$N$	$t^*$	$\omega^*$
$F(x)$	0.7	0	1	-0.0008	0.6834
$G(x)$	0.7	0	1	-0.1910	0.5427
$F(x)$	0.7	0.10	5	-0.0023	0.9072
$G(x)$	0.7	0.10	5	-0.2050	0.5522

tions, because investors will assign some probability that they are an extremely high valued firm. Disclosure frequency decreases as a result.

### Example 2: More Volatility: More disclosure

Compare two distributions:

$$F(x) = x + 0.5$$

$$G(x) = \frac{\sin(4\pi(x))}{4\pi} + x + 0.5.$$

Here we consider a shift from a uniform distribution to one with mass in the middle and the tails. This represents a situation where the initial uniformly distributed information is trumped by a larger development that may or may not affect the firm. This might the case if, for example, investors are uncertain of whether a particular asset is even present on a firm's balance sheet, and also uncertain as to the value of the asset itself. The central mode represents the possibility that the firm does not own the asset, and the tails represent owning the asset and its value being either high or low.

Graphically, it can be seen that  $F(x)$  second-order stochastically dominates  $G(x)$ . Again, the disclosure threshold level is certainly lower under distribution  $G(x)$ . But unlike the previous example, we show that the change in frequency is higher. The addition of competition for a prize does not change the result. The results are summarized below.

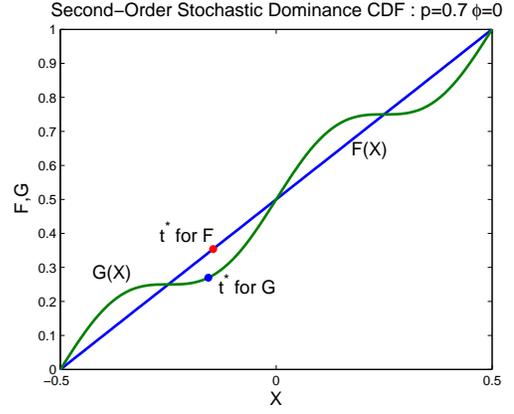
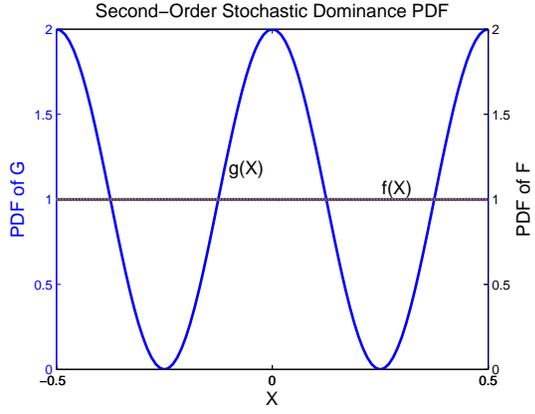


Table 2: SOSD Numerical Results

Distribution	$p$	$\phi$	$N$	$t^*$	$\omega^*$
$F(x)$	0.7	0	1	-0.1460	0.6460
$G(x)$	0.7	0	1	-0.1572	0.7303
$F(x)$	0.7	0.10	5	-0.1544	0.6544
$G(x)$	0.7	0.10	5	-0.1630	0.7337