Option prices and disclosure

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Abstract

In this paper, I develop an option-pricing model that formally incorporates a disclosure event. The model suggests that an understanding of a firm's disclosure policies can aid in efficiently pricing its options. The reason is that these policies impact the distributions of jumps in the firm's equity price, which affect the expected payoff to the firm's options. Specifically, I find that 1) more informative disclosures lead to greater volatility in the firm's equity price upon their release, raising pre-disclosure option prices and 2) disclosures that are more informative for good-versus-bad news lead to skewness in the firm's equity price upon their release, adjusting the relative pre-disclosure prices of out-of-the-money and in-the-money options. The magnitude of these effects depends upon investors' uncertainty and the extent of systematic versus idiosyncratic information contained in the disclosure. Using these results, I develop measures of a disclosure's properties based on option prices that may be calculated on an event-specific basis.

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1 Introduction

The effect of firms' disclosures on their market prices is a topic at the core of accounting research. This research is grounded in disclosure theory, which analyzes how a firm's disclosure affects its equity price when investors update their beliefs regarding the firm's value in response to the release of new information (e.g., Holthausen and Verrecchia (1988)). Yet, empirical research also finds that firms' disclosures impact their option prices.[1] Furthermore, option-pricing theory suggests that these prices should impound investors' beliefs regarding an asset's value differently than equity prices, as options have non-linear payoff structures (e.g., Breeden and Litzenberger (1978)). This raises the theoretical questions of how a disclosure impacts a firm's option prices and whether the traded prices of options can be used to assess the properties of a disclosure. To address these questions, I develop an option-pricing model that incorporates a disclosure event and characterize its impact on option prices. In the process, I demonstrate that option prices may be used to measure the disclosure's properties on an event-specific basis, including the overall amount of novel information it provides to investors and the amount of information it provides given good-versus-bad news.

In developing my analysis, I depart from the framework applied in conventional option-pricing models, such as the Black-Scholes-Merton (BSM) model. This framework takes the process followed by a firm's stock price as an exogenous input, yielding an option's price as a function of this process. As a result, incorporating disclosure into these models requires making a direct assumption on how the disclosure affects this process. For example, prior literature incorporates a disclosure into the BSM model by assuming that it increases equity-return volatility by an arbitrary amount around the disclosure's announcement (Patell and Wolfson (1979, 1981)). This approach is not well suited to address how a disclosure's properties influence its effect on option prices because it is not clear how these features affect the firm's equity-price process. To remedy this issue in my model, I begin with the

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[1]See Patell and Wolfson (1979, 1981), Rogers, Skinner, and Van Buskirk (2009), Diavatopoulos et al. (2012), Atilgan (2014), amongst others.

distribution of the firm's cash flows, rather than stock returns, as the primitive. I then derive the firm's equity-price process as an endogenous outcome of the information that investors receive regarding these cash flows, including a disclosure event. This enables me to analyze how the disclosure's properties impact the equity-price process, and in turn, how they impact option prices.

I model the disclosure event as the public release of novel information to investors. This release leads to an endogenous jump (i.e., discontinuity) in the firm's equity price. While consistent with empirical evidence (e.g., Lee and Mykland (2006)), this finding contradicts prior studies of disclosure's impact on option prices, which assume that disclosure has a continuous impact on equity prices in order to satisfy the assumptions necessary to employ the BSM framework. In my model, the distribution of the jump induced by the disclosure is directly determined by the disclosure's properties.

I focus on how two widely-studied properties of the disclosure affect the jump's distribution: the expected amount of information contained in the disclosure, which I term the disclosure's informativeness, and the amount of information it contains regarding "good" relative to "bad" news, which I term the disclosure's asymmetry. The disclosure's informativeness is relevant to studies of disclosure quality or decision usefulness to equity holders, while the disclosure's asymmetry is relevant to several settings found in prior work. For instance, models of voluntary disclosure suggest that when firms have discretion in a disclosure decision, they release high-quality information when performing well and no information when performing poorly (Verrecchia (1983), Dye (1985), Jung and Kwon (1988)). Conversely, specific accounting procedures may produce disclosures that are inherently more informative for losses than for gains (Basu (1997), Guay and Verrecchia (2006)). Likewise, models of earnings management suggest that firms' disclosures may be more informative for bad than for good news (Laux and Stocken (2012), Bertomeu, Darrough, and Xue (2015)).

Consistent with classical results from disclosure theory, I show that a more informative disclosure increases the expected magnitude of the disclosure-induced equity-price jump in

proportion to investors' prior uncertainty regarding the firm's value (Holthausen and Verrecchia (1988)). I then link the expected magnitude of this jump to the level of pre-disclosure option prices. Since options have convex payouts, when the expected magnitude of this jump is larger, the expected payoffs to options of all strikes increase, causing their prices to rise. Therefore, pre-disclosure option prices of all strikes increase in the disclosure's informativeness in proportion to investors' prior uncertainty regarding the firm's value. This result suggests that the run-up in implied volatility documented prior to earnings guidance and earnings announcements might be broken down into the product of the amount of novel information contained in earnings and investors' prior uncertainty (Rogers, Skinner, and Van Buskirk (2009), Van Buskirk (2011), Billings, Jennings, and Lev (2015)).[2]

Next, I show that a disclosure that is more informative for good-versus-bad news creates positive skewness in the disclosure-induced equity-price jump. To understand this result, consider a firm releasing earnings that might reflect either positive or negative news. Should these earnings be more informative for good news than bad news, equity prices will respond more strongly to positive earnings surprises and less strongly to negative earnings surprises. This implies that the distribution of the jump in the equity price upon the earnings' release will exhibit more variation on the upside than the downside. I find that through this jump skewness, disclosure's asymmetry increases the pre-disclosure prices of out-of-the-money (henceforth, OTM) call options relative to the prices of in-the-money (henceforth, ITM) call options (and vice versa for the prices of put options). The reason is that jump skewness implies a greater probability of equity-price spikes, which are necessary for an OTM call option to pay off.

Conceptually, the model that I develop should yield option prices around disclosure events that are closer to options' fundamental values than those generated by prior option-pricing models, which do not explicitly consider the properties of firms' disclosures. A subset of

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[2]Implied volatility is derived using the Black-Scholes model, which does not hold in my setting as the disclosure leads to a price jump and prices that are not log-normally distributed. Nonetheless, numerical simulations suggest that implied volatility, while calculated using the "wrong" model, still behaves as stated here.

prior option-pricing models incorporate jumps in firms' prices with varying statistical distributions; these jumps are thought to capture information events including firm disclosures (e.g., Merton (1976), Bates (1996)). However, in these models, the distribution of equity-price jumps is taken as a given, and thus they must be implemented by using historical data to estimate this distribution. This approach generally cannot fully capture the characteristics of future disclosures, as this data may be limited and subject to noise, and firms' accounting procedures may periodically change.

In the remainder my analysis, I assume that option traders at least in part incorporate the features of a firm's disclosures in their pricing model. In this case, I find that option prices contain information regarding a disclosure's properties that cannot be gleaned from equity prices. To make this idea concrete, consider again the example of a firm announcing its annual earnings. If earnings are above expectations, the magnitude of the resulting equity-price reaction reveals how informative the firm's earnings are given that the firm has performed well, since the size of this reaction is proportional to the disclosure's informativeness (Holthausen and Verrecchia (1988)). However, this price reaction does not reveal the counterfactual of how informative the earnings report would have been if the firm instead had performed poorly.

Importantly, both of these reactions are necessary to assess earnings' overall informativeness and asymmetry, since these properties depend on both how informative earnings are for good and bad news. Researchers implicitly address this issue by using a time series of equity-price reactions for a given firm or the equity-price reactions of a cross-section of comparable firms. These approaches come at the expense of strong assumptions: the first assumes that disclosure regimes are stationary, while the second assumes that a large subset of firms have similar disclosure policies. This implies that neither approach can be applied to study the properties of disclosures that are not similar to other firm disclosures.[3]

On the contrary, I find that a researcher can learn both the disclosure's informativeness

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[3]Many types of 8-K's might fall into this category, such as impairments, outcomes of director elections, issuance of debt, etc., which capture events that occur infrequently.

and asymmetry by examining a single firm's option prices prior to a single news event. Intuitively, the model predicts a one-to-one mapping between these properties of the disclosure and observed pre-disclosure option prices. Thus, just as a researcher can use option prices to back into the level of return volatility using the BSM model, so too can they use these prices to back into a disclosure's properties using my model. I demonstrate precisely how to empirically measure a disclosure's properties using the model. The measures I develop obviate the need to assume stationarity of a firm's disclosure policies or similarity across firms and increase statistical power. Furthermore, they provide an ex-ante view of disclosure's properties, which may be more fitting to some empirical settings than the ex-post view provided by equity-price measures (Rogers, Skinner, and Van Buskirk (2009)).

Finally, my results imply that the BSM model should fail to explain observed option prices around disclosure events. It has long been known that empirically-observed option prices differ from those predicted by the BSM model, which suggests that the market uses more sophisticated models (e.g., Derman and Miller (2016)). Prior work attributes empirical inconsistencies with the BSM model to violations of its assumptions that stock prices are continuous and log-normally distributed, but refrains from addressing the economic forces that create these features in firms' returns (e.g., Merton (1976), Heston (1993), Bakshi, Cao, and Chen (1997), Dupire (1997)). My results suggest that disclosures cause firms' returns to violate these assumptions since they induce discontinuities into returns that are potentially skewed.[4] An implication of this result is that around disclosure events, investors' risk-aversion should play a role in pricing options even upon conditioning on the firm's equity price. I show that the magnitude of a disclosure's effect on option prices depends on investors' risk aversion and the amount of systematic versus idiosyncratic information contained in the disclosure.

Other work has studied the effect of jumps in equity prices on the prices of options. The

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[4]Dubinsky and Johannes (2006) also develop a model in which disclosure leads to a jump in a firm's equity price, but exogenously assume that the jump is Gaussian rather than formally modeling an information release. Furthermore, they focus on measuring the degree of uncertainty created by a disclosure as opposed to its properties.

first such paper was Merton (1976), which models an exogenous jump in the stock price and assumes that this jump is a diversifiable risk. Naik and Lee (1990) generalize his model by instead taking the dividend process as primitive and assuming that there are non-diversifiable jumps in this process. In Naik and Lee (1990), investors learn about future dividends from present dividends; I build on their analysis by allowing investors to also learn from a firm information release.

Prior literature also studies the information content of option prices, demonstrating that, under certain assumptions, they can be used to (i) invert the risk-neutral density (Breeden and Litzenberger (1978)), (ii) invert both state prices and investors' belief distribution about future returns (Ross (2015)), and (iii) derive the term structure of cost-of-equity capital (Callen and Lyle (2014)). I contribute to this literature by demonstrating that because the risk-neutral density around a disclosure is an invertible function of the disclosure's informativeness and asymmetry, one can invert these properties from option prices.

My paper is organized as follows: I first demonstrate the major findings in a parsimonious two-state discrete-time framework with risk-neutral pricing (Section 2). In the remaining sections, I extend the model to consider investor risk aversion, continuous trade, a general prior distribution over the equity's payoff, a general distribution of the disclosure given the equity's payoff, and multiple heterogeneous investors. In Appendix A, I develop empirical measures of a disclosure's properties using my results.

2 Parsimonious model

In this section, I develop a version of the model with two states, three periods and risk-neutral pricing, which transparently conveys my main findings. In the subsequent sections, I extend the model to consider investor risk aversion, continuous trade, and general distributions, and find that the results in this section continue to hold. To begin, consider a risk-neutral representative investor who trades in a firm's equity, a risk-free bond in unlimited supply
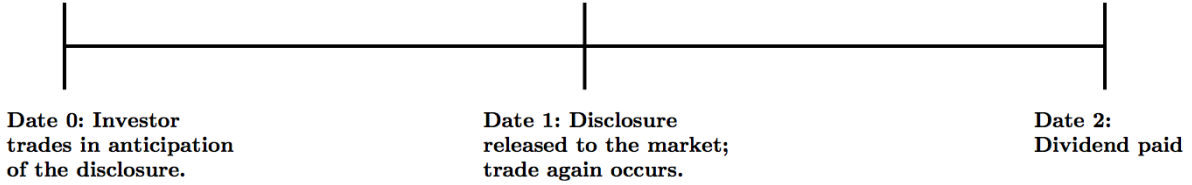
Date 0: Investor
trades in anticipation
of the disclosure.

Date 1: Disclosure
released to the market;
trade again occurs.

Date 2:
Dividend paid

Figure 1: Timeline.

with return normalized to zero, and European call and put options. The firm's payoff takes the form of a dividend $\tilde{x}$ paid to its equity holders at the end of the model, which takes values of x_L or $x_H > x_L$. Ex ante, the market perceives x_L and x_H to be equally likely.

Prior to the payment of the dividend, the firm releases a disclosure $\tilde{y}$ concerning the outcome of $\tilde{x}$. The model's timing is intended to reflect a scenario where the market anticipates this disclosure and, prior to the disclosure, trades in both equity and options that expire after the disclosure. Specifically, the model has three dates. First, there is an initial "pre-disclosure" date (date 0) during which trade occurs in anticipation of the disclosure event. Then, at date 1, the firm releases the disclosure $\tilde{y}$ and the market reopens. Finally, at date 2, the dividend is paid. The timeline of the model is depicted in Figure 1.

The options traded by the investor take on strike prices $k \in [x_L, x_H]$ and mature at date 1 (i.e., after the disclosure's release); call payoffs are defined as $\max(P_1 - k, 0)$ and put payoffs as $\max(k - P_1, 0)$, where P_1 is the firm's price at date 1. I assume that the disclosure $\tilde{y}$ takes one of two possible values that correspond to good and bad news, y_H and y_L, respectively, where:

$$\Pr(\tilde{y} = y_H | \tilde{x} = x_H) = \lambda - \eta \tag{1}$$
$$\Pr(\tilde{y} = y_L | \tilde{x} = x_L) = \lambda + \eta,$$

and $\lambda + \eta; \lambda - \eta \in [\frac{1}{2}, 1]$. Let a disclosure *regime* correspond to a set of parameters (λ, η), which capture the disclosure's statistical relationship with the firm's performance. The parameter λ captures the disclosure's overall, or on-average, informativeness, as a larger

value of λ reflects a disclosure regime that is more likely to accurately reflect the true state of the world. The parameter η captures the disclosure's informativeness for good-versus-bad news, which I also refer to as its asymmetry. As η rises, the investor's outlook regarding the firm's performance rises more given good news and falls less given bad news, that is, $\frac{\partial}{\partial \eta} \Pr(\tilde{x} = x_H | \tilde{y} = y_H) > 0$ and $\frac{\partial}{\partial \eta} \Pr(\tilde{x} = x_H | \tilde{y} = y_L) > 0$.

The disclosure's overall informativeness, as captured by λ, corresponds to the amount of novel information it provides to investors, and thus applies to empirical studies that examine the amount of valuation-relevant information a firm provides to investors. The disclosure's asymmetric informativeness, as captured by η, applies to at least two distinct empirical settings. First, models of voluntary disclosure suggest that when allowed discretion in accounting choices, firms release more information given good than bad performance, suggesting that discretion corresponds to a larger level of η (Verrecchia (1983), Dye (1985), Jung and Kwon (1988)).[5] Second, this notion of a disclosure's informativeness for good-versus-bad news corresponds directly to the definition of accounting conservatism found in Gigler and Hemmer (1999), Bagnoli and Watts (2005), Chen et al. (2007), Suijs (2008), and Bertomeu et al. (2016). Under this definition, conservatism leads to more frequent issuance of bad news irrespective of the state and hence disclosure that is more informative for good news than bad news. Other theoretical work uses different definitions of conservatism that often have opposing predictions (see Ewert and Wagenhofer (2012) and Beyer (2016) for insightful discussions of this issue). The model speaks only to the informativeness of disclosure for good-versus-bad news; the precise mapping between this concept and conservatism depends upon how one defines conservatism.[6]

Note that while I take the disclosure regime as exogenous, the model could be applied

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[5]While voluntary disclosure equilibria are trivially unravelling in a two-state Verrecchia (1983) model, general voluntary disclosure equilibria can be analyzed in the set up I consider in Section 5. The finding that discretion in disclosure choices tends to lead to greater prices of OTM options relative to ITM options continues to hold in that section.

[6]From an empirical perspective, this implies there is an ambiguity in how to map conservatism into the measure I develop. However, as discussed in Ewert and Wagenhofer (2012), this is equally a concern for conventional measures of conservatism such as the Basu measure. A higher value of η in my model corresponds to a *lower* value of the Basu measure.

to study endogenous disclosure equilibria (voluntary disclosure, disclosure bias, etc.). The important property of these equilibria in affecting option prices is their impact on the distribution of the post-disclosure equity price. For example, if the disclosure regime results from a voluntary disclosure game, the results of the model could be applied to the endogenous properties of the disclosure regime that arise in equilibrium.

2.1 Analysis

I begin by deriving the equilibrium equity and option prices. Since the investor is risk neutral, the firm's price at date t is simply the investor's expectation of the terminal dividend. Therefore, at date 0 the firm's price is $E\left[\tilde{x}\right]$ for any disclosure regime. At date 1 the firm's disclosure is public, such that the firm's price is the investor's expectation of $\tilde{x}$ given the disclosure, $E\left[\tilde{x}|\tilde{y}\right]$. Risk neutrality also implies that options are priced at their expected payoffs; I focus on pre-disclosure option prices for reasons that I discuss at the end of this section.

Lemma 1 *The firm's pre-disclosure stock price, P_0, equals $E\left[\tilde{x}\right]$. The firm's post-disclosure stock price equals:*

$$P_1\left(\tilde{y}\right) = \begin{cases} \frac{(\lambda-\eta)x_H+(1-\lambda-\eta)x_L}{1-2\eta} & \text{if } \tilde{y} = y_H \\ \frac{(1-\lambda+\eta)x_H+(\lambda+\eta)x_L}{1+2\eta} & \text{if } \tilde{y} = y_L. \end{cases} \tag{2}$$

The pre-disclosure prices of call and put options with strike price of k equal:

$$\Phi^C\left(k\right) = E\left[\max\left(P_1\left(\tilde{y}\right)-k,0\right)\right]; \tag{3}$$
$$\Phi^P\left(k\right) = E\left[\max\left(k-P_1\left(\tilde{y}\right),0\right)\right].$$

Note that the option price can be explicitly calculated by using the distribution of equity prices that is implied by the lemma. With these results established, we may examine how the disclosure regime impacts the prices of equities and options.

2.1.1 Disclosure's impact on equity prices

I first study the impact of the disclosure regime on equity prices in order to establish a baseline of what may be learned by a researcher who observes equity prices alone.[7] Note that the disclosure's properties have no impact on the pre-disclosure equity price because it is priced at its ex-ante expected payoff $E[\tilde{x}]$. As this expected payoff is a fundamental feature of the firm's dividend, it is not changed by the properties of information that is released about this dividend. The result suggests that *pre-disclosure* equity prices contain no information regarding the properties of the disclosure.[8]

Although the disclosure's properties do not affect pre-disclosure equity prices, they do affect the distribution of equity returns on the disclosure date. Specifically, a more informative disclosure increases the variance of returns on the disclosure date in proportion to $x_H - x_L$. Note that $x_H - x_L$ captures the investor's uncertainty regarding the firm's payoffs, since $Var[\tilde{x}] \propto (x_H - x_L)^2$. Thus, this result follows directly from Bayes' rule, which suggests that a more informative signal increases the variation in posterior beliefs in proportion to prior uncertainty. Furthermore, disclosure that is more informative for good-versus-bad news leads to greater positive skewness in returns. Such asymmetric disclosure causes the market to place greater weight on the disclosure when it contains good news and less weight on the disclosure when it contains bad news. This creates a distribution that exhibits more variation conditional on its value exceeding its mean, which manifests as skewness. Note that these findings are consistent with empirical studies that use firms' return variances around disclosures to measure their informativeness (e.g., Beaver (1968)) and return skewnesses around disclosures to measure their conservatism (e.g., Givoly and Hayn (2000)).

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[7]One might conjecture that in a two-state model, since options can be replicated by trading in an equity and the risk-free asset, a researcher could acquire the same information from equity prices as they could from option prices. Note this is not the case, since the weights required to replicate the option using the stock and the risk-free asset are themselves a function of the disclosure's properties, and thus, are unknown to the researcher.

[8]While this result might seem fairly specific to the set up at hand, it in fact holds for any utility function or distribution as long as there is a representative investor or investors are homogenous. Even when this is not the case, the essential point is that since option prices with different strikes are differentially reflected by future returns, observing these prices provides more information than observing equity prices alone.

The following lemma formalizes these results, where "equity returns on the disclosure date" are defined as the change in price induced by the disclosure, $P_1(\tilde{y}) - P_0$, and skewness refers to Pearson's measure, $\frac{E\left[(\tilde{z}-E[\tilde{z}])^3\right]}{E\left[(\tilde{z}-E[\tilde{z}])^2\right]^{\frac{3}{2}}}$.

Lemma 2 *1) The properties of the disclosure regime have no impact on the pre-disclosure equity price.*

2) An increase in the disclosure's informativeness increases the variance of equity returns on the disclosure date in proportion to payoff uncertainty, $x_H - x_L$, and has no effect on return skewness.

3) An increase in the disclosure's informativeness for good-versus-bad news increases the skewness of equity returns on the disclosure date.

Despite the fact that disclosure affects the distribution of equity returns on the disclosure date, the amount of information a researcher can learn from equity prices is limited. The reason is that a researcher does not directly observe this distribution but instead observes only the equity returns induced by the realized disclosure report, $\tilde{y}$, which translates into a single observation from this distribution. In order to fully understand the disclosure's properties, one would have to observe the equity-price reaction to *every possible* outcome of the disclosure, $\tilde{y}$, an impossible task. Prior empirical literature addresses this issue by estimating the distribution using multiple firm disclosures and appealing to the law-of-large numbers (Beaver (1968), Givoly and Hayn (2000)), or by assuming that disclosure is equally informative for any level of firm performance (the earnings-response coefficient literature). The former approach requires the assumption that the properties of the firm's disclosures do not change over time and cannot be used for sporadic disclosures that are dissimilar from other firm disclosures, such as 8-K's, and reduces statistical power. The latter approach rules out the possibility of asymmetric disclosure regimes.

2.1.2 Disclosure's impact on option prices

Next, I consider how the disclosure regime impacts option prices, demonstrating their incremental information content. In my analysis, I focus on the pre-disclosure prices of options that mature immediately after the disclosure; at the end of the subsection, I discuss why the information in these prices is sufficient for the information in the prices of short- and long-maturity options before and after the disclosure.

First, since more informative disclosure increases the variability in equity prices in proportion to payoff uncertainty, $x_H - x_L$, it increases the pre-disclosure prices of all options in proportion to $x_H - x_L$. Second, by creating skewness in equity returns, increasing the informativeness of the disclosure for good-versus-bad news increases (decreases) the prices of OTM call (put) options and decreases (increases) the prices of ITM call (put) options. Intuitively, this skewness increases the probability of upper-tail equity returns. These extreme returns increase the expected payoffs to OTM call options, which require an increase in the equity price to pay off (the converse holds for put options). This effect is familiar from the prior option-pricing literature that prices options as a function of exogenously given equity-return moments (e.g., Bakshi et al. (2003), Christoffersen et al. (2006)). I summarize these results in the following proposition.

Proposition 1 *1) An increase in the disclosure's informativeness weakly increases the pre-disclosure prices of options of all strikes and strictly increases equally the pre-disclosure prices of options with strikes $k \in (P_1(y_L), P_1(y_H))$. The size of this effect increases in payoff uncertainty, $x_H - x_L$.*

2) An increase in the disclosure's informativeness for good-versus-bad news weakly increases the pre-disclosure prices of OTM call (ITM put) options and weakly decreases the pre-disclosure prices of ITM call (OTM put) options that mature just after the disclosure; the relationships are strict for options with strikes $k \in (P_1(y_L), P_1(y_H))$.

The proposition suggests that by examining option prices of different strikes, a researcher

can determine both the overall informativeness of the disclosure and its informativeness for good-versus-bad news. This is formalized in the following corollary.

Corollary 1 *Observing pre-disclosure option prices reveals both the disclosure's informativeness and its informativeness for good-versus-bad news, i.e., it reveals the parameters (λ, η) given knowledge of $x_H - x_L$.*

The proof shows how λ and η may theoretically be backed out from observed call option prices. In Appendix A, I develop simple empirical measures for the parameters λ and η that are robust to investor risk aversion and continuous trade. First, λ may be captured by the price of an ATM option normalized by a measure of investor uncertainty such as equity-price volatility or firm size. Intuitively, Proposition 1 states that λ increases the prices of options of all strikes. Note, however, there are two hurdles in implementing this approach empirically. First, the firm's payoff uncertainty, $x_H - x_L$, determines the magnitude of the effect that λ has on option prices; this can serve as an omitted variable in empirical analysis. In Appendix A, I show that dividing by an estimate of $x_H - x_L$ corrects for this potential bias. The second hurdle is the fact that pre-disclosure option prices are also affected by the extent to which they are ITM or OTM (i.e., $P_0 - k$), in a nonlinear fashion that interacts with $x_H - x_L$; by examining ATM options, this issue can be avoided.

Next, I show that η may be captured by the difference between the prices of a moderately OTM and a moderately ITM call option divided by the difference in their strike prices, controlling for the asymmetry of the firm's cash flows and the measure of informativeness. Note that choosing which ITM and OTM contracts to compare involves a trade-off. First, the size of the effect detailed in Proposition 1 is larger for options that are further from being ATM. However, options that are further from being ATM are typically less liquid; this is especially true for deep ITM options, which, given that their returns resemble those of equities, are infrequently traded.

Prior literature typically applies a very different approach to utilizing the information in option prices. This literature calculates model-free implied return variances and skewnesses,

which capture the variance and skewness of the *risk-neutral* distribution, and associate them with variables of interest (e.g., Jackwerth and Rubinstein (1996), Britten-Jones and Neuberger (2000), Bakshi et al. (2003), Figlewski (2009)). As Lemma 2 suggests that the disclosure's informativeness and asymmetry manifest in return variance and skewness, one might conjecture that these such measures could be used to capture the disclosure's properties. Indeed, these measures capture the disclosure's properties when the disclosure concerns idiosyncratic risk, as in the current section, since in this case the risk-neutral distribution is the same as the true distribution. However, in the Internet Appendix,[9] I show that this approach entails several identification problems when the disclosure contains a systematic component, which arises from the disconnect between the risk-neutral distribution and the true return distribution.

To this point, I have considered only the pre-disclosure prices of options that expire soon after the disclosure. Note that their *post*-disclosure prices cannot contain incremental information over the equity price, as they are simply a function of the equity price. However, one may question whether the prices of options that mature further into the future might also contain information regarding the disclosure's properties. Thus, consider options that mature at date 2; to ensure these options have value, assume the firm's dividend is paid after their expiration or that the options are dividend adjusted. The payoffs to long-horizon call (put) options equal $\max(\tilde{x} - k, 0)$ $(\max(k - \tilde{x}, 0))$. Applying the results from Breeden and Litzenberger (1978), the *post*-disclosure prices of these options enable the derivation of the conditional distribution of $\tilde{x}$ given the realized disclosure $\tilde{y}$, $f(\tilde{x}|\tilde{y})$. While this distribution contains more information regarding the disclosure's properties than the realized equity price, $E[\tilde{x}|\tilde{y}]$, it is still not sufficient to calculate the properties of the disclosure in general. Therefore, an analysis of pre-disclosure short-horizon option prices alone is sufficient to capture the information contained in option prices of all maturities both before and after the disclosure.[10]

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[9]The Internet Appendix may be found at https://sites.google.com/site/kcsmith2231/internet-appendices.
[10]I note that this is somewhat specific to the present set up. Post-disclosure option prices may be useful in

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3 Investor risk aversion and systematic disclosure

In this section, I extend the model to the case where the investor is risk averse with respect to the outcome of the information disclosed by the firm. This corresponds to a disclosure that concerns the outcome of a *systematic* event, which may represent a disclosure by a large firm or a macro-forecast. To implement investor risk aversion into the model, I make one modification to the assumptions in the prior section. Specifically, assume now that the representative agent has a general risk-averse utility function $u\left(\cdot\right)$ as a function of their wealth at time 2, satisfying $u'\left(\cdot\right) > 0$ and $u''\left(\cdot\right) \leq 0$. While the reader might express concern that I model risk aversion and systematic risk in a model with only a single equity security, I note that the results extend naturally to the case of many correlated equities.

The BSM model argues that investors' risk preferences play no role in pricing an option conditional on the present level of and distribution of equity prices, as option prices are determined purely by the assumption of no-arbitrage. However, options can be priced by no arbitrage only when the firm's stock price follows a continuous process (see, e.g., Merton (1976)). As the disclosure in my model causes the equity price to jump, investors' preferences must be considered in pricing options (note that the relationship between my model and BSM will become more clear in the next section, in which I consider continuous trade).

I find that in the presence of risk aversion, disclosure has a nuanced effect on option prices because it both increases options' expected payoffs and the riskiness of their payoffs. Nonetheless, Proposition 1 continues to hold, but the *magnitude* of the effects outlined in the proposition depend upon the degree of the investor's risk aversion. To begin, again consider how the disclosure impacts equity prices.

Lemma 3 *The firm's pre-disclosure stock price P_0 equals $E\left[u'\left(\tilde{x}\right)\right]^{-1} E\left[\tilde{x} u'\left(\tilde{x}\right)\right]$ and the firm's post-disclosure stock price $P_1\left(\tilde{y}\right)$ equals $E\left[u'\left(\tilde{x}\right)|\tilde{y}\right]^{-1} E\left[\tilde{x} u'\left(\tilde{x}\right)|\tilde{y}\right]$. Consequently,*

1) The firm's ex-ante and ex-post equity prices include risk premia.

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examining other properties of the disclosure that I do not consider here, such as its informativeness regarding the firm's risk.

2) The ex-ante equity price is unaffected by the disclosure.

3) The expected post-disclosure equity price, $E[P_1(\tilde{y})]$, increases in the informativeness of the disclosure.

4) Observing pre- and post- disclosure equity prices $(P_0, P_1(\tilde{y}))$ is insufficient to learn the disclosure's properties λ and η.

The equity is priced using the standard asset-pricing Euler equation, and thus equals the sum of the equity's payoff in each state of the world multiplied by the representative investor's marginal utility in that state. This price exhibits three intuitive features that are important in pricing options. First, it exhibits a risk premium, that is, P_0 and $P_1(\tilde{y})$ fall short of the market's expectations of terminal value at the respective dates, $E[\tilde{x}]$ and $E[\tilde{x}|\tilde{y}]$, implying that the firm's expected returns exceed the risk-free rate. Second, the *ex-ante* (date 0) equity price is unaffected by the disclosure and its properties, λ and η. This result mirrors the findings of Ross (1989) and Christensen et al. (2010) and is directly assumed in Patell and Wolfson (1979, 1981). Finally, the size of the post-disclosure risk premium decreases as the firm releases a more informative disclosure, consistent with the findings in Lambert, Leuz, and Verrecchia (2007). Intuitively, disclosure reduces uncertainty, which in turn reduces the investor's effective risk aversion. Again, equity prices are insufficient to learn the disclosure's properties, λ and η, because the researcher only observes the equity response associated with the realized disclosure $\tilde{y}$ and because the ex-ante equity price is independent of λ and η.

Next, consider disclosure's effect on pre-disclosure option prices.

Proposition 2 *The pre-disclosure prices of call and put options with strike $k \in (P_1(y_L), P_1(y_H))$ that expire just after the disclosure equal:*

$$
\begin{aligned}
\Phi^C(k) &= \frac{E[\max(P_1(\tilde{y}) - k, 0) u'(\tilde{x})]}{E[u'(\tilde{x})]}; \\
\Phi^P(k) &= \frac{E[\max(k - P_1(\tilde{y}), 0) u'(\tilde{x})]}{E[u'(\tilde{x})]}.
\end{aligned}
\tag{4}
$$

Consequently,

1) Investor risk aversion decreases (increases) the pre-disclosure prices of call (put) options of all strikes.

2) An increase in the disclosure's informativeness weakly increases the pre-disclosure prices of options of all strikes and strictly increases the pre-disclosure prices of options with strikes $k \in (P_1(y_L), P_1(y_H))$. The size of this effect increases in payoff uncertainty, $x_H - x_L$.

3) An increase in the disclosure's informativeness for good-versus-bad news increases the pre-disclosure prices of OTM call (ITM put) options and decreases the pre-disclosure prices of ITM call (OTM put) options.

4) Conditional on knowledge of the investor's utility function $u(\cdot)$, pre-disclosure option prices reveal the disclosure's properties, λ and η.

As with the equity price, the equilibrium option price follows from the Euler equation and equals the sum of the option's payoff in each state of the world multiplied by the representative investor's marginal utility of wealth in that state. As the investor's wealth at the end of the model stems from the firm's dividend and call (put) options' payoffs are positively (negatively) correlated with this dividend, the price of these options include a positive (negative) risk premium.

The next part of the proposition concerns the robustness of results in the prior section to investor risk aversion. Note that when the investor is risk averse, the disclosure's informativeness has three effects on option prices; I refer to these effects as the *expected-payoff* effect, the *option-risk* effect, and the *cost-of-capital* effect. I provide the intuition underlying these effects for call options. First, the expected-payoff effect carries over from the risk-neutral analysis conducted in Lemma 2: more informative disclosure affects options' expected payoffs by increasing the variance of the equity price. However, this increase in variance also increases the riskiness of the options payoff, which I term the option-risk effect. For instance, if an option is ITM prior to a disclosure event, it is possible that price falls in response to the disclosure, leading the option to expire OTM. Importantly, this risk is priced by the investor, pushing down the option's pre-disclosure price. Finally, the fact that more

informative disclosure reduces the equity risk premium after its release tends to increase call options' expected payoffs, pushing up their prices; I refer to this as the cost-of-capital effect. Part 2 of the proposition states that the expected-payoff and cost-of-capital effects dominate the option-risk effect: more informative disclosure continues to increase option prices.

An increase in the disclosure's asymmetry also impacts option prices through the expected-payoff, option-risk, and cost-of-capital effects. As in the risk-neutral case studied in the prior section, the expected-payoff effect is positive for OTM call options and negative for ITM call options. Furthermore, asymmetry in the disclosure causes options to be more likely to pay off when the underlying state is high; that is, loosely speaking, it increases call options' betas, which drives their prices downward. Finally, asymmetric disclosure can impact the firm's cost of capital, but the direction of this effect is not signable in general, and depends upon the precise shape of the investor's preferences. Nonetheless, the net effect of an increase in the disclosure's informativeness for good-versus-bad news remains positive for OTM options and negative for ITM options. Again, option prices reveal the parameters λ and η conditional on knowledge of $u\left(\cdot\right)$. In Appendix A, I show that from an empirical point of view, the qualifier that knowledge of $u\left(\cdot\right)$ is required to back out λ and η generally does not represent a problem to estimation if the investors holding different firms have similar preferences.

I next show that the *magnitude* of the effect disclosure has on option prices depends upon investor risk aversion. Define an increase in investor risk aversion as a concavification of the utility function: u_1 is more risk averse than u_2 if and only if there exists an increasing, concave function g such that $u_1 = g\left(u_2\right)$.[11]

Corollary 2 *1) An increase in investor risk aversion magnifies (attenuates) the effect of the disclosure's informativeness on the pre-disclosure prices of call options with strikes $k > E\left[\tilde{x}\right]$ $(k < E\left[\tilde{x}\right])$.*
2) An increase in investor risk aversion causes the disclosure's informativeness for good-versus-bad news to have a more positive impact on all pre-disclosure option prices.

---

[11]See Pratt (1964) and Gollier (2004) for the development of this notion.

The corollary provides testable predictions on how the extent of systematic versus idiosyncratic information contained in a disclosure moderates how it influences option prices. The intuition underlying the first part of the corollary for call options is as follows. An increase in risk aversion amplifies the negative option-risk and positive cost-of-capital effects that the disclosure's informativeness has on option prices. However, the relative size of these effects depends on an option's strike. Specifically, the (positive) cost-of-capital effect is similar for call options of differing strikes; it simply pushes up the equity price, increasing options' ex-post payoffs. On the other hand, the (negative) option-risk effect has a greater impact on low-strike than high-strike call options, as investors holding ITM options have "more to lose" from a downswing in the equity price. The second part of the corollary follows because risk aversion amplifies the effect that η has on the equity price when call options pay off, $P(y_H)$. The reason is that η reduces the probability that a high signal results from poor performance, and thus decreases the investor's uncertainty given y_H.

4   Continuous-time formulation

The model developed to this point may be criticized on the grounds that its results are difficult to compare to conventional option-pricing models in which investors trade continuously and the firm's stock price evolves according to a diffusion process. In this section, I demonstrate that the results in the prior section continue to hold in such a setting. Specifically, assume now that the investor trades the bond, stock, and options continuously over a period $[0, T]$. The final period T corresponds to time 2 in the discrete-time model: it is the time at which the firm pays off $\tilde{x}$ to its equity holders. I now assume that $\tilde{x}$ can be decomposed into two independent subcomponents, one that the firm discloses about, $\tilde{o}$, and one related to other information released by external sources, $\tilde{d}$:

$$\tilde{x} = \tilde{o} + \tilde{d}. \tag{5}$$

I choose to include this second component of cash flows, $\tilde{o}$, in the model in order to allow the firm's price to evolve continuously for reasons unrelated to the disclosure event. Its presence leads to a price process similar to the one found in the BSM and related option-pricing models. The results in this section continue to hold in the absence of this term, or if this term is correlated with $\tilde{d}$. At date 0, the investor has a prior that $\tilde{o}$ has a log-normal distribution with parameters μ_0 and $\sigma_0^2 > 0$. The investor receives information continuously regarding $\tilde{o}$, which captures information that is gradually embedded into the firm's price. This may stem from forces such as information processing or private information gathering. In particular, assume that the posterior beliefs of the investor regarding $\tilde{o}$ evolve according to the following stochastic process:

$$
\begin{aligned}
d\mu_t &= \frac{\sigma_0}{T^{\frac{1}{2}}} dB_t; \\
d\sigma_t^2 &= -\frac{\sigma_0^2}{T} dt,
\end{aligned}
\tag{6}
$$

where B_t is a Brownian motion. Intuitively, these belief dynamics capture the limit of a discrete-time model in which investors receive normally-distributed signals regarding $\log \tilde{o}$ in each of many time periods, as the time between each period and the precision of each signal approach zero (Lipster and Shiryaev (2001)). Moreover, since $\sigma_T^2 = \sigma_0^2 + \int_0^T -\frac{\sigma_0^2}{T} dt = 0$, at the final date T, investors know $\tilde{o}$, i.e., $e^{\mu_T} = \tilde{o}$.[12] Note that while I make rather specific assumptions on the stochastic process followed by the investor's beliefs regarding $\tilde{o}$, as I discuss at the end of the section, the results are highly robust to various assumptions on this process.

Next, assume that $\tilde{d}$ has the same distribution as the dividend in Section 2: $\tilde{d} = x_H$ with probability $\frac{1}{2}$ and $\tilde{d} = x_L$ with probability $\frac{1}{2}$. Assume that the firm releases a disclosure $\tilde{y}$ regarding $\tilde{d}$ at date $\tau_D \in (0, T)$ that has the same conditional distribution as in Section 2. Finally, assume that $\tilde{y}$ is independent of $\tilde{o}$ and $E_t[\tilde{o}]$, $\forall t \in (0, T)$.

---

[12]Note that this type of framework is standard in the continuous-time asset pricing literature; see, e.g., Naik and Lee (1990), Scheinkman and Xiong (2003), and Buraschi and Jiltsov (2006).

Denote a call (put) option's price at time t as a function of the current stock price P_t, the option's maturity date τ_M and strike price k as $\Phi_t^C\left(P_t, k, \tau_M\right)$ $\left(\Phi_t^P\left(P_t, k, \tau_M\right)\right)$. Applying Bayes' rule to determine the representative investor's beliefs at each time point, solving her optimization problem, and substituting the market-clearing condition yields the following lemma:

Lemma 4 *The firm's share price equals:*

$$P_t = \frac{E_t\left[\tilde{x}u'\left(\tilde{x}\right)\right]}{E_t\left[u'\left(\tilde{x}\right)\right]}. \tag{7}$$

The call and put option prices are equal to:

$$
\begin{aligned}
\Phi_t^C\left(P_t, k, \tau_M\right) &= \frac{E_t\left[\max\left(P_{\tau_M} - k, 0\right)u'\left(\tilde{x}\right)\right]}{E_t\left[u'\left(\tilde{x}\right)\right]}; \\
\Phi_t^P\left(P_t, k, \tau_M\right) &= \frac{E_t\left[\max\left(k - P_{\tau_M}, 0\right)u'\left(\tilde{x}\right)\right]}{E_t\left[u'\left(\tilde{x}\right)\right]}.
\end{aligned} \tag{8}
$$

The equity and option prices are continuous during the non-disclosure windows $[0, \tau_D)$ and $(\tau_D, T]$, and jump on the disclosure date τ_D.

The lemma states that the firm's equity and option prices continue to be valued using the conventional Euler equation in the continuous-trade framework. These prices evolve continuously in the non-disclosure windows as investors continuously receive information about the terminal dividend and jump on the date of the disclosure. Figure 2 plots a numerical example of pre- and post- disclosure equity and option prices under the assumption that $\lambda = 1$ and $\eta = 0$. Notice that the equity and option prices evolve continuously prior to the date of the disclosure, $T = 10$, at which point they jump up or down depending upon the news provided in the disclosure. After the disclosure, they again evolve continuously until the dividend is paid at date $T = 20$.

I next show that the effects of disclosure on equity and option prices highlighted in Lemma 2 and Proposition 1 continue to hold in the continuous-trade setting. In order to state this
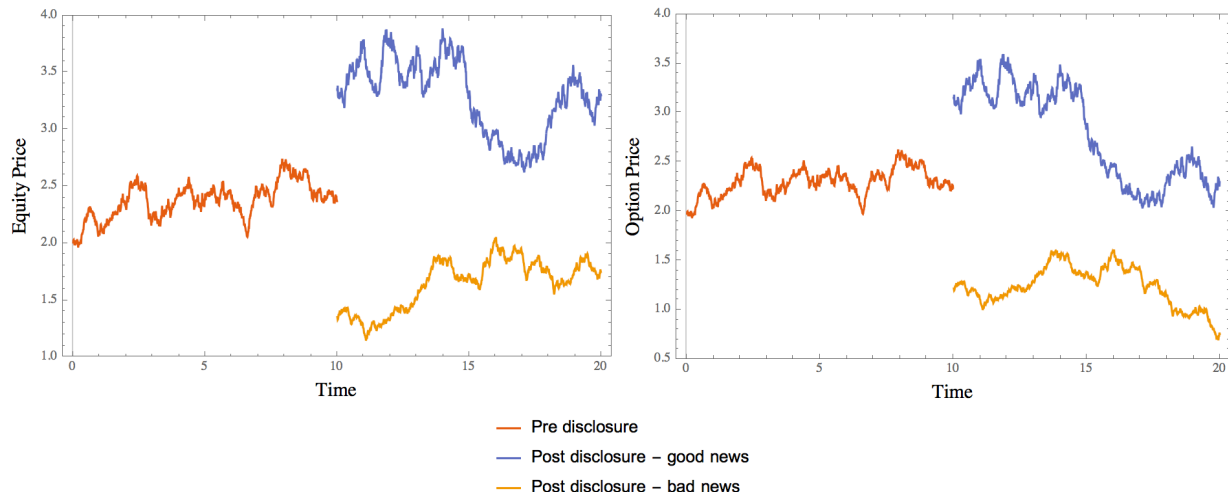
Figure 2: This figure was generated by simulating pre- and post- disclosure equity and call option prices, given binary $\tilde{d} \in \{-1, 1\}$ and a symmetric disclosure that perfectly recognizes the true $\tilde{d}$. In the example, disclosure occurs at day 10, and the option matures at day 20.

formally, let the "pre-disclosure equity price" refer to $\lim_{t \to \tau_D^-} P_t$ and the "pre-disclosure call (put) option price" refer to $\lim_{t \to \tau_D^-} \Phi_t^C(P_t, k, \tau_M)$ $(\lim_{t \to \tau_D^-} \Phi_t^P(P_t, k, \tau_M))$. Furthermore, refer to the "equity returns at the disclosure date" as the change in the firm's equity price induced by the disclosure, $P_{\tau_D} - \lim_{t \to \tau_D^-} P_t$. Given these definitions, the statements in Lemma 3, Proposition 1, and Corollary 2 apply directly to the continuous-trade setting.

Proposition 3 *Results 1-4 in Proposition 2 continue to hold in the continuous-trade framework for options that mature just after the disclosure (at date τ_D). Results 1-2 in Corollary 2 also continue to hold in the continuous-trade framework for these options if $u(\cdot)$ exhibits non-increasing absolute risk aversion.*

The intuition for this result is straightforward: in the continuous-trade setting, the disclosure's properties affect the jump in price on the disclosure date in the same manner in which they affect the change in price from date 0 to date 1 in discrete-trade setting. A slight complexity arises because $\tilde{o}$ serves as a source of background risk that can modify the representative investor's risk preferences. This does not affect the results in Proposition 2, since it holds for any parameterization of investor risk aversion. However, for the comparative statics results articulated in Corollary 2 to continue to hold in the presence of this
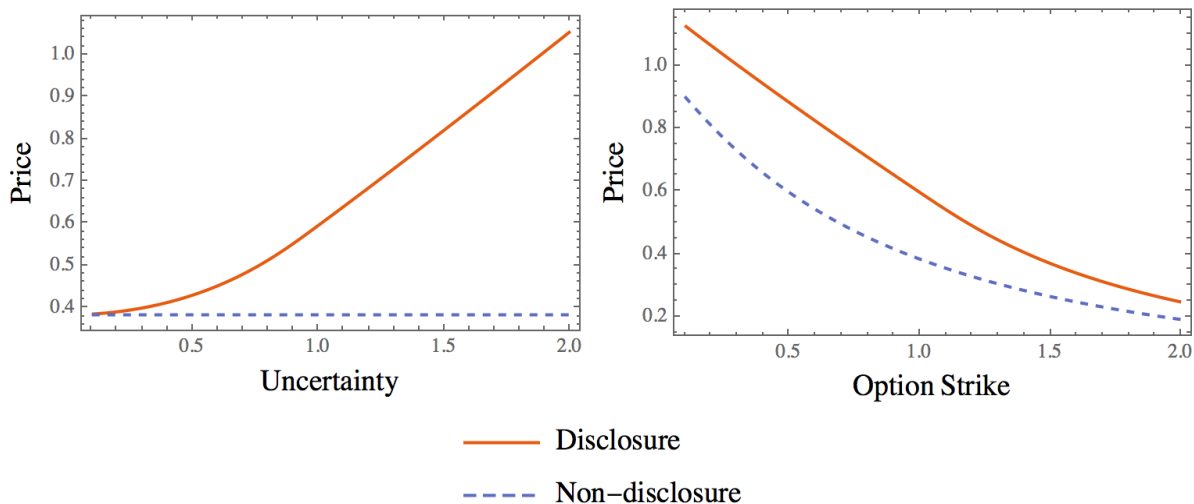
23

Figure 3: This figure compares pre-disclosure option prices under a fully informative disclosure $\left(\lambda = 1, \eta = 0\right)$ and a completely uninformative disclosure $\left(\lambda = \frac{1}{2}, \eta = 0\right)$. The left-hand plot depicts an ATM call option's price as a function of $x_H - x_L$ under the two policies. The right-hand plot depicts call options' prices as a function of their strike under the two policies.

background risk, a technical, albeit reasonable condition must hold: the investor must have non-increasing absolute risk aversion. Figure 3 presents comparative statics on the effect of disclosure's informativeness on call option prices, taking the extreme approach of comparing a fully informative disclosure $\left(\lambda = 1, \eta = 0\right)$ to the case of completely noisy disclosure $\left(\lambda = \frac{1}{2}, \eta = 0\right)$. The left figure demonstrates that the effect of disclosure on option prices increases in uncertainty over $\tilde{d}$, $x_H - x_L$. The right figure plots the effect of disclosure on an option's price against the option's strike.

Figure 4 depicts the impact of asymmetric informativeness on call option prices, comparing the case in which the disclosure is more informative for good than bad news $\left(\lambda = 0.7, \eta = 0.1\right)$ to the case in which the disclosure is symmetric $\left(\lambda = 0.7, \eta = 0\right)$. The upper plot demonstrates that the effect of asymmetric informativeness on the price of an option depends on whether the option is OTM or ITM; the pre-disclosure stock price in the figure equals 1, the point at which the two price lines cross. The lower-left plot demonstrates the effect on an ITM call option, while the lower-right plot demonstrates the effect on an OTM call option, as a function of uncertainty regarding $\tilde{d}$. Intuitively, greater uncertainty magnifies
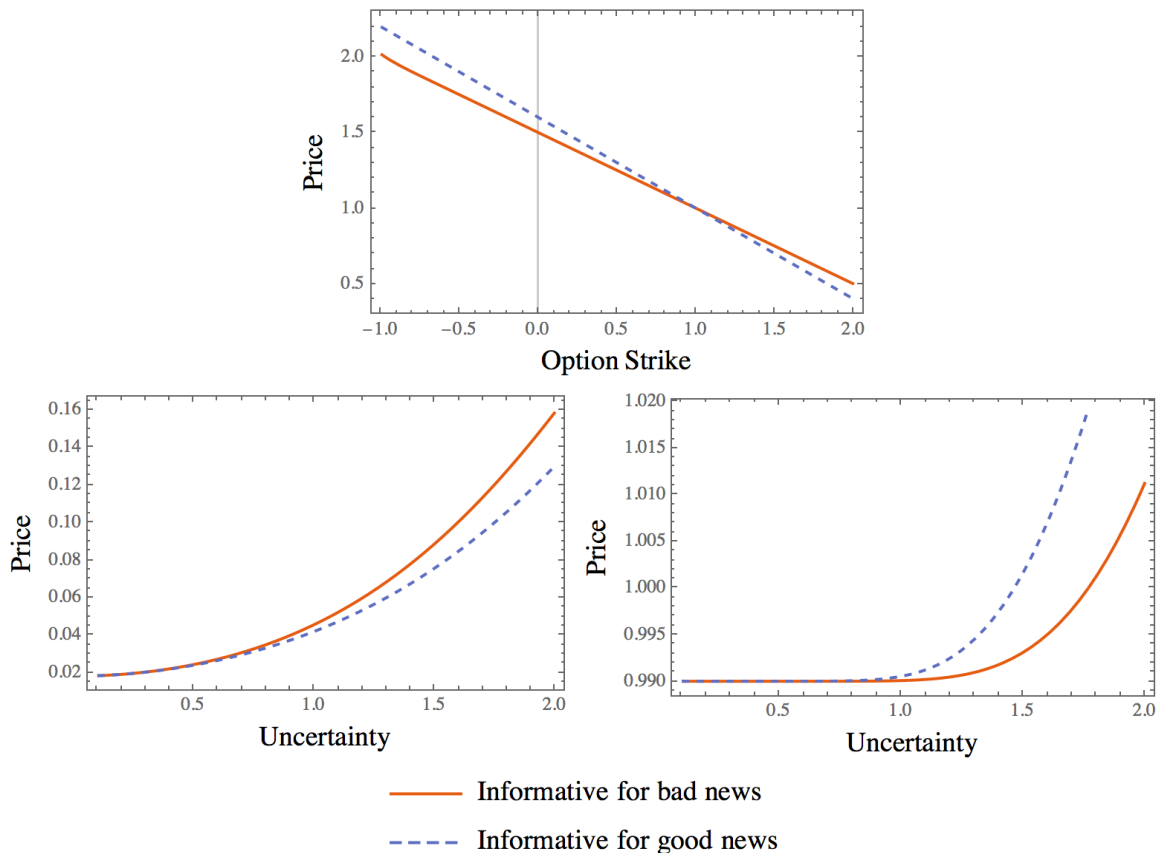
Figure 4: This figure depicts pre-disclosure call option prices under the regimes $(\lambda = 0.7, \eta = 0.1)$ and $(\lambda = 0.7, \eta = 0)$; the former is represented by the dashed lines and the latter by the solid lines. The upper plot depicts call options' prices as a function of their strike; the lower-left plot depicts the price of an ITM call option as a function of $x_H - x_L$; the lower-right hand plot depicts the price an OTM call option as a function of $x_H - x_L$.

the response to disclosure and hence amplifies how asymmetric disclosure affects the relative prices of OTM and ITM options.

Many option-pricing models allow for greater generality in the stochastic process followed by the firm's equity than the one that endogenously arises in this section. For instance, several models allow the volatility of price to depend upon time and/or the present equity price or to possess a stochastic component (Hull and White (1987), Heston (1993), Dupire (1997)). Moreover, models allow for exogenous jumps in the stock price with varying distributions (Kou (2002)). Since in my framework the terminal dividend is taken as the exogenous construct, to be included in the model, these features of the stock-price process would have to

arise endogenously from changes in the market's beliefs. For instance, stochastic volatility could arise due to uncertainty over the amount of information to arrive regarding $\tilde{o}$. Jumps in the stock price at times other than τ_D may arise due to information releases other than the disclosure, large investors' liquidity shocks, etc. Time- and price- dependent volatility might arise if the market's incentives to acquire information depend upon their wealth or otherwise dynamically change (Vanden (2008)).

Nonetheless, the introduction of these additional features would have no qualitative impact on my results. The reason is that, subject to minor regularity conditions, the proof of Proposition 3 does not depend upon the stochastic process followed by the stock price in the periods $[0, \tau_D)$ and $(\tau_D, T]$. Intuitively, the proposition concerns the prices of options just prior to the disclosure that expire soon after the disclosure. The dynamics of price in non-disclosure periods only impact these options' prices through introducing a source of background risk in the representative investor's consumption. But, since the proposition holds for any risk-averse investor preference function, and since introducing background risk preserves risk aversion (Gollier 2004), the results are robust to the price dynamics in the non-disclosure windows.

5 Generalized information structures

In this section, I generalize the binary information structure in the previous section in order to demonstrate that my focal results are applicable to a broad range of settings found in the prior theoretical-disclosure literature. The approach I take is to allow for full generality in the distribution of the firm's payoff and the conditional distribution of the firm's disclosure given this payoff. I then characterize properties of the disclosure that are both necessary and sufficient for the results in Proposition 1 to hold, which capture general conceptions of the disclosure's informativeness and asymmetry in an intuitive matter. Finally, in the Internet Appendix, I show that these conditions are met in several settings studied in prior disclosure

literature.

Suppose now that the representative investor is risk-neutral.[13] Let $\tilde{d}$ now follow an arbitrary distribution satisfying $E\left[\left|\tilde{d}\right|\right] < \infty$ that possesses a CDF $F_{\tilde{d}}(\cdot)$ with support $[d_L, d_H]$ where $d_L \in [-\infty, d_H)$ and $d_H \in (d_L, \infty]$.[14] Moreover, suppose the disclosure $\tilde{y}$, which takes values in Υ, has an arbitrary statistical relationship with $\tilde{d}$. Denote the CDF of $\tilde{y}$ given $\tilde{d}$ as $F_{\tilde{y}|\tilde{d}}(\cdot)$ and assume that $E\left[\left|\tilde{d}|\tilde{y} = z\right|\right] < \infty \ \forall z \in \Upsilon$. I now refer to a disclosure regime R_i as a distribution function of $\tilde{y}$ given $\tilde{d}$.

The general notions of a disclosure's informativeness and asymmetry definitions that I develop are based on the fact that the disclosure impacts the equity price through its effect on the investor's posterior expectation of $\tilde{d}$, $\tilde{\xi}_{R_i}$. An uninformative disclosure regime rarely changes the investor's beliefs, leaving her posterior expectation of $\tilde{y}$, $E\left[\tilde{d}|\tilde{y}\right]$ very close to her prior belief, $E\left[\tilde{d}\right]$. On the other hand, a highly informative disclosure causes the investor's beliefs, $E\left[\tilde{d}|\tilde{y}\right]$, to change substantially based upon the information contained in the disclosure. Generalizing this idea, a disclosure regime can be considered more informative than another if it leads to more variation in the investor's posterior expectations. Thus, consider the following definition of informativeness, which makes this idea precise by appealing to the concept of second-order stochastic dominance.

Definition 1 *Let $\tilde{\xi}_{R_i} \equiv E\left[\tilde{d}|\tilde{y}; R_i\right]$ denote the posterior expectation of $\tilde{d}$ under a disclosure regime R_i. A disclosure regime R_2 is higher quality than a disclosure regime R_1 if and only if $\forall a > 0$, $\int_{d_L}^{a} F_{\tilde{\xi}_{R_2}}(z)\, dz \geq \int_{d_L}^{a} F_{\tilde{\xi}_{R_1}}(z)\, dz$, that is, $\tilde{\xi}_{R_1}$ second-order stochastic dominates $\tilde{\xi}_{R_2}$.*[15]

---

[13]Note that the effect of disclosure on security prices when both payoff distributions and investor utility are fully general is a difficult question even in the absence of a derivative (Gollier and Schlee (2011)). Thus, tractably analyzing more general distributions requires a simpler assumption on investor preferences. The results in this section are most applicable to idiosyncratic disclosure.

[14]Generally, in the applications, it makes sense to restrict d_L to be nonnegative, such that the firm's share price is nonnegative. However, in demonstrating how definitions of conservatism in prior literature that often include unbounded normal distributions conform to the present model, it is necessary to allow d_L to be negative.

[15]Note that by the law-of-iterated expectations, $E\left(\tilde{\xi}_{\Delta_1}\right) = E\left(\tilde{\xi}_{\Delta_2}\right)$ is fixed at the prior mean, $E\left(\tilde{\eta}\right)$. As a result, an equivalent definition is that $\tilde{\xi}_{\Delta_2}$ is a mean-preserving spread of $\tilde{\xi}_{\Delta_1}$.

Importantly, this definition is both necessary and sufficient for Part 1 of Proposition 1 to hold.

Proposition 4 *A disclosure regime R_2 is more informative than a disclosure regime R_1 if and only if the pre-disclosure prices of options of all strike prices are higher under R_2 than R_1.*

In the Internet Appendix, I demonstrate that several conventional definitions of disclosure informativeness found in the literature (including the one used in the previous sections) indeed rank disclosure regimes according to Definition 1, suggesting that for a fairly large set of distributions, my results continue to hold. However, note that some disclosure policies are not capable of being ranked using this definition of informativeness. For instance, consider two disclosure regimes: the first is a setting of voluntary disclosure studied by Verrecchia (1983) whereby a firm discloses $\tilde{d}$ whenever it lies above some threshold T_V, and refrains from disclosing $\tilde{d}$ whenever it falls below T_V. Conversely, consider the conservative disclosure regime studied by Guay and Verrecchia (2006) whereby a firm discloses $\tilde{d}$ whenever it falls below the threshold T_C and refrains from disclosing whenever it lies above T_C. Then, for *any pair* of thresholds (T_C, T_V), it can be shown that these disclosure regimes cannot be ranked based on this definition.

An implication of this result is that even if the voluntary disclosure regime perfectly reveals the firm's performance to investors except in the case of a highly unlikely large loss, and the conservative regime reveals only highly extreme, very unlikely losses, the regimes still cannot be ranked based on informativeness. Moreover, because the definition is both necessary and sufficient to increase the prices of options of all strikes, this implies that the conservative regime increases the price of some options relative to the voluntary regime, even when it on average reveals much less information (specifically, deep ITM options). The takeaway is that empirical tests may indeed use the prices of options to compare the informativeness of two disclosure regimes, but only if option prices of all traded strikes are

greater under one regime than under the other (controlling for the present stock price and investors' prior uncertainty).[16]

Next, consider a general notion of disclosure's asymmetry, which is an extension of the previous definition.

Definition 2 *A disclosure regime R_2 is more informative for good-versus-bad news than a disclosure regime R_1 if and only if for $a < E\left[\tilde{d}\right]$, $\int_{d_L}^{a} F_{\tilde{\xi}_{R_2}}(z)\,dz \leq \int_{d_L}^{a} F_{\tilde{\xi}_{R_1}}(z)\,dz$, while for $a > E\left[\tilde{d}\right]$, $\int_{d_L}^{a} F_{\tilde{\xi}_{R_2}}(z)\,dz \geq \int_{d_L}^{a} F_{\tilde{\xi}_{R_1}}(z)\,dz$.*

The definition extends the previous one in the sense that a disclosure policy may be called more informative for good-versus-bad news when it leads to more variation in the investor's beliefs given that it leads her beliefs to be revised upwards ($\tilde{\xi}_{R_i} > E\left[\tilde{d}\right]$), and less variation given that it leads her beliefs to be revised downwards ($\tilde{\xi}_{R_i} < E\left[\tilde{d}\right]$). Also in the Internet Appendix, I demonstrate how several conventional definitions of conservative and aggressive disclosure found in the literature map into this criterion including the one used in the previous sections. Given this definition, Part 2 of Proposition 1 extends naturally to the case of a general distribution, and again, it is in fact both a necessary and sufficient condition for the result to hold.

Proposition 5 *A disclosure regime R_2 is more informative for good-versus-bad news than disclosure regime R_1 if and only if:*

1) The pre-disclosure prices of OTM call (put) options that mature at time τ_D are higher (lower) under R_2 than R_1, and

2) the pre-disclosure prices of ITM call (put) options that mature at time τ_D are higher (lower) under R_1 than R_2.

---

[16]Note this condition may be violated due to liquidity reasons absent from the model, even when the disclosure is in fact more informative.

6 Multiple investors with heterogenous beliefs

While the model is framed in terms of a representative investor, in reality, there are many investors trading in firms' options that likely have heterogenous information and beliefs. In this case, I demonstrate that option prices reveal a weighted average of investors' beliefs about the properties of the disclosure. In particular, suppose that there exists a continuum $[0, 1]$ of competitive risk-averse investors again with arbitrary utility function $u(\cdot)$. Their beliefs are heterogenous in the sense that the ith investor perceives the CDF's of $\tilde{d}$, $\tilde{y}|\tilde{d}$, and $\tilde{o}$ to be $F_{\tilde{d}}^i$, $F_{\tilde{y}|\tilde{d}}^i$, and $F_{\tilde{o}}^i$, respectively. In order to rule out the case in which an investor wishes to buy or sell an infinite amount of an asset, suppose that the investors' beliefs are mutually absolutely continuous. Then, the following result establishes that this extension is equivalent to the case in which there is a representative investor with some risk-averse utility function and an average of the individual investors' beliefs. As a result, the directional effect of the results considered in the previous sections remain unchanged.

Proposition 6 *The equilibrium equity and option prices in a model with heterogenous investors is equivalent to one in which there is a single risk-averse representative investor with beliefs equal to the average market belief.*

This result suggests that even if only a subset of investors in the market understand the properties of an upcoming disclosure, their beliefs will be impounded into prices. Thus, option prices may still be used to measure a disclosure's properties.

7 Conclusion

In this paper, I analyze an option-pricing model that formally incorporates an anticipated disclosure event. I demonstrate how the disclosure's informativeness and asymmetry affect option prices prior to its release. The model suggests that the disclosure's properties are an important determinant of options' expected payoffs, suggesting that a knowledge of ac-

counting systems can lead to more efficient pricing of option contracts. Moreover, my results suggest that in an efficient market, option prices can serve as a useful measure of investor's beliefs regarding an upcoming disclosure's properties. The measures developed can be calculated on a disclosure-event basis, obviating the need for strong assumptions underlying prior empirical measures.

In part, the paper's contribution is to build a rigorous, yet tractable, framework in which the effect of a disclosure on option prices may be analyzed. While the present paper focuses on only two properties of a disclosure, it may also be interesting to study how other features of a disclosure, such as bias, persistence, smoothness, etc., manifest in option prices. The model also takes the statistical properties of the disclosure as exogenous in order to maintain a focus on how these properties affect option prices. Another extension of the model would endogenize the disclosure to be made by a decision maker, such as a manager, who cares both about equity and option prices, in order to show how features such as proprietary costs or information uncertainty might be backed out from option prices.

8 Appendix A: Empirical estimation

In this appendix, I detail the empirical approach to measuring a disclosure's informativeness and asymmetry using call option prices. For simplicity, I develop the measures in the discrete-time risk-aversion case, but they are easily shown to be robust to continuous trade.[17] In the Internet Appendix, I show how these measures extend to the case of an asymmetric prior, and demonstrate the need to control for asymmetry in the firm's fundamentals.

Note that the model suggests that attention should be restricted to call options whose expiration date is after the disclosure date but as close to the disclosure date as possible; furthermore, option prices should be measured just prior to the disclosure event. Intuitively, this ensures that the option's price is minimally affected by sources of volatility other than the

---

[17]In the case of general distributions, there is no single parameter corresponding to informativeness or asymmetry that can be measured, but Propositions 4 and 5 nonetheless suggest a directional relationship between these properties and the measures developed in this section.

disclosure at hand, which could confound the measures. Suppose that the traded options with expiration closest to the announcement have strike prices $k_1,...,k_n$. According to Proposition 2, recall that the theoretical price of a call option with strike $k_i \in (P_1(y_L), P_1(y_H))$ equals:

$$\Phi^C(k_i) = \frac{(\lambda - \eta)(x_H - k_i)u'(x_H) + (1 - \lambda - \eta)(x_L - k_i)u'(x_L)}{u'(x_H) + u'(x_L)}. \tag{9}$$

We wish to map observed option prices into this formula in order to develop estimators of λ and η. First, consider an estimator of disclosure's informativeness, λ. Let P^* denote the last-quoted equity price prior to the disclosure event and let $\Phi^C(P^*)$ denote the price of the call option with strike closest to P^* at time close to the time P^* is quoted. Substituting $k_i = P^*$ into expression (9) and simplifying, we find that:

$$\Phi^C(P^*) = \frac{u'(x_H)u'(x_L)}{(u'(x_H) + u'(x_L))^2}(x_H - x_L)(2\lambda - 1). \tag{10}$$

Assuming that the investors holding any given firm have similar preferences, the term $\frac{u'(x_H)u'(x_L)}{(u'(x_H) + u'(x_L))^2}$ can be seen as a constant. This implies that:

$$\lambda \propto \frac{\Phi^C(P^*)}{x_H - x_L}. \tag{11}$$

Note that if the investors holding any given firm have different risk aversions, this might confound empirical tests. Expression (11) is not quite an empirical estimate of λ, as the denominator $x_H - x_L$, which captures investors' prior uncertainty regarding the firm's performance, clearly varies across disclosure dates and is likely correlated with prominent firm characteristics such as firm size and leverage. However, suppose we have a consistent estimator $\hat{z}$ of $x_H - x_L$; then, we can use expression (11) to derive a consistent estimator $\hat{\lambda}$ for λ:

$$\hat{\lambda} = \frac{\Phi^C(P^*)}{\hat{z}}. \tag{12}$$

Intuitively, we simply normalize the ATM option price by $\hat{z}$. This leaves the question of how

to estimate $x_H - x_L$; I offer two possibilities. First, suppose that investors receive information regarding $\tilde{x}$ leading up to the disclosure date either publicly or privately. Then, equity prices leading up to the disclosure date vary as this information is impounded into price, and the size of this variation should be directly related to $x_H - x_L$, such that historical equity-*price* volatility leading up to the disclosure may proxy for $x_H - x_L$.[18] However, this measure may be confounded by the properties that drive the amount of information regarding $\tilde{x}$ that is impounded into returns prior to the disclosure. A second possible estimator $\hat{z}$ is the firm's stock price, which roughly captures the amount of (dollar) uncertainty faced by investors if firms' expected cash flows and cash flow variances are linked. Note that another approach is to match on size, price volatility, and/or other measures of $x_H - x_L$ rather than normalizing by their values.

Next, consider the estimation of η. Expression (9) implies that for any $k_j \neq k_i$,

$$\eta = \frac{\Phi^C(k_j) - \Phi^C(k_i)}{k_j - k_i} + \frac{u'(x_L) + (u'(x_H) - u'(x_L))\lambda}{u'(x_H) + u'(x_L)}. \tag{13}$$

Thus, consider an estimator:

$$\hat{\eta} = \frac{\Phi^C(k_j) - \Phi^C(k_i)}{k_j - k_i}. \tag{14}$$

Expression (13) suggests that this estimate is valid contingent on controlling for our estimator $\hat{\lambda}$; this is because λ also affects the relative price of option contracts with different strikes. Expression (13) also suggests that a linear control is sufficient. When the representative agent is risk neutral, note that expression (13) reduces to:

$$\hat{\eta} = \frac{\Phi^C(k_j) - \Phi^C(k_i)}{k_j - k_i} - \frac{1}{2}, \tag{15}$$

suggesting that a control for λ is unnecessary in this case.

While $\hat{\eta}$ may be calculated using the prices of any two option contracts in this simple

---

[18]It is critical to use price, not return volatility. Using a measure that normalizes by return volatility will fail to correct for scale effects, i.e., it will be mechanically impacted by firm size.

setting, the most robust approach is to compare the price of an ITM to the price of an OTM option contract. The reason is that, as discussed in Section 4, for very general distributions, OTM option prices relative to ITM option prices increase in disclosure's informativeness for good-versus-bad news. On the other hand, in general, the relative prices of, say, deep OTM to slightly OTM option prices might not exhibit such a pattern.

Next, I note that call options that are substantially ITM are typically illiquid. However, the effect of η on options that are too close to being ATM is small and thus may be strongly influenced by noise, leading to low power tests. Thus, in calculating $\hat{\eta}$, the optimal choice may be a moderately ITM and a moderately OTM option contract. In large cross-sectional studies, a facile approach may be to choose options that are as close as possible to a fixed fractional percentage away from ATM for each firm. In sum, we have the following estimator:

$$\hat{\eta} = \frac{\Phi^C(k_j) - \Phi^C(k_i)}{k_j - k_i} \tag{16}$$

for k_i moderately greater than P^*

and k_j moderately smaller than P^*.

9 Appendix B: Proofs of technical results

Throughout the appendix, I demonstrate the results for call options, as the results for put options are proved in the same manner.

Proof of Lemma 2. Proof of Part 1) This follows trivially given that $P_0 = \frac{x_L + x_H}{2}$ is not a function of λ or η.

Proof of Part 2) Note that the variance of returns at date 1 is equal to:

$$
\begin{aligned}
Var\left[\frac{P_1 - P_0}{P_0}\right] &= \frac{1 - 2\eta}{2P_0^2}\left[\frac{(\lambda - \eta)x_H + (1 - \lambda - \eta)x_L}{1 - 2\eta} - \frac{x_H + x_L}{2}\right]^2 \\
&\quad + \frac{1 + 2\eta}{2P_0^2}\left[\frac{(1 - \lambda + \eta)x_H + (\lambda + \eta)x_L}{1 + 2\eta} - \frac{x_H + x_L}{2}\right]^2 \\
&= \frac{1}{4P_0^2}\frac{(2\lambda - 1)^2}{1 - 4\eta^2}(x_H - x_L)^2.
\end{aligned}
\tag{17}
$$

34

Differentiating with respect to λ yields:

$$\frac{\partial}{\partial \lambda} Var \left[\frac{P_1 - P_0}{P_0} \right] = \frac{2\lambda - 1}{1 - 4\eta^2} \frac{(x_H - x_L)^2}{P_0^2} > 0. \tag{18}$$

Clearly, this increases in $x_H - x_L$. Next, note that skewness of returns can be reduced to:

$$Skewness \left[\frac{P_1 - P_0}{P_0} \right] = 4 \frac{\eta}{\sqrt{(1 - 4\eta^2)}}, \tag{19}$$

which is unaffected by λ.

Proof of Part 3) Differentiating skewness with respect to η yields:

$$\frac{\partial}{\partial \eta} Skewness \left[\frac{P_1 - P_0}{P_0} \right] = \frac{\partial}{\partial \eta} \left(4 \frac{\eta}{\sqrt{(1 - 4\eta^2)}} \right) > 0, \tag{20}$$

since $\lambda \geq \frac{1}{2}$ and $\eta \leq \frac{1}{2}$. ∎

Proof of Proposition 1 and Corollary 1. These results are a special case of Proposition 2 when $u(x) = x$. ∎

Proof of Proposition 3. Denote by $(\Omega, \mathcal{F}, \Pi)$ a probability space that generates the distributions of x and P_1 described in the main text. In this case, we may view $\tilde{x}$ and $\tilde{P}_1$ as functions mapping states $\omega \in \Omega$ into the real line, and we can write $\Pr \left(\left(\tilde{P}_1, \tilde{x} \right) \in A \right) = \int_{\{\omega : (P_1(\omega), x(\omega)) \in A\}} d\Pi(\omega)$. Using this notation, we have the following result, which is a variation of the well-known Euler condition that holds in complete markets with utility-maximizing agents.

Lemma 5 *The price of an asset that pays off $\varphi(\omega)$ in state $\omega \in \Omega$ is equal to $\frac{\int_\Omega \varphi(\omega) u'(x(\omega)) d\Pi(\omega)}{\int_\Omega u'(x(\omega)) d\Pi(\omega)}$.*

Proof. First, it is well known that markets are dynamically complete given the existence of a complete set of options, which implies the existence of a stochastic discount factor, $\pi(\omega)$. Therefore, the representative agent's problem assuming they have some wealth W can be written as (for a proof, see Back (2010), pg. 150):

$$\max_{\substack{c(\omega) \\ \forall \omega \in \Omega}} \int_\Omega u(c(\omega)) d\Pi(\omega) \tag{21}$$

$$\text{s.t.} \quad \int_\Omega \pi(\omega) c(\omega) d\Pi(\omega) \quad = \quad W.$$

This problem has Lagrangian, where κ is the multiplier:

$$L \left(\{c(\omega)\}_{\omega \in \Omega}, \kappa \right) = \int_\Omega u(c(\omega)) d\Pi(\omega) + \kappa \left(W - \int_\Omega \pi(\omega) c(\omega) d\Pi(\omega) \right). \tag{22}$$

Differentiating pointwise with respect to $c(\omega)$ yields:

$$u'(c(\omega))\Pi(\omega) - \kappa\pi(\omega) = 0 \tag{23}$$
$$\kappa = \frac{u'(c(\omega))}{\pi(\omega)}.$$

Utilizing the fact that the risk-free rate is 1, no arbitrage requires that the state prices sum to 1, i.e., $\int \pi(\omega) d\Pi(\omega) = 1$. This yields:

$$\kappa = \int_\Omega u'(c(\omega)) d\Pi(\omega), \tag{24}$$

such that $\pi(\omega) = \frac{u'(c(\omega))}{\int_\Omega u'(c(\omega))d\Pi(\omega)}$. By the market-clearing condition, in equilibrium, we must have $c(\omega) = x(\omega)$, such that $\pi(\omega) = \frac{u'(x(\omega))}{\int_\Omega u'(x(\omega))d\Pi(\omega)}$ By the definition of the stochastic discount factor, the lemma now follows. ∎

Now, note that the vector function $(x(\omega), P_1(\omega))$ maps the state space Ω into the set $\left\{ \binom{x_H}{P_1(y_H)}, \binom{x_L}{P_1(y_H)}, \binom{x_H}{P_1(y_L)}, \binom{x_L}{P_1(y_L)} \right\}$. Applying the prior lemma and the joint distribution of these events, we arrive at the following equilibrium price at time 0:

$$P_0 = \frac{x_H \Pr(\tilde{x} = x_H) u'(x_H) + x_L \Pr(\tilde{x} = x_L) u'(x_L)}{\Pr(\tilde{x} = x_H) u'(x_H) + u'(x_L) \Pr(\tilde{x} = x_L)} \tag{25}$$
$$= \frac{x_H u'(x_H) + x_L u'(x_L)}{u'(x_H) + u'(x_L)},$$

and the following equilibrium price given y_H and y_L:

$$P_1(y_H) = \frac{\Pr(\tilde{x} = x_H|y_H) x_H u'(x_H) + \Pr(\tilde{x} = x_L|y_H) x_L u'(x_L)}{\Pr(\tilde{x} = x_H|y_H) u'(x_H) + \Pr(\tilde{x} = x_L|y_H) u'(x_L)} \tag{26}$$
$$= \frac{(\lambda - \eta) x_H u'(x_H) + (1 - \eta - \lambda) x_L u'(x_L)}{(\lambda - \eta) u'(x_H) + (1 - \eta - \lambda) u'(x_L)} \quad \text{and}$$
$$P_1(y_L) = \frac{\Pr(\tilde{x} = x_H|y_L) x_H u'(x_H) + \Pr(\tilde{x} = x_L|y_L) x_L u'(x_L)}{\Pr(\tilde{x} = x_H|y_L) u'(x_H) + \Pr(\tilde{x} = x_L|y_L) u'(x_L)} \tag{27}$$
$$= \frac{(1 + \eta - \lambda) x_H u'(x_H) + (\lambda + \eta) x_L u'(x_L)}{(1 + \eta - \lambda) u'(x_H) + (\lambda + \eta) u'(x_L)}.$$

Proof of Part 1) To see this, notice that for any concave utility function $u\left(\cdot\right)$, we have:

$$
\begin{aligned}
P_0 &= \frac{x_H u'\left(x_H\right) + x_L u'\left(x_L\right)}{u'\left(x_H\right) + u'\left(x_L\right)} < \frac{x_H + x_L}{2} = E\left(\tilde{x}\right); \\
P_1\left(y_H\right) &= \frac{\left(\lambda - \eta\right) x_H u'\left(x_H\right) + \left(1 - \eta - \lambda\right) x_L u'\left(x_L\right)}{\left(\lambda - \eta\right) u'\left(x_H\right) + \left(1 - \eta - \lambda\right) u'\left(x_L\right)} \\
&< \frac{\left(\lambda - \eta\right) x_H + \left(1 - \eta - \lambda\right) x_L}{\left(\lambda - \eta\right) + \left(1 - \eta - \lambda\right)} = E\left(\tilde{x}|\tilde{y} = y_H\right); \\
P_1\left(y_L\right) &= \frac{\left(1 + \eta - \lambda\right) x_H u'\left(x_H\right) + \left(\lambda + \eta\right) x_L u'\left(x_L\right)}{\left(1 + \eta - \lambda\right) u'\left(x_H\right) + \left(\lambda + \eta\right) u'\left(x_L\right)} \\
&< \frac{\left(1 + \eta - \lambda\right) x_H + \left(\lambda + \eta\right) x_L}{\left(1 + \eta - \lambda\right) + \left(\lambda + \eta\right)} = E\left(\tilde{x}|\tilde{y} = y_L\right).
\end{aligned}
\tag{28}
$$

Proof of Part 2) This follows because $\frac{x_H u'(x_H) + x_L u'(x_L)}{u'(x_H) + u'(x_L)}$ is unaffected by λ and η.

Proof of Part 3) Note that:

$$
\frac{\partial E\left[P_1\left(\tilde{y}\right)\right]}{\partial\lambda} = \frac{\partial}{\partial\lambda}\left[\left(1 - 2\eta\right)\frac{\frac{\lambda - \eta}{1 - 2\eta} x_H u'\left(x_H\right) + \left(1 - \frac{\lambda - \eta}{1 - 2\eta}\right) x_L u'\left(x_L\right)}{\frac{\lambda - \eta}{1 - 2\eta} u'\left(x_H\right) + \left(1 - \frac{\lambda - \eta}{1 - 2\eta}\right) u'\left(x_L\right)}\right.
\tag{29}
$$

$$
\left.+ \left(1 + 2\eta\right)\frac{\frac{1 + \eta - \lambda}{2\eta + 1} x_H u'\left(x_H\right) + \left(1 - \frac{1 + \eta - \lambda}{2\eta + 1}\right) x_L u'\left(x_L\right)}{\frac{1 + \eta - \lambda}{2\eta + 1} u'\left(x_H\right) + \left(1 - \frac{1 + \eta - \lambda}{2\eta + 1}\right) u'\left(x_L\right)}\right]
$$

$$
\propto \left[u'\left(x_L\right) - u'\left(x_H\right)\right]\left(x_H - x_L\right)\left(2\lambda - 1\right)
$$

$$
* \left[2\eta\left(u'\left(x_H\right) - u'\left(x_L\right)\right)\left(2\lambda - 1\right) + \left(1 - 4\eta^2\right)\left(u'\left(x_H\right) + u'\left(x_L\right)\right)\right].
$$

Since u is concave, $u'\left(x_L\right) - u'\left(x_H\right) > 0$. To complete the proof, I show the final term is positive by considering the two cases in which $\eta \geq 0$ and $\eta < 0$. First consider the case $\eta \geq 0$. Then, $\lambda + \eta \leq 1$ implies that $\lambda \leq 1 - \eta$. We thus have:

$$
2\eta\left(u'\left(x_H\right) - u'\left(x_L\right)\right)\left(2\lambda - 1\right) + \left(1 - 4\eta^2\right)\left(u'\left(x_H\right) + u'\left(x_L\right)\right)
\tag{30}
$$

$$
\geq 2\eta\left(u'\left(x_H\right) - u'\left(x_L\right)\right)\left(2\left(1 - \eta\right) - 1\right) + \left(1 - 2\eta\right)\left(1 + 2\eta\right)\left(u'\left(x_H\right) + u'\left(x_L\right)\right)
$$

$$
= \left(1 - 2\eta\right)\left(u'\left(x_H\right)\left(1 + 4\eta\right) + u'\left(x_L\right) + 4A\eta\right) \geq 0,
$$

with equality only when $\eta = \frac{1}{2}$. However, note that $\eta = \frac{1}{2}$ can only occur when $\lambda = \frac{1}{2}$, in which case λ cannot be increased any further; thus, it must be the case this expression is strictly positive. Next, consider

the case in which $\eta < 0$. Note that $\lambda + \eta > \frac{1}{2}$ implies $\lambda > \frac{1}{2} - \eta$ such that:

$$2\eta \left(u' \left(x_H \right) - u' \left(x_L \right) \right) \left(2\lambda - 1 \right) + \left(1 - 4\eta^2 \right) \left(u' \left(x_H \right) + u' \left(x_L \right) \right) \tag{31}$$

$$> \ 2\eta \left(u' \left(x_H \right) - u' \left(x_L \right) \right) \left[2 \left(\frac{1}{2} - \eta \right) - 1 \right] + \left(1 - 2\eta \right) \left(1 + 2\eta \right) \left(u' \left(x_H \right) + u' \left(x_L \right) \right)$$

$$= \ \left(1 - 8\eta^2 \right) u' \left(x_H \right) + u' \left(x_L \right)$$

$$\geq \ 2 \left(1 - 4\eta^2 \right) u' \left(x_H \right) \geq 0.$$

Proof of Part 4) Let $P_1^* \left(\tilde{y} \right)$ be the observed equity price at time 1 given a report $\tilde{y}$. Note that because P_0 is unaffected by disclosure's properties, nothing may be learned from this price. Next, note that an arbitrary two-dimensional vector (λ, η) cannot be derived from the single equation:

$$P_1^* \left(\tilde{y} \right) \ = \ I \left(\tilde{y} = y_H \right) \frac{\frac{\lambda - \eta}{1 - 2\eta} x_H u' \left(x_H \right) + \left(1 - \frac{\lambda - \eta}{1 - 2\eta} \right) x_L u' \left(x_L \right)}{\frac{\lambda - \eta}{1 - 2\eta} u' \left(x_H \right) + \left(1 - \frac{\lambda - \eta}{1 - 2\eta} \right) u' \left(x_L \right)} \tag{32}$$

$$+ I \left(\tilde{y} = y_L \right) \frac{\frac{1 + \eta - \lambda}{2\eta + 1} x_H u' \left(x_H \right) + \left(1 - \frac{1 + \eta - \lambda}{2\eta + 1} \right) x_L u' \left(x_L \right)}{\frac{1 + \eta - \lambda}{2\eta + 1} u' \left(x_H \right) + \left(1 - \frac{1 + \eta - \lambda}{2\eta + 1} \right) u' \left(x_L \right)}.$$

■

Proof of Proposition 2. Again, applying Lemma 5, the price of an option with strike $k \in \left(P_1 \left(y_L \right), P_1 \left(y_H \right) \right)$ is equal to:

$$\Phi^C \left(k \right) = 2 \frac{\left(P_1 \left(y_H \right) - k \right) \left[\Pr \left(\tilde{x} = x_H, \tilde{y} = y_H \right) u' \left(x_H \right) + \Pr \left(\tilde{x} = x_L, \tilde{y} = y_H \right) u' \left(x_L \right) \right]}{u' \left(x_H \right) + u' \left(x_L \right)}. \tag{33}$$

Substituting the expression for $P_1 \left(y_H \right)$ and simplifying yields:

$$\Phi^C \left(k \right) \ = \ 2 \Pr \left(\tilde{y} = y_H \right) \frac{\Pr \left(\tilde{x} = x_H | y_H \right) \left(x_H - k \right) u' \left(x_H \right) + \Pr \left(\tilde{x} = x_L | y_H \right) \left(x_L - k \right) u' \left(x_L \right)}{u' \left(x_H \right) + u' \left(x_L \right)} \tag{34}$$

$$= \ \frac{\left(\lambda - \eta \right) \left(x_H - k \right) u' \left(x_H \right) + \left(1 - \lambda - \eta \right) \left(x_L - k \right) u' \left(x_L \right)}{u' \left(x_H \right) + u' \left(x_L \right)}.$$

Proof of Part 1) Consider two utility functions u_1 and u_2 such that u_1 is more risk averse than u_2. Without loss of generality (since utilities are ordinal), normalize $u_1' \left(x_L \right) = u_2' \left(x_L \right) = \nu$. Let $A_i \equiv \frac{u_i'(x_H)}{u_i'(x_H) + u_i'(x_L)}$; I

show now that $A_2 > A_1$. Note first that:

$$
\begin{aligned}
A_2 &> A_1 \\
&\Leftrightarrow \frac{u_2'(x_H)}{u_2'(x_H) + \nu} > \frac{u_1'(x_H)}{u_1'(x_H) + \nu} \\
&\Leftrightarrow u_2'(x_H) > u_1'(x_H).
\end{aligned}
\tag{35}
$$

To see that $u_2'(x_H) > u_1'(x_H)$, note:

$$
\begin{aligned}
u_1(x_L) &= u_2(x_L) = \nu \text{ and } u_1(\cdot) = g(u_2(\cdot)) \\
&\implies g'(u_2(x_L)) u_2'(x_L) = u_2'(x_L) \\
&\implies g'(u_2(x_L)) = 1 \\
&\implies g'(u_2(x_H)) < 1.
\end{aligned}
\tag{36}
$$

Finally, using the fact that $u_1'(x_H) = g'(u_2(x_H)) u_2'(x_H)$, we have desired result. Now, note that given a utility function $u_i(\cdot)$, $\Phi(k)$ may be expressed as:

$$
\Phi^C(k) = (\lambda - \eta)(x_H - k) A_i + (1 - \lambda - \eta)(x_L - k)(1 - A_i).
\tag{37}
$$

Differentiating with respect to A_i yields:

$$
\frac{\partial \Phi^C(k)}{\partial A_i} = (\lambda - \eta)(x_H - k) - (1 - \lambda - \eta)(x_L - k).
\tag{38}
$$

Note that this is decreasing in k and equal to zero when $k = \frac{(\lambda - \eta)x_H - (1 - \lambda - \eta)x_L}{2\lambda - 1}$, the post-disclosure price of the firm when the investor is risk neutral and $\tilde{y} = y_H$. As this is an upper bound on the price of the firm given risk-aversion, any k with strike greater than this value pays off zero always. This completes the proof.

Proof of Part 2) Differentiating expression (34) with respect to λ yields:

$$
\begin{aligned}
\frac{\partial \Phi^C(k)}{\partial \lambda} &= \frac{\partial}{\partial \lambda} \frac{(\lambda - \eta)(x_H - k) u'(x_H) + (1 - \lambda - \eta)(x_L - k) u'(x_L)}{u'(x_H) + u'(x_L)} \\
&= \frac{u'(x_H)(x_H - k) - u'(x_L)(x_L - k)}{u'(x_H) + u'(x_L)}.
\end{aligned}
\tag{39}
$$

Note that, because $k \in (x_L, x_H)$, this expression is definitively positive. To prove that this increases in $x_H - x_L$, note that:

$$
\frac{\partial}{\partial (x_H - x_L)} \frac{u'(x_H)(x_H - k) - u'(x_L)(x_L - k)}{u'(x_H) + u'(x_L)} = 1 > 0.
\tag{40}
$$

Proof of Part 3) Differentiating expression (34) with respect to η yields:

$$\begin{aligned}\frac{\partial \Phi^C (k)}{\partial \eta} &= \frac{\partial}{\partial \eta} \frac{(\lambda - \eta)(x_H - k) u'(x_H) + (1 - \lambda - \eta)(x_L - k) u'(x_L)}{u'(x_H) + u'(x_L)} \\ &= -\frac{u'(x_H)(x_H - k) + u'(x_L)(x_L - k)}{u'(x_H) + u'(x_L)}.\end{aligned} \tag{41}$$

Setting $\frac{u'(x_H)(x_H - k) + u'(x_L)(x_L - k)}{u'(x_H) + u'(x_L)} = 0$ yields $k = \frac{u'(x_H)x_H + u'(x_L)x_L}{u'(x_H) + u'(x_L)}$. Furthermore, note that this expression is decreasing in k; this implies it is positive for $k < \frac{u'(x_H)x_H + u'(x_L)x_L}{u'(x_H) + u'(x_L)}$ and negative for $k > \frac{u'(x_H)x_H + u'(x_L)x_L}{u'(x_H) + u'(x_L)}$.

Proof of Part 4) Note that examining the observed option prices with strikes x_L and $\frac{x_H + x_L}{2}$ yields an invertible system of equations in η and λ (these strikes were chosen arbitrarily in the interval (x_L, x_H):

$$\begin{aligned}\Phi^C (x_L) &= \frac{(\lambda - \eta)(x_H - x_L) u'(x_H)}{u'(x_H) + u'(x_L)} \\ \Phi^C \left(\frac{x_H + x_L}{2}\right) &= \frac{(\lambda - \eta)\left(\frac{x_H - x_L}{2}\right) u'(x_H) - (1 - \lambda - \eta)\left(\frac{x_L - x_H}{2}\right) u'(x_L)}{u'(x_H) + u'(x_L)}.\end{aligned} \tag{42}$$

∎

Proof of Corollary 2. Proof of Part 1) To see this, note that:

$$\begin{aligned}\frac{\partial^2 \Phi^C (k)}{\partial \lambda \partial A_i} &= \frac{\partial}{\partial A_i} [A_i (x_H - k) - (1 - A_i)(x_L - k)] \\ &= x_H + x_L - 2k,\end{aligned} \tag{43}$$

which has the sign of $\frac{x_H + x_L}{2} - k$.

Proof of Part 2) Note that:

$$\begin{aligned}\frac{\partial \Phi^C (k)}{\partial \eta \partial A_i} &= -\frac{\partial}{\partial A_i} [A_i (x_H - k) + (1 - A_i)(x_L - k)] \\ &= x_L - x_H < 0.\end{aligned} \tag{44}$$

Since an increase in risk aversion translates to a decrease in A_i and an increase in disclosure's informativeness for good-versus-bad news translates to an increase in η, this proves the result. ∎

Proof of Lemma 4. Let $(\Omega, \mathcal{F}, \Pi)$ now denote the probability space generating the distribution of $\{E_t (\tilde{o})\}_{t \in [0,T]}$, $\tilde{o}$, $\tilde{d}$ and $\tilde{y}$ denoted in the text and let $\{\mathcal{F}_t : t \in [0,T]\}$ denote the filtration generated by the Brownian motion B_t. I show that Lemma 5 extends to this setting. To see this, I appeal to the result from martingale-pricing theory (e.g., Duffie (2010) pg. 217), that states when markets are complete and attention is restricted to the standard definition of admissible trading strategies, the investor's optimization problem

may be written:

$$\max_{\substack{c(\omega) \\ \forall \omega \in \Omega}} \int u\left(c\left(\omega\right)\right) d\Pi\left(\omega\right) \tag{45}$$

$$\text{s.t.} \quad \int c\left(\omega\right) \pi\left(\omega\right) d\Pi\left(\omega\right) = W_0,$$

where $\pi\left(\cdot\right)$ is the unique stochastic discount factor. As in the proof of Lemma 5, taking first-order conditions and substituting the market-clearing condition yields $\pi\left(\omega\right) = \frac{u'(x(\omega))}{E[u'(x(\omega))]}$. The expressions for the prices of the equity and options now follow directly from the definition of the stochastic discount factor. To see that the equity price exhibits a jump with probability 1 on the disclosure date, note that:

$$P_{\tau_D} - \lim_{t \to \tau_D^-} P_t \tag{46}$$

$$= \frac{E_{\tau_D}\left[\tilde{x}u'\left(\tilde{x}\right)\right]}{E_{\tau_D}\left[u'\left(\tilde{x}\right)\right]} - \lim_{t \to \tau_D^-} \frac{E_t\left[\tilde{x}u'\left(\tilde{x}\right)\right]}{E_t\left[u'\left(\tilde{x}\right)\right]}$$

$$= \frac{E_{\tau_D}\left[\tilde{d}u'\left(\tilde{x}\right)\right]}{E_{\tau_D}\left[u'\left(\tilde{x}\right)\right]} - \lim_{t \to \tau_D^-} \frac{E_t\left[\tilde{d}u'\left(\tilde{x}\right)\right]}{E_t\left[u'\left(\tilde{x}\right)\right]}.$$

This is positive for $\tilde{y} = y_H$ and negative for $\tilde{y} = y_L$. Option prices may likewise be shown to jump. ∎

Proof of Proposition 4. To begin, I prove the following lemma.

Lemma 6 *Let $\Phi^D\left(k; u\left(\cdot\right)\right)$ and $P^D\left(u\left(\cdot\right)\right)$ represent the price of the call option with strike k and the pre-disclosure price of the equity, respectively, in Section 3 when the representative investor has utility function $u\left(\cdot\right)$. There exists an increasing concave function $h\left(\cdot\right)$ such that:*

$$\lim_{t \to \tau_D^-} \Phi_t^C\left(P_t, k, \tau_D\right) = \Phi^D\left(k + P^D\left(h\left(\cdot\right)\right) - \lim_{t \to \tau_D^-} P_t; h\left(\cdot\right)\right). \tag{47}$$

Proof. First, note that P_{τ_D} may be written:

$$P_{\tau_D} = \frac{E\left[\left(\tilde{d} + \tilde{o}\right) u'\left(\tilde{d} + \tilde{o}\right) | \tilde{y}, \mathcal{F}_{\tau_D}\right]}{E\left[u'\left(\tilde{d} + \tilde{o}\right) | \tilde{y}, \mathcal{F}_{\tau_D}\right]} \tag{48}$$

$$= \frac{E\left\{E\left[\left(\tilde{d} + \tilde{o}\right) u'\left(\tilde{d} + \tilde{o}\right) | \tilde{d}, \mathcal{F}_{\tau_D}\right] | \tilde{y}, \mathcal{F}_{\tau_D}\right\}}{E\left[u'\left(\tilde{d} + \tilde{o}\right) | \tilde{y}, \mathcal{F}_{\tau_D}\right]}$$

$$= \frac{\Pr\left(x_H | \tilde{y}\right) x_H E\left[u'\left(x_H + \tilde{o}\right) | \mathcal{F}_{\tau_D}\right] + \Pr\left(x_L | \tilde{y}\right) x_L E\left[u'\left(x_L + \tilde{o}\right) | \mathcal{F}_{\tau_D}\right] + E\left[\tilde{o}u'\left(\tilde{d} + \tilde{o}\right) | \mathcal{F}_{\tau_D}\right]}{\Pr\left(x_H | \tilde{y}\right) E\left[u'\left(x_H + \tilde{o}\right) | \mathcal{F}_{\tau_D}\right] + \Pr\left(x_L | \tilde{y}\right) E\left[u'\left(x_L + \tilde{o}\right) | \mathcal{F}_{\tau_D}\right]}$$

$$= \frac{\Pr\left(x_H | \tilde{y}\right) x_H h'\left(x_H\right) + \Pr\left(x_L | \tilde{y}\right) x_L h'\left(x_L\right) + E\left[\tilde{o}u'\left(\tilde{d} + \tilde{o}\right) | \mathcal{F}_{\tau_D}\right]}{\Pr\left(x_H | \tilde{y}\right) h'\left(x_H\right) + \Pr\left(x_L | \tilde{y}\right) h'\left(x_L\right)},$$

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where $h(z) \equiv E[u(\tilde{o}+z)|\mathcal{F}_{\tau_D}]$. I note that $h(z)$ is increasing and concave, which follows from differentiation. Now, we can write:

$$\lim_{t\to\tau_D^-} \Phi_t^C(P_t, k, \tau_D) \tag{49}$$

$$= \lim_{t\to\tau_D^-} E\left[\max\left(\frac{\Pr(x_H|\tilde{y})\, x_H h'(x_H) + \Pr(x_L|\tilde{y})\, x_L h'(x_L) + E\left[\tilde{o}u'\left(\tilde{d}+\tilde{o}\right)|\mathcal{F}_{\tau_D}\right]}{\Pr(x_H|\tilde{y})\, h'(x_H) + \Pr(x_L|\tilde{y})\, h'(x_L)} - k, 0\right) u'(\tilde{x})\,|\mathcal{F}_t\right]$$

$$= \lim_{t\to\tau_D^-} E\left[\max\left(\frac{\Pr(x_H|\tilde{y})\, x_H h'(x_H) + \Pr(x_L|\tilde{y})\, x_L h'(x_L)}{\Pr(x_H|\tilde{y})\, h'(x_H) + \Pr(x_L|\tilde{y})\, h'(x_L)} - k^*(\mathcal{F}_t), 0\right) u'(\tilde{x})\,|\mathcal{F}_t\right],$$

where $k^*(\mathcal{F}_t) = k - \frac{E\left[\tilde{o}u'\left(\tilde{d}+\tilde{o}\right)|\mathcal{F}_{\tau_D}\right]}{\Pr(x_H|\tilde{y})h'(x_H) + \Pr(x_L|\tilde{y})h'(x_L)}$ is adapted to $\mathcal{F}_t$. Applying the law-of-iterated expectations:

$$\lim_{t\to\tau_D^-} E\left[\max\left(\frac{\Pr(x_H|\tilde{y})\, x_H h'(x_H) + \Pr(x_L|\tilde{y})\, x_L h'(x_L)}{\Pr(x_H|\tilde{y})\, h'(x_H) + \Pr(x_L|\tilde{y})\, h'(x_L)} - k^*(\mathcal{F}_{\tau_D}), 0\right) u'(\tilde{x})\,|\mathcal{F}_t\right] \tag{50}$$

$$= \lim_{t\to\tau_D^-} E\left[\max\left(\frac{\Pr(x_H|\tilde{y})\, x_H h'(x_H) + \Pr(x_L|\tilde{y})\, x_L h'(x_L)}{\Pr(x_H|\tilde{y})\, h'(x_H) + \Pr(x_L|\tilde{y})\, h'(x_L)} - k^*(\mathcal{F}_{\tau_D}), 0\right) h'\left(\tilde{d}\right)|\mathcal{F}_t\right]$$

$$+ \lim_{t\to\tau_D^-} E\left[\max\left(\frac{\Pr(x_H|\tilde{y})\, x_H h'(x_H) + \Pr(x_L|\tilde{y})\, x_L h'(x_L)}{\Pr(x_H|\tilde{y})\, h'(x_H) + \Pr(x_L|\tilde{y})\, h'(x_L)} - k^*(\mathcal{F}_{\tau_D}), 0\right)|\mathcal{F}_t\right] \lim_{t\to\tau_D^-} E\left[h'\left(\tilde{d}\right) - u'(\tilde{x})|\mathcal{F}_t\right]$$

$$+ \lim_{t\to\tau_D^-} Cov\left[\max\left(\frac{\Pr(x_H|\tilde{y})\, x_H h'(x_H) + \Pr(x_L|\tilde{y})\, x_L h'(x_L)}{\Pr(x_H|\tilde{y})\, h'(x_H) + \Pr(x_L|\tilde{y})\, h'(x_L)} - k^*(\mathcal{F}_{\tau_D}), 0\right), h'\left(\tilde{d}\right) - u'(\tilde{x})|\mathcal{F}_t\right].$$

Note that the second term in this sum is zero. We have:

$$\lim_{t\to\tau_D^-} E\left[h'\left(\tilde{d}\right) - u'(\tilde{x})|\mathcal{F}_t\right] \tag{51}$$

$$= E\left[h'\left(\tilde{d}\right)\right] - \lim_{t\to\tau_D^-} E\left[u'(\tilde{x})|\mathcal{F}_t\right].$$

Now, letting $f_{\tilde{o}}(\cdot|\mathcal{F}_t)$ be the distribution of $\tilde{o}$ given the information available at time t, note that an application of the bounded convergence theorem implies that:[19]

$$\lim_{t\to\tau_D^-} E\left[u'(\tilde{x})|\mathcal{F}_t\right] = \lim_{t\to\tau_D^-} \int_0^\infty u\left(\tilde{d}+z\right) f_{\tilde{o}}(z|\mathcal{F}_t)\, dz \tag{52}$$

$$= \int_0^\infty u\left(\tilde{d}+z\right) \lim_{t\to\tau_D^-} f_{\tilde{o}}(z|\mathcal{F}_t)\, dz$$

$$= \int_0^\infty u\left(\tilde{d}+z\right) f_{\tilde{o}}(z|\mathcal{F}_{\tau_D})\, dz = E\left[u'(\tilde{x})|\mathcal{F}_{\tau_D}\right],$$

---

[19]To apply the theorem, note that for z large, since u is concave, there exists a $c > 0$ such that $u'(z) < c$, and thus for some $a > 0$, $u\left(\tilde{d}+z\right) < a + cz$. Further applying the fact that $f_{\tilde{o}}(z|\mathcal{F}_t)$ is the PDF of a log-normal distribution, this implies that $u\left(\tilde{d}+z\right) f_{\tilde{o}}(z|\mathcal{F}_t) \to 0$ as $z \to \infty$ $\forall t \in [0, \tau_D]$. From here, we can easily construct a bound on $u\left(\tilde{d}+z\right) f_{\tilde{o}}(z|\mathcal{F}_t)$.

where the last line follows from the fact that the distribution of $\tilde{o}$ given $\mathcal{F}_t$ is continuous in t for any trajectory of this distribution, since it is log-normal with continuously evolving mean and variance parameters. Furthermore, by the definition of $h\left(\cdot\right)$, $h\left(\hat{d}\right) = E\left[u\left(\tilde{x}\right)|\mathcal{F}_{\tau_D}\right]$, and thus $\lim_{t\to\tau_D^-} E\left[h'\left(\hat{d}\right) - u'\left(\tilde{x}\right)|\mathcal{F}_t\right] = 0$. Next, note that the third term in the sum is zero. To see this, we have that $\frac{\Pr(x_H|\tilde{y})x_H h'(x_H)+\Pr(x_L|\tilde{y})x_L h'(x_L)}{\Pr(x_H|\tilde{y})h'(x_H)+\Pr(x_L|\tilde{y})h'(x_L)} - k^*\left(\mathcal{F}_{\tau_D}\right)$ is non-random conditional on $\tilde{y}$ and $\mathcal{F}_{\tau_D}$ and $h'\left(\hat{d}\right) - u'\left(\tilde{x}\right)$ is not affected by either $\tilde{y}$ or $\mathcal{F}_{\tau_D}$. Therefore,

$$\lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D\right) = E\left[\max\left(\frac{\Pr\left(x_H|\tilde{y}\right)x_H h'\left(x_H\right) + \Pr\left(x_L|\tilde{y}\right)x_L h'\left(x_L\right)}{\Pr\left(x_H|\tilde{y}\right)h'\left(x_H\right) + \Pr\left(x_L|\tilde{y}\right)h'\left(x_L\right)} - k^*\left(\mathcal{F}_{\tau_D}\right), 0\right) h'\left(\tilde{y}\right)|\mathcal{F}_{\tau_D}\right].$$
(53)

This is equal to $\Phi^D\left(k + P^D\left(h\left(\cdot\right)\right) - \lim_{t\to\tau_D^-} P_{\tau_D}; h\left(\cdot\right)\right)$. To see this, recall that the post-disclosure option price in Section 3 equals $\frac{\Pr(x_H|\tilde{y})x_H h'(x_H)+\Pr(x_L|\tilde{y})x_L h'(x_L)}{\Pr(x_H|\tilde{y})h'(x_H)+\Pr(x_L|\tilde{y})h'(x_L)}$ given a disclosure $\tilde{y}$, and $k^*\left(\mathcal{F}_t\right) = k - \frac{E\left[\tilde{o}u'\left(\tilde{d}+\tilde{o}\right)|\mathcal{F}_{\tau_D}\right]}{\Pr(x_H|\tilde{y})h'(x_H)+\Pr(x_L|\tilde{y})h'(x_L)} = k - \left[\lim_{t\to\tau_D^-} P_{\tau_D} - P^D\left(h\left(\cdot\right)\right)\right]$. ∎

Note that Proposition 2 implies that an increase in risk aversion or a decrease in λ leads to a decrease in $\Phi^D\left(k; h\left(\cdot\right)\right)$ for any k and risk-averse $h\left(\cdot\right)$. Thus, by the previous lemma, that parts 1) and 2) of the proposition generalize to the continuous-trade setting. Next, applying part 3) of Proposition 2 and the prior lemma, we have that $\lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D\right)$ increases in η when $k - P^D\left(h\left(\cdot\right)\right) - \lim_{t\to\tau_D^-} P_{\tau_D} < P^D\left(h\left(\cdot\right)\right)$ and decreases in η otherwise. Note that this condition may be written:

$$
\begin{aligned}
k + P^D\left(h\left(\cdot\right)\right) - \lim_{t\to\tau_D^-} P_{\tau_D} &< P^D\left(h\left(\cdot\right)\right) \\
k &< \lim_{t\to\tau_D^-} P_{\tau_D},
\end{aligned}
$$
(54)

which is exactly the condition for the option to be ITM prior to the disclosure; this demonstrates that part 3) of Proposition 2 generalizes to the continuous-trade setting. Finally, part 4) of the proposition follows again from considering the price of options with two strikes; this yields an invertible set of equations in λ and η.

I next prove that the results in Corollary 2 generalize to continuous time when $u\left(\cdot\right)$ exhibits non-increasing risk aversion. To do so, I utilize the following result, which is a restatement of Gollier (2004), Proposition 24.

Lemma 7 *Suppose u_1 and u_2 are increasing concave utility functions and that one of these functions exhibits non-increasing absolute risk aversion. If $u_1\left(\cdot\right)$ is more risk averse than $u_2\left(\cdot\right)$ in the sense of Arrow-Pratt, then $u_1^*\left(r\right) \equiv E\left[u_1\left(r + \tilde{z}\right)\right]$ is more risk averse than $u_2^*\left(r\right) \equiv E\left[u_2\left(r + \tilde{z}\right)\right]$ for any random variable $\tilde{z}$ that is independent of all other modeled risks.*

Using this result, it is easily seen that an increase in the risk aversion of $u(\cdot)$ likewise increases the risk aversion of the function $h(\cdot)$ defined in Lemma 6. Thus, we may again apply the arguments in the proof of Corollary 2 to the continuous-trade setting. ∎

Proof of Proposition 4. First, I show that pre-disclosure option prices rise in the disclosure's informativeness. Given that the investor is risk neutral, we have that for $t > \tau_D$, $P_t = E_t[\tilde{o}] + \tilde{\xi}_{R_i}$. Since $E_t[\tilde{o}]$ is independent of $\tilde{\xi}_{R_i}$ and has the same distribution under R_1 and R_2, the distribution of P_t as of time any time $t > \tau_D$ under R_2 is second-order stochastic dominated by this distribution under R_1. I next prove the following lemma.

Lemma 8 *The call option price $\Phi_t^C(P_t, k, \tau_M; R_i)$ following the disclosure ($\tau_M > \tau_D$), which is implicitly a function of $\tilde{\xi}_{R_i}$ through P_t, is convex in $\tilde{\xi}_{R_i}$.*

Proof. Applying the law of iterated expectations, we have:

$$
\begin{aligned}
\Phi_t^C(P_t, k, \tau_M; R_i) &= E_t\left[\max\left(E[\tilde{o}|\mathcal{F}_{\tau_M}] + \tilde{\xi}_{R_i} - k, 0\right)\right] \qquad (55)\\
&= E_t\left\{E_t\left[\max\left(E[\tilde{o}|\mathcal{F}_{\tau_M}] + \tilde{\xi}_{R_i} - k, 0\right)|\tilde{\xi}_{R_i}\right]\right\}\\
&= E_t\left[g_t\left(\tilde{\xi}_{R_i}\right)\right],
\end{aligned}
$$

where $g_t(z) \equiv E_t[\max(E[\tilde{o}|\mathcal{F}_{\tau_M}] + z - k, 0)]$. Note that $\Phi_t^C(P_t, k, \tau_M; R_i)$ is convex in $\tilde{\xi}_{R_i}$ if and only if g_t is convex. This holds because $g_t(z)$ has a bounded derivative, and thus, by the dominated convergence theorem, $\frac{\partial^2}{\partial z^2} E_t[g_t(z)] = E_t\left[\frac{\partial^2}{\partial z^2} g_t(z)\right]$. To see that g_t is convex, let $f_{E[\tilde{o}|\mathcal{F}_{t_2}]|\mathcal{F}_{t_1}}(\cdot)$ denote the density function of $E[\tilde{o}|\mathcal{F}_{\tau_2}]$ given the information available at time $t_1 < t_2$. We have that:

$$
\begin{aligned}
\frac{\partial^2 g_t}{\partial z^2} &= \frac{d^2}{dz^2} \int_{k-z}^{\infty} (q + z - k) f_{E[\tilde{o}|\mathcal{F}_{\tau_M}]|\mathcal{F}_t}(q)\, dq \qquad (56)\\
&= \frac{\partial}{\partial x} \int_{k-z}^{\infty} f_{E[\tilde{o}|\mathcal{F}_{\tau_M}]|\mathcal{F}_t}(q)\, dq\\
&= f_{E[\tilde{o}|\mathcal{F}_{\tau_M}]|\mathcal{F}_t}(k - z)(k - z) > 0.
\end{aligned}
$$

∎

Now, applying second-order stochastic dominance, we have that $\Phi_t^C(P_t, k, \tau_M; R_2) > \Phi_t^C(P_t, k, \tau_M; R_1)$. Next, I show if all pre-disclosure option prices are higher under R_2 than R_1, R_2 must be more informative

than R_1. Note that:

$$\lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_i\right) = \lim_{t\to\tau_D^-} E\left[\max\left(E_{\tau_D}\left[\tilde{o}\right] + E\left[\tilde{d}|\tilde{y}; R_i\right] - k, 0\right)|\mathcal{F}_t\right] \tag{57}$$

$$= \int_{\rho(k)}^{d_H} \left(E_{\tau_D}\left[\tilde{o}\right] + q - k\right) f_{\tilde{\xi}_{R_i}}\left(q\right) dq.$$

where $\rho\left(k\right) \equiv k - E_{\tau_D}\left[\tilde{o}\right]$. Applying integration by parts, we can show that this expression equals $\int_{\rho(k)}^{d_H}\left(1 - F_{\tilde{\xi}_{R_i}}\left(q\right)\right) dq$ and that $E\left[\tilde{\xi}_{R_i}\right] = \int_0^{d_H}\left(1 - F_{\tilde{\xi}_{R_i}}\left(q\right)\right) dq - \int_{d_L}^0 F_{\tilde{\xi}_{R_i}}\left(q\right) dq$. Thus, we have:

$$\lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_i\right) \tag{58}$$

$$= \int_0^{d_H}\left(1 - F_{\tilde{\xi}_{R_i}}\left(q\right)\right) dq - \int_0^{\rho(k)}\left(1 - F_{\tilde{\xi}_{R_i}}\left(q\right)\right) dq - \int_{d_L}^0 F_{\tilde{\xi}_{R_i}}\left(q\right) dq + \int_{d_L}^0 F_{\tilde{\xi}_{R_i}}\left(q\right) dq$$

$$= \int_0^{d_H}\left(1 - F_{\tilde{\xi}_{R_i}}\left(q\right)\right) dq - \int_{d_L}^0 F_{\tilde{\xi}_{R_i}}\left(q\right) dq - \rho\left(k\right) + \int_{d_L}^{\rho(k)} F_{\tilde{\xi}_{R_i}}\left(q\right) dq$$

$$= \int_{d_L}^{\rho(k)} F_{\tilde{\xi}_{R_i}}\left(q\right) dq - \rho\left(k\right).$$

Now, using the fact that $\rho\left(k\right)$ does not depend upon the disclosure regime R_i, we have:

$$\lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_2\right) - \lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_1\right)$$

$$= \int_{d_L}^{\rho(k)}\left[F_{\tilde{\xi}_{R_2}}\left(q\right) - F_{\tilde{\xi}_{R_1}}\left(q\right)\right] dq. \tag{59}$$

By assumption, $\lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_2\right) > \lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_1\right) \ \forall k$. By varying t and using expression (59), this implies $\int_{d_L}^q \left[F_{\tilde{\xi}_{R_2}}\left(t\right) - F_{\tilde{\xi}_{R_1}}\left(t\right)\right] dt > 0$. ∎

Proof of Proposition 5. First, I demonstrate that Definition 2 is sufficient for the results to hold. From expression (59), we have:

$$\int_{d_L}^{\rho(k)}\left[F_{\tilde{\xi}_{R_2}}\left(q\right) - F_{\tilde{\xi}_{R_1}}\left(q\right)\right] dq = \lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_2\right) - \lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_1\right). \tag{60}$$

If R_2 is more informative for good-versus-bad news than R_1, the left hand side of this equation is positive when $\rho\left(k\right) > E\left[\tilde{d}\right]$, i.e., when $k - E_{\tau_D}\left[\tilde{o}\right] > E\left[\tilde{d}\right]$, and negative otherwise. Note that $k - E_{\tau_D}\left[\tilde{o}\right] > E\left[\tilde{d}\right]$ states that the option is OTM prior to the disclosure since $\lim_{t\to\tau_D^-} P_t = E\left[\tilde{d}\right] + E_{\tau_D}\left[\tilde{o}\right]$. Necessity of Definition 2 follows similarly, since, if $\lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_2\right) - \lim_{t\to\tau_D^-} \Phi_t^C\left(P_t, k, \tau_D; R_1\right)$ crosses zero in k from below when $k - E_{\tau_D}\left[\tilde{o}\right] = E\left[\tilde{d}\right]$, the equation implies $\int_{d_L}^z \left[F_{\tilde{\xi}_{R_2}}\left(q\right) - F_{\tilde{\xi}_{R_1}}\left(q\right)\right] dq$ must cross zero from below when $z = E\left(d\right)$. ∎

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Proof of Proposition 6. Note that investor i maximizes the following objective function as a function of consumption $c_i(\omega)$:

$$E_i[u(c_i(\omega))] = \int_{\omega \in \Omega} u(c_i(\omega)) d\Pi_i(\omega). \tag{61}$$

Let $\Pi(\omega) = \int \Pi_i(\omega) di$ denote the average investor belief, and let $\tilde{\kappa}_i$ denote the Radon-Nikodym derivative of Π_i with respect to Π. Then, we can write the investor's objective as:

$$E_\Pi[\tilde{\kappa}_i u(\tilde{c}_i)] \equiv \int_{\omega \in \Omega} \kappa_i(\omega) u(c_i(\omega)) d\Pi(\omega). \tag{62}$$

Now, the First Welfare Theorem implies that the competitive equilibrium in the model is Pareto optimal, which implies that the equilibrium allocation of wealth, $\{c_i(\omega)\}_{i \in [0,1]}$ solves the following maximization problem for some positive function $\lambda(i)$:

$$\max \int \lambda(i) E_\Pi[\tilde{\kappa}_i u(\tilde{c}_i)] di \tag{63}$$

$$\text{subject to} \quad \int c_i(\omega) di \quad = \quad x_i(\omega).$$

Let $u_i^*(t) = E_\Pi[\tilde{\kappa}_i u(\tilde{c}_i)|\tilde{c}_i = t]$. It is easily seen that u^* is increasing and concave by differentiation. Moreover, applying iterated expectations, we can rewrite maximization problem (63) as:

$$\max \int \lambda(i) E_\Pi[u_i^*(\tilde{c}_i)] di \tag{64}$$

$$\text{subject to} \int_i c_i(\omega) di \quad = \quad x_i(\omega).$$

Standard results now imply that there exists a representative agent with concave utility $u^*(\cdot)$ equal to the value function of this maximization problem and beliefs Π (see, e.g., Back (2010) pg. 122). ∎

References

[1] Atilgan, Yigit. "Volatility spreads and earnings announcement returns." Journal of Banking & Finance 38 (2014): 205-215.

[2] Back, Kerry. Asset pricing and portfolio choice theory. Oxford University Press, (2010).

[3] Bakshi, Gurdip, Charles Cao, and Zhiwu Chen. "Empirical performance of alternative option pricing models." The Journal of Finance 52.5 (1997): 2003-2049.

[4] Bakshi, Gurdip, Nikunj Kapadia, and Dilip Madan. "Stock return characteristics, skew laws, and the differential pricing of individual equity options." The Review of Financial Studies 16.1 (2003): 101-143.

[5] Bagnoli, Mark, and Susan G. Watts. "Conservative accounting choices." Management Science 51.5 (2005): 786-801.

[6] Basu, Sudipta. "The conservatism principle and the asymmetric timeliness of earnings." Journal of Accounting and Economics 24.1 (1997): 3-37.

[7] Bates, David. "Jumps and stochastic volatility: exchange rate processes implicit in Deutsche mark options." Review of Financial Studies 9 (1996): 69-107.

[8] Beaver, William H. "The information content of annual earnings announcements." Journal of Accounting Research 6 (1968): 67-92.

[9] Bertomeu, Jeremy, Masako Darrough, and Wenjie Xue. "Optimal conservatism with earnings manipulation." Contemporary Accounting Research (2016): 252-284.

[10] Beyer, Anne. "Conservatism and aggregation: The effect on cost of equity capital and the efficiency of debt contracts." (2013). Working.

[11] Billings, Mary Brooke, Robert Jennings, and Baruch Lev. "On guidance and volatility." Journal of Accounting and Economics 60.2 (2015): 161-180.

[12] Breeden, Douglas T., and Robert H. Litzenberger. "Prices of state-contingent claims implicit in option prices." The Journal of Business 51.4 (1978): 621-651.

[13] Britten-Jones, Mark, and Anthony Neuberger. "Option prices, implied price processes, and stochastic volatility." The Journal of Finance 55.2 (2000): 839-866.

[14] Buraschi, Andrea, and Alexei Jiltsov. "Model uncertainty and option markets with heterogeneous beliefs." The Journal of Finance 61.6 (2006): 2841-2897.

[15] Callen, Jeffrey L., and Matthew R. Lyle. "The term structure of implied costs of equity capital." (2014). Working.

[16] Chen, Q., T. Hemmer, and Y. Zhang. "On the relation between conservatism in accounting standards and incentives for earnings management." Journal of Accounting Research, 45.3 (2007): 541-565.

[17] Christensen, Peter, de la Rosa, L., and E. Feltham. Information and the cost of capital: An ex ante perspective. The Accounting Review, 85.3 (2010): 817-848.

[18] Derman, Emanuel, and Michael B. Miller. The Volatility Smile. John Wiley & Sons, 2016.

[19] Diavatopoulos, Dean, et al. "The information content of implied skewness and kurtosis changes prior to earnings announcements for stock and option returns." Journal of Banking & Finance 36.3 (2012): 786-802.

[20] Dubinsky, Andrew, and Michael Johannes. "Earnings announcements and option prices." (2006). Working.

[21] Duffie, Darrell. Dynamic asset pricing theory. Princeton University Press, (2010).

[22] Dupire, Bruno. Pricing and hedging with smiles. Mathematics of derivative securities. Dempster and Pliska eds., Cambridge Uni. Press, 1997.

[23] Dye, Ronald A. "Disclosure of nonproprietary information." Journal of Accounting Research (1985): 123-145.

[24] Ewert, Ralf, and Alfred Wagenhofer. "Earnings management, conservatism, and earnings quality." Foundations and Trends in Accounting 6.2 (2012): 65-186.

[25] Figlewski, Stephen. "Estimating the Implied Risk Neutral Density." Volatility and time series econometrics: Essays in honor of Robert F. Engle (2009).

[26] Gigler, Frank B., and Thomas Hemmer. "Conservatism, optimal disclosure policy, and the timeliness of financial reports." The Accounting Review 76.4 (2001): 471-493.

[27] Givoly, Dan, and Carla Hayn. "The changing time-series properties of earnings, cash flows and accruals: Has financial reporting become more conservative?" Journal of Accounting and Economics 29.3 (2000): 287-320.

[28] Gollier, Christian. The economics of risk and time. MIT press, 2004.

[29] Gollier, Christian, and Edward Schlee. "Information and the equity premium." Journal of the European Economic Association 9.5 (2011): 871-902.

[30] Guay, Wayne R., and Robert E. Verrecchia. "Conservative disclosure." (2006). Working.

[31] Heston, Steven L. "A closed-form solution for options with stochastic volatility with applications to bond and currency options." Review of Financial Studies 6.2 (1993): 327-343.

[32] Holthausen, Robert W., and Robert E. Verrecchia. "The effect of sequential information releases on the variance of price changes in an intertemporal multi-asset market." Journal of Accounting Research 26.1 (1988): 82-106.

[33] Hull, John, and Alan White. "The pricing of options on assets with stochastic volatilities." The Journal of Finance 42.2 (1987): 281-300.

[34] Jackwerth, Jens Carsten, and Mark Rubinstein. "Recovering probability distributions from option prices." The Journal of Finance 51.5 (1996): 1611-1631.

[35] Jung, Woon-Oh, and Young K. Kwon. "Disclosure when the market is unsure of information endowment of managers." Journal of Accounting Research 26.1 (1988): 146-153.

[36] Kou, Steven G. "A jump-diffusion model for option pricing." Management Science 48.8 (2002): 1086-1101.

[37] Lambert, Richard, Christian Leuz, and Robert E. Verrecchia. "Accounting information, disclosure, and the cost of capital." Journal of Accounting Research 45.2 (2007): 385-420.

[38] Laux, Volker, and Phillip C. Stocken. "Managerial reporting, overoptimism, and litigation risk." Journal of Accounting and Economics 53.3 (2012): 577-591.

[39] Lee, Suzanne S., and Per A. Mykland. "Jumps in financial markets: A new nonparametric test and jump dynamics." Review of Financial Studies 21.6 (2008): 2535-2563.

[40] Lipster, Robert, and Albert Shiryaev. Statistics of Random Processes, Vol. 2: Applications, chapter 13: Conditionally Gaussian Sequences: Filtering and Related Problems. (2001).

[41] Naik, Vasanttilak, and Moon Lee. "General equilibrium pricing of options on the market portfolio with discontinuous returns." Review of Financial Studies 3.4 (1990): 493-521.

[42] Merton, Robert C. "Option pricing when underlying stock returns are discontinuous." Journal of Financial Economics 3.1-2 (1976): 125-144.

[43] Patell, James M., and Mark A. Wolfson. "Anticipated information releases reflected in call option prices." Journal of Accounting and Economics 1.2 (1979): 117-140.

[44] Patell, James M., and Mark A. Wolfson. "The ex ante and ex post price effects of quarterly earnings announcements reflected in option and stock prices." Journal of Accounting Research 19.2 (1981): 434-458.

[45] Pratt, John W. "Risk Aversion in the Small and Large." Econometrica 44.2 (1964): 122-136.

[46] Rogers, Jonathan L., Douglas J. Skinner, and Andrew Van Buskirk. "Earnings guidance and market uncertainty." Journal of Accounting and Economics 48.1 (2009): 90-109.

[47] Ross, Stephen A. "Information and volatility: The no-arbitrage martingale approach to timing and resolution irrelevancy." The Journal of Finance 44.1 (1989): 1-17.

[48] Ross, Stephen A.. "The recovery theorem." The Journal of Finance 70.2 (2015): 615-648.

[49] Scheinkman, Jose A., and Wei Xiong. "Overconfidence and speculative bubbles." Journal of Political Economy 111.6 (2003): 1183-1220.

[50] Suijs, Jeroen. "On the value relevance of asymmetric financial reporting policies." Journal of Accounting Research 46.5 (2008): 1297-1321.

[51] Van Buskirk, Andrew. "Volatility skew, earnings announcements, and the predictability of crashes." (2011). Working.

[52] Vanden, Joel M. "Information quality and options." Review of Financial Studies 21.6 (2008): 2635-2676.

[53] Verrecchia, Robert E. "Discretionary disclosure." Journal of Accounting and Economics 5 (1983): 179-194.

10 Notation

10.1 Sections 2-3

$\tilde{x}$	firm dividend
x_L, x_H	realizations of the firm's dividend
$\tilde{y}$	firm disclosure
y_H, y_L	realized disclosure signals
λ, η	statistical properties of the disclosure
P_t	equity price at time t
k	strike price of an option
$\Phi^C(k)$	price of a call option with strike k
$\Phi^P(k)$	price of a put option with strike k

10.2 Sections 4-6

T	terminal date at which dividend is paid
$\tilde{o}$	component of the firm's dividend orthogonal to the disclosure
$\tilde{d}$	component of the firm's dividend concerned by the disclosure
μ_0, σ_0	initial parameters of market beliefs regarding $\tilde{o}$
μ_t, σ_t	parameters of market beliefs regarding $\tilde{o}$ at date t
B_t	Brownian motion that generates market beliefs
τ_D	date of the disclosure released by the firm
$\Phi_t^C(P_t, k, \tau_M)$	price of a call option at time t given equity price P_t, strike price k, and maturity τ_M
$\Phi_t^P(P_t, k, \tau_M)$	price of a put option at time t given equity price P_t, strike price k, and maturity τ_M
R_i	a disclosure regime; corresponds to the conditional distribution of $\tilde{y}$ given $\tilde{d}$
$\tilde{\xi}_{R_i}$	the conditional expectation of $\tilde{d}$ after the disclosure $\tilde{y}$ under R_i: $E\left(\tilde{d}\vert\tilde{y}; R_i\right)$
λ_i	weight placed on investor i's belief in the representative investor's belief