Option prices and disclosure: theory and measurement

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Abstract

In this paper, I develop an option-pricing model that formally incorporates a disclosure event. Using the model, I first theoretically examine how two properties of the disclosure – its overall informativeness and its informativeness given good relative to bad news – influence the impact that it has on option prices around its release. I then show that, by jointly examining the prices of options with different strikes, a researcher can measure the properties of a single disclosure event, an impossible task using equity prices alone. Finally, I develop and analyze methods of performing this measurement task.

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1 Introduction

Extensive research studies how corporate disclosures, such as earnings announcements and forecasts, affect firms’ stock prices. A major contribution of this literature has been to develop and implement measures of the underlying features of firms’ disclosures that are derived from the stock-market reactions to these disclosures (e.g., earnings response coefficients and measures of asymmetric timeliness). While these methods are based exclusively upon behavior in the stock market, growing evidence suggests that disclosures also strongly impact option markets.\(^1\) Furthermore, for many stocks, investors trade in several option contracts whose prices each contain information regarding investors’ beliefs that is not available from stock prices given options’ unique payoff structures (Breeden and Litzenberger (1978)). This raises the question of whether and how researchers might utilize option-market responses to disclosures to better understand and estimate their underlying features.

To address this question, I develop an option-pricing model that formally incorporates a disclosure event. The disclosure can vary along two dimensions that are focal in the accounting literature: the average amount of information it contains (the disclosure’s “informative-ness”), and the amount of information it contains when it exceeds investors’ expectations relative to when it falls short of these expectations (the disclosure’s “asymmetry”). The disclosure’s informativeness is relevant to studies of disclosure quality and value relevance, while the disclosure’s asymmetry is relevant to studies of accounting conservatism, earnings manipulation, and voluntary disclosure, each of which has been linked to information events that vary in their informativeness for good versus bad news.\(^2\) I begin by analyzing how these two properties of the disclosure influence its effect on option prices. I then demonstrate that a researcher can use option prices prior to a single disclosure event to measure its informativeness and asymmetry, an impossible task using stock prices alone. I conclude

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\(^1\) See Patell and Wolfson (1979, 1981), Rogers, Skinner, and Van Buskirk (2009), Diavatopoulos et al. (2012), Atilgan (2014), and Dubinsky et al. (2018), amongst others.

\(^2\) See, for instance, Basu (1997) for the link between reporting conservatism and asymmetry, Laux and Stocken (2012), Bertomeu, Darrough, and Xue (2015) for the link between earnings manipulation and asymmetry, and Verrecchia (1983) for the link between voluntary disclosure and asymmetry.
by developing and analyzing methods of performing this measurement task.

At the model’s core is a set of risk-averse investors who face uncertainty regarding a firm’s future value and trade in the firm’s stock and options written on the stock. These investors receive both a gradual flow of information regarding the firm’s value and a sudden shock of information that arrives at a time known in advance, which captures a disclosure event. The disclosure event leads to a jump in the firm’s otherwise continuously evolving price, with a distribution that is determined by the disclosure’s informativeness and asymmetry.

I first examine how the disclosure’s properties influence expected option returns on the disclosure date. Option returns around disclosure events are highly significant, but their determinants are not well understood.3 In the model, options earn non-zero returns on the disclosure date if and only if the disclosure contains systematic information; should it contain this information, option returns depend on the disclosure’s informativeness and asymmetry. Specifically, a more informative disclosure leads to greater release-date expected returns to call options of all strikes. The reason is that investors place more weight on such a disclosure, causing it to lead to a larger jump in the stock price (in magnitude). This, in turn, exposes options to greater systematic movements in the stock price on the disclosure date.

Interestingly, an increase in the disclosure’s asymmetry also leads to greater expected returns to call options. To understand this result, consider an earnings release that may reflect either positive or negative news. Should earnings be more informative for good news than bad news, stock 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 stock price upon earnings’ release will exhibit more variation on the upside than the downside, corresponding to return skewness. Importantly, the payoffs to a call option are sensitive to the firm’s price when it moves upwards, but, given the downside protection embedded in a call, are insensitive to the firm’s price when it moves downwards. As a result, the return skewness created by an asymmetric disclosure increases the riskiness of a call

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3For instance, Dubinsky et al. (2018) document median straddle returns below –10% on the date of earnings releases.
I next study the effect of the disclosure’s informativeness and asymmetry on the prices leading up to the disclosure event of call options whose horizons span the disclosure date. To reiterate, an increase in the disclosure’s informativeness leads to a larger absolute jump in the stock price on the disclosure date. Given that options have convex payout structures, this increases the expected payoffs to an option that spans the disclosure event. However, as previously discussed, it also causes call options to become riskier around the announcement, increasing their required returns. Nevertheless, netting these forces, an increase in the disclosure’s informativeness leads to an increase in the pre-disclosure price of an option of any strike. The size of this increase depends upon the extent to which the information in the disclosure is systematic versus idiosyncratic. Next, note again that asymmetry in the disclosure creates positive return skewness on the disclosure date. I find that this skewness 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. The reason is that skewness is associated with the possibility of spikes in the stock price that create large returns to OTM call options.

With these results established, assuming that traders incorporate the properties of a disclosure when pricing options, I move to consider the information that is contained in option prices regarding these properties that is not contained in stock prices. I find that stock prices alone are insufficient for a researcher to measure the properties of a single disclosure event. To see why, consider again a firm announcing its annual earnings. If earnings are above expectations, the magnitude of the resulting stock-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. 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.

4Note these, and the results I discuss next, reverse for put options, given their negative exposure to market risk.
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. Conventional, regression-based stock price measures of disclosure properties, such as earnings-response coefficients, avoid this problem by focusing on the average properties across large samples of stock-price reactions to many disclosure events. These approaches entail substantial information loss, cannot be used to estimate the properties of a single disclosure event, and are subject to econometric challenges (Kothari (2001), Dietrich, Muller, and Riedl (2007)). Focusing on the case in which the disclosure contains idiosyncratic information, I find that option prices in fact enable a researcher to learn the informativeness and asymmetry underlying a single news event. Specifically, the model suggests that option prices prior to the disclosure provide the most direct means deriving the disclosure’s properties, as it predicts a one-to-one mapping between the disclosure’s properties and these prices. I conclude by demonstrating various approaches to backing out a disclosure’s properties from option prices and studying their relative merits using simulations.

My model departs from the approach found in prior work studying option prices around disclosure events (e.g., Patell and Wolfson (1979, 1981), Rogers, Skinner and Van Buskirk (2009), Billings and Jennings (2011)). This work applies the Black-Scholes-Merton (hereafter, BSM) model to demonstrate that, if a disclosure creates an increase in stock price volatility, it will cause option-implied volatility to climb leading up to its release. However, this approach is fundamentally limited by the assumptions implicit in the BSM framework. First, the BSM model is a partial-equilibrium model in that it takes the process followed by a firm’s stock price as a given, which implies that incorporating disclosure into the model requires making an unmodeled assumption on how it affects this process. While this approach is suitable when disclosure can be purely captured a shift in volatility, it cannot be applied to consider disclosures that contain systematic risk and/or are asymmetric, since it is not clear how these features affect the stock-return process. This raises a second concern with the BSM model: it requires that stock returns are normally distributed and continuous over
time, assumptions that are clearly violated around disclosure events. Markets quickly incorporate the information contained in firm disclosures, causing stock prices to jump upon their release (Lee and Mykland (2008), Dubinsky et al. (2018)). In addition, extensive evidence suggests that stock returns around disclosure events often deviate from normality, precisely because they exhibit asymmetry.\(^5\)

Instead, my model fits into the class of general-equilibrium option pricing models, i.e., those which explicitly model price formation in the stock market. In early work, Naik and Lee (1990) develop a general-equilibrium option pricing model in which investors trade in a stock and options, and update on the stock’s value from a stream of dividends that experience non-diversifiable jumps. My paper builds on their analysis by incorporating a potentially asymmetric information release. Other work has studied the effect of investor risk aversion and systematic stock-price jumps on the prices of options (e.g., Pan (2002)). The disclosure-induced jump in my model occurs on a known date and thus does not entail a conventional jump-risk premium. Nevertheless, this jump increases short-horizon options’ expected returns as it creates an additional source of stock-price movement. Additionally, other models consider option prices in the presence of non-normal returns by incorporating features such as stochastic or time- and price-dependent volatility (e.g., Heston (1993), Dupire (1997)). I find that asymmetric disclosure events cause option prices to exhibit some of the same patterns identified in this work.

Prior literature also studies the information content of option prices in other contexts, 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), Jensen, Lando, and Pedersen (2018)), and (iii) derive the term structure of cost-of-equity capital (Callen and Lyle (2014)). A large

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\(^5\)See, for example, Verrecchia (1983), Dye (1985), and accompanying empirical evidence in Bertomeu, Ma, and Marinovic (2018) for evidence that voluntary disclosures, which are more informative for good news, lead to complex return distributions. See also Basu (1997) and Givoly and Hayn (2000), among others, who demonstrate that conservative accounting can lead to varying skewness in returns that creates a deviation from the normal distribution.
literature reviewed by Christoffersen et al. (2013) explores various statistical techniques to implementing the procedures analyzed in these papers. I contribute to this body of work by demonstrating that because the return distribution around a disclosure is an invertible function of the disclosure’s informativeness and asymmetry, one can invert these properties from option prices, and by developing techniques to perform this inversion.

My paper is organized as follows. In Section 2, I set up the underlying framework of option prices around a disclosure event. In Section 3, I analyze stock and option prices and their relationship with the disclosure’s properties. In Section 4, I study the information content of traded option prices and discuss methods of implementing these results empirically, and I conclude in Section 5.

2 Option-pricing framework

2.1 Assumptions

In this section, I develop the core framework of option prices around a disclosure event that serves as the basis for my analysis. Assume that a representative investor (or, equivalently, a set of homogenous investors) trades continuously over a period $[0, T]$ in a risk-free bond, a firm’s stock, and European options written on the firm’s stock. While I assume a representative investor in the main text, in the Online Appendix, I demonstrate robustness of the results to the case in which there are many traders with different prior beliefs. Assume that the representative investor has a generic risk-averse utility function of her wealth at time $T$, $u(W)$ with $u' > 0$ and $u'' < 0$.

The bond provides the investor with an exogenous risk-free rate of return; for simplicity of exposition, and because the results are not sensitive to the risk-free rate, I set this rate to 1. The options traded by the investor include call and put options of all strikes $k > 0$ and maturity dates in $[0, T]$; their payoffs are defined as usual. The stock pays off a terminal cash flow at time $T$, which I refer to as $\bar{x}$. Assume the firm’s cash flow, $\bar{x}$, may be broken
down into the sum of two components, $\tilde{o}$ and $\tilde{d}$:

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

(1)

The information structure of the model is intended to capture a setting in which the market receives two types of information regarding the firm’s value over time. The first type of information, which concerns the component $\tilde{o}$ of firm value, arrives gradually, representing the perpetual flow of information investors receive regarding the stock’s value from sources such as the media, data processing, patterns in prices and volume, changes in currency prices and interest rates, etc. In equilibrium, this information will lead to the perpetual movements in the market price of the stock that we observe empirically. To capture this, assume that investors randomly update their posterior beliefs of regarding $\tilde{o}$ such that these beliefs evolve according to the following stochastic process:

$$ d\mu_t = \frac{\sigma_0}{T^2} dB_t; $$

$$ d\sigma_t^2 = -\frac{\sigma_0^2}{T^2} dt, $$

(2)

where $B_t$ is a Brownian motion. At time 0, the investor has a prior that $\tilde{o}$ has a log-normal distribution with arbitrary parameters $\mu_0$ and $\sigma_0^2 > 0$. Intuitively, these belief dynamics capture the limit of a discrete-time model in which investors learn small components of the firm’s value over many time periods, as the time between each period and the size of each component learned approaches zero. Moreover, since $\sigma_T^2 = \sigma_0^2 + \int_0^T -\frac{\sigma_0^2}{T^2} dt = 0$, at the final date $T$, investors know $\tilde{o}$, i.e., $e^{\mu_T} = \tilde{o}$.$^6$ Note that while I make rather specific assumptions

$^6$Note these beliefs can be formally derived as the result of a standard model of learning over time. Suppose that $\tilde{o} = \log(R_T)$, where $R_t$ follows the stochastic process:

$$ R_0 = 0; $$

$$ dR_t = \frac{\mu_0}{T} dt + \frac{\sigma_0}{T^2} dB_t. $$

Furthermore, assume that investors observe the stochastic process $R_t$. Then, beliefs follow the process (2).
on the stochastic process followed by the investor’s beliefs regarding $\tilde{o}$, I will later argue that the results are largely robust to various assumptions on this process.

The second type of information arrives suddenly and is digested and incorporated into the firm’s price quickly; this is what I refer to as the disclosure $\tilde{y}$. In equilibrium, this information will lead to a jump in the price of the stock and options that resembles the price jumps observed around corporate information events (Lee and Mykland (2008)). I assume the disclosure $\tilde{y}$ concerns the component of the firm’s cash flows $\tilde{d}$ and is independent of $B_t$ (and thus, $\tilde{o}$). Note for sake of simplicity, I assume that the firm’s value is linearly separable in the components of risk concerned by the disclosure and by other, continuously arriving information.\footnote{Alternatively, it might be the case that between times 0 and $T$, other information arrives smoothly regarding $\tilde{d}$. In this case, the disclosure’s effect on the price a long-horizon option will be dampened given that at least a fraction of the information contained in the disclosure would have come out even in its absence. However, the direction of the effects studied in this paper should be unchanged.}

I study a parsimonious formulation of disclosure here; in the Online Appendix, I study the robustness of the results to a fully general formulation of disclosure. Specifically, I assume here that $\tilde{d}$ takes on values in $\{d_L, d_H\}$ where $d_H > d_L$ with ex-ante equal probabilities, and 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:

$$\Pr (\tilde{y} = y_H | \tilde{d} = d_H) = \lambda - \eta$$
$$\Pr (\tilde{y} = y_L | \tilde{d} = d_L) = \lambda + \eta,$$

and $\lambda + \eta; \lambda - \eta \in \left[\frac{1}{2}, 1\right]$. The parameter $\lambda$ captures the disclosure’s overall, or on-average, informativeness, as a larger value of $\lambda$ leads to a disclosure regime that is more likely to accurately reflect the true state of the world. The parameter $\eta$ captures the disclosure’s informativeness for good-versus-bad news, which I refer to as its asymmetry. As $\eta$ rises, the investor’s outlook regarding the firm’s performance rises more given good news and falls less given bad news, that is, $\frac{\partial}{\partial y} \Pr (\tilde{d} = d_H | \tilde{y} = y_H) > 0$ and $\frac{\partial}{\partial y} \Pr (\tilde{d} = d_H | \tilde{y} = y_L) > 0$.\footnote{Alternatively, it might be the case that between times 0 and $T$, other information arrives smoothly regarding $\tilde{d}$. In this case, the disclosure’s effect on the price a long-horizon option will be dampened given that at least a fraction of the information contained in the disclosure would have come out even in its absence. However, the direction of the effects studied in this paper should be unchanged.}
The disclosure’s overall informativeness, as captured by $\lambda$, 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 asymmetry, as captured by $\eta$, applies to at least three 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 $\eta$ (Verrecchia (1983), Dye (1985)). Second, this notion of a disclosure’s asymmetry 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 (2013) 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. Finally, some models of earnings management predict that disclosures subject to such management are more informative for losses than gains (Laux and Stocken (2012), Bertomeu et al. (2016)). Intuitively, investors can be certain that losses arise from poor economic performance, while gains might arise from either positive performance or successful earnings manipulation.

As part of the analysis, I would like to consider how the disclosure’s effect on option prices depends upon the extent to which the information it contains is “systematic,” i.e.,

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8 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 the Online Appendix. The relationship between discretion in disclosure choices and option prices is more nuanced, but nonetheless exhibits some of the same qualitative features as that between option prices and an asymmetric disclosure in this two-state formulation.

9 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.

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leads to updating on economy-wide performance, versus firm-specific. To accomplish this in the simplest way possible, I assume that there is a “market portfolio,” corresponding to the representative agent’s consumption at date $T$, that has payoffs $\tilde{M} = \tilde{\delta} + \alpha \tilde{d} + (1 - \alpha) \tilde{d}_{\varepsilon}$, where $\alpha \in [0, 1]$ and where $\tilde{d}_{\varepsilon}$ is independent of the other variables in the model. The term $\tilde{d}_{\varepsilon}$ is included as a tool to modify the correlation between the disclosed component of risk and the market portfolio without changing the distribution of the market portfolio’s payoffs; to accomplish this, assume $\tilde{d}_{\varepsilon}$ has the same statistical distribution as $\tilde{d}$. The term $\alpha$ captures the extent to which the firm’s risk represents a systematic component of the economy, and can be viewed as a notion of correlation: as $\alpha$ increases, revisions in the market’s beliefs regarding the outcome of the firm’s performance $\tilde{d}$ lead to greater shifts in their beliefs about the outcome of the market portfolio. I emphasize that the main results in the paper continue to hold given perturbations to this statistical structure. For example, the market portfolio could be specifically modelled as arising from the aggregate payoffs stemming from multiple firms with correlated cash flows. However, this would introduce a large amount of notation that is unnecessary to convey the main ideas.

3 Theoretical analysis

Let $P_t$ denote the stock’s price at time $t$ and $\Phi_t^C (k, \tau_M)$ ($\Phi_t^P (k, \tau_M)$) denote the price at time $t$ of a call (put) option with strike $k$ that expires at time $\tau_M \geq t$. Solving the representative agent’s optimization problem and substituting the market-clearing condition yields the following lemma.

**Lemma 1** The firm’s date $t$ stock price satisfies:

$$
P_t = \frac{E_t \left[ \tilde{\pi} u' \left( \tilde{M} \right) \right]}{E_t \left[ u' \left( \tilde{M} \right) \right]}.
$$

(4)
The firm’s date $t$ call and put option prices satisfy:

$$
\Phi^C_t(k, \tau_M) = \frac{E_t\left[\max(P_{\tau_M} - k, 0) u'(\bar{M})\right]}{E_t\left[u'(\bar{M})\right]},
$$

$$
\Phi^P_t(k, \tau_M) = \frac{E_t\left[\max(k - P_{\tau_M}, 0) u'(\bar{M})\right]}{E_t\left[u'(\bar{M})\right]}.
$$

The stock and option prices evolve continuously during the non-disclosure windows $[0, \tau_D)$ and $(\tau_D, T]$, and jump on the disclosure date $\tau_D$.

The lemma states that the firm’s stock and option prices are valued using a conventional Euler equation. 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 1 plots a numerical example of pre- and post- disclosure stock and option prices under the assumption that $\lambda = 1$ and $\eta = 0$. Notice that the stock 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 $T = 20$.

With the core framework established, I next discuss in detail how the disclosure affects market prices.

### 3.1 Stock prices, stock returns, and the disclosure’s properties

I first analyze stock prices and the disclosure’s effect on these prices. This analysis is important for understanding option prices as options’ payoffs are defined as a function of the stock price on their maturity date. Moreover, the analysis will be useful in Section 4, to serve as a baseline for what information can be gleaned from stock prices regarding a disclosure’s properties. Note the results do not follow directly from prior single-period models of disclosure, such as Lambert, Leuz, and Verrecchia (2007) or Christensen et al. (2010), given
Figure 1: This figure was generated by simulating pre- and post- disclosure stock and call option prices, given $\tilde{d} \in \{-1, 1\}$ and a symmetric disclosure that perfectly reveals $\tilde{d}$. In the example, disclosure occurs at day 10, and the option matures at day 20.

that the model is framed in continuous time and the representative investor has a general preference function. I summarize the features of the stock price in the following lemma, where 1) skewness refers to Pearson’s measure, $\frac{E[(\tilde{z}-E[\tilde{z}])^3]}{E[(\tilde{z}-E[\tilde{z}])^2]^{3/2}}$, 2) defining $P_{\tau_D}^- \equiv \lim_{\tau \to \tau_D^-} P_t$, stock returns on the disclosure date refer to the quantity $\frac{P_{\tau_D}^- - P_{\tau_D}}{P_{\tau_D}}$.

**Lemma 2**

(i) The firm’s stock prices at all dates include risk premia: $E_t [\tilde{x} - P_t] > 0$.

(ii) Assuming that the disclosure contains systematic information ($\alpha > 0$), expected stock prices following the disclosure, as of any date prior to the disclosure, increase in the informativeness of the disclosure: $\forall 0 < t_1 < \tau_D \leq t_2 < T$, $\frac{\partial}{\partial \alpha} E_{t_1} [P_{t_2}] > 0$.

(iii) Stock prices prior to the disclosure are unaffected by the disclosure’s properties:
$\forall 0 < t < \tau_D$, $\frac{\partial P_t}{\partial \alpha} = \frac{\partial P_t}{\partial \beta} = 0$.\(^{10}\)

(iv) An increase in the disclosure’s informativeness increases the variance of stock returns on the disclosure date and has no effect on return skewness on the disclosure date.

(v) An increase in the disclosure’s asymmetry increases the skewness of stock returns on the disclosure date and has an ambiguous effect on return variance on the disclosure date.

\(^{10}\)More formally, these derivatives hold for any possible realization of the investor’s information regarding $\tilde{d}$ until time $t$, i.e., for any sample path of $\{P_{\tau}\}_{\tau \in [0,t]}$. 

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Stock prices exhibit several intuitive features that are important in pricing options. First, they exhibit a risk premium, that is, $P_t$ falls short of the market’s expectations of terminal value $E_t [\bar{r}]$, implying that the firm’s expected returns exceed the risk-free rate. Second, 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. In contrast, the ex-ante (date 0) stock price is unaffected by the disclosure and its properties, $\lambda$ and $\eta$. This result mirrors the findings of Ross (1989) and Christensen et al. (2010).

Although the disclosure’s properties do not affect pre-disclosure stock prices, they do affect the distribution of stock returns on the disclosure date, i.e., the distribution of $\frac{P_{t,D} - P_{t,D}^{-}}{P_{t,D}^+}$. Specifically, a more informative disclosure increases the variance of returns on the disclosure date. 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 asymmetric leads to greater positive skewness in returns. Asymmetry in the 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)).

I next consider the features of option prices surrounding the disclosure event. These prices diverge from the prices of options that would arise in the absence of a disclosure, as the disclosure influences the distribution of stock returns. Moreover, in analyzing these prices, the investor’s risk preferences will play a key role even conditional on the stock price, unlike in models where options can be priced by no arbitrage. The reason is that because the disclosure creates a jump, options cannot be perfectly hedged by trading in the stock
3.2 Option returns and the disclosure’s properties

To begin my analysis of option prices, I consider option returns and risk premia and the effect of disclosure on these quantities. In conventional models where options can be perfectly hedged in the stock, the expected return to an option can be calculated by integrating the product of the option’s delta over time and the underlying’s expected returns over time. However, as the disclosure creates a jump and thus precludes hedging, the calculation of option returns around disclosure events requires additional analysis.

Denote $\Phi^C_{\tau_D} (k, \tau_M) \equiv \lim_{t \to \tau_D} \Phi^C_t (k, \tau_M)$ and $\Phi^P_{\tau_D} (k, \tau_M) \equiv \lim_{t \to \tau_D} \Phi^R_t (k, \tau_M)$ as the prices of calls and puts just prior to the disclosure. Then, we have the following remark, which signs risk premia and returns around the disclosure, following straightforwardly from the investor’s Euler condition.

**Remark 1** Suppose the disclosure contains systematic information, i.e., $\alpha > 0$. Then,

(i) Call (put) options at all dates display a positive (negative) risk premium:

$$\forall t < \tau_M, \quad E_t \left[ \frac{\max(P_{\tau_M} - k, 0) - \Phi^C_t (k, \tau_M)}{\Phi^C_t (k, \tau_M)} \right] > 0 \quad \text{and} \quad E_t \left[ \frac{\max(k - P_{\tau_M}, 0) - \Phi^P_t (k, \tau_M)}{\Phi^P_t (k, \tau_M)} \right] < 0.$$

(ii) The magnitude of the risk premia embedded in call and put options decrease following the disclosure, that is, call options experience positive expected returns and put options experience negative expected returns on the disclosure date:

$$\forall \tau_M \geq \tau_D, \quad E \left[ \frac{\Phi^C_{\tau_D} (k, \tau_M) - \Phi^C_{\tau_D} (k, \tau_M)}{\Phi^C_{\tau_D} (k, \tau_M)} \right] > 0 \quad \text{and} \quad E \left[ \frac{\Phi^P_{\tau_D} (k, \tau_M) - \Phi^P_{\tau_D} (k, \tau_M)}{\Phi^P_{\tau_D} (k, \tau_M)} \right] < 0.$$

Intuitively, as market returns at the end of the model are positively correlated with the firm’s cash flow and call (put) options’ payoffs are positively (negatively) correlated with this cash flow, the price of these options include a positive (negative) risk premium. The
disclosure reduces this risk premium as it resolves a source of uncertainty regarding the market’s payoff. It is important to note that part (ii) of this remark relies heavily on the disclosure containing systematic information and does not hold when \( \alpha = 0 \); moreover, the magnitudes of all return effects studied in the paper increase in \( \alpha \).

I next examine how the disclosure’s properties, \( \lambda \) and \( \eta \), affect the magnitude of options’ expected returns on the disclosure date. I specifically focus on the returns to options that expire just after the disclosure, i.e.,

\[
E \left[ \frac{\Phi_{C_D}(k,\tau_D) - \Phi_{C_D}(k,\tau_D)}{\sigma_{C_D}(k,\tau_D)} \right] \quad \text{and} \quad E \left[ \frac{\Phi_{P_D}(k,\tau_D) - \Phi_{P_D}(k,\tau_D)}{\sigma_{P_D}(k,\tau_D)} \right].
\]

These returns are most directly affected by the disclosure and its properties, and thus are the most straightforward to study. Note options that expire immediately after the disclosure are not literally traded, but, by continuity, the results extend to options that expire soon after the disclosure. Theoretical results are difficult to produce for longer-dated options as they are subject to returns that follow a mixture distribution and are priced by investors with general preferences, but numerical results suggest that quantitatively similar results hold for options of further maturity dates when investors have power utility. Note further that investor learning regarding \( \tilde{o} \) still affects the value of options whose horizons span only the disclosure, as it represents a source of background risk in the representative investor’s consumption.

Within the class of options that expire just after the disclosure, I also constrain attention to options with strikes within the bounds of the firm’s equity price given that it releases good and bad news. Formally, letting \( P_{\tau_D}(\tilde{y}) \) equal the price after the disclosure conditional on the disclosure \( \tilde{y} \), I focus on options with strikes \( k \in (P_{\tau_D}(y_L), P_{\tau_D}(y_H)) \). Options with strikes out of this range are uninteresting to examine: those with strikes above this range always have a value of zero and those with strikes below it are effectively equities (with payoffs shifted by \( k \)), given that they always expire in-the-money.

**Proposition 1** (i) An increase in the disclosure’s informativeness increases call options’ expected returns and decreases put options’ expected returns on the disclosure date with strikes
An increase in the disclosure’s asymmetry increases call and put options’ expected returns on the disclosure date with strikes \( k \in (P_{\tau_D} (y_L), P_{\tau_D} (y_H)) \) and maturity date \( \tau_D \):

\[
\frac{\partial}{\partial \lambda} \mathbb{E} \left[ \frac{\Phi^C_{\tau_D} (k, \tau_D) - \Phi^C (k, \tau_D)}{\Phi^C (k, \tau_D)} \right] > 0; \quad \frac{\partial}{\partial \lambda} \mathbb{E} \left[ \frac{\Phi^P_{\tau_D} (k, \tau_D) - \Phi^P (k, \tau_D)}{\Phi^P (k, \tau_D)} \right] < 0.
\]

The first part of the proposition states that a more informative disclosure increases the magnitude of option returns. The reason is simple: a more informative disclosure receives more weight by investors, and thus, leads to greater risk on the disclosure date. The second part of the proposition states that a more asymmetric disclosure increases call option returns. The reason is that it concentrates the payoffs of these options to the high state, when investors have lower marginal utility. To see this, note these options pay off only when \( \tilde{y} = y_H \). As \( \eta \) increases, the probability of observing \( \tilde{y} = y_H \) when \( \tilde{d} = d_L \) declines. An increase in \( \eta \) also shifts put options’ payoffs towards the high state, leading to earn expected returns closer to zero.

Note that, in this section, I have only considered the returns to single call and put options. Empirical research has documented patterns in the returns to combinations of option positions on disclosure dates, including straddles and variance swaps (Barth and So (2014), Dubinsky et al. (2018)). The model suggests that the returns to such positions can be complex functions of investors’ risk preferences and the properties of the disclosure. I leave a full theoretical analysis of the returns to portfolios of options to future research.

Before moving on, I also note that many option-pricing models allow for greater generality in the stochastic process followed by the firm’s stock price 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 stock 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 cash flow 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 $\bar{\sigma}$. Jumps in the stock price at times other than $\tau_D$ 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)).

While the introduction of these additional features would change the magnitude of option returns on the disclosure date in the model, they would not change the direction of the impact that disclosure’s properties have on these returns. The dynamics of price in non-disclosure periods only impact the options that expire soon after the disclosure by introducing a source of background risk in the representative investor’s consumption. Moreover, since the results hold 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. I conjecture that this would continue to hold for options with longer maturity dates.

3.3 Pre-disclosure option prices and the disclosure’s properties

I next consider how the disclosure affects the prices of options just prior to the disclosure event. I again examine options that expire just after the disclosure. Note that this analysis is distinct from the analysis of option returns, as disclosure’s properties influence both pre- and post- disclosure option prices. Moreover, pre-disclosure option prices have been the focus of prior research on option prices around disclosures, perhaps due to the large, easily identified effect that the disclosure has on these prices (Patell and Wolfson (1979, 1989) and Dubinsky
et al. (2018)). I will later show, in fact, that these option prices are the most useful in extracting information about the disclosure’s properties.

The next proposition states that all pre-disclosure option prices increase in a disclosure’s informativeness, while the effect of disclosure’s asymmetry on the pre-disclosure price of an option depends upon whether it is ITM or OTM prior to the disclosure (i.e., whether \( k \) is greater or less than the price just before the disclosure, \( P_{\tau_D^-} \)). Again, in the proposition, I focus on the set of options with strikes \( k \in (P_{\tau_D^-}(y_L), P_{\tau_D^-}(y_H)) \).

**Proposition 2** Consider the pre-disclosure prices of options that expire on the disclosure date \( \tau_D \) with strikes \( k \in (P_{\tau_D^-}(y_L), P_{\tau_D^-}(y_H)) \).

(i) An increase in the disclosure’s informativeness increases these prices:

\[
\forall k \in (P_{\tau_D^-}(y_L), P_{\tau_D^-}(y_H)), \frac{\partial}{\partial \lambda} \Phi_{\tau_D^-}^C(k, \tau_D) > 0 \text{ and } \frac{\partial}{\partial \lambda} \Phi_{\tau_D^-}^P(k, \tau_D) > 0.
\]

(ii) An increase in the disclosure’s asymmetry increases the prices of OTM call (ITM put) options and decreases the pre-disclosure prices of ITM call (OTM put) options:

\[
\forall k \in (P_{\tau_D^-}(y_L), P_{\tau_D^-}(y_H)), \frac{\partial}{\partial \eta} \Phi_{\tau_D^-}^C(k, \tau_D) > 0 \text{ and } \frac{\partial}{\partial \eta} \Phi_{\tau_D^-}^P(k, \tau_D) > 0; \\
\forall k \in (P_{\tau_D^-}, P_{\tau_D^+}(y_H)), \frac{\partial}{\partial \eta} \Phi_{\tau_D^-}^C(k, \tau_D) < 0 \text{ and } \frac{\partial}{\partial \eta} \Phi_{\tau_D^-}^P(k, \tau_D) < 0.
\]

To understand the proposition, I break down the disclosure’s impact on option prices into three distinct effects, which I refer to 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 captures the effect that the disclosure would have on an option’s price if investors were risk neutral. To understand this effect, consider again parts (iv) and (v) of Lemma 2. Since a more informative disclosure increases the variability in stock prices, it increases the expected payoff to any option whose horizon spans the disclosure; this is the effect documented in prior studies that employ the Black-Scholes framework. Second,
recall a more asymmetric disclosure creates skewness in stock returns. Such skewness tends to increase the expected payoff to an OTM call option and decrease the expected payoff to an ITM call option. Intuitively, skewness increases the probability of upper-tail stock returns that lead to large returns to OTM call options. This effect is familiar from the prior option-pricing literature that prices options as a function of exogenously given stock-return moments (e.g., Bakshi et al. (2003), Christoffersen et al. (2006)).

The remaining effects, the option-risk effect, and the cost-of-capital effect, arise from investor risk aversion. The option-risk effect refers to the fact that changes in variance and skewness also affect the riskiness of options’ payoffs. The directional effects of the disclosure’s properties on an option’s riskiness follow from the previous study of option returns. Finally, the cost-of-capital effect refers to the impact that the disclosure’s properties have on the risk premium embedded in the stock price after the disclosure’s release. Recall from Lemma 2 that a more informative disclosure reduces the stock’s risk premium; this tends to increase call options’ expected payoffs, pushing up their prices. In contrast, the effect of disclosure’s asymmetry on post-disclosure uncertainty, and thus the stock’s post-disclosure risk premium, depends upon whether the firm releases good or bad news: it pushes up this risk premium given bad news, and pushes down this risk premium given good news. Since call options have payoffs that are concentrated when the firm releases good news, this implies that asymmetry amplifies the cost-of-capital effect. The proof of Proposition 2 demonstrates that, in spite of these additional forces created by investor risk aversion, the direction (but not magnitude) of the predicted effects of informativeness and asymmetry on the price of an option are the same as in the risk-neutral case.

Figure 2 presents comparative statics on the effect of disclosure’s informativeness on call option prices, taking the extreme approach of comparing a fully informative disclosure \((\lambda = 1, \eta = 0)\) to the case of completely noisy disclosure \((\lambda = \frac{1}{2}, \eta = 0)\). The figure was produced by examining options with maturities substantially after the disclosure date, and suggests that the results are robust to this case. The figure further suggests that (1) the
impact of a disclosure on an option’s price tapers off as non-disclosure window volatility increases; (2) that the effect of a disclosure on the price of an option is maximized for options with moderate strikes; (3) that the effect of a disclosure on option prices increases in prior disclosure-related uncertainty ($d_H - d_L$), and (4) that the effect of a disclosure on an option of moderate strike price declines in investor risk aversion. Figure 3 depicts the impact of the disclosure’s asymmetry on pre-disclosure call option prices, comparing the case in which the disclosure is more informative for good than bad news ($\lambda = 0.7, \eta = 0.1$) to the case in which the disclosure is symmetric ($\lambda = 0.7, \eta = 0$). The figure demonstrates that the effect of asymmetry on option prices is highly nonlinear in the underlying parameters of the model. It also suggests that (1) the effect of asymmetry on the price of an option declines in
Figure 3: This figure depicts pre-disclosure call option prices under the regimes \( \lambda = 0.7, \eta = 0.1 \) and \( \lambda = 0.7, \eta = 0 \) when the investor has power utility. In the bottom left plot, uncertainty is captured by \( d_H - d_L \).

non-disclosure window volatility and (2) the effect of asymmetry on the price of an option is non-monotonic in disclosure-related uncertainty.

### 3.4 Systematic versus idiosyncratic disclosure

Finally, I study how the disclosure’s effect on pre-disclosure option prices depends upon the extent to which the information contained in the disclosure is systematic versus idiosyncratic, as captured by \( \alpha \). Note that, based upon the discussion above, investor risk-aversion does not change the directional relationships between the informativeness and asymmetry of the disclosure and option prices. Consequently, whether the disclosure is fully systematic or completely idiosyncratic will not affect the directional relationships previously discussed. However, it can have a material impact on the magnitudes of these relationships by ampli-
fying the (price-reducing) option-risk and (price-increasing) cost-of-capital effects. I discuss this in the following proposition.

**Proposition 3** Consider the pre-disclosure prices of options that expire on the disclosure date $\tau_D$ with strikes $k \in (P_{\tau_D}(y_L), P_{\tau_D}(y_H))$.

(i) An increase in the extent to which the information in the disclosure is systematic $\alpha$ magnifies (attenuates) the effect of the disclosure’s informativeness on the pre-disclosure prices of call options with strikes $k > E\left(\tilde{d}\right) + \frac{E_{\tau_D}(\tilde{\omega'}(M))}{E_{\tau_D}(w'(M))}$ ($k < E\left(\tilde{d}\right) + \frac{E_{\tau_D}(\tilde{\omega'}(M))}{E_{\tau_D}(w'(M))}$).

Likewise, an increase in $\alpha$ magnifies (attenuates) the effect of the disclosure’s informativeness on the pre-disclosure prices of put options with strikes $k < E\left(\tilde{d}\right) + \frac{E_{\tau_D}(\tilde{\omega'}(M))}{E_{\tau_D}(w'(M))}$ ($k > E\left(\tilde{d}\right) + \frac{E_{\tau_D}(\tilde{\omega'}(M))}{E_{\tau_D}(w'(M))}$).

(ii) An increase in the extent to which the information in the disclosure is systematic $\alpha$ causes the disclosure’s asymmetry to have a more positive impact on all pre-disclosure call and put option prices.

The first part of the corollary states that when a disclosure contains more systematic information, an increase in its informativeness has a more positive impact on the pre-disclosure prices of high-strike call options and a less positive impact on the pre-disclosure prices of low-strike call options. To see why, consider the relative magnitudes of the (price-reducing) option-risk and (price-increasing) cost-of-capital effects created by investor risk aversion. The (positive) cost-of-capital effect is similar for call options of differing strikes; it simply pushes up the stock 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 an investor holding a low-strike call option has more to lose from a downswing in the stock price.

The second part of the corollary states when a disclosure contains more systematic information, an increase in its asymmetry has a more positive impact on all call option prices. This might be surprising since, along with the result in Proposition 1, it implies that an
increase in $\alpha$ amplifies the positive effect that $\eta$ has on both call options’ returns and their ex-ante prices. This result can be reconciled by considering the cost-of-capital effect: recall that an increase in $\eta$ decreases conditional uncertainty given good news, thereby pushing up the equity price given good news and increasing options’ expected payoffs in proportion to $\alpha$. From an ex-ante perspective, this increase in expected payoffs more than compensates for the increase in options’ risks.

4 The information content of option prices

I next consider the information that option prices contain regarding the properties of a disclosure. I first use the theoretical results in the prior sections to demonstrate that option prices contain more information regarding a disclosure’s properties than stock prices. I then formally outline three procedures that may be used to measure disclosure’s properties using option prices and assess their merits using simulations.

As a baseline, first consider what can be learned regarding a disclosure’s informativeness and asymmetry by a researcher who examines the series of stock prices leading up to and following the disclosure event. Lemma 2 offers two key insights into the information contained in these prices. First, it demonstrates that pre-disclosure stock prices are wholly unaffected by the disclosure. Thus, they offer the researcher no information regarding the disclosure’s properties. In contrast, the disclosure’s properties do affect the distribution of stock returns on the disclosure date: the disclosure’s informativeness increases the stock-return variance and the disclosure’s asymmetry increases stock-return skewness. Nevertheless, the amount of information a researcher can learn from stock returns on the disclosure date is limited. The reason is that a researcher does not directly observe the entire distribution of stock returns, but instead observes only the stock returns induced by the realized disclosure report, $\tilde{y}$, which translates into a single observation from this distribution. For example, if the market releases good news, one can use the price response to assess earnings quality given good news,
but not given bad news. However, both reactions are essential to learning how informative
the disclosure is on average, or how informative it is for good relative to bad news.

The result that stock prices cannot be used to learn the disclosure’s properties may be
rigorously proved under one of two assumptions: (1) the investor has a CARA utility function
with known risk aversion parameter $\rho$ or (2) the investor has a general preference function
but the disclosure concerns purely idiosyncratic performance ($\alpha \to 0$). If the disclosure has
a systematic component and the investor has general, wealth-dependent risk preferences, it
appears possible to use the path of post-disclosure stock prices to learn the properties of
the disclosure. Intuitively, as investors learn new information from sources other than the
disclosure, it can change their effective risk aversion with respect to the information contained
in the disclosure. This can lead to differential pricing of the disclosure’s properties over time,
enabling these properties to be inverted. However, performing this inversion problem requires
a large amount of knowledge regarding the precise shape of investors’ preferences, and thus
appears challenging to implement.

**Corollary 1** Assume that either (1) the investor has a CARA utility function with known
risk aversion parameter $\rho$ or (2) the investor has a general preference function but the disclo-
sure concerns purely idiosyncratic performance ($\alpha \to 0$). Then, observing the path followed
by stock prices around a disclosure event is insufficient to learn either the disclosure’s inform-
ativeness or its asymmetry.

Note, if we were to generalize the model by relaxing the distributional assumptions on
the disclosure’s properties, in order to back out these disclosure’s properties from equity
prices, one would have to observe the stock-price reaction to *every possible* outcome of the
disclosure, $\tilde{y}$, an impossible task. Similar logic implies that it is also generally not possible
to use equity prices around the disclosure even to approximate the disclosure’s properties.
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)). That is, this literature either uses regression approaches that incorporate the price
responses to many disclosures, or calculates volatility and skewness around many disclosure events. This approach is effective at capturing the average properties of the disclosure events being studied. However, even within a firm, the multitude of features that determine the properties of their accounting system are constantly changing, such as the incentives of management, the competitive environment, and the regulatory environment. Thus, stock-price based approaches entail substantial information loss. Furthermore, they cannot be used for sporadic disclosures that are dissimilar from other firm disclosures.

I next show that observing option prices prior to a disclosure event resolves the concern that one only observes a single outcome from the distribution of potential stock-price responses to a disclosure. Intuitively, the return distribution on the disclosure date differentially affects the prices of options with different strikes. Thus, by jointly examining these prices, one can get insight into the entire return distribution on the disclosure date. More precisely, the thought experiment underlying the following proposition is as follows: suppose investors price options around the disclosure using the model discussed in Section 2. Can a researcher take the traded prices of options and back out the properties of the disclosure? In the proposition, I focus on the case in which the disclosure contains exclusively idiosyncratic information.\textsuperscript{11}

**Proposition 4** Assume that the disclosure concerns purely idiosyncratic performance (i.e., $\alpha = 0$). Observing the pre-disclosure prices of options that expire soon after the disclosure alongside the pre-disclosure equity price reveals the disclosure’s informativeness $\lambda$ and its asymmetry $\eta$ given knowledge of disclosure-related uncertainty $d_H - d_L$.

The proposition states that only the prices of options prior to the disclosure are needed to back out its properties. Intuitively, by observing the prices of options with several strikes prior to the disclosure, one obtains a system of equations in $\lambda$ and $\eta$. This system generally

\textsuperscript{11}Note that, under certain sets of assumptions on market preferences, the proposition can be extended to the case in which the disclosure contains systematic information. However, the resulting estimators are implicit functions, and thus lack the intuitive closed-form characterizations that appear in the idiosyncratic case. Moreover, it is not clear how robust the resulting estimators are to the specific shape of investor preferences.
has multiple solutions, which implies that there are multiple ways to back out the theoretical parameters $\lambda$ and $\eta$ (i.e., it is overidentified). However, these solutions generally require knowledge of both of the underlying parameters the $d_H$ and $d_L$. One of these solutions is particularly intuitive and relies only on the knowledge of the difference $d_H - d_L$, which intuitively captures disclosure-related uncertainty, as opposed to knowledge of both of the underlying parameters $d_H$ and $d_L$. This solution is as follows, for $k_2 \neq k_1$:

\[
\hat{\lambda}^T = \frac{1}{2} + \frac{2\Phi^C_{\tau_D} \left( P_{\tau_D}, \tau_D \right)}{d_H - d_L};
\]

\[
\hat{\eta}^T = \frac{1}{2} + \frac{\Phi^C_{\tau_D} (k_2, \tau_D) - \Phi^C_{\tau_D} (k_1, \tau_D)}{k_2 - k_1}.
\]

Stated in words, this solution backs out $\lambda$ by taking the price of an ATM call option and normalizing by disclosure-related uncertainty, and backs out $\eta$ by taking the difference between options of two strikes and dividing by the difference in strikes. Note the intuitive reason that this solution requires knowledge of disclosure-related uncertainty $d_H - d_L$ is that an increase in fundamental uncertainty affects option prices prior to the disclosure in the same way as an increase in the disclosure’s informativeness, and thus, separating these two quantities is impossible without ex-ante knowledge of one of them. The same conundrum also arises in when examining stock-price reactions: a greater stock-price reaction to a disclosure could either stem from greater uncertainty or more precise information (Nikolaev (2017)).

While Proposition 4 is derived under a very specific assumptions on the distributions of $\tilde{d}$ and $\tilde{y} | \tilde{d}$ (Bernoulli distributions), the theme of the proposition, that option prices contain information not in equity prices regarding the disclosure’s properties, is robust given that one observes multiple option prices that are nonsingular functions of the disclosure’s features. Additionally, while under other distributional assumptions, the precise formulas for backing out the properties of a disclosure would differ, note that the intuition underlying the calculation of expressions (6) and (7) appears to capture robust, fundamental effects of a disclosure’s informativeness and asymmetry. That is, the level of option prices captures
the disclosure’s on average informativeness, since a symmetrically more informative disclosure creates more volatility throughout the distribution of returns. Moreover, the slope over option prices of different strikes captures its asymmetry, since a more asymmetric disclosure concentrates the volatility in returns in the upper portion of the return distribution. In the Internet Appendix, I show that these relationships between option prices and the disclosure’s properties generalize to a broad range of definitions of disclosure quality and asymmetry found throughout the theoretical literature under the assumption the disclosure contains only idiosyncratic information.

I next discuss the implementation of expressions (6) and (7) and develop alternative methods to measuring the disclosure’s properties.

4.1 Approaches to measuring the disclosure’s properties

4.1.1 Price-based measures and Black-Scholes measures

The measures in expressions (6) and (7) can be implemented directly given an estimator for \(d_H - d_L\). Since these measures are calculated by using a straightforward manipulation of the prices of options, I refer to them as “price-based” measures. Many of the earnings and returns normalizers used in the earnings-response coefficient literature may also work as estimators for \(d_H - d_L\), including firm size, earnings level in the case of an earnings announcement, analyst forecast dispersion, and volatility leading up to the disclosure (e.g., Kothari (1992)). Note the price-based informativeness measure in expression (6) has been studied in Billings and Jennings (2011), who set \(d_H - d_L\) equal to analyst forecast dispersion and find that it is statistically related to conventional, equity-based measures of informativeness.

While the price-based measures are very simple to implement, they are derived under the assumption that one observes options that expire very shortly after the disclosure, in order to ensure that volatility in the non-disclosure periods is not a significant driver of their value (and thus, a potentially endogenous source of noise in the measure). In many cases, investors may not trade options that mature soon after the disclosure’s release. I next consider two
alternative estimators that seek to address this concern. I refer to the first set of measures as the time-series estimators, a term borrowed from Dubinsky et al. (2018). These estimators aim to control for non-disclosure window volatility by utilizing the fact that, as long as price movements created by sources other than the disclosure do not systematically shift leading up to the disclosure, any changes in the patterns of option-implied volatility leading up to the disclosure must be the result of the disclosure event itself. The resulting measure for the disclosure’s informativeness resembles the statistics developed by Patell and Wolfson (1981) and Dubinsky et al. (2018); however, to translate their statistics from measures of disclosure-related volatility to measures of a disclosure’s informativeness, it is essential to normalize these measures by an estimate of disclosure-related uncertainty.

I refer to the second set of measures as term-structure estimators. These estimators utilize the fact that the differences in option-implied volatility calculated using options with different maturity dates stem from non-disclosure window volatility. This, in turn, enables a measure of non-disclosure window volatility that can then be used as a correction. More formally, to arrive at these measures, I first transform the price-based measures into Black-Scholes implied-variance space, and then examine the differences of the resulting implied-variances over time, across maturity dates, and across strike prices.\textsuperscript{12} Formally, consider the following estimators \( \left( \lambda_{BSM}, \eta_{BSM} \right) \), given a positive \( z \), a positive integer \( \delta \), and maturity date \( \tau_M \geq \tau_D \) where \( IV_t(P_t, k, \tau) \) refers to the Black-Scholes implied volatility of an option with strike \( k \) at time \( t \) that expires at date \( \tau \) when the equity price is \( P_t \), and \( d_H - d_L \) refers to the estimator used for disclosure-related uncertainty.

\textsuperscript{12}While the Black-Scholes model does not formally hold, the formula still enables an approximate intuitive mapping from option prices to the distribution of returns implicit in these prices. Translating prices into Black-Scholes implied volatility space even when the model does not hold is frequently applied in other contexts; see, e.g., Christofferson et al. (2013) and Carr and Wu (2016)).
The timing of the two estimators is depicted in Figure 4. Note in the calculation of $\hat{\eta}^{BSM}$, one has flexibility in the choice of strikes. However, call options that are substantially ITM or OTM are typically illiquid, and the effect of $\eta$ 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 $\eta$, the optimal choice appears to be a moderately ITM and a moderately OTM option contract. The estimators also offer freedom in the choice of $\delta$, which refers to the length of time over which one calculates the time-series or term-structure slope of option-implied volatilities.

I next perform simulations in order to (a) detect if there is substantial variation in the quality of the measures based upon the choice of the time period $\delta$; and (b) assess the performance of the transformed measures at eliminating confounding of the measures by non-disclosure window volatility $\sigma_0^2$. In the simulation, I generate a dataset of option prices

\[ \lambda^{BSM} = d_H - d_L^{-1} \left[ (\tau_M - \tau_D + 1)^{-1} IV_{\tau_D-1} (P_{\tau_D-1}, P_{\tau_D-1}, \tau_M)^2 - (\tau_M - \tau_D + \delta + 1)^{-1} IV_{\tau_D-\delta-1} (P_{\tau_D-\delta-1}, P_{\tau_D-\delta-1}, \tau_M)^2 \right] \]

\[ \hat{\eta}^{BSM} = (\tau_M - \tau_D + 1)^{-1} IV_{\tau_D-1} (P_{\tau_D-1} + z, \tau_M)^2 - (\tau_M - \tau_D + \delta + 1)^{-1} IV_{\tau_D-\delta-1} (P_{\tau_D-\delta-1}, P_{\tau_D-\delta-1} + z, \tau_M)^2 - [(\tau_M - \tau_D + 1)^{-1} IV_{\tau_D-1} (P_{\tau_D-1}, P_{\tau_D-1} - z, \tau_M)^2 - (\tau_M - \tau_D + \delta + 1)^{-1} IV_{\tau_D-\delta-1} (P_{\tau_D-\delta-1}, P_{\tau_D-\delta-1} - z, \tau_M)^2] \]
that expire either 10 or 20 days after the disclosure using the model developed in Section 2. It is critical for the simulations to ensure that the relative amount of cross-sectional variation in the parameters governing disclosure-window and non-disclosure window volatility are representative of a true sample. The reason is that it is this relative variation that will determine how much the measures are confounded by $\sigma_0^2$. In accordance with the descriptive evidence in Dubinsky et al. (2018), I let non-disclosure window return volatility, $\sigma_0$, vary uniformly between 1% and 3%, and I set $d_H - d_L$ in order to create 10% volatility on the disclosure date given an “average” disclosure regime $\lambda = \frac{3}{4}$; $\eta = 0$. Finally, I let the disclosure’s informativeness $\lambda$ and asymmetry $\eta$ vary uniformly across their feasible range, $\{(\lambda, \eta) : \lambda \in \left[\frac{1}{2}, 1\right], \eta \leq \min\{1 - \lambda, \lambda - \frac{1}{2}\}\}$. The outcome of the simulation is depicted in Figures 5 and 6.

Figure 5 suggests that the choice of time period $\delta$ has only a minor impact on the quality of the estimators; periods of 3 days and further appear to perform slightly better than shorter horizons. Figure 6, which was calculated using a time period of 3 days reveals that the IV slope-based measures greatly outperform their price-based counterparts when the options considered expire 20 days after the disclosure, given large reductions in the extent to which they are driven by outside volatility, $\sigma_0^2$.\(^{13}\) For options that expire only 10 days after\(^{13}\) From a theoretical point of view, given constant $\sigma_0^2$, whether the time-series or term-structure estimators are used will have no impact on the results in Figure 6.
Figure 5: This figure depicts the correlations between $\hat{\lambda}^{BSM}$ and $\hat{\eta}^{BSM}$ and the underlying constructs $\sigma_0^2$, $\lambda$, and $\eta$ used to generate the data as $\delta$ varies from 1 to 10. The left-hand plots depict the correlations for $\hat{\eta}^{BSM}$ and the right-hand plots depict the correlations for $\hat{\lambda}^{BSM}$. 
Figure 6: This figure depicts the correlations between the measures $(\hat{\lambda}^T, \hat{\eta}^T, \hat{\lambda}^{BSM}, \hat{\eta}^{BSM})$ and the underlying theoretical parameters $\lambda$, $\eta$, and $\sigma_0^2$. The correlations were produced by setting $\delta = 3$.

the disclosure, the price-based measures of asymmetry appear to outperform those using slopes in implied volatility. Note that the simulations suggest that the asymmetry measure, while mostly driven by the disclosure’s true asymmetry, is also somewhat correlated with the disclosure’s informativeness, especially when the options considered expire further into the future.

### 4.1.2 Model-free implied moments

The price-based and Black-Scholes estimators discussed in the previous section are simple to implement, as they use only the prices of three option strikes. However, these estimators ignore option prices of other strikes. Moreover, the price of any given option contract is subject to a variety of demand-related shocks (Garleanu, Pedersen, and Poteshman (2008)), and thus is noisy. Therefore, incorporating the information contained in other option prices into the estimators of the disclosure’s properties could improve their quality. I next develop

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<tr>
<th></th>
<th>20 days to maturity</th>
<th>10 days to maturity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Price Inform. $\hat{\lambda}^T$</td>
<td>Price Asymm. $\hat{\eta}^T$</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.934</td>
<td>0.093</td>
</tr>
<tr>
<td>$\eta$</td>
<td>-0.019</td>
<td>0.828</td>
</tr>
<tr>
<td>$\sigma_0^2$</td>
<td>0.306</td>
<td>0.197</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.983</td>
<td>0.040</td>
</tr>
<tr>
<td>$\eta$</td>
<td>-0.012</td>
<td>0.881</td>
</tr>
<tr>
<td>$\sigma_0^2$</td>
<td>0.129</td>
<td>0.101</td>
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estimators that incorporate these prices, which utilize model-free implied return variances and skewnesses leading up to the disclosure (details on the calculation of implied variance and skewness can be found in Britten-Jones and Neuberger (2000) and Bakshi et al. (2003), respectively).

Note that model-free implied variances and skewnesses capture the variance and skewness of returns, respectively, under the risk-neutral measure over a specified time period. To understand why there exists a relationship between these moments and the disclosure’s properties, first note that, under the assumption that investors are risk neutral, the risk-neutral return distribution around the disclosure event corresponds to the actual return distribution. Now, when a disclosure contains purely idiosyncratic information, investors are effectively risk neutral around its release, and thus, the model-free variance and skewness will capture the actual variance and skewness around the disclosure event. Finally, since Lemma 2 demonstrates that the disclosure’s informativeness and asymmetry manifest in return variance and skewness, model-free implied variance and skewness around a disclosure event should capture the disclosure’s informativeness and asymmetry, respectively.\footnote{The quality of the model-free estimators will depend upon the extent of systematic information in the disclosure, as well as the variation in the degree to which the disclosures included in a sample contain systematic information. The same holds true for the Black-Scholes and price-based measures. Note it has been common practice in prior literature to use model-free implied moments to capture fundamental moments, despite the difference in these two quantities (see Christofferson et al. (2013)).}

Note further that model-free implied moments in fact capture the same intuitive constructs as the measures discussed in the previous section. The model-free implied variance is a weighted sum across the prices of all traded options of a given maturity, where the weights are greatest for options close to ATM. Thus, like the informativeness measures from the previous section, it captures the level of option prices. The model-free implied skewness is calculated as a weighted difference between prices of high- versus low-strike options, and thus, like the asymmetry measures in the previous section, captures the slope in option prices as a function of their strike. Despite these similarities, empirical evidence suggests that Lemma 2 also shows that $\eta$ can impact the variance of the underlying return distribution. However, the simulations below suggest that this effect is quantitatively small relative to the effect of $\lambda$.\footnote{Lemma 2 also shows that $\eta$ can impact the variance of the underlying return distribution. However, the simulations below suggest that this effect is quantitatively small relative to the effect of $\lambda.$}
differences in Black-Scholes implied volatilities by strike prices and the model-free implied skewness do not always move together, perhaps due to market imperfections and dynamic demand pressures, suggesting a potential benefit to jointly examining the measures in the previous section and those in this section (Mixon (2011)).

As in the previous section, I perform a manipulation on model-free implied variance and skewness in order to minimize potential confounding by disclosure-related uncertainty $d_H - d_L$ and non-disclosure window volatility $\sigma_0^2$. Specifically, I again divide the informativeness measure by an estimator of $d_H - d_L$, and examine either the time-series or term-structure slopes in model-free implied moments. Formally, let $V_{t,\tau}^{MF}$ denote the implied variance calculated at time $t$ until the period $\tau$ and $S_{t,\tau}^{MF}$ the implied skewness of returns calculated at time $t$ until the period $\tau$, and choose a positive integer $\delta$. Then, consider the following measures:

<table>
<thead>
<tr>
<th>Model-free time-series estimators</th>
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<tbody>
<tr>
<td>$\hat{\lambda}^{MF} = d_H - d_L^{-1} \left[ (\tau_M - \tau_D + 1)^{-1} V_{\tau_D - 1, \tau_M}^{MF} - (\tau_M - \tau_D + \delta + 1)^{-1} V_{\tau_D - \delta - 1, \tau_M}^{MF} \right]$</td>
</tr>
<tr>
<td>$\hat{\eta}^{MF} = (\tau_M - \tau_D + 1)^{-1} S_{\tau_D - 1, \tau_M}^{MF} - (\tau_M - \tau_D + \delta + 1)^{-1} S_{\tau_D - \delta - 1, \tau_M}^{MF}$</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Model-free term-structure estimators</th>
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<tbody>
<tr>
<td>$\hat{\lambda}^{MF} = d_H - d_L^{-1} \left[ (\tau_M - \tau_D + 1)^{-1} V_{\tau_D - 1, \tau_M}^{MF} - (\tau_M - \tau_D + \delta + 1)^{-1} V_{\tau_D - \delta - 1, \tau_M}^{MF} \right]$</td>
</tr>
<tr>
<td>$\hat{\eta}^{MF} = (\tau_M - \tau_D + 1)^{-1} S_{\tau_D - 1, \tau_M}^{MF} - (\tau_M - \tau_D + \delta + 1)^{-1} S_{\tau_D - \delta - 1, \tau_M}^{MF}$</td>
</tr>
</tbody>
</table>

Compared with the price-based and Black-Scholes estimators, one has less freedom in calculating these measures; only the time horizon $\delta$ can be chosen by the researcher.

I next conduct simulations to test the performance of the model-free measures relative to the price-based and Black-Scholes measures. The simulations are carried out using the same parameters as in the prior section, including the same time horizon, $\delta = 3$. Given the multiplicity of techniques to approximate the model-free measures given a finite set of strikes, I conduct the simulations under theoretically optimal conditions, i.e., as if one observed the prices of options with strikes of every price on the continuum $[0, \infty)$. Thus, these simulations are optimistic, and their true performance will depend upon the number of liquidly-traded
Figure 7: This figure depicts the correlations between the measures \((\hat{\lambda}^{MF}, \hat{\eta}^{MF})\), as well as pre-disclosure levels of model-free implied variance and skewness, and the underlying theoretical parameters \(\lambda\), \(\eta\), and \(\sigma_0^2\). The correlations were produced by setting \(\delta = 3\).

Finally, as a basis of comparison, I simulate model-free implied variance and skewness levels in addition to the slope measures. Figure 7 depicts the outcome of the simulations, indicating that the model-free measures generally outperform both the price and implied-volatility based measures discussed in the prior section.

As a final point, I note that the measures developed in the paper are founded upon the assumption that investors’ prior regarding the firm’s performance is symmetric. To the extent that firms exhibit different degrees of fundamental skewness, and this skewness is correlated with the construct of interest, the measures developed here will exhibit a bias. I note regression or matching-based analysis may partially alleviate this concern by controlling for fundamental skewness. Moreover, measures that control for fundamental skewness could be derived by extending the model to allow for such skewness. This approach leads to a system of equations from which one may (implicitly) solve for fundamental skewness and uncertainty, and the disclosure’s informativeness and asymmetry. I leave the exploration of

<table>
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<th></th>
<th>20 days to maturity</th>
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<tbody>
<tr>
<td></td>
<td>MF Variance Level</td>
<td>MF Skewness Level</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>0.847</td>
<td>-0.169</td>
</tr>
<tr>
<td>(\eta)</td>
<td>-0.061</td>
<td>0.900</td>
</tr>
<tr>
<td>(\sigma_0^2)</td>
<td>0.494</td>
<td>-0.113</td>
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such measures, and their robustness to alternative statistical assumptions, to future research.

5 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 returns around the disclosure and option prices prior to the disclosure’s release. The model suggests that the disclosure’s properties are a major determinant of both options’ expected payoffs and their riskiness, and thus should drive the prices and expected returns of options. Moreover, the 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 stock and option prices, in order to show how features such as proprietary costs or information uncertainty might be backed out from option prices.

6 Appendix: 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 1. Let \((\Omega, \mathcal{F}, \Pi)\) denote a probability space that generates the distributions outlined
in the paper. That is, suppose that there exist functions \( d(\omega), \{ B_t(\omega) \}_{t \in [0,T]} \), and \( d_x(\omega) \) that generate the distributions of \( \tilde{d}, \{ \tilde{B}_t \}_{t \in [0,T]} \), and \( \tilde{d}_x \) under \( \Pi \) that are denoted in the text, such that we may write \( \Pr \left( \left( \tilde{d}, \{ B_t(\omega) \}_{t \in [0,T]}, \tilde{d}_x \right) \in S \right) = \int_{\Omega} I \left\{ d(\omega), \{ B_t(\omega) \}_{t \in [0,T]}, d_x(\omega) \in S \right\} d\Pi(\omega) \). Then, we have the following lemma, which is well-known; I prove it only to clear any doubts that it may not hold given the deterministically-timed jump.

**Lemma 3** The price at time \( t \) of an asset that pays off \( \varphi(\omega) \) in state \( \omega \in \Omega \) is equal to
\[
\frac{\int_{\Omega} \varphi(\omega) u'(M(\omega)) d\Pi_t(\omega)}{\int_{\Omega} u'(M(\omega)) d\Pi_t(\omega)} ,
\]
where \( \Pi_t(\omega) \) denotes the measure with respect to the information available at time \( t \).

**Proof.** First, note that the absence of arbitrage implies the existence of a state-price deflator, \( \pi_t(\omega) \). Given that the existence of a full set of traded options implies markets are complete,\(^{16}\) classic results from martingale-pricing theory imply that the representative agent’s problem at time \( 0 \) assuming they have initial wealth \( W \) can be written as (for a proof, see Duffie (2010), pages 214-218):

\[
\max_{c(\omega) \in C(\omega)} \int_{\Omega} u(c(\omega)) d\Pi_0(\omega) \quad \text{s.t.} \quad \int_{\Omega} \pi_T(\omega) c(\omega) d\Pi_0(\omega) = W. \tag{8}
\]

This problem has Lagrangian, where \( \kappa \) is the multiplier:

\[
L \left( \{ c(\omega) \}_{\omega \in \Omega}, \kappa \right) = \int_{\Omega} u(c(\omega)) d\Pi_0(\omega) + \kappa \left( W - \int_{\Omega} \pi_T(\omega) c(\omega) d\Pi_0(\omega) \right). \tag{9}
\]

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

\[
u' \left( c(\omega) \right) \Pi_0(\omega) - \kappa \pi_T(\omega) \Pi_0(\omega) = 0 \quad \kappa = \frac{u'(c(\omega))}{\pi_T(\omega)}.
\]

Utilizing the fact that the risk-free rate is 1, we must have that \( \int_{\Omega} \pi_T(\omega) d\Pi_0(\omega) = 1 \). This yields:

\[
\kappa = \int_{\Omega} u' \left( c(\omega) \right) d\Pi_0(\omega) , \tag{10}
\]

\(^{16}\)In fact, markets are complete in the simple setting even without option trade. To see this, note that markets are complete in the windows \([0, T_D)\) and \((T_D, T]\) by conventional martingale-representation arguments. Moreover, at time \( T_D \), there are only two possible price outcomes, and thus, the market is also complete given trade in a bond and stock. Note further that market completeness is not essential to this result. A utility-gradient approach yields the same result in incomplete markets, under minor technical conditions (Duffie (2010), pages 221-223).
such that \( \pi_T (\omega) = \frac{u'(c(\omega))}{\int_{\Omega} u'(c(\omega)) \, d\Pi(\omega)} \). By the market-clearing condition, in equilibrium, we must have \( c(\omega) = M(\omega) \), such that \( \pi_T (\omega) = \frac{u'(M(\omega))}{\int_{\Omega} u'(M(\omega)) \, d\Pi(\omega)} \). Now, let \( J_t \) denote the price of the security paying off \( \varphi(\omega) \).

By the definition of the state-price deflator, we have that \( \pi_t = E_t[\pi_T] \) and \( \pi_t J_t \) is a martingale. Thus,

\[
J_t = \frac{E_t[\pi_T(\omega) \varphi(\omega)]}{\pi_t} = \frac{E_t[u'(M(\omega)) \varphi(\omega)]}{E_t[u'(M(\omega))]}.
\]

The expressions for the prices of the stock and options follow directly from Lemma 3. To see that the stock price exhibits a jump with probability 1 on the disclosure date, note that:

\[
P_{\tau_D} - \lim_{t \to \tau_D} P_t = \frac{E_{\tau_D} [\hat{x} u'(\hat{M})]}{E_{\tau_D}[u'(\hat{M})]} - \lim_{t \to \tau_D} \frac{E_t[\hat{x} u'(\hat{M})]}{E_t[u'(\hat{M})]} = \frac{E_{\tau_D} [\hat{d} u'(\hat{M})]}{E_{\tau_D}[u'(\hat{M})]} - \lim_{t \to \tau_D} \frac{E_t[\hat{d} u'(\hat{M})]}{E_t[u'(\hat{M})]}.
\]

This is positive for \( \hat{y} = y_H \) and negative for \( \hat{y} = y_L \). Option prices may likewise be shown to jump.

**Proof of Lemma 2. Proof of Part (i)** Applying Lemma 1, note that:

\[
E_t[\hat{x} - P_t] = -\text{Cov}_t \left[ \frac{\hat{x} u'(\hat{M})}{E_t[u'(\hat{M})]} \right].
\]

Note that \( \text{Cov}_t \left[ \frac{\hat{x} u'(\hat{M})}{E_t[u'(\hat{M})]} \right] < 0 \) since \( u'(\hat{M}) \) is decreasing in \( \hat{x} \) through \( \hat{M} \).

**Proof of Part (ii)** Let \( h(t, z) \equiv E_t \left[ u' \left( \hat{o} + \alpha z + (1 - \alpha) \hat{d} \right) \right] \), so that \( h(t, \hat{d}) = E_t \left[ u'(\hat{M}) \mid \hat{d} \right] \). Note that \( h \) is positive and decreasing in \( z \). Moreover, let \( \hat{\theta}_t \equiv E_t \left[ \frac{\hat{d} u'(\hat{M})}{E_t[u'(\hat{M})]} \right] \) and let \( \xi_t(\hat{y}) \equiv \frac{\Pr(\hat{d} = d_H | \hat{y}) d_H h(t, d_H) + \Pr(\hat{d} = d_L | \hat{y}) d_L h(t, d_L)}{\Pr(\hat{d} = d_H | \hat{y}) h(t, d_H) + \Pr(\hat{d} = d_L | \hat{y}) h(t, d_L)} \). Recall that for \( t \geq \tau_D \), \( P_t(y) \) refers to the stock price given that the realized disclosure is \( y \). Substituting into expression (4) and simplifying, we have that, at times \( t \geq \tau_D \), given \( \hat{y} \), \( P_t(\hat{y}) = \hat{\theta}_t + \xi_t(\hat{y}) \). Using Bayes’ rule, this yields:

\[
P_t(y_H) = \hat{\theta}_t + \frac{(\lambda - \eta) d_H h(t, d_H) + (1 - \eta - \lambda) d_L h(t, d_L)}{(\lambda - \eta) h(t, d_H) + (1 - \eta - \lambda) h(t, d_L)} \quad \text{and} \quad P_t(y_L) = \hat{\theta}_t + \frac{(1 + \eta - \lambda) d_L h(t, d_L) + (\lambda + \eta) d_H h(t, d_H)}{(1 + \eta - \lambda) h(t, d_H) + (\lambda + \eta) h(t, d_L)}.
\]
Thus, for any \( t_1 \) and \( t_2 \) satisfying the statement of the Corollary, we have:

\[
\frac{\partial}{\partial \lambda} E_{t_1} [P_{t_2}] = \frac{\partial}{\partial \lambda} \frac{1 - 2\eta (\lambda - \eta) d_H h (t, d_H) + (1 - \eta - \lambda) d_L h (t, d_L)}{2 (\lambda - \eta) h (t, d_H) + (1 - \eta - \lambda) h (t, d_L)} + \frac{\partial}{\partial \lambda} \frac{1 + 2\eta (1 + \eta - \lambda) d_H h (t, d_H) + (\lambda + \eta) d_L h (t, d_L)}{2 (1 + \eta - \lambda) h (t, d_H) + (\lambda + \eta) h (t, d_L)}
\]

\[
\propto [h (t, d_L) - h (t, d_H)] (d_H - d_L) (2\lambda - 1) + [2\eta (h (t, d_H) - h (t, d_L)) (2\lambda - 1) + (1 - 4\eta^2) (h (t, d_H) + h (t, d_L))] .
\]

Note \( h (t, d_L) > h (t, d_H) \). 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:

\[
2\eta (h (t, d_H) - h (t, d_L)) (2\lambda - 1) + (1 - 4\eta^2) (h (t, d_H) + h (t, d_L)) \geq 2\eta (h (t, d_H) - h (t, d_L)) (2 (1 - \eta) - 1) + (1 - 2\eta)(1 + 2\eta)(h (t, d_H) + h (t, d_L)) = (1 - 2\eta)(h (t, d_H) + h (t, d_L)) \geq 0,
\]

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 \( \lambda \) 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:

\[
2\eta (h (t, d_H) - h (t, d_L)) (2\lambda - 1) + (1 - 4\eta^2) (h (t, d_H) + h (t, d_L)) \geq 2\eta (h (t, d_H) - h (t, d_L)) \left[ 2 \left( \frac{1}{2} - \eta \right) - 1 \right] + (1 - 2\eta)(1 + 2\eta)(h (t, d_H) + h (t, d_L)) = (1 - 8\eta^2) (h (t, d_H) + h (t, d_L)) \geq 2 (1 - 4\eta^2) (h (t, d_H) + h (t, d_L)) \geq 0.
\]
Proof of Part (iii) Simplifying expression (4), we find:

\[
\begin{align*}
\dot{P}_t &= E_t \left[ \frac{u'(\dot{M})}{E_t [u'(M)]} \right] + E_t \left[ \frac{\dot{d} u'(\dot{M})}{E_t [u'(M)]} \right] \\
&= E_t \left[ \frac{u'(\dot{M})}{E_t [u'(M)]} \right] + E_t \left\{ \frac{\dot{d}}{E_t [u'(M)]} \left[ u'(\dot{M}) \right] \right\} \\
&= E_t \left[ \frac{u'(\dot{M})}{E_t [u'(M)]} \right] + E_t \left\{ \frac{\dot{d}}{E_t [u'(M)]} \right\} \\
&= \dot{\gamma}_t + \frac{d_H h(t,d_H) + d_L h(t,d_L)}{h(t,d_H) + h(t,d_L)},
\end{align*}
\]

which is not a function of \( \lambda \) or \( \eta \).

Proof of Part (iv) Since, from Part (iii), \( P_{\tau_d} \) is unaffected by \( \lambda \), we have:

\[
\frac{\partial}{\partial \lambda} \text{Var} \left( \frac{P_{\tau_D} - P_{\tau_D}}{P_{\tau_D}} \right) = (1+2\eta)(1-2\eta) \frac{\partial}{\partial \lambda} (P_{\tau_D}(y_H) - P_{\tau_D}(y_L))^2 < 0,
\]

since it can be checked that \( \frac{\partial}{\partial \lambda} P_{\tau_D}(y_H) > 0 \) and \( \frac{\partial}{\partial \lambda} P_{\tau_D}(y_L) < 0 \). Note further that:

\[
\text{Skew} \left( \frac{P_{\tau_D} - P_{\tau_D}}{P_{\tau_D}} \right) = \frac{4\eta}{\sqrt{1 - 4\eta^2}},
\]

which is unaffected by \( \lambda \).

Proof of Part (v) Differentiating expression (20) with respect to \( \eta \), we find that \( \frac{\partial}{\partial \eta} \text{Skew} \left( \frac{P_{\tau_D} - P_{\tau_D}}{P_{\tau_D}} \right) > 0. \)

Moreover, note that:

\[
\frac{\partial}{\partial \eta} \text{Var} \left( \frac{P_{\tau_D} - P_{\tau_D}}{P_{\tau_D}} \right) = \frac{\partial}{\partial \eta} \left( \frac{1+2\eta}{1-2\eta} \right) (P_{\tau_D}(y_H) - P_{\tau_D}(y_L))^2 \\
\propto -4\eta (h(\tau_D,d_H) - h(\tau_D,d_L))^2 \lambda^2 + 2(h(\tau_D,d_H) - h(\tau_D,d_L))(h(\tau_D,d_H)(1+2\eta) + h(\tau_D,d_L)(1-2\eta)) \lambda \\
+ 4(h(\tau_D,d_H) + h(\tau_D,d_L))^2 \eta^3 - 2(h(\tau_D,d_H)^2 + h(\tau_D,d_L)^2) \eta - h(\tau_D,d_H)^2 + h(\tau_D,d_L)^2,
\]

which cannot be signed in general.
Proof of Proposition 1. To begin, I prove the following lemma.

Lemma 4 Let \( h^* \left( \bar{d} \right) = h \left( \tau_D, \bar{d} \right) \). Then, \( \forall k \in (P_{\tau_D} (y_L), P_{\tau_D} (y_H)), \) we have:

\[
\Phi_{\tau_D}^C (k, \tau_D) = \frac{(\lambda - \eta) \left( \tilde{\omega}_{\tau_D} + d_H - k \right) h^* (d_H) + (1 - \lambda - \eta) \left( \tilde{\omega}_{\tau_D} + d_L - k \right) h^* (d_L)}{h^* (d_H) + h^* (d_L)}.
\]  

(21)

Proof. Denote by \( \mathcal{F}_t^B \) the filtration generated by the Brownian motion \( B_t \). Then, note that, since \( \mathcal{F}_t^B \) is continuous, we have:

\[
\Phi_{\tau_D}^C (k, \tau_D) = \lim_{t \rightarrow \tau_D} \frac{E_t \left[ \max \left( P_{\tau_D} (\bar{y}) - k, 0 \right) u' \left( \bar{M} \right) \right]}{E_t \left[ u' \left( \bar{M} \right) \right]}.
\]  

(22)

Now, conditioning with respect to \( \bar{y} \) on the numerator and denominator and substituting the definition of \( h^* \) yields:

\[
\frac{E \left[ \max \left( P_{\tau_D} (\bar{y}) - k, 0 \right) u' \left( \bar{M} \right) \right]}{E \left[ u' \left( \bar{M} \right) \right]} = \frac{E \left[ \max \left( P_{\tau_D} (\bar{y}) - k, 0 \right) \right] E \left[ u' \left( \bar{M} \right) \right]}{E \left[ u' \left( \bar{M} \right) \right] E \left[ \mathcal{F}_{\tau_D}^B \right]}.
\]  

(23)

Now, note that for any \( k \in (P_{\tau_D} (y_L), P_{\tau_D} (y_H)), \) we have that \( P_{\tau_D} (\bar{y}) \geq k \) if and only if \( \bar{y} = y_H \). Thus,

\[
\Phi_{\tau_D}^C (k, \tau_D) = 2 \left( \tilde{\omega}_{\tau_D} + \xi_{\tau_D} (y_H) - k \right) \Pr (\bar{y} = y_H) E \left[ h^* \left( \bar{d} \right) \mathcal{F}_{\tau_D}^B \right] = \frac{2 \left( \tilde{\omega}_{\tau_D} + \xi_{\tau_D} (y_H) - k \right) \Pr (\bar{d} = d_H, \bar{y} = y_H) h^* (d_H) + \Pr (\bar{d} = d_L, \bar{y} = y_H) h^* (d_L)}{h^* (d_H) + h^* (d_L)}.
\]  

(24)

Substituting for \( \xi_{\tau_D} (y_H) \) and simplifying yields:

\[
= \frac{2 \left( \tilde{\omega}_l + \left( \lambda - \eta \right) d_H h^* (d_H) + \left( 1 - \eta - \lambda \right) d_L h^* (d_L) - k \right) \lambda - \eta) h^* (d_H) + (1 - \lambda - \eta) h^* (d_L)}{h^* (d_H) + h^* (d_L)}
\]  

(25)

\[
= \frac{2 \left( \tilde{\omega}_{\tau_D} + d_H - k \right) h^* (d_H) + (1 - \lambda - \eta) \left( \tilde{\omega}_{\tau_D} + d_L - k \right) h^* (d_L)}{h^* (d_H) + h^* (d_L)}.
\]  

(26)
Proof of Part (i) Applying the dominated convergence theorem and the fact that \( \Phi_{\tau_D}^C (k, \tau_D) - \Phi_{\tau_D}^- (k, \tau_D) \) has a derivative that is bounded in \( \lambda \) on \( \left[ \frac{1}{2}, 1 \right] \), we have:

\[
\frac{\partial}{\partial \lambda} E \left[ \frac{\Phi_{\tau_D}^C (k, \tau_D) - \Phi_{\tau_D}^- (k, \tau_D)}{\Phi_{\tau_D}^- (k, \tau_D)} \right] = E \left[ \frac{\partial}{\partial \lambda} E \left[ \frac{\Phi_{\tau_D}^C (k, \tau_D) | \mathcal{F}_{\tau_D}^B}{\Phi_{\tau_D}^- (k, \tau_D)} \right] \right].
\]

(27)

Now, note that \( E \left[ \Phi_{\tau_D}^C (k, \tau_D) | \mathcal{F}_{\tau_D}^B \right] = \frac{1-2\eta}{2} \left( \hat{\vartheta}_{\tau_D} + \xi_{\tau_D} (y_H) - k \right) \). Therefore, applying expression (25), we have:

\[
E \left[ \frac{\partial}{\partial \lambda} E \left[ \frac{\Phi_{\tau_D}^C (k, \tau_D) | \mathcal{F}_{\tau_D}^B}{\Phi_{\tau_D}^- (k, \tau_D)} \right] \right] = E \left[ \frac{\partial}{\partial \lambda} \left( \frac{1-2\eta}{2} \left( \hat{\vartheta}_{\tau_D} + \xi_{\tau_D} (y_H) - k \right) \right) \right]
\]

(28)

\[
= E \left[ \frac{1-2\eta}{2} \cdot \frac{\partial}{\partial \lambda} (\lambda - \eta) h^\ast (d_H) + (1 - \lambda - \eta) h^\ast (d_L) \right]
\]

\[
= \frac{1-2\eta}{2} E \left[ (\lambda - \eta) h^\ast (d_H) + (1 - \lambda - \eta) h^\ast (d_L)\right] > 0.
\]

Proof of Part (ii) By the same argument as in the proof of part (i), we can write:

\[
\frac{\partial}{\partial \eta} E \left[ \frac{\Phi_{\tau_D}^C (k, \tau_D) - \Phi_{\tau_D}^- (k, \tau_D)}{\Phi_{\tau_D}^- (k, \tau_D)} \right] = E \left[ \frac{\partial}{\partial \eta} E \left[ \frac{\Phi_{\tau_D}^C (k, \tau_D) | \mathcal{F}_{\tau_D}^B}{\Phi_{\tau_D}^- (k, \tau_D)} \right] \right]
\]

(29)

\[
= E \left[ \frac{\partial}{\partial \eta} \left( \frac{1-2\eta}{2} \left( \hat{\vartheta}_{\tau_D} + \xi_{\tau_D} (y_H) - k \right) \right) \right]
\]

\[
= \frac{1-2\eta}{2} E \left[ (\lambda - \eta) h^\ast (d_H) + (1 - \lambda - \eta) h^\ast (d_L)\right] > 0.
\]

Proof of Proposition 2. Proof of Part (i) Differentiating expression (26) with respect to \( \lambda \) yields:

\[
\frac{\partial}{\partial \lambda} \left[ \Phi_{\tau_D}^C (k, \tau_D) \right] = \frac{\partial}{\partial \lambda} (\lambda - \eta) \left( \hat{\vartheta}_{\tau_D} + d_H - k \right) h^\ast (d_H) + (1 - \lambda - \eta) \left( \hat{\vartheta}_{\tau_D} + d_L - k \right) h^\ast (d_L)
\]

(30)

\[
= \frac{\left( \hat{\vartheta}_{\tau_D} + d_H - k \right) h^\ast (d_H) - \left( \hat{\vartheta}_{\tau_D} + d_L - k \right) h^\ast (d_L)}{h^\ast (d_H) + h^\ast (d_L)}.
\]

Note that, because \( k \in \left( \hat{\vartheta}_{\tau_D} + \xi_{\tau_D} (y_L), \hat{\vartheta}_{\tau_D} + \xi_{\tau_D} (y_H) \right) \subseteq \left( \hat{\vartheta}_{\tau_D} + d_L, \hat{\vartheta}_{\tau_D} + d_H \right) \), this expression is definitively positive.
Proof of Part (ii) Differentiating expression (26) with respect to \( \eta \) yields:

\[
\frac{\partial}{\partial \eta} \left[ \Phi^C_{\tau_D}(k, \tau_D) \right] = \frac{\partial}{\partial \eta} \left[ (\lambda - \eta) \left( \tilde{\eta}_{\tau_D} + d_H - k \right) h^*(d_H) + (1 - \lambda - \eta) \left( \tilde{\eta}_{\tau_D} + d_L - k \right) h^*(d_L) \right] \frac{h^*(d_H) + h^*(d_L)}{h^*(d_H) + h^*(d_L)}
\]

\[= - \frac{\left( \tilde{\eta}_{\tau_D} + d_H - k \right) h^*(d_H) + \left( \tilde{\eta}_{\tau_D} + d_L - k \right) h^*(d_L)}{h^*(d_H) + h^*(d_L)}.\]

Setting this expression to zero yields \( k = \tilde{\eta}_{\tau_D} + \frac{d_H h^*(d_H) + d_L h^*(d_L)}{h^*(d_H) + h^*(d_L)} = P_{\tau_D} \). Furthermore, note that this expression is increasing in \( k \); this implies it is negative for \( k < P_{\tau_D} \) and positive for \( k > P_{\tau_D} \). \( \blacksquare \)

Proof of Proposition 3. Proof of Part (i) Let \( A = \frac{h^*(d_H)}{h^*(d_L)} \). Clearly, \( A \) increases in \( \alpha \) if and only if \( \frac{h^*(d_H)}{h^*(d_L)} \) increases in \( \alpha \). From the definition of \( h^* \), we have:

\[
\frac{\partial}{\partial \alpha} h^*(d_H) = \frac{\partial E_{\tau_D}}{\partial \alpha} \left[ u' \left( \tilde{\alpha} + \alpha d_H + (1 - \alpha) \tilde{d}_e \right) \right] \]

\[= E_{\tau_D} \left[ u' \left( \tilde{\alpha} + \alpha d_H + (1 - \alpha) \tilde{d}_e \right) \right] E_{\tau_D} \left[ \left( d_H - \tilde{d}_e \right) u'' \left( \tilde{\alpha} + \alpha d_H + (1 - \alpha) \tilde{d}_e \right) \right]
- E_{\tau_D} \left[ u' \left( \tilde{\alpha} + \alpha d_H + (1 - \alpha) \tilde{d}_e \right) \right] E_{\tau_D} \left[ \left( d_L - \tilde{d}_e \right) u'' \left( \tilde{\alpha} + \alpha d_L + (1 - \alpha) \tilde{d}_e \right) \right]
\]

This is negative because \( d_L \leq \tilde{d}_e \leq d_H \) with probability 1, \( d_L < \tilde{d}_e \) with probability \( \frac{1}{2} \), and \( \tilde{d}_e < d_H \) with probability \( \frac{1}{2} \). Now, we can write:

\[
\frac{\partial \Phi^C_{\tau_D}(k, \tau_D)}{\partial \lambda} = \left( \tilde{\eta}_{\tau_D} + d_H - k \right) A - \left( \tilde{\eta}_{\tau_D} + d_L - k \right) (1 - A).
\]

This implies:

\[
\frac{\partial^2 \Phi^C_{\tau_D}(k, \tau_D)}{\partial \lambda^2} = 2 \left( k - \tilde{\eta}_{\tau_D} \right) - d_H - d_L,
\]

which has the sign of \(- \left( \frac{d_H + d_L}{2} + \tilde{\eta}_{\tau_D} - k \right)\).

Proof of Part (ii) This follows since:

\[
\frac{\partial \Phi^C_{\tau_D}(k, \tau_D)}{\partial \eta} = \frac{\partial^2 \Phi^C_{\tau_D}(k, \tau_D)}{\partial \lambda \partial \alpha} - \frac{\partial^2 \Phi^C_{\tau_D}(k, \tau_D)}{\partial \lambda \partial A}
\]

\[= \frac{\partial}{\partial A} \left[ A \left( \tilde{\eta}_{\tau_D} + d_H - k \right) + (1 - A) \left( \tilde{\eta}_{\tau_D} + d_L - k \right) \right]
- d_H - d_L > 0.
\]

\( \blacksquare \)

Proof of Corollary 1. The researcher observes a path of the process \( \{P_t\}_{t \in [0, \tau]} \). Lemma 2 demonstrates
that the pre-disclosure path of stock prices \( \{P_t\}_{t \in [0, \tau_D]} \) exhibits no relationship with \( \lambda \) or \( \eta \). In the remainder of the proof, I demonstrate that the post-disclosure path of stock prices \( \{P_t\}_{t \in [\tau_D, T]} \) also does not reveal the disclosure’s properties under either assumption (1) or (2). Begin with assumption (1). In this case, given the independence of \( \hat{\alpha} \) and \( \hat{M} - \hat{\alpha} \), we have, for any \( t \in [\tau_D, T] \):

\[
P_t = \frac{E_t \left[ (\hat{\alpha} + \hat{d}) \exp (-\rho \hat{M}) \right]}{E_t \left[ \exp (-\rho \hat{M}) \right]} = \frac{E_t \left[ (\hat{\alpha} + \hat{d}) \exp (-\rho \hat{\alpha}) \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]}{E_t \left[ \exp (-\rho \hat{\alpha}) \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]} = \frac{E_t \left[ \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right] E_t \left[ \hat{\alpha} \exp (-\rho \hat{\alpha}) \right] + E_t \left[ \exp (-\rho \hat{\alpha}) \right] E_t \left[ \hat{d} \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]}{E_t \left[ \exp (-\rho \hat{\alpha}) \right] E_t \left[ \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]} = \frac{E_t \left[ \hat{\alpha} \exp (-\rho \hat{\alpha}) \right]}{E_t \left[ \exp (-\rho \hat{\alpha}) \right]} + \frac{E_t \left[ \hat{d} \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]}{E_t \left[ \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]}.
\]

Now, notice that \( \frac{E_t \left[ \hat{\alpha} \exp (-\rho \hat{\alpha}) \right]}{E_t \left[ \exp (-\rho \hat{\alpha}) \right]} \) is unaffected by \( \lambda \) and \( \eta \), and that \( \frac{E_t \left[ \hat{d} \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]}{E_t \left[ \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]} \) takes the same value for any \( t \geq \tau_D \) since the investor’s beliefs regarding \( \hat{M} - \hat{\alpha} \) do not change in this period. This implies that the information contained in \( \{P_t\}_{t \in [\tau_D, T]} \) regarding \( \lambda \) and \( \eta \) is equivalent to that in \( \frac{E_{\tau_D} \left[ \hat{d} \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]}{E_{\tau_D} \left[ \exp \left(-\rho \left( \hat{M} - \hat{\alpha} \right) \right) \right]} \).

However, note that this is a single statistic that is jointly affected by both \( \lambda \) and \( \eta \), and thus, it is mathematically impossible to invert either parameter from this statistic. Next, consider assumption (2). Without loss of generality, suppose \( \tilde{y} = y_H \). Then, using expression (13), for any \( t \in [\tau_D, T] \), we have:

\[
P_t = E_t \left[ \frac{\hat{\alpha} u^\prime \left( \hat{M} \right)}{E_t \left[ u^\prime \left( \hat{M} \right) \right]} \right] + \frac{(\lambda - \eta) d_H h(t, d_H) + (1 - \eta - \lambda) d_L h(t, d_L)}{(\lambda - \eta) h(t, d_H) + (1 - \eta - \lambda) h(t, d_L)}.
\]

Given the assumption that \( \alpha = 0 \), \( u^\prime \left( \hat{M} \right) \) is independent of \( \hat{d} \), and thus \( h(t, d_L) = h(t, d_H) \). This implies that:

\[
P_t = E_t \left[ \frac{\hat{\alpha} u^\prime \left( \hat{M} \right)}{E_t \left[ u^\prime \left( \hat{M} \right) \right]} \right] + \frac{(\lambda - \eta) d_H + (1 - \eta - \lambda) d_L}{1 - 2\eta}.
\]

Therefore, the information in \( \{P_t\}_{t \in [\tau_D, T]} \) is equivalent to \( \frac{(\lambda - \eta) d_H + (1 - \eta - \lambda) d_L}{1 - 2\eta} \), which again is insufficient to invert either \( \lambda \) or \( \eta \).}

**Proof of Proposition 4.** Given that the disclosure concerns purely idiosyncratic performance, \( h^\ast (d_L) =
$h^* (d_H)$, and thus:

$$
\Phi_{\tau_D}^C (k, \tau_D) = \frac{(\lambda - \eta) \left( \tilde{\varphi}_{\tau_D} + d_H - k \right) + (1 - \lambda - \eta) \left( \tilde{\varphi}_{\tau_D} + d_L - k \right)}{2} 
= \frac{1 - 2\eta}{2} \left( \tilde{\varphi}_{\tau_D} + \frac{(\lambda - \eta) d_H + (1 - \lambda - \eta) d_L}{1 - 2\eta} - k \right). 
$$

(36)

First, note that, for $k_2 \neq k_1$, we have:

$$
\eta = \frac{\Phi_{\tau_D}^C (k_2, \tau_D) - \Phi_{\tau_D}^C (k_1, \tau_D)}{k_2 - k_1} + \frac{1}{2}. 
$$

(37)

Next, note that, given the assumption that $P_{\tau_D}$ is observable, we also have that the price of an ATM option, $\Phi_{\tau_D}^C \left( P_{\tau_D}, \tau_D \right)$, is observable. Solving for this price, we have:

$$
\Phi_{\tau_D}^C \left( P_{\tau_D}, \tau_D \right) = \frac{1 - 2\eta}{2} \left( \frac{(\lambda - \eta) d_H + (1 - \lambda - \eta) d_L}{1 - 2\eta} - \frac{d_H + d_L}{2} \right) 
= \frac{1}{4} \left( d_H - d_L \right) (2\lambda - 1), 
$$

(38)

which implies:

$$
\lambda = \frac{2\Phi_{\tau_D}^C \left( P_{\tau_D}, \tau_D \right)}{d_H - d_L} + \frac{1}{2}. 
$$

(39)
References


