Measuring Risk Information*

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Abstract

We develop and implement a measure of how information events impact investors' perceptions of firms' riskiness. We derive this measure from a dynamic model in which investors anticipate and observe an announcement that contains information on both the mean and risk of a firm's future cash flows. The model yields a measure of the announcement's risk information that is based upon the time-series and term-structure of option-implied volatility. We apply the measure to a sample of quarterly earnings announcements and show it has many desirable properties: it predicts innovations in firms' return volatilities, risk-factor exposures, and implied costs of capital, helps identify the timing of heightened volatility, tracks shocks to firms' pre-announcement disclosure requirements, and forecasts deterioration in firms' fundamental performance. Taken together, our study offers an approach for studying the risk information conveyed by information events that is simple to implement and broadly applicable across a variety of research settings.

JEL Classifications: G10, G11, G12, G14, M40, M41

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1. Introduction

Information is frequently impounded into stock prices in the form of discrete, anticipated events such as earnings announcements, press releases, and 10K's. Research on the impact of such events typically focuses on the information they contain regarding firms' expected future cash flows (which we call "mean information" for short). Yet, in many cases, these events also provide information on the riskiness of firms' cash flows (which we call "risk information" for short). For example, firms' quarterly financial reports may signal the scope of their risky investments, their exposure to risk factors, and their financial liquidity.

Determining the nature and impact of the risk information contained in an information event is central to understanding its effects on the efficiency of resource allocation. The severity and nature of risk influences most interactions between economic agents, including decisions over debt contracting, compensation design, and portfolio choice, but is typically stochastic and must be estimated. Studying the transmission of information on risks is of particular importance for understanding how and why interactions among economic agents evolve over time, the efficacy of firms' financial reports, and the roles of informational intermediaries such as analysts and the financial press.

In this study, we develop a measure of the risk information conveyed by an anticipated information event. We derive this measure from a model of stochastic information flows, implement it empirically, and run a battery of tests that yield support for its use as a proxy for risk information. The measure can be used to analyze not only the risk information contained in the event, but also the time at which the risks signaled by the event will be resolved and the quantity of risk information that information events provide.

Measuring risk information presents a significant challenge, as reflected in the scarcity and limitations of existing proxies. Existing methods for studying the information content of an announcement based upon stock prices, such as earnings-response coefficients and announcement-induced return volatility, cannot be used to quantify risk information for at least two reasons. First, under prevailing asset pricing theory, stock prices are independent of firm-specific risks. Second, stock prices (as well as bond prices) are jointly and simultaneously influenced by information on expected cash flows and risk-factor exposures, which makes it impossible to use them to separately identify mean information versus risk information.

To address these measurement challenges, we turn attention to option markets surrounding information events, where risk has a first-order impact on prices. Specifically, we model a market in which investors trade in a firm's stock and options and observe an information event that contains both mean and risk information regarding the firm's value. The model's central output is our measure of the risk information in the news event, which we call *RiskInfo*.

To derive *RiskInfo*, we first analyze the realized change in the option-implied stock-return variance on the announcement date, which captures the revision in investors' expectations of the future return variance. As the variation in a firm's returns depends upon the firm's risk, this change in implied variance is linked to the risk information contained in the event. However, we find that it also depends upon, and is thus confounded by, the expected *quantity* of price-relevant information contained in the announcement. Intuitively, even when the announcement does not contain risk information, the implied variance shifts on the announcement date, climbing in advance of this date and subsequently reverting to its normal level (Patell and Wolfson (1979), Dubinsky et al. (2018)). This predictable pattern is driven by the expected increase in stock-price volatility on the announcement date, whose magnitude is determined by the quantity of information the event contains.

Our model shows that researchers can isolate the risk information in the news event by adjusting the realized change in the implied variance on the announcement date by investors' ex-ante expectations of this change. Moreover, researchers can measure and adjust for these expectations using the term structure of implied variances (i.e., the difference in the return variance implied by short- versus long-dated option prices) just prior to the announcement.[1]

[1]Note this is the same metric derived by Dubinsky et al. (2018) in the context of the Black-Scholes model.

This term structure captures the predictable pattern in volatility around the announcement, and stems from the magnified impact that short-term spikes in volatility have on short- relative to long-term options. In sum, *RiskInfo* is calculated as the realized change in the option-implied variance on the announcement date less the expected change in this variance, as measured by the term-structure of option prices prior to this date.

As we derive *RiskInfo* from readily-available option prices, it is portable across a variety of research questions and settings. To illustrate how it may be applied, we calculate *RiskInfo* for a sample of approximately 134 thousand quarterly earnings announcements spanning 1996 through 2017. Our findings suggest that investors learn an economically significant amount of information on firms' riskiness from their quarterly earnings announcements. Specifically, we estimate that investors receive information on firms' riskiness that is equivalent in magnitude to approximately 15% (6%) of the implied variance in firms' stock returns expected over the month (six months) following the announcement. Moreover, our point estimates suggest the amount of risk information conveyed by earnings announcements has grown over time.

We next perform a series of tests on our sample of earnings announcements to validate the measure and demonstrate the variety of ways in which it may be used. We begin by examining the relation between *RiskInfo* and the innovations in return volatility that follow firms' earnings announcements. The derivation of *RiskInfo* rests on the assumption that option traders, at least in part, understand the risk information in the information event and incorporate this information into option prices. If this assumption is satisfied, then the measure should predict the volatility of stock returns over time as the underlying risks are resolved and make their way into prices. We indeed find that *RiskInfo* powerfully predicts return volatility. Moreover, its predictive power is incremental to the simple change in the implied return variance on the announcement date, demonstrating the importance of correcting for the expected change in implied volatility on this date.

In a related test, we use *RiskInfo* to examine whether the risk information in earnings concerns firm-specific risk and/or firm's risk-factor exposures. Our model predicts that, if an announcement contains information on both of these types of risk, then *RiskInfo* should forecast innovations in both firms' idiosyncratic volatility and absolute exposures to risk factors. We find that *RiskInfo* offers strong predictive power for changes in firms' idiosyncratic volatilities, sensitivities to the market portfolio, and sensitivities to multiple asset pricing factors known to explain variation in the cross-section of returns. This suggests that earnings provide a diversity of information on risk. Further supporting this view, we show that *RiskInfo* forecasts increases in the discount rate that investors apply to firms' future earnings, as measured by variation in firms' implied costs of capital.

Our model also shows that it is possible to measure the amount of information the announcement contains on risks that will be resolved during specific time windows by taking the difference in *RiskInfo* when calculated using options of varying maturity dates. For example, the difference in *RiskInfo* calculated from 30- versus 60-day options yields an estimate of the information the announcement contains on risks that will be resolved between 30 and 60 days following its release. Empirically, we find that such estimates successfully predict the time-series of return volatility. This implies that not only are option traders able to process the total risk information in earnings, they are also able to determine the time at which these risks will be resolved and their outcome incorporated into prices.

We next use *RiskInfo* to decipher the nature of the risk information contained in earnings announcements. To do so, we examine the relationship between *RiskInfo* and subsequent changes in firms' fundamentals as reported in their next fiscal quarter. We find that greater values of *RiskInfo* predict deteriorations in firms' profitability, which suggests that the risk information in earnings results in part from their ability to signal drops in firm performance. In addition, we find that higher values of *RiskInfo* foreshadow increases in firms' spending on research and development, as well as summary indicators of firms' distress risk, consistent with earnings announcements conveying information on the scope of risky investments.

Our model also shows that the absolute value of *RiskInfo* signals the quantity of risk information that information events provide. Intuitively, larger unexpected revisions in investors' beliefs regarding future volatility translate into large absolute values of *RiskInfo* and indicate greater amounts of new risk information. We find that the earnings announcements of smaller value firms on average have larger absolute values of *RiskInfo*, consistent with these firms providing more risk information. Firms with more earnings volatility and those that provide less guidance also offer more risk information on the earnings date.

To further illustrate how researchers can apply the absolute value of *RiskInfo* to measure the quantity of risk information that an announcement provides, we next use it to study the impact of a regulatory change in disclosure requirements. In particular, we examine changes in the magnitude of *RiskInfo* following the SEC's 2004 regulation requiring that firms' file material contracts on a more timely basis via 8K's. Following Noh et al. (2019), we measure the extent to which a given firm filed material contracts on a delayed basis with their 10K/Qs. After the 2004 regulation, these firms were required to disclose material contracts as 8Ks, and on a much more timely basis compared to their 10K/Qs, which we predict results in less risk information being conveyed at the announcement. Consistent with this prediction, we find that the affected firms conveyed less risk information at their earnings announcement after the 2004 regulation, suggesting that the 2004 regulation pulled risk information forward into 8K filings.

In our final analysis, we apply the measure to firms' 10K filings and compare it with text-driven proxies that count the quantity of uncertainty-related words. We find the frequency of uncertainty words is positively related to the level of firms' past and future return volatility, but does not significantly forecast innovations in risk. By contrast, *RiskInfo* again offers significant incremental forecasting power for both levels and changes in firms' return volatility. These tests underscore an important appeal of our proposed methodology, which can be applied to a variety of research settings and events including those without textual disclosures.

Related studies examine option prices surrounding information events. For instance, Patell and Wolfson (1979) demonstrate that option-implied volatility climbs leading up to earnings announcements and Dubinsky et al. (2018) demonstrate that the magnitude of this climb predicts, with noise, realized volatility on the announcement date. Rogers et al. (2009) show that implied volatility systematically rises following earnings announcements that are preceded by an earnings forecast and Barth and So (2014) show that some firms earnings announcements convey systematic risk reflected in option prices. Kelly et al. (2016) examines index option prices surrounding anticipated political information events. We contribute to this literature by showing that the difference between the expected and realized drop in implied volatility on the date of an information event captures risk information conveyed by the announcement. Moreover, unlike the existing work, in our model, the volatility of returns is a stochastic process, and the announcement contains information on this process.

Prior literature demonstrates that option prices can provide information regarding investors' beliefs in other contexts. For instance, Breeden and Litzenberger (1978) show that option prices can be used to invert the risk-neutral return distribution; Ross (2015) and Jensen et al. (2019) build on this finding by characterizing assumptions under which option prices can be used to invert both state prices and investors' belief distribution about future returns. Note our methodology moves beyond inverting the distribution of returns to inverting the underlying information that drives this distribution. Finally, Borochin and Golec (2016) demonstrate that option prices may be used to measure the value-effect of an event and Smith (2018) demonstrates that the option-implied volatility surface surrounding a disclosure reveals the disclosure's informativeness for both good and bad news regarding expected future cash flows. We contribute to this work by demonstrating that the time-series in conjunction with the term-structure of option-implied volatility around an announcement can be exploited to isolate the announcement's information on risk.

2. Theoretical Development

2.1. Intuitive Overview

In this section, we provide a heuristic overview of how option prices may be used to measure the amount of risk information contained in an anticipated information event. We specifically refer to the risk information in an announcement as any new information that it contains that causes investors to revise their beliefs regarding a firm's future cash-flow variance. For instance, the announcement may adjust investors' perceptions of future cash-flow variance by signalling the magnitude of the firm's exposure to a risk factor, the scope of a new risky investment, a change in the firm's strategy, or an event whose implications for the firm's value are yet to be determined (e.g., Kumar et al. (2008), Armstrong et al. (2013), Heinle et al. (2018)). We seek to separate such information from the information that the announcement provides on the firm's expected future cash flows, e.g., information on the outcome of an investment.

As a first pass, one might consider using the change in the Black-Scholes implied variance (or volatility) on the announcement date to quantify the risk information the announcement contains. Prior work has used this change to study the impact of earnings on investors' perceptions of future volatility (e.g., Rogers et al. (2009), Neururer et al. (2016)). To see how this measure relates to the information content of the announcement, consider a firm that has value $\tilde{x}$. Assume that investors continuously trade in the firm's stock over a time interval $[0, T]$ and that an announcement $\tilde{s}$ is released at date $\tau_D \in (0, T)$ that allows investors to update on $\tilde{x}$. Let P_t refer to the firm's stock price at date t and, for purposes of demonstration, suppose that the firm's value $\tilde{x}$ is perfectly known by a date $\tau_M \in (\tau_D, T)$, such that $P_{\tau_M} = \tilde{x}$. Then, assuming the Black-Scholes assumptions hold, the change in the return variance implied by an option with maturity τ_M on the announcement date, which we refer to as ΔIV, equals:

$$\begin{aligned}\Delta IV &\equiv (\tau_M - \tau_D)^{-1}\left[Var\left(\frac{P_{\tau_M} - P_{\tau_D}}{P_{\tau_D}}|\tilde{s}\right) - Var\left(\frac{P_{\tau_M} - P_{\tau_D}}{P_{\tau_D}}\right)\right] \\ &\propto Var\left(P_{\tau_M}|\tilde{s}\right) - Var\left(P_{\tau_M}\right) \\ &= Var\left(\tilde{x}|\tilde{s}\right) - Var\left(\tilde{x}\right).\end{aligned} \tag{1}$$

This expression states that ΔIV is proportional to the change in investor uncertainty over firm value created by the announcement, $Var(\tilde{x}|\tilde{s}) - Var(\tilde{x})$. However, critically, ΔIV is *not* equivalent to the risk information the disclosure contains. The reason is that, in addition to the disclosure's risk information, the information in the disclosure regarding expected future cash flows also impacts investor uncertainty. Intuitively, when investors act as Bayesians, information on expected future cash flows lowers uncertainty. This reduction in uncertainty arises even when investors face no uncertainty regarding a firm's risk and thus should not be thought of as information on risk.

To demonstrate the two distinct effects that an information event has on investor uncertainty more formally, consider decomposing the change in investor uncertainty induced by the event, $Var(\tilde{x}|\tilde{s}) - Var(\tilde{x})$, as follows:

$$\begin{aligned}Var(\tilde{x}|\tilde{s}) - Var(\tilde{x}) &= E\left[Var(\tilde{x}|\tilde{s}) - Var(\tilde{x})\right] + Var(\tilde{x}|\tilde{s}) - E\left[Var(\tilde{x}|\tilde{s})\right] \\ &= \underbrace{-Var\left[E(\tilde{x}|\tilde{s})\right]}_{\text{Reduction in uncertainty created by mean info.}} + \underbrace{Var(\tilde{x}|\tilde{s}) - E\left[Var(\tilde{x}|\tilde{s})\right]}_{\text{Risk information}},\end{aligned} \tag{2}$$

where the second line results from an application the law of total variance. This law states that the expected reduction in uncertainty that results from a disclosure, $E\left[Var(\tilde{x}|\tilde{s}) - Var(\tilde{x})\right]$, depends only upon the amount of mean information the announcement contains, that is, it is independent of the information it contains on risk. Thus, the unexpected change in uncertainty resulting from a disclosure, $Var(\tilde{x}|\tilde{s}) - E\left[Var(\tilde{x}|\tilde{s})\right]$, captures the novel information in the disclosure for firm risk. This decomposition demonstrates that it is only when the disclosure contains no mean information, i.e., $E(\tilde{x}|\tilde{s})$ is a constant, that the change in the option-implied variance on the disclosure date can exclusively be attributed to risk information.

The decomposition in expression (2) reveals how option prices can be used to measure the amount of risk information in a disclosure. The expected reduction in uncertainty that results from the disclosure, $Var\left[E\left(\tilde{x}|\tilde{s}\right)\right]$, is roughly equal to the ex-ante variance in the stock price on the disclosure date (and is thus proportional to returns on this date). Together with expression (2), this implies that the risk information in the disclosure is equal to the sum of the ex-ante variance in returns on the disclosure date and ΔIV. Importantly, the ex-ante variance in returns on the disclosure date can also be measured using option prices: the difference in the return variances implied by options with short- and long-horizons prior to the disclosure is proportional to this variance. This follows because the temporary spike in the return variance created by the disclosure more strongly influences options with shorter maturities (Dubinsky et al. (2018)). To summarize, the sum of the drop in the option-implied variance following the disclosure date and the difference in the return variance implied by short- and a long-maturity options prior to the disclosure captures the disclosure's information content regarding firm risk.

The heuristic analysis in this section is subject to several limitations. First, we made no distinction between the disclosure's information on idiosyncratic risk and risk-factor exposures. Moreover, we assumed that the variance in prices on the disclosure date was driven only by changes in investors' expectations of firm value $Var\left[E\left(\tilde{x}|\tilde{s}\right)\right]$, ignoring any effects the disclosure has on the risk premium. Next, we assumed that uncertainty over the firm's value was entirely resolved by the maturity date of the option used to measure risk information. Finally, while the focus of our analysis centered on information on risk, which mandates uncertain volatility, we employed the Black-Scholes model, which assumes that the process followed by volatility is known in advance. In the next section, we resolve these concerns by formally deriving the measure within a general-equilibrium model of option prices.

2.2. Formal Model: Assumptions

We model a representative investor who trades continuously over a time interval $[0, T]$ in a firm's stock and European call options of all relevant strikes and maturity dates. Let r denote the exogenous risk-free rate of interest. The investor faces uncertainty regarding the expected value of the stock's value as well as its riskiness. In particular, the firm's value, which we refer to as $\tilde{x}_T$, is the value at date T of the following stochastic process:[2]

$$\begin{aligned} x_0 &= \mu_x; \\ \frac{dx_t}{x_t} &= \sigma_d dW_t^d + \tilde{\sigma}_{v,t} dW_t^v, \end{aligned} \tag{3}$$

where W_t^d and W_t^v are independent standard Brownian motions. As we will see, the purpose of assuming that the firm's value is subject to two independent Brownian motions is to allow us to separately discuss the information in a disclosure concerning the firm's expected value and risk.[3] Note that the firm's exposure to W_t^v, $\tilde{\sigma}_{v,t}$, is itself a stochastic process, which reflects uncertainty over the riskiness, as captured by the variance, of the terminal value $\tilde{x}_T$. We assume that the process followed by $\tilde{\sigma}_{v,t}$ is continuous and is such that a solution to equation (3) exists and that the investor's utility is finite. Moreover, assume that $\tilde{\sigma}_{v,t}$ is independent of W_t^d and W_t^v.

The investor consumes once at the terminal date T; let $\tilde{c}_T$ denote the representative investor's consumption. Assume the investor has CRRA utility with risk-aversion coefficient α: $u(c_T) = \frac{c_T^{1-\alpha}}{1-\alpha}$, and that $\tilde{c}_T$ is the outcome of the following stochastic process:

$$\begin{aligned} c_0 &= \mu_c; \\ \frac{dc_t}{c_t} &= \sigma_c dW_t^c. \end{aligned}$$

At time t, the investor observes x_t and c_t, i.e., their information set at time t includes $\mathscr{F}_t^x$ and

[2] Note that the market outcomes in the case of a non-zero drift in firm value and consumption are equivalent to those in which the integrated drift is added to their initial values.

[3] Note the model and resulting measure are robust to the case in which the firm's exposure to the Brownian motion W_t^d also depends upon $\tilde{\sigma}_{v,t}$.

$\mathscr{F}_t^c$ where $\mathscr{F}_t^x$ and $\mathscr{F}_t^c$ are the filtrations generated by x_t and c_t, and thus, they continuously learn information about the firm's future cash flows. In addition, at a time τ_D that is known in advance to the investor, a disclosure is instantaneously released. The disclosure reveals W_T^d, which captures the mean information in the disclosure, as it determines the investor's posterior perception of the expected terminal value, but not the variance of this value.[4] The disclosure also reveals $\{\tilde{\sigma}_{v,t}\}_{t\in[\tau_D,T]}$, which captures its information on risk. Formally, the risk information in the disclosure as defined in the prior section, $Var\left(\tilde{x}|\tilde{s}\right) - E\left[Var\left(\tilde{x}|\tilde{s}\right)\right]$, is equal to $\int_{\tau_D}^{T} \tilde{\sigma}_{v,z}^2 dz$. Note while we assume that these two components of the disclosures are "perfect" in that they reveal W_T^d and $\{\tilde{\sigma}_{v,t}\}_{t\in[\tau_D,T]}$ without noise, it is possible to accommodate imperfect learning with no change in the resulting measure.

In order to allow the disclosure to contain information on the aggregate economy, we let W_t^d covary with the consumption process W_t^c: $Cov\left[W_t^c, W_t^d\right] = \rho * t$. We also allow the component of the firm's value over which volatility is stochastic, W_t^v, to covary with the consumption process W_t^c: $Cov\left[W_t^c, W_t^v\right] = \gamma * t$. This enables the model to accommodate both uncertainty over the firm's systematic risk exposures and uncertainty over the amount of idiosyncratic risk it faces. Moreover, it creates time-series variation in the stock's discount rate as investors learn about the volatility process $\tilde{\sigma}_{v,t}$.

The parameter γ determines the extent to which the disclosure concerns idiosyncratic versus systematic risk. At the end of this section, we show that the measure we develop does not depend upon γ. Thus, the measure does not distinguish between whether the disclosure concerns idiosyncratic or systematic risks; it captures the impact of the disclosure on investors' *total* perception of firm risk. Intuitively, this results because option value increases in volatility whether or not this volatility is systematic or idiosyncratic. Note it is straightforward to generalize the model to one in which risk takes on a multi-factor structure. In this case, the measure is a joint function of the information the disclosure contains on all of the firm's risk-factor exposures as well as the firm's idiosyncratic risk.

[4]It is not important whether the disclosure reveals W_T^d or $\left\{W_t^d\right\}_{t\in[\tau_D,T]}$; we demonstrate this fact in the proof of Lemma 1 below.

Finally, we assume that $\tilde{\sigma}_{v,t}$ and W_t^c are independent. This assumption is essential to enabling us to express our measure in terms of the Black-Scholes formula, which makes it simple to implement using readily-available data. However, this assumption rules out a variance risk premium and thus the possibility that the disclosure, by reducing uncertainty over the future variance of consumption, reduces the variance risk premium. Note that since the variance risk premium increases option prices, a decline in this premium on the disclosure date would cause an increased drop in the option-implied variance on this date. Thus, by ignoring this force, our measure may exhibit a downward bias. The size of this bias is likely small when applying the measure to individual firms' announcements: its magnitude is determined by the amount that investors learn on the announcement date regarding their future consumption variance, which depends upon the state of the entire economy. In addition, a similar bias is shared by existing stock-price-based measures of an announcement's information content such as earnings-response coefficients, as the effect of information on risk premia, including the variance risk premium, also manifest in stock prices.

2.3. Equilibrium Prices

We now solve for stock and option prices in equilibrium. The firm's price satisfies a standard Euler equation:

$$P_t = \exp[-r(T-t)]\frac{E_t\left[u'(\tilde{c}_T)\tilde{x}_T\right]}{E_t\left[u'(\tilde{c}_T)\right]} = \exp[-r(T-t)]\frac{E_t\left[\tilde{c}_T^{-\alpha}\tilde{x}_T\right]}{E_t\left[\tilde{c}_T^{-\alpha}\right]}.$$

Let $\tilde{D}_t = \sigma_d \tilde{W}_t^d - \frac{1}{2}t\sigma_d^2$ and $\tilde{V}_t = \int_0^t \tilde{\sigma}_{v,z} dW_z^v - \frac{1}{2}\int_0^t \tilde{\sigma}_{v,z}^2 dz$, such that $E\left[\tilde{x}_T|\tilde{x}_t\right] = \mu_x \exp\left[\tilde{D}_t + \tilde{V}_t\right]$. Evaluating the expectations in this expression, we have the following lemma.

Lemma 1. *The firm's stock price at time t satisfies:*

$$t < \tau_D\text{: } P_t = \mu_x \exp\left[\tilde{D}_t + \tilde{V}_t\right] E_t\left\{\exp\left[-r(T-t) - \alpha(T-t)\rho\sigma_c\sigma_d - \alpha\gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\right]\right\};$$

$$t \geq \tau_D\text{: } P_t = \mu_x \exp\left[\tilde{D}_T + \tilde{V}_t - r(T-t) - \alpha\gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\right].$$

The lemma states that, prior to the disclosure, the firm's price equals expected firm value discounted at an expectation over the rate $r + \alpha\rho\sigma_c\sigma_d + \alpha\gamma\sigma_c\tilde{\sigma}_{v,t}$. Note the latter two components of the discount rate reflect risk premia for uncertainty over $\tilde{D}_T$ and $\tilde{V}_T$, respectively. As investors face uncertainty over $\int_t^T \tilde{\sigma}_{v,z}dz$, they discount based upon expected uncertainty, as opposed to actual uncertainty. Following the disclosure, the component of price related to expected firm value is updated to $\exp\left[\tilde{D}_T + \tilde{V}_t\right]$, which accounts for the disclosure's information on the mean. Moreover, the discount rate embedded in price no longer includes $\alpha\rho\sigma_c\sigma_d$, which reflects the reduction in uncertainty created by the disclosure. Furthermore, the post-disclosure risk premium related to $\tilde{V}_T$ reflects the firm's actual, as opposed to expected, risk-factor exposure. Thus, both the expected cash flow and discount rate components of price jump discretely on the disclosure date. Finally, note the amount that the stock price varies over time following the disclosure depends upon the level of risk $\{\tilde{\sigma}_{v,t}\}_{t\in[\tau_D,T]}$, as it determines the amount to which investors revise their beliefs regarding the firm's value from observing x_t.

We can now derive option prices in equilibrium. The next proposition states that an option's price can be expressed as an expectation over the Black-Scholes value of the option, where the expectation is taken over possible values of its future volatility; this holds since fluctuations in the firm's volatility are idiosyncratic in the model (Hull and White (1987)). In stating the result, let $\Phi_t^C(k,\tau_M)$ denote the price of a call option with strike k and maturity date τ_M at time t and let $BS[P_t,k,\sigma,\tau]$ denote the Black-Scholes price of a call option when the current stock price is P_t, the option's strike is k, volatility is σ, the risk-free rate of interest is r, and the time to maturity of the option is τ.

Theorem 1. *The price of a call option with strike k and maturity date τ_M at a time $t<\tau_D$ is equal to:*

$$\Phi_t^C(k,\tau_M) = E_t\left\{BS\left[P_t, k, \left(\frac{(T-t)\,\sigma_d^2 + \alpha^2\gamma^2\sigma_c^2 Var_t\left(\int_{\tau_M}^T \tilde{\sigma}_{v,z}dz\right) + \int_t^{\tau_M}\tilde{\sigma}_{v,z}^2 dz}{\tau_M - t}\right)^{\frac{1}{2}}, \tau_M - t\right]\right\},$$

and at a time $t \geq \tau_D$ is equal to:

$$\Phi_t^C(k, \tau_M) = BS\left[P_t, k, \left(\frac{\int_t^{\tau_M} \tilde{\sigma}_{v,z}^2 dz}{\tau_M - t}\right)^{\frac{1}{2}}, \tau_M - t\right].$$

There are three components to the return variance that enters the option-pricing formula prior to τ_D. The first, $(T-t)\,\sigma_d^2$, captures the variance in price created by the announcement's information on the mean. The second, $\alpha^2\gamma^2\sigma_c^2 Var\left(\int_{\tau_M}^T \tilde{\sigma}_{v,z} dz\right)$, captures variation in the risk premium that stems from the announcement's information on the firm's risk-factor exposure. Finally, the third, $\int_t^{\tau_M} \tilde{\sigma}_{v,z}^2 dz$, captures the amount of learning over the component of firm value with stochastic volatility. Following the announcement, both the first and second components of the variance disappear, as the mean information and risk premium become known and integrated into price.

We next illustrate an approximation that will be useful in deriving the measure of risk information. Specifically, for $k \approx P_t$, $E_t\left[BS\left[P_t, k, \tilde{z}^{\frac{1}{2}}, \tau\right]\right] \approx BS\left[P_t, k, E_t(\tilde{z})^{\frac{1}{2}}, \tau\right]$. Thus, we have, for $t < \tau_D$:[5]

$$\Phi_t^C(k, \tau_M) \approx BS\left[P_t, k, \left(\frac{(T-t)\,\sigma_d^2 + E_t\left(\int_t^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right) + \alpha^2\gamma^2\sigma_c^2 Var_t\left(\int_{\tau_M}^T \tilde{\sigma}_{v,z} dz\right)}{\tau_M - t}\right)^{\frac{1}{2}}, \tau_M - t\right], \quad (4)$$

and, for any $\tau_D \leq t < \tau_M$:

$$\Phi_t^C(k, \tau_M) \approx BS\left[P_t, k, \left(\frac{E_t\left(\int_t^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right)}{\tau_M - t}\right)^{\frac{1}{2}}, \tau_M - t\right]. \quad (5)$$

2.4. Deriving the Measure of Risk Information

We now derive a measure of the amount of information the disclosure contains on risk that will realize prior to a date τ_m. Let $IV^{ATM}[t, \tau_M]$ denote the implied *variance* derived from an at-the-money option as of time t that matures at date τ_M; note we use at-the-money options as these are the least prone to model misspecification. Applying expressions (4) and

[5] See, e.g., Hull and White (1987), who show that for reasonable parameters, a similar approximation to the one below is roughly 98% accurate.

(5), for any $\tau_A < \tau_D \leq \tau_P < \tau_M$, we have:

$$\begin{aligned} IV^{ATM}[\tau_A, \tau_M] &\approx \frac{(T-\tau_A)\,\sigma_d^2 + \alpha^2\gamma^2\sigma_c^2 Var_{\tau_A}\left(\int_{\tau_M}^{T} \tilde{\sigma}_{v,z} dz\right) + E_{\tau_A}\left(\int_{\tau_A}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right)}{\tau_M - \tau_A} \text{ and} \\ IV^{ATM}[\tau_P, \tau_M] &\approx \frac{\int_{\tau_P}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz}{\tau_M - \tau_P}. \end{aligned}$$

Thus, for an option with maturity $\tau_M \in [\tau_D, T)$, the jump in the option-implied variance on the disclosure date scaled by its time to maturity equals:

$$\begin{aligned} \Delta IV[\tau_M] &\equiv (\tau_M - \tau_D)\left\{IV^{ATM}[\tau_D, \tau_M] - \lim_{t \to \tau_D^-} IV^{ATM}[t, \tau_M]\right\} \qquad (6) \\ &= -(T-\tau_D)\,\sigma_D^2 - \alpha^2\gamma^2\sigma_c^2 Var_{\tau_D^-}\left[\int_{\tau_M}^{T} \tilde{\sigma}_{v,z} dz\right] + \int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz - E_{\tau_D^-}\left[\int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right]. \end{aligned}$$

Similar to the discussion in Section 2.1, the jump in the implied variance, $\Delta IV[\tau_M]$, has two components. The first component, $-(T-\tau_D)\,\sigma_D^2 - \alpha^2\gamma^2\sigma_c^2 Var_{\tau_D^-}\left[\int_{\tau_M}^{T} \tilde{\sigma}_{v,z} dz\right]$, equals $E[Var(P_{\tau_M}) - Var(P_{\tau_M}|\tilde{s})]$, the predictable drop in investor uncertainty that results on the disclosure date. The second component, $\int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz - E_{\tau_D^-}\left[\int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right]$, captures the information the disclosure contains on risks. Note it captures only risks that will resolve by the option's maturity, τ_m.

The final step to deriving the estimator is to add to $\Delta IV[\tau_M]$ an estimator of $-(T-\tau_D)\,\sigma_D^2 - \alpha^2\gamma^2\sigma_c^2 Var_{\tau_D^-}\left[\int_{\tau_M}^{T} \tilde{\sigma}_{v,z} dz\right]$. We use the term-structure estimator of disclosure-induced return variance proposed by Dubinsky et al. (2018). Intuitively, the term-structure estimator exploits the fact that the disclosure creates an increase in price volatility that is roughly constant across options of different maturity dates. Thus, the disclosure more strongly influences the per-day price variance implied by a short-maturity option than that implied by a long-maturity option. Thus, taking the difference between these two variances yields an estimate of the variation in prices created by the disclosure. Using the present notation, for any $t < \tau_D \leq \tau_1 < \tau_2$, this estimator takes the following form:

$$\frac{IV^{ATM}\left[t,\tau_1\right] - IV^{ATM}\left[t,\tau_2\right]}{\left(\tau_1 - t\right)^{-1} - \left(\tau_2 - t\right)^{-1}}.$$

Formally calculating this estimator, which we refer to as $AnnVar[\tau_1, \tau_2]$, at time t less than but close to τ_D, we arrive at:

$$\begin{aligned} &AnnVar[\tau_1,\tau_2] \\ &\quad \equiv \left(T-\tau_D\right)\sigma_d^2 + \frac{\left(\tau_2-\tau_D\right)\int_{\tau_D}^{\tau_1} E_{\tau_D^-}\left(\tilde{\sigma}_{v,z}^2\right)dz - \left(\tau_1-\tau_D\right)\int_{\tau_D}^{\tau_2} E_{\tau_D^-}\left(\tilde{\sigma}_{v,z}^2\right)dz}{\tau_2-\tau_1} + \\ &\quad \frac{\left(T-\tau_2\right)\alpha^2\rho^2\sigma_f^2 Var_{\tau_D^-}\left[\int_{\tau_1}^{T}\tilde{\sigma}_{v,z}dz\right] - \left(T-\tau_1\right)\alpha^2\rho^2\sigma_f^2 Var_{\tau_D^-}\left[\int_{\tau_2}^{T}\tilde{\sigma}_{v,z}dz\right]}{\tau_2-\tau_1}. \end{aligned} \tag{7}$$

Note in general, in our model, $AnnVar[\tau_1, \tau_2]$ is not precisely equal to the disclosure-induced return variance, $\left(T-\tau_D\right)\sigma_d^2 + \frac{(T-\tau_m)\alpha^2\rho^2\sigma_f^2 Var_{\tau_D^-}\left[\int_{\tau_m}^{T}\tilde{\sigma}_{v,z}dz\right]}{T-\tau_m}$. The first reason is that differences in the variances of options with different maturity dates may capture changes in investors' expectations of volatility unrelated to the disclosure; this manifests in the second term of expression (7). Dubinsky et al. (2018) quantitatively assess the magnitude of this effect in a variety of option-pricing models and find that it is small enough to be reasonably ignored.

The second reason for the deviation between $AnnVar[\tau_1, \tau_2]$ and the disclosure-induced return variance arises from the information in the disclosure on the firm's risk-factor exposures. Specifically, note the third term in expression (7), which is related to the price variance induced by the disclosure's information on these exposures, deviates from the actual amount of this variance $\frac{(T-\tau_m)\alpha^2\rho^2\sigma_f^2 Var_{\tau_D^-}\left[\int_{\tau_m}^{T}\tilde{\sigma}_{v,z}dz\right]}{T-\tau_m}$. The estimator accurately captures the variance only when $Var_{\tau_D^-}\left[\int_{\tau_m}^{T}\tilde{\sigma}_{v,z}dz\right] \approx Var_{\tau_D^-}\left[\int_{\tau_1}^{T}\tilde{\sigma}_{v,z}dz\right] \approx Var_{\tau_D^-}\left[\int_{\tau_2}^{T}\tilde{\sigma}_{v,z}dz\right]$. Intuitively, the disclosure's relevance for the risk premium can change over time depending upon the stochastic process followed by the risk-factor exposure, $\tilde{\sigma}_{v,t}$. As the existing sources of consumption risk become known, prior risk-factor exposures may become less relevant. If the model were extended to allow for renewed sources of uncertainty over time as opposed to a single terminal dividend, new risk-factor exposures would arise that offset this drop in relevance. Thus, we posit this source of error is small. Note also that this bias goes to zero when the risk information in the disclosure is purely idiosyncratic, i.e., when $\gamma \to 0$.

Assuming that $AnnVar[\tau_1, \tau_2]$ is a reasonable estimator of the disclosure-induced variance, we arrive at our measure of risk info by summing $\Delta IV\,[\tau_M]$ and $AnnVar[\tau_1, \tau_2]$:

$$\int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz - E_{\tau_D^-}\left[\int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right] \approx \Delta IV\,[\tau_M] + AnnVar[\tau_1, \tau_2]. \tag{8}$$

Note that we can also construct from this measure a metric of the amount of risk that will manifest between any two dates. Specifically, expression (8) implies that the difference in $RiskInfo_{\tau_M}$ calculated at two dates, t_1 and t_2, is equal to:

$$RiskInfo_{t_2} - RiskInfo_{t_1} = \int_{t_1}^{t_2} \tilde{\sigma}_{v,z}^2 dz - E_{\tau_D^-}\left[\int_{t_1}^{t_2} \tilde{\sigma}_{v,z}^2 dz\right], \tag{9}$$

which is precisely the amount risk that manifests in prices between t_1 and t_2.

2.5. Theoretical Properties of the Measure

We next discuss the model's predictions for the relationship between $RiskInfo_{\tau_M}$ and the properties of stock prices, which we will test when validating the measure in our empirical results. First, note from Lemma 1 that the total variance of returns between the announcement date and τ_M equals:

$$\begin{aligned}
Var\left[\log\left(\frac{P_{\tau_M}}{P_{\tau_D}}\right)\right] &= Var\left[\tilde{V}_{\tau_M} - \tilde{V}_{\tau_D}\right] + Var\left[\int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right] \\
&= RiskInfo_{\tau_M} + Var\left[\int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right].
\end{aligned}$$

That is, the variance is equal to the sum of risk information and a constant that captures the amount of variation in the risk premium. Thus, this return variance increases in $RiskInfo_{\tau_M}$. Intuitively, when investors face a large amount of risk, they place more weight on the arrival of new information, leading to more variation in prices. Similar reasoning implies that the difference measure in expression (9) should be related to the amount of volatility between times t_1 and t_2.

Next, we consider the relationship between $\mathit{RiskInfo}_{\tau_M}$ and systematic and idiosyncratic return volatility. In order to distinguish between these two types of volatility, let M_t denote the price of a claim to consumption as of time t, which roughly corresponds to the price of a market portfolio. Note first that systematic volatility is driven by the firm's *squared* risk-factor exposure. The firm's average squared beta between dates τ_D and τ_M, which we refer to as $\int_{\tau_D}^{\tau_M} \tilde{\beta}_z^2 dz$, reduces as follows:

$$\begin{aligned} \int_{\tau_D}^{\tau_M} \tilde{\beta}_z^2 dz &\equiv \int_{\tau_D}^{\tau_M} \left\{ \frac{Cov\left[d\log(P_z), d\log(M_z)\right]}{Var\left[d\log(M_z)\right]} \right\}^2 dz \\ &= \frac{\rho^2}{\sigma_c^2} \int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz = RiskInfo_{\tau_M}. \end{aligned}$$

Thus, the model predicts a positive correlation between $\mathit{RiskInfo}_{\tau_M}$ and the firm's average squared beta between the announcement date and τ_M. Next, note we can calculate the firm's idiosyncratic return volatility by examining its return variance conditional on c_t to be $(1-\rho^2)\int_{\tau_D}^{\tau_M} \tilde{\sigma}_{v,z}^2 dz$, that is, $(1-\rho^2)\mathit{RiskInfo}_{\tau_M}$. Thus, the model also predicts a positive relationship between $\mathit{RiskInfo}_{\tau_M}$ and idiosyncratic volatility.

Finally, note that the discount rate applied by investors to the firm's cash flows following the disclosure is equal to $r+\alpha\rho\int_{\tau_D}^{T} \tilde{\sigma}_{v,z} dz$. Note this cannot precisely be expressed in terms of $\mathit{RiskInfo}_{\tau_M}$, as it depends upon the level of $\tilde{\sigma}_{v,z}$ as opposed to its square. However, restricting attention to firms with positive discount rates incremental to the market, i.e., $\int_{\tau_D}^{T} \tilde{\sigma}_{v,z} dz > 0$, it is reasonable to expect a positive relationship between $\mathit{RiskInfo}_{\tau_M}$ and the discount rate. We summarize these results in the following corollary.

Corollary 1.

i. *$\mathit{RiskInfo}_{\tau_M}$ is positively associated with total return volatility between the announcement date and τ_M.*

ii. *$\mathit{RiskInfo}_{\tau_M}$ is positively associated with idiosyncratic return volatility and the firm's squared risk-factor exposures between the announcement date and τ_M.*

iii. *Among firms with positive discount rates, RiskInfo*$_{\tau_M}$ *is positively associated with the discount rate applied to firms' expected future cash flows following the announcement.*

iv. *For* $t_2 > t_1$, *RiskInfo*$_{t_2}$*-RiskInfo*$_{t_1}$ *is positively associated with total return volatility between dates* t_1 *and* t_2.

3. Data and Results

In this section, we empirically implement our proposed measure of risk information, subject it to a battery of validity tests based upon our model, and offer preliminary evidence on its determinants. We start by providing details on the characteristics of our sample and the empirical construction of the measure *RiskInfo*$_{\tau_M}$. We then test the predictions of the model documented in Corollary 1 by analyzing the ability of *RiskInfo*$_{\tau_M}$ to forecast: (1) changes in return volatility; (2) changes in risk-factor exposures from a four-factor model and idiosyncratic volatility; (3) changes in firms' implied costs of capital; (4) the time-series of total volatility. Next, we examine the ability of *RiskInfo*$_{\tau_M}$ to forecast changes in firms' accounting fundamentals. We then examine the determinants of the average absolute level of *RiskInfo*$_{\tau_M}$ for a given firm, which proxies for the *amount* of risk information that a firm's quarterly earnings provide. As part of this analysis, we examine the influence of the 2004 8-K regulation, which plausibly pushed the initial publication of many new sources of risk to precede the announcement of quarterly earnings.

3.1. Sample Construction and Descriptive Statistics

We construct the main dataset used in our analyses from four sources. We obtain price and return data from CRSP, firm fundamentals from Compustat, standardized option data from Option Metrics, and analysts' forecasts of earnings from IBES. Our main tests center on firms' quarterly earnings announcements. We identify earnings announcement dates using the approach taken by DellaVigna and Pollet (2009). Specifically, we compare announcement dates in IBES and Compustat, and use the earlier of the two if the announcement dates differ. We do so because identifying the precise announcement date is important for studying short-window changes in option prices. DellaVigna and Pollet (2009) show their approach yields an accuracy rate of greater than 95% and Johnson and So (2018) show these corrections help reduce bias in short-window return tests centered on earnings announcements.

We eliminate firms that have been in the CRSP database for less than six months to ensure there is sufficient data to calculate historical return volatility and momentum. We also require that firms have coverage in the IBES database to calculate analyst-based earnings surprises, and eliminate firms with prices below $1 to mitigate the influence of illiquidity on our inferences, though our results do not appear highly sensitive to this choice. The Option Metrics database, and hence the sample for this study, spans from 1996 through 2017, consisting of 134,914 firm-quarter earnings announcements.

Table 1 contains descriptive statistics for the main variables in our main earnings announcement sample. Panel A contains annual descriptive statistics and shows that the number of observations steadily grows over time. This growth reflects the rapid growth of options trading in recent years as noted in Johnson and So (2017), suggesting our proposed measure offers increasing coverage for the cross-section of firms over time.

Panel A also reports time-series sample averages and corresponding t-statistics for *RiskInfo* estimated from 30-day and 182-day standardized options. For illustration purposes, we implement *RiskInfo* for options of two horizons, though our approach can easily be modified to options of alternative horizons. For example, if a researcher is interested in capturing risk information over the next year, they can estimate *RiskInfo* using 365-day options.

We implement $RiskInfo_{\tau_M}$ using the derivation outlined via Expression (8) in Section 2. Consistent with the standard approach in short-window event studies, to account for the possibility of information leakage, in calculating $\Delta IV\,[\tau_M]$, we approximate the pre-disclosure implied variance with the implied variance two days prior to to the firm's earnings announcement date, EA, $IV^{ATM}\,[EA-2,\tau_M]$. Likewise, to account for a gradual reaction to earnings, we the approximate post-disclosure implied variance with the implied variance two days after the announcement, $IV^{ATM}\,[EA+2,\tau_M]$. Finally, we calculate $AnnVar$ two days prior to EA and set $\tau_1 = 30$ and $\tau_2 = 60$. To summarize, for example, we implement our 30-day measure of risk information, $RiskInfo_{30}$, as:

$$\begin{aligned} RiskInfo_{30} &= (30-2)\left\{IV^{ATM}\left[EA+2,\tau_{30}\right]-IV^{ATM}\left[EA-2,\tau_{30}\right]\right\} \\ &\quad + \frac{IV^{ATM}\left[EA-2,\tau_{30}\right]-IV^{ATM}\left[EA-2,\tau_{60}\right]}{(1/30-1/60)}, \end{aligned}$$

where the scalar for the first term, (30-2), reflects our use of 30-day options two days prior to the EA date, $EA-d$ denotes that we use options measured d days prior to the announcement date, IV^{ATM} denotes the daily implied variance of an at-the-money option, and τ_{30} denotes the use of a 30-day option. Finally, the denominator in the second term, (1/30 - 1/60), reflects the need to estimate the option term-structure by converting the daily implied variance into variance over the life of the option.

The left side of Panel A provides averages of the absolute levels of risk information over the 30- and 182-day horizons. The average of absolute risk information is 0.008 over the 30-day horizon and 0.021 over the 182 day-horizon. These figures indicate the average impact of earnings announcements on investors' perception of the future return variance. To illustrate the economic significance of these effects, we create scaled measures of risk information, denoted *SRiskInfo*, that scale the average absolute values of $RiskInfo_{30}$ and $RiskInfo_{182}$ by firms' diffusive return variance, where diffusive variance reflects the units of variance expected over the remaining life of the option.[6] Using this scaled approach, our results in the bottom of Panel A indicate that investors update on firms' riskiness by approximately 14.5% of the expected diffusive variance of stock returns over the 30 days following the announcement, and 5.8% of diffusive variance expected over the 182 days following the announcement. These sample averages suggest that investors receive an economically large amount of information on firms' risks from earnings announcements. Moreover, the annual time-series suggests that the amount of risk information that firms convey via their earnings announcements has increased substantially over our sample period.

[6]We calculate diffusive variance using the approaches in Barth and So (2014) and Dubinsky et al. (2018) that use the term-structure of implied volatility prior to earnings announcements to remove the influence of heightened volatility associated with firms' earnings announcements.

The right side of Panel A of Table 1 shows the means of each signed risk information measure tend to be indistinguishable from zero. This result is intuitive in that *RiskInfo* captures "news" about firms' riskiness, and thus we would not expect news to be on average positive or negative. If the average of *RiskInfo* were predictably positive or negative, rational traders should anticipate the predictable sign and incorporate them into market prices ahead of the announcement.

Panel B of Table 1 presents Pearson (Spearman) correlations above (below) the main diagonal for 30-day options. *RiskInfo* is positively correlated with changes in implied volatility, ΔIV measured using option prices on days t-2 and t+2, where day t is the firm's earnings announcement date. *RiskInfo* is also negatively related to firms' return volatility over the year prior to the announcement, $VLTY$, and positively related to $\Delta VLTY$, which reflects changes in return volatility over the year pre- versus post-announcement.

3.2. Forecasting Tests: Total Volatility

To explore the validity and usefulness of *RiskInfo* as a metric of risk information, we start by examining its ability to predict changes in return volatility. Specifically, in Panel A of Table 2 we sort firms into quintile portfolios on a rolling basis based upon the distributional breakpoints of our 30-day measure of risk information $RiskInfo_{30}$ from the prior calendar quarter. Then, we calculate the average changes in the level and log of firms' volatilities relative to their earnings announcement date for each portfolio. We conduct this procedure for both level and log changes in volatility to ensure our results are not driven by outliers.

The row in Panel A corresponding to $\Delta VLTY$ is the post-announcement change in return volatility, defined as the log of the standard deviation of firm's daily returns over the 252 trading days starting 5 days after the earnings announcement, scaled by the standard deviation of firm's daily returns over the 252 trading days ending 5 days prior to the earnings announcement. The row corresponding to $\Delta VLTY$ *(Levels)* is the post-announcement change in the level of return volatility. The column labeled 'High-Low' denotes the difference between the first and fifth quintile.

Panel A reports log changes in volatility increase across quintiles of *RiskInfo*$_{30}$. The spread in $\Delta VLTY$ across the highest and lowest quintile is 0.048 (t-statistic = 13.89) indicating the highest quintile of *RiskInfo*$_{30}$ experiences an approximate 5% larger increase in return volatility than the lowest quintile surrounding earnings announcements. We find similar inferences using level changes in volatility, which increase across quintiles of *RiskInfo*. The findings are consistent with our model's prediction that investors glean information about firms' riskiness from their earnings announcements, and incorporate this information into option prices.

3.3. Forecasting Tests: Risk-Factor Exposures and Idiosyncratic Volatility

In our next tests, we examine the prediction from our model that *RiskInfo* captures information the firm provides on both its idiosyncratic risk and its risk-factor exposures. This result implies that the predictive power of *RiskInfo* for future volatility could stem either from idiosyncratic risk information, systematic risk information, or both. To determine whether firms provide information on both of these types of risk, we next separately examine the ability of *RiskInfo* to predict idiosyncratic volatility and risk-factor exposures.

Panel B of Table 2 reports changes in firms' idiosyncratic volatility over the 252 trading days starting 5 days after the earnings announcement, relative to the 252 trading days ending 5 days prior to the earnings announcement volatility forecasting tests. We measure idiosyncratic volatility on day d by taking the squared residual from a firm-specific market-model regression with three lags. These tests show that part of the predictive power of *RiskInfo*$_{30}$ for total returns stems from investors learning about firm-specific risks.

In Panel C, we provide evidence that *RiskInfo*$_{30}$ also reflects information on firms' risk-factor loadings, for example, reflecting changes in the sensitivity of a firm's business to macroeconomic conditions. Specifically, we report year-over-year changes in squared risk-factor loadings from a four-factor model estimated in the year immediately before versus after firms' earnings announcement. We examine the change in the square of these factor loadings as squared loadings determine the variance of a firm's returns. $\Delta(\beta^2_{MKT})$ is the change in firms' squared sensitivity to the market factor; $\Delta(\beta^2_{SMB})$ is the change in firms' squared sensitivity to the small-minus-big factor; $\Delta(\beta^2_{HML})$ is the change in firms' squared sensitivity to the high-minus-low book to market factor; and $\Delta(\beta^2_{UMD})$ is the change in firms' squared sensitivity to the up-minus-down momentum factor.

Panel C of Table 2 shows that squared changes in risk-factor loadings increase across portfolios of $\mathit{RiskInfo}_{30}$ and that the difference across the highest and lowest quintile is statistically significant. In standard factor-based asset pricing models, the variance of firms' returns equals the squared factor loadings times the variance of the factors, plus the variance of the residual. Thus, the collective results in Table 2 suggest that $\mathit{RiskInfo}_{30}$ helps forecast changes in firms' total return volatility because earnings announcements convey information about firms' sensitivities to risk factors as well as firms' idiosyncratic risks.

3.4. Forecasting Tests: Multivariate Analysis

To further characterize the ability of *RiskInfo* to predict future volatility, Table 3 contains multivariate volatility forecasting results that analyze the components of *RiskInfo*, *AnnVar* and ΔIV, as well as standard predictors of return volatility. Building upon the tests in Table 2, the dependent variables for these regressions are log changes (Panel A) and level differences (Panel B) in volatility. We rank all independent variables into quintiles ranging from zero to one to facilitate the estimation of economic magnitudes and reduce the impact of outliers. Unless otherwise noted in the table, all of our regression tests include firm- and year-quarter fixed effects throughout to explore within-firm variation and mitigate the influence of secular trends across time-periods. The parentheses contain t-statistics based on standard errors clustered by firm and quarter.

Column (1) of both panels in Table 3 shows simple changes in implied volatility around the announcement help forecast changes in volatility, as expected. Similarly, column (2) indicates *AnnVar* also positively predicts changes in volatility when controlling for ΔIV in specifications with firm-fixed effects.[7] Column (3) shows the predictive power of ΔIV and

[7] In untabulated tests, we find that changes in volatility are weakly decreasing across quintile portfolios

AnnVar hold incremental to standard controls known to explain variation in return volatility: firm size, log book-to-market ratio, and analyst-based surprise (e.g. Sridharan (2015)).

Columns (4) through (6) of both panels provide evidence that within-firm variations in $RiskInfo_{30}$ positively predict innovations in firms' volatility incremental to changes in ΔIV. The incremental predictive power of $RiskInfo_{30}$ for changes in return variance over the change in implied variance on the announcement date underscores the importance of correcting for the expected change in implied variance on the disclosure date, *AnnVar*. Our model suggests this effect stems from investors learning about firms' cash flows via the announcement, independent of uncertainty about firms' riskiness.

Note in our model, the firm's mean and risk are independent. However, for several reasons, mean and risk may be correlated. As a notable example, for firms with a material likelihood of bankruptcy, the levered nature of equity may induce a substantive relationship between mean information and firm risk. In this case, our measure will pick up the risk-impact of mean information, which is a legitimate source of news regarding the firm's equity risk. However, in certain applications, one may not wish to pick up this type of news. For example, if one wishes to capture the information in an announcement regarding total firm risk (i.e., the sum of the firm's equity and debt values), as opposed to equity risk alone, this leverage effect should be excluded.

The last two columns of each panel in Table 3 seek to address this concern by examining a version of *RiskInfo* that approximately corrects for this leverage effect. To create this version of the measure, we adjust *RiskInfo* for the average change in firms' implied volatility conditional on their earnings news. Specifically, we obtain coefficients from the following cross-sectional regression within portfolio groupings based on two-digit SIC and leverage

sorted by *AnnVar* consistent with the resolution of uncertainty over risk foreshadowing lower return volatility.

(i.e., debt-to-equity) quintiles:[8]

$$\Delta IV_{t-1,t+1} = \alpha + \beta_{LC} Ret_{t-1,t+1} + \epsilon, \tag{10}$$

where $\Delta IV_{t-1,t+1}$ is the change in implied volatility coinciding with the three-day announcement window, $Ret_{t-1,t+1}$ is the announcement return, and t denotes the announcement date. We then calculate the leverage-corrected measure for the earnings announcement of firm i in quarter by subtracting $\hat{\beta_{LC}} \cdot Ret_{t-1,t+1}$, where $\hat{\beta_{LC}}$ reflects the estimated coefficient over the prior year for firms in the same leverage-industry grouping. The last two columns of Table 3 show that our main inferences largely continue to hold when using the leverage-corrected measure.

3.5. *Forecasting Tests: Implied Cost of Capital*

Together with our model, the finding in the section 3.3 that *RiskInfo* captures information on firms' future risk-factor exposures suggests that the discount rate that investors apply to firms' cash flows should rise with *RiskInfo*. This prediction can be seen from Lemma 1, which shows that the firm's realized level of risk, $\int_t^T \tilde{\sigma}_{v,z} dz$, manifests in the post-announcement discount rate.

In Table 4, we test this prediction by examining variation in firms' implied cost of capital (ICCs) using the estimation approach in Gebhardt et al. (2001), which reconciles analysts' forecasts of future earnings with firms' prevailing stock price.[9] A key appeal of using ICCs is that they relate prevailing market prices with the analysts' most recent expectations of earnings, and thus is less likely to reflect news about the level of future cash flows.

To estimate how investors update discount rates in response to earnings news, we calculate the change in ICCs from the month after firms' earnings announcement date relative to the month prior to firms' earnings announcement date. In Panel A, we show time-series

[8]This formulation allows for the effect of leverage to vary across industries. We obtain similar results using firm size in place of industry groupings.

[9]We eliminate observations with negative implied cost of capital to mitigate measurement error and facilitate the interpretation of the results.

average changes in ICCs across portfolios of *RiskInfo*, whereas in Panel B we estimate the same relation using cross-sectional regressions.

The results in Table 4 indicate that increases in $RiskInfo_{30}$ helps explain variation in post-announcement ICCs. Because the independent variables in the Panel B regressions are again ranked into quintile portfolios, columns (1) through (5) indicate that pre- versus post-announcement-month changes in ICCs are roughly 14 to 22 basis points higher for the highest versus lowest quintile of $RiskInfo_{30}$. Similarly, column (6) shows similar inferences using our leverage-corrected measure of $RiskInfo_{30}$. Both sets of results are consistent with $RiskInfo_{30}$ capturing variation in investors perceptions of firms' riskiness and responding by raising the discount rate applied to firms' future cash flows.

3.6. Forecasting Tests: Time-Series of Volatility

Our tests up to this point have focused exclusively on the forecasting power of $RiskInfo_{30}$, which captures the amount of information on risks that investors expect to manifest in prices over the 30 days following the announcement. In untabulated tests, we find that similar results hold when using $RiskInfo_{182}$ to forecast proxies for risk over the two quarters following the announcement. We next examine an additional implication of the model: the difference in $RiskInfo_{t_1}$ and $RiskInfo_{t_2}$ should capture the amount of risk investors expect to realize in prices between times t_1 and t_2.

Table 5 shows that differences in *RiskInfo* across shorter- and longer-dated options successfully predict the timing of heightened return volatility. We implement these tests by first by assigning firms to portfolios based on $\Delta RiskInfo$, which reflects the difference in risk information derived from 30-day and 182-day options and is defined as $RiskInfo_{30}$ minus $RiskInfo_{182}$. We then test whether $\Delta RiskInfo$ predicts within-firm variation in volatility in the next 30 days versus 182 days.[10]

In Table 5, we measure differences in volatility in two ways. The first is the log ratio,

[10] In untabulated results, our findings do not appear highly sensitive to alternative option horizons, for example by comparing 30 versus 60 day options.

log$[VLTY(+5,+26)/VLTY(+27,+182)]$, which we measure as the log of the standard deviation of firm's daily market-adjusted returns from 5 to 26 trading days after the earnings announcement, scaled by the standard deviation of firm's daily returns from 27 to 182 trading days after the earnings announcement. Second, we estimate level differences in volatility by first accounting for differences in scale across the two windows of measurement. We do so by standardizing the two return volatility measures each calendar quarter to have a mean zero and unit standard deviation and then calculate $STVLTY(+5,+26) - STVLTY(+27,+182)$ as the level difference in the standardized versions.

Table 5 shows that Δ*Riskinfo* positively predicts variation in both log changes in return volatility, $log[VLTY(+5,+26)/VLTY(+27,+182)]$, as well as the level difference in standardized volatilties $STVLTY(+5,+26)$ - $STVLTY(+27,+182)$. These findings suggest that option traders not only learn about total risk information from firms' earnings announcements, but also glean information about the horizon at which these risks will be resolved and their outcome incorporated into prices.

3.7. Forecasting Tests: Firm Fundamentals

Our results thus far establish that *RiskInfo* forecasts changes in firms' future volatility, which is consistent with traders learning about the resolution of risk from firms' earnings announcements. We next extend these findings by linking our measure to changes in firms' subsequently reported behavior and fundamental performance.

To the extent that investors learn about the risk of firms facing financial constraints and/or solvency concerns from their earnings announcements, we predict that *RiskInfo* helps forecast changes in firms' subsequently announced fundamental performance. In Panel A of Table 6, we focus on firms' profitability using two distinct measures. The first is firms' standardized unexplained earnings, $FutureSUE$, defined as the fiscal-quarter adjusted innovations in quarterly earnings, scaled by the standard deviation of earnings innovations over the trailing eight quarters. The second is firm's analyst-based surprise, $FutureSURP$, defined as earnings per share minus the consensus forecast immediately prior to the announcement.

Panel A shows that *RiskInfo* foreshadow declines in firms' earnings as measured by their SUE and $SURP$ reported at their next quarterly earnings announcement. The results in columns (1) and (2) of Panel A are consistent with *RiskInfo* capturing risk associated with seasonally-adjusted declines in firms' profit generating ability. The results in columns (3) and (4) suggest that analysts fail to fully incorporate this information into their forecasts of earnings, perhaps reflecting behavioral limitations and/or incentive misalignment problems (see Kothari et al. (2016) for a review of this literature).

Panel B of Table 6 contains results exploring changes in firms investment behavior and distress risk. The dependent variable for the regression results in columns (1) and (2) of Panel B is firms' research and development expenditure scaled by total assets, $FutureRND$, which we measure in the fiscal quarter after our measurement of *RiskInfo*. Our findings suggest that *RiskInfo* is greater in anticipation of increased risky investments as proxied by spending on research and development.

Panel B also contains results of regressions where the dependent variable is firms' distress risk based on the fundamentals reported in the fiscal quarter after our measurement of *RiskInfo*. Our distress risk proxy comes from Campbell et al. (2008), where higher values indicate a greater likelihood of financing constraints. Columns (3) and (4) show that greater values of *RiskInfo* positively forecast firms' distress risk, which is consistent with investors learning about potential threats to firms' solvency risk from their earnings announcements.

4. Applications of Risk Information Measures

Our empirical tests up to this point center on validating our proposed approach as a measure risk information conveyed by an information event. In this section, we build upon our validation tests by providing two sets of analyses that illustrate how researchers can apply our methodology toward studying the drivers of risk information.

4.1. Determinants of the Quantity of Risk Information

In this section, we illustrate a potential application of out methodology toward studying the quantity of risk information conveyed by firms' earnings announcements. These tests leverage a prediction of our model that variation in *RiskInfo* signals the quantity of the information firms provide in their earnings announcements about risk. Intuitively, large quantities risk information leads to larger unexpected revisions in investors' beliefs regarding future volatility, which translates into large absolute values of *RiskInfo*. More formally, our model shows that the absolute magnitude of *RiskInfo* signals the quantity of risk information that firms provide during an information event.

Table 7 contains regression results where the dependent variables are the absolute value of our risk measure, *AbsRiskInfo*, measured from 30-options. All of the independent variables from this regression are measured prior to, or contemporaneous with, our measurement of *RiskInfo*. For example, our measures of earnings news, $SURP$ and SUE, are defined as in Table 6 but measured during the announcement coinciding with our measure of *RiskInfo*. To capture uncertainty over firms' earnings, our regression includes $EarnVol$ defined as the standard deviation of firms' earnings-per-share over the prior eight quarters. Additionally, to capture variation in firms' information environment, we also include COV defined as the log of one plus analyst coverage, $Guidance$ is the log of one plus the number of times a company has issued guidance over the prior quarter, and $DiscQuality$ defined as the level of disclosure quality as proxied by the extent of dissagregation in firms' financial statements.

The results in Table 7 indicate that earnings announcements of smaller value firms and firms with more volatile earnings tend to have larger absolute values of *RiskInfo*, consistent with these firms providing more risk information during their earnings announcements. The negative signs on SUE and $SURP$ indicate that negative earnings conveys more risk information than positive news, consistent with firms delaying negative news and earnings being asymmetrically informative of firms' insolvency risks (e.g., Kothari et al. (2009)). Additionally, we find that firms that provide more guidance also offer less risk info on the earnings date, consistent with voluntary disclosures reducing uncertainty over firms' riskiness in advance of their earnings announcements.

In many research settings, researchers examine equity market returns around an event to gauge whether the event was "decision relevant" in the sense that the event induced investors to change their valuation of a company. Our results offer a new technique for studying the decision relevance of an information event, such as a disclosure, by examining whether the event conveys risk information. To the extent an event triggers variation in *RiskInfo*, the event could be characterized as decision relevant by conveying information on firms' risks, even in the absence of a significant equity market response. The results in Table 7 provide an illustration of how these tests could be applied to earnings announcements, though this approach is easily portable to other events where option prices are available.

4.2. Regulatory Changes in Risk Information

Our next tests illustrate how researchers can apply our methodology toward studying regulatory changes in disclosure requirements. We do so by examining changes in absolute *RiskInfo* following the SEC's 2004 regulation requiring that firms' file material contracts on a more timely basis via 8-K filings. As noted in Noh et al. (2019), Congress enacted new rules as part of the Sarbanes-Oxley Act legislating that publicly traded firms employ greater use of real-time disclosures using Form 8K filings for material changes in their financial condition or operations between their periodic 10K/Q filings starting in August of 2004.

Following Noh et al. (2019), we study the relation between increases in 8Ks and risk information conveyed during firms' earnings announcements by measuring the extent to which a given firm filed material contracts on a delayed basis with their 10K/Qs, rather than 8Ks, prior to the 2004 regulation. After the 2004 regulation, these firms were required to disclose material contracts as 8Ks, and on a much more timely basis compared to their 10K/Qs, which we predict results in less risk information being conveyed at the announcement.

Table 8 contains results from a regression of absolute risk information from 30-day options, $AbsRiskInfo_{30}$, on firms' use of material contract filings *not* filed as 8Ks prior to the

2004 SEC Regulation mandating that material contracts be filed on a more timely basis via 8Ks. For this analysis, we limit the sample to 4,692 earnings announcements in the three years immediately before and after the regulation for firms that have at least one Exhibit 10 not filed as an 8K in the pre-period.

Our main regression estimate of interest in Table 8 is the interaction term between the post-regulation indicator variable, *post*, and firm's average number of material contract filings *not* filed as an 8K per pre-regulation quarter scaled by the firm's average number of 8K filings per pre-regulation quarter, *Pre-Period Non-8K Exhibit 10s*. In these tests, we do not include main effects for *Pre-Period Non-8K Exhibit 10s* and the post-period indicator, *Post*, because they are absorbed by firm- and year-quarter fixed effects.

Consistent with our prediction, we find affected firms that file greater material contracts outside of 8Ks prior the 2004 regulation conveyed less risk information at their earnings announcement after the 2004 regulation. The negative interaction effect we document is consistent with the 2004 regulation pulling risk information forward into 8K filings, and thus pre-empting the amount of risk information conveyed during earnings announcements.

5. Extensions

A key strength of our measure of risk information is that it easily portable across research settings and questions where options data is available. To underscore this strength, our final analyses extends our main findings on earnings announcements by examining risk information conveyed by firms' 10K filings. In doing so, we compare our measure of risk information calculated around firms' 10K filing dates against alternative measures of risk information calculated from the number of uncertainty-related words contained in firms' 10Ks as part of the section labeled "Management Discussion and Analysis" (MDA).

In Table 9, we compare the ability of our measure to forecast firms' volatility against existing textual-analysis based-measures that count the quantity of uncertainty-related words as a proxy for risk information. The three panels in Table 9 report averages of volatility relative to firms' 10K filing date, across quintiles sorted by $RiskInfo_{30}$ in Panel A, the total number of uncertainty words in the 10K in Panel B, and the fraction of uncertainty words in the 10K in Panel C. Measures of uncertainty words come from the Wharton Research Data Services Readability and Sentiment file corresponding to firms' 10K SEC filings.

The first row if all three panels of Table 9 report averages of firm's market capitalization, denoted $SIZE$. Panel A shows that firm size does not significantly vary across portfolios of $RiskInfo_{30}$ suggesting that our proposed proxy is unlikely to simply reflect larger or smaller firms conveying more risk information. By contrast, Panels B and C shows larger firms tend to use a large quantity of uncertainty-related words, but use less uncertainty words as a fraction of total words in their 10K.

The remaining rows of Table 9 report levels and changes in firms' volatility relative to their 10K filing date. Analgous to our earnings announcement tests, *VLTY (Pre-10K)* is the standard deviation of firm's daily returns over the 252 trading days ending 5 days prior to the 10K filing date and *VLTY (Post-10K)* is the standard deviation of firm's daily returns over the 252 trading days beginning 5 days after the 10K filing date. $\Delta VLTY$ is the post-announcement change in return volatility, defined as the log of the ratio of *VLTY (Post-10K)* to *VLTY (Pre-10K)*. $\Delta VLTY$ *(Levels)* is defined analogously using the level change in volatility.

Panel A shows *RiskInfo* is negatively related to lagged volatility, consistent with investors learning more about risks from 10Ks when they are less likely preceded by other information events. We also find *RiskInfo* is again positively related to log changes and level differences in firms' return volatility relative to their 10K, consistent with investors learning about firms' riskiness via their 10Ks and incorporating the information into option prices.

Panels B and C provide evidence that the frequency of uncertainty words is positively related to the level of firms' past and future return volatility, but does not significantly forecast innovations in risk. These findings suggest risk-word-based proxies are more likely to convey the level of firms' risks, rather than capturing the information investors glean about risks from firms' 10Ks.

In Table 10 we present results from regressing changes in firms' volatility around the 10K filing date on the two textual-based proxies for risk, as well as $RiskInfo$, standard controls, and firm- and time-fixed effects. These tests show that uncertainty words in 10Ks fail to positively forecast changes in firms' return volatility. In fact, the number of uncertainty words negatively forecasts changes in firms' return volatility, which is consistent with uncertainty words explaining heightened volatility in the most recent fiscal period. By contrast, we again find evidence that $RiskInfo$ positively forecasts innovations in volatility, which reinforce our earlier findings focus on firms' earnings announcements.

Together, the results in Tables 9 and 10 suggest that our market-based approach toward measuring risk information offers significant advantages, relative to the use of text-based proxies, for studying risk information conveyed by information events. Conceptually, our findings suggest that greater uncertainty words may in part reflect managers explaining past volatility, rather than conveying novel risk information. Empirically, our findings illustrate a path forward for researchers to study risk information using options, even for information events where textual analyses are not applicable.

6. Conclusion

The central contribution of this paper is the development of a new approach for estimating how information events impact investors' perceptions of firms' riskiness. We formally develop this approach from a model in which investors anticipate an information event that leads them to update their perception of both mean and risk. Our model shows that researchers cannot estimate risk information from equity prices alone and that the change in option-implied volatility is confounded by the quantity of price-relevant information contained in the event. We empirically implement our measure on a large sample of quarterly earnings announcements, finding that these announcements contain a material amount of information on both idiosyncratic risk and systematic risk-factor exposures.

Taken together, our study offers a novel approach for studying the informativeness of disclosures regarding firms' risks, which is simple to implement and broadly applicable across a variety of research settings. Potential applications of the measure include the study of the value of risk information in debt contracting and optimal compensation design, the nature of the risk information contained in specific components of the financial statements, and the impact of risk information on investor behavior.

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7. Appendix

Proof of Lemma 1. Let $\tilde{C}_t \equiv \log \frac{\tilde{c}_t}{\mu_c}$ and $\tilde{X}_t \equiv \log \frac{\tilde{x}_t}{\mu_x} = \tilde{D}_t + \tilde{V}_t$. Note that:

$$\begin{aligned}
P_t &= \exp\left[-r\left(T-t\right)\right] \frac{E_t\left[\tilde{c}_T^{-\alpha}\tilde{x}_T\right]}{E_t\left[\tilde{c}_T^{-\alpha}\right]} \\
&= \exp\left[-r\left(T-t\right)\right] \frac{E_t\left[\exp\left(-\alpha\left(\tilde{C}_T+\log\left(\mu_c\right)\right)+\tilde{X}_T+\log\left(\mu_x\right)\right)\right]}{E_t\left[\exp\left(-\alpha\left(\tilde{C}_T+\log\left(\mu_c\right)\right)\right)\right]} \\
&= \mu_x \exp\left[-r\left(T-t\right)\right] \frac{E_t\left[\exp\left(-\alpha\tilde{C}_T+\tilde{X}_T\right)\right]}{E_t\left[\exp\left(-\alpha\tilde{C}_T\right)\right]}.
\end{aligned}$$

We begin by explicitly solving for this price for $t<\tau_D$. In this case, the investor's information set at time t consists of $\left\{\tilde{X}_z, \tilde{C}_z\right\}_{z\in[0,t]}$. Applying iterated expectations:

$$P_t = \mu_x \exp\left[-r\left(T-t\right)\right] \frac{E_t\left\{E_t\left[\exp\left(-\alpha\tilde{C}_T+\tilde{X}_T\right) \mid \{\tilde{\sigma}_{v,\tau}\}_{\tau\in[0,T]}\right]\right\}}{E_t\left[\exp\left(-\alpha\tilde{C}_T\right)\right]}.$$

In order to calculate the numerator, note that:

$$Var_t\left[\begin{pmatrix}\tilde{D}_T\\ \tilde{V}_T\\ \tilde{C}_T\end{pmatrix} \mid \{\tilde{\sigma}_{v,\tau}\}_{\tau\in[0,T]}\right] = \begin{pmatrix}\sigma_d^2\left(T-t\right) & 0 & \rho\sigma_c\sigma_d\left(T-t\right)\\ 0 & \int_t^T \tilde{\sigma}_{v,z}^2 dz & \gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\\ \rho\sigma_c\sigma_d\left(T-t\right) & \gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz & \sigma_c^2\left(T-t\right)\end{pmatrix}.$$

This implies that:

$$\begin{aligned}
&Var\left(-\alpha\tilde{C}_T+\tilde{X}_T|\tilde{D}_t,\tilde{V}_t,\tilde{C}_t,\{\tilde{\sigma}_{v,\tau}\}_{\tau\in[0,T]}\right)\\
&= \begin{pmatrix}1 & 1 & -\alpha\end{pmatrix}\begin{pmatrix}\sigma_d^2\left(T-t\right) & 0 & \rho\sigma_c\sigma_d\left(T-t\right)\\ 0 & \int_t^T \tilde{\sigma}_{v,z}^2 dz & \gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\\ \rho\sigma_c\sigma_d\left(T-t\right) & \gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz & \sigma_c^2\left(T-t\right)\end{pmatrix}\begin{pmatrix}1\\ 1\\ -\alpha\end{pmatrix}\\
&= \sigma_d^2\left(T-t\right)+\int_t^T\tilde{\sigma}_{v,z}^2dz+\alpha^2\sigma_c^2\left(T-t\right)-2\alpha\rho\left(T-t\right)\sigma_c\sigma_d-2\alpha\gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz.
\end{aligned}$$

Thus, applying $\tilde{X}_t = \tilde{D}_t + \tilde{V}_t$, we have:

$$\begin{aligned}
& E\left\{\exp\left[-\alpha\tilde{C}_T + \tilde{X}_T\right]|\tilde{D}_t, \tilde{V}_t, \tilde{C}_t, \{\tilde{\sigma}_{v,\tau}\}_{\tau\in[0,T]}\right\} \\
= \;& \exp\left[-\alpha\tilde{C}_t + \frac{1}{2}\alpha(T-t)\sigma_c^2 + \tilde{D}_t + \tilde{V}_t - \frac{1}{2}\left(\sigma_d^2(T-t) + \int_t^T \tilde{\sigma}_{v,z}^2 dz\right)\right. \\
& \left.+\frac{1}{2}\left(\sigma_d^2(T-t) + \int_t^T \tilde{\sigma}_{v,z}^2 dz + \alpha^2(T-t)\sigma_c^2 - 2\alpha(T-t)\rho\sigma_c\sigma_d - 2\alpha\gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\right)\right] \\
= \;& \exp\left[-\alpha\tilde{C}_t + \frac{1}{2}\alpha(T-t)\sigma_c^2 + \tilde{X}_t + \frac{1}{2}\left(\alpha^2(T-t)\sigma_c^2 - 2\alpha(T-t)\rho\sigma_c\sigma_d - 2\alpha\gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\right)\right].
\end{aligned}$$

As this is a function only of $\tilde{X}_t$ and not $\tilde{D}_t$ or $\tilde{V}_t$ individually, it is equivalent to $E_t\left\{\exp\left[\alpha\tilde{C}_T + \tilde{X}_T\right]|\{\tilde{\sigma}_{v,z}\}_{z\in[0,T]}\right\}$. Moreover, $Var\left(-\alpha\tilde{C}_T + \tilde{X}_T|\tilde{D}_t, \tilde{V}_t, \tilde{C}_t, \{\tilde{\sigma}_{v,z}\}_{z\in[0,T]}\right) = Var_t\left(-\alpha\tilde{C}_T + \tilde{X}_T|\{\tilde{\sigma}_{v,z}\}_{z\in[0,T]}\right)$. Next, note that:

$$E_t\left[\exp\left(-\alpha\tilde{C}_T\right)\right] = \exp\left[-\alpha\tilde{C}_t + \frac{1}{2}\alpha(T-t)\sigma_c^2 + \frac{\alpha^2(T-t)\sigma_c^2}{2}\right].$$

Given that $\tilde{\sigma}_{v,t}$ has continuous sample paths, it is measurable with respect to the investor's information set at time t. Thus, for $t < \tau_D$,

$$\begin{aligned}
P_t \;=\; & \mu_x \exp[-r(T-t)]\exp\left[-\alpha\tilde{C}_t + \frac{1}{2}\alpha(T-t)\sigma_c^2 + \frac{\alpha^2(T-t)\sigma_c^2}{2}\right]^{-1} \\
& * E_t\left\{\exp\left[-\alpha\tilde{C}_t + \frac{1}{2}\alpha(T-t)\sigma_c^2 + \tilde{X}_t\right.\right. \\
& \left.\left.+\frac{1}{2}\left(\alpha^2(T-t)\sigma_c^2 - 2\alpha(T-t)\rho\sigma_c\sigma_d - 2\alpha\gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\right)\right]\right\} \\
=\; & \mu_x E_t\left\{\exp\left[\tilde{X}_t - r(T-t) - \alpha(T-t)\rho\sigma_c\sigma_d - \alpha\gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\right]\right\}.
\end{aligned}$$

Next, consider the price at time $t \geq \tau_D$. We first solve for the joint distribution of $\tilde{V}_T$ and $\tilde{C}_T$ given $\tilde{C}_t$ and $\left\{\tilde{D}_z\right\}_{z\in[\tau_D,T]}$. Note that for any $\Delta \in [t,T)$, we have:

$$\begin{aligned}
& Var\left[\begin{pmatrix}\tilde{C}_T \\ \tilde{D}_T \\ \tilde{D}_\Delta\end{pmatrix}|\tilde{C}_t, \tilde{D}_t\right] \\
= & \begin{pmatrix}(T-t)\sigma_c^2 & (T-t)\rho\sigma_c\sigma_d & (T-\Delta)\rho\sigma_c\sigma_d \\ (T-t)\rho\sigma_c\sigma_d & (T-t)\sigma_d^2 & (T-\Delta)\sigma_d^2 \\ (T-\Delta)\rho\sigma_c\sigma_d & (T-\Delta)\sigma_d^2 & (T-\Delta)\sigma_d^2\end{pmatrix}.
\end{aligned}$$

Thus, we have that:

$$E\left[\tilde{C}_T|\tilde{C}_t,\tilde{D}_T,\tilde{D}_\Delta,\tilde{D}_t\right]=E\left[\tilde{C}_T|\tilde{C}_t\right]$$
$$+\begin{pmatrix}(T-t)\,\rho\sigma_c\sigma_d & (T-\Delta)\,\rho\sigma_c\sigma_d\end{pmatrix}\begin{pmatrix}(T-t)\,\sigma_d^2 & (T-\Delta)\,\sigma_d^2\\(T-\Delta)\,\sigma_d^2 & (T-\Delta)\,\sigma_d^2\end{pmatrix}^{-1}\begin{pmatrix}\tilde{D}_T-E\left[\tilde{D}_T|\tilde{C}_t,\tilde{D}_t\right]\\\tilde{D}_\Delta-E\left[\tilde{D}_\Delta|\tilde{C}_t,\tilde{D}_t\right]\end{pmatrix}$$
$$=E\left[\tilde{C}_T|\tilde{C}_t\right]+\rho\frac{\sigma_c}{\sigma_d}\left\{\tilde{D}_T-E\left[\tilde{D}_T|\tilde{D}_t\right]\right\}.$$

Since, for any $\Delta\in[t,T)$, this does not depend on Δ, $\tilde{V}_T$ and $\tilde{C}_T$ are independent of $\left\{\tilde{D}_z\right\}_{z\in[\tau_D,T)}$ given $\tilde{C}_t$ and $\tilde{D}_T$. This implies that:

$$Var_t\left[\tilde{C}_T,\tilde{V}_T,\tilde{D}_T\right]=\begin{pmatrix}(T-t)\,\sigma_c^2 & \gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz & (T-t)\,\rho\sigma_c\sigma_d\\\gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz & \int_t^T\tilde{\sigma}_{v,z}^2dz & 0\\(T-t)\,\rho\sigma_c\sigma_d & 0 & (T-t)\,\sigma_d^2\end{pmatrix},$$

and thus:

$$Var_t\left[\tilde{C}_T,\tilde{X}_T|\tilde{D}_T\right]=Var_t\left[\tilde{C}_T,\tilde{V}_T|\tilde{D}_T\right]$$
$$=\begin{pmatrix}(T-t)\,\sigma_c^2 & \gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz\\\gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz & \int_t^T\tilde{\sigma}_{v,z}^2dz\end{pmatrix}-\frac{1}{(T-t)\,\sigma_d^2}\begin{pmatrix}(T-t)\,\rho\sigma_c\sigma_d\\0\end{pmatrix}\begin{pmatrix}(T-t)\,\rho\sigma_c\sigma_d & 0\end{pmatrix}$$
$$=\begin{pmatrix}\sigma_c^2\,(T-t)\,(1-\rho^2) & \gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz\\\gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz & \int_t^T\tilde{\sigma}_{v,z}^2dz\end{pmatrix}.$$

Now,

$$Var_t\left(-\alpha\tilde{C}_T+\tilde{X}_T|\tilde{V}_t,\tilde{C}_t,\tilde{D}_T,\{\tilde{\sigma}_{v,z}\}_{z\in[0,T]}\right)$$
$$=\begin{pmatrix}-\alpha & 1\end{pmatrix}\begin{pmatrix}\sigma_c^2\,(T-t)\,(1-\rho^2) & \gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz\\\gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz & \int_t^T\tilde{\sigma}_{v,z}^2dz\end{pmatrix}\begin{pmatrix}-\alpha\\1\end{pmatrix}$$
$$=\int_t^T\tilde{\sigma}_{v,z}^2dz+\alpha^2\,(T-t)\left(1-\rho^2\right)\sigma_c^2-2\alpha\gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz.$$

Now, we have:

$$E_t\left\{\exp\left[-\alpha\tilde{C}_T+\tilde{X}_T\right]|\,\{\tilde{\sigma}_{v,z}\}_{z\in[0,T]}\right\}$$
$$=\exp\left[-\alpha\left[E\left[\tilde{C}_T|\tilde{C}_t\right]+\rho\frac{\sigma_c}{\sigma_d}\left(\tilde{D}_T-\tilde{D}_t\right)\right]+\tilde{D}_T+\tilde{V}_t-\frac{1}{2}\int_t^T\tilde{\sigma}_{v,z}^2dz\right.$$
$$\left.+\frac{1}{2}\left(\int_t^T\tilde{\sigma}_{v,z}^2dz+\alpha^2\,(T-t)\left(1-\rho^2\right)\sigma_c^2-2\alpha\gamma\sigma_c\int_t^T\tilde{\sigma}_{v,z}dz\right)\right],$$

and:

$$\begin{aligned} & E_t\left\{\exp\left[-\alpha\tilde{C}_T\right] \mid \{\tilde{\sigma}_{v,z}\}_{z\in[0,T]}\right\} \\ = \quad & \exp\left\{-\alpha\left[E\left[\tilde{C}_T|\tilde{C}_t\right]+\rho\frac{\sigma_c}{\sigma_d}\left(\tilde{D}_T-\tilde{D}_t\right)\right]+\frac{\alpha^2}{2}\left(1-\rho^2\right)(T-t)\,\sigma_c^2\right\}. \end{aligned}$$

Combining and simplifying, we have that:

$$P_t = \mu_x \exp\left[\tilde{D}_T+\tilde{V}_t - r\,(T-t) - \alpha\gamma\sigma_c\int_t^T \tilde{\sigma}_{v,z}dz\right].$$

□

Proof of Proposition 1. From the representative investor's first-order condition, we have:

$$\begin{aligned} \Phi_t^C(k,\tau_M) &= \exp\left[-r\,(\tau_M-t)\right]E_t\left[\frac{\tilde{c}_T^{-\alpha}}{E_t\left[\tilde{c}_T^{-\alpha}\right]}\max\left(P_{\tau_M}-k,0\right)\right] \\ &= \exp\left[-r\,(\tau_M-t)\right]E_t\left\{E_t\left[\frac{\tilde{c}_T^{-\alpha}}{E_t\left[\tilde{c}_T^{-\alpha}\right]}\max\left(P_{\tau_M}-k,0\right) \mid \{\tilde{\sigma}_{v,z}\}_{t\in[0,\tau_M]}\right]\right\}. \end{aligned}$$

Note that, for $\tau_D<\tau_M$,

$$\log P_{\tau_M} = \log\mu_x - r\,(T-\tau_M)+\tilde{D}_T+\tilde{V}_{\tau_M}-\alpha\gamma\sigma_c\int_{\tau_M}^T\tilde{\sigma}_{v,z}dz.$$

As of time $t<\tau_D$, this is normally distributed with mean:

$$E_t\left[\log P_{\tau_M}\right] = \log\mu_x - r\,(T-\tau_M)+\tilde{X}_t-\alpha\gamma\sigma_c E_t\left[\int_{\tau_M}^T\tilde{\sigma}_{v,z}dz\right]. \tag{11}$$

Moreover, its variance may be calculated as follows:

$$\begin{aligned} Var_t\left[\log P_{\tau_M}\right] &= Var_t\left(\tilde{D}_T+\tilde{V}_{\tau_M}-\alpha\gamma\sigma_c\int_{\tau_M}^T\tilde{\sigma}_{v,z}dz\right) \qquad (12) \\ &= (T-t)\,\sigma_D^2+E_t\left[Var_t\left(\tilde{V}_{\tau_M}-\alpha\gamma\sigma_c\int_{\tau_M}^T\tilde{\sigma}_{v,z}dz|\,\{\tilde{\sigma}_{v,z}\}_{t\in[0,\tau_M]}\right)\right] \\ &\quad +Var_t\left[E_t\left(\tilde{V}_{\tau_M}-\alpha\gamma\sigma_c\int_{\tau_M}^T\tilde{\sigma}_{v,z}dz|\,\{\tilde{\sigma}_{v,z}\}_{t\in[0,\tau_M]}\right)\right] \\ &= (T-t)\,\sigma_D^2+E_t\left[\int_t^{\tau_M}\tilde{\sigma}_{v,z}^2dz\right]+\alpha^2\gamma^2\sigma_c^2 Var_t\left(\int_{\tau_M}^T\tilde{\sigma}_{v,z}dz\right). \end{aligned}$$

Next, for $t > \tau_D$, we have:

$$\begin{aligned} E_t\left[\log P_{\tau_M}\right] &= \log \mu_x - r\left(T-\tau_M\right) - \tilde{D}_T + \tilde{V}_t - \alpha\gamma\sigma_c \int_{\tau_M}^{T} \tilde{\sigma}_{v,z} dz; \\ Var_t\left[\log P_{\tau_M}\right] &= \int_t^{\tau_M} \tilde{\sigma}_{v,z}^2 dz. \end{aligned}$$

Now, let $\mathbb{P}$ denote a probability measure that generates the distributions discussed in the text (given an appropriately defined probability space). Given the fundamental theorem of asset pricing, there exists a risk-neutral probability measure $\mathbb{Q}$ defined by the Radon-Nikodym derivative $\frac{d\mathbb{Q}}{d\mathbb{P}} = \frac{\tilde{c}_T^{-\alpha}}{E_t\left[\tilde{c}_T^{-\alpha}\right]}$ such that:

$$\begin{aligned} \Phi_t^C\left(k,\tau_M\right) &= \exp\left[-r\left(\tau_M - t\right)\right] E_t\left[\frac{\tilde{c}_T^{-\alpha}}{E_t\left[\tilde{c}_T^{-\alpha}\right]} \max\left(P_{\tau_M} - k, 0\right) \mid \left\{\tilde{\sigma}_{v,z}\right\}_{z\in[t,\tau_M]}\right] \\ &= \exp\left[-r\left(\tau_M - t\right)\right] E_t^{\mathbb{Q}}\left[\max\left(P_{\tau_M} - k, 0\right) \mid \left\{\tilde{\sigma}_{v,z}\right\}_{t\in[z,\tau_M]}\right]. \end{aligned} \tag{13}$$

Note that this is this is identical to the price that would arise if the stock price was continuous over time with distribution defined by expressions (11) and (12). Thus, by Girsanov's theorem, under $\mathbb{Q}$, P_{τ_M} is again log-normally distributed with the same variance parameter. Therefore, expression (13) is precisely the Black-Scholes price of a European call option, for $t < \tau_D$:

$$\begin{aligned} &\Phi_t^C\left(k,\tau_M\right) \\ &= E_t\left\{BS\left[P_t, k, \left(\frac{\left(T-t\right)\sigma_D^2 + E_t\left[\int_t^{\tau_M} \tilde{\sigma}_{v,z}^2 dz\right] + \alpha^2\gamma^2\sigma_c^2 Var_t\left(\int_{\tau_M}^{T} \tilde{\sigma}_{v,z} dz\right)}{\tau_M - t}\right)^{\frac{1}{2}}, \tau_M - t, r\right]\right\}, \end{aligned}$$

and for $t \geq \tau_D$,

$$\Phi_t^C\left(k,\tau_M\right) = BS\left[P_t, k, \left(\frac{\int_t^{\tau_M} \tilde{\sigma}_{v,z}^2 dz}{\tau_M - t}\right)^{\frac{1}{2}}, \tau_M - t, r\right].$$

$\square$

Table 1. Descriptive Statistics

Panel A contains sample counts as well as time-series averages of absolute values and signed values and corresponding t-statistics for *RiskInfo* using 1- and 6-month options around earnings announcements. *RiskInfo* is our proxy for the amount of information about risk contained in a firm's disclosure. *SRiskInfo* is defined as risk information scaled by diffusive volatility. We calculate the average of *RiskInfo* each month and report the annual mean of the monthly time-series. Panel B contains Pearson (Spearman) correlations of key variables in our analyses above (below) the main diagonal. ΔIV is change in 30-day implied volatility from standardized options in the three-day window centered on firms' announcement date. $SIZE$ is the log of market capitalization, LBM is the log of firm's book-to-market ratio, $VLTY$ is the standard deviation of firm's daily returns over the 252 trading days ending 5 days prior to the earnings announcement, and $\Delta VLTY$ is the post-announcement change in return volatility, defined as the log of the standard deviation of firm's daily returns over the 252 trading days starting 5 days after the earnings announcement, scaled by $VLTY$. The sample for this analysis spans 1996 through 2017 and consists of 134,914 quarterly earnings announcements.

Panel A: Risk Info Descriptive Statistics by Year

		Absolute Risk Info				Signed Risk Info			
	OBS	$\|RiskInfo_{30}\|$	$\|SRiskInfo_{30}\|$	$\|RiskInfo_{182}\|$	$\|SRiskInfo_{182}\|$	$RiskInfo_{30}$	t-statistic	$RiskInfo_{182}$	t-statistic
1996	2,722	0.007	0.135	0.018	0.060	0.002	3.022	0.001	0.476
1997	4,077	0.007	0.117	0.018	0.049	0.001	2.383	0.001	0.542
1998	4,533	0.009	0.131	0.025	0.058	0.001	1.242	0.002	0.738
1999	4,863	0.009	0.121	0.025	0.052	0.001	1.620	0.001	0.917
2000	3,856	0.013	0.143	0.037	0.072	0.000	-0.060	0.007	1.855
2001	3,875	0.008	0.114	0.022	0.047	0.000	0.337	-0.002	-0.651
2002	4,459	0.008	0.120	0.023	0.051	0.002	2.525	0.004	1.300
2003	4,377	0.006	0.101	0.015	0.041	0.000	0.020	-0.002	-1.981
2004	5,065	0.005	0.090	0.011	0.035	0.000	0.748	0.001	0.448
2005	5,345	0.005	0.116	0.011	0.040	0.001	2.610	0.000	0.502
2006	5,602	0.005	0.106	0.011	0.041	0.000	0.884	0.000	-0.229
2007	6,125	0.006	0.138	0.015	0.052	0.002	3.212	0.004	2.238
2008	6,111	0.013	0.164	0.040	0.076	0.002	1.269	0.004	0.459
2009	6,112	0.009	0.125	0.029	0.062	-0.002	-2.504	-0.004	-2.080
2010	6,818	0.008	0.153	0.020	0.063	0.002	1.506	0.003	1.313
2011	6,981	0.010	0.182	0.026	0.078	0.002	1.439	0.007	1.707
2012	6,777	0.010	0.179	0.021	0.069	0.000	0.378	0.002	1.754
2013	7,889	0.007	0.171	0.015	0.056	0.003	3.444	0.002	1.823
2014	8,415	0.010	0.202	0.019	0.074	0.002	2.082	0.005	1.213
2015	8,696	0.010	0.202	0.022	0.071	0.003	5.868	0.007	1.995
2016	9,232	0.011	0.204	0.027	0.073	0.002	1.353	-0.001	-0.306
2017	12,984	0.008	0.184	0.017	0.061	0.001	1.700	0.003	1.434
All	134,914	0.008	0.145	0.021	0.058	0.001	1.594	0.002	0.703

Panel B: Pearson (Spearman) Correlations Above (Below) Main Diagonal

	$RiskInfo_{30}$	$SRiskInfo_{30}$	ΔIV	$SIZE$	LBM	$VLTY$	$\Delta VLTY$
$RiskInfo_{30}$		0.692	0.891	-0.005	0.023	-0.029	0.034
$SRiskInfo_{30}$	0.982		0.559	-0.017	0.039	-0.052	0.027
ΔIV	0.533	0.528		0.021	0.010	-0.034	0.027
$SIZE$	0.036	0.067	0.045		-0.210	-0.356	0.040
LBM	0.024	0.022	0.060	-0.242		-0.037	-0.047
$VLTY$	-0.099	-0.145	-0.134	-0.464	-0.084		0.405
$\Delta VLTY$	0.094	0.100	0.070	0.050	-0.062	0.338	

Table 2. Changes in Return Volatility

Panel A contains average changes in, and corresponding t-statistics for, firms' volatility relative to their earnings announcement date, sorted into quintile portfolios of $RiskInfo_{30}$. $RiskInfo_{30}$ is our proxy for the amount of information about risk contained in a firm's disclosure from 30-day options. Quintile portfolios are formed on a rolling basis, using the distributional breakpoints of *RiskInfo* from the prior calendar quarter. High-Low denotes the difference between the first and fifth quintile. $\Delta VLTY$ is the post-announcement change in return volatility, defined as the log of the standard deviation of firm's daily returns over the 252 trading days starting 5 days after the earnings announcement, scaled by the standard deviation of firm's daily returns over the 252 trading days ending 5 days prior to the earnings announcement. $\Delta VLTY$ *(Levels)* is defined analogously using the level change in volatility. Panel B contains analogous tests across quintile portfolios of $RiskInfo_{30}$ based on changes in firms' idiosyncratic volatility over the 252 trading days starting 5 days after the earnings announcement, relative to the 252 trading days ending 5 days prior to the earnings announcement. We measure idiosyncratic volatility on day d by taking the squared residual from a firm-specific market-model regression with three lags. Panel C contains year-over-year changes in squared risk factor loadings from a four-factor model estimated in the year after firms' 10K relative to the year prior to firms' 10K. $\Delta(\beta^2_{MKT})$ is the change in firms' squared sensitivity to the market factor; $\Delta(\beta^2_{SMB})$ is the change in firms' squared sensitivity to the small-minus-big factor; $\Delta(\beta^2_{HML})$ is the change in firms' squared sensitivity to the high-minus-low book to market factor; and $\Delta(\beta^2_{UMD})$ is the change in firms' squared sensitivity to the up-minus-down momentum factor available from Ken French's website. The sample for this analysis spans 1996 through 2017 and consists of 134,914 quarterly earnings announcements.

Panel A: Changes in Total Volatility

	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	High-Low
$\Delta VLTY$	-0.061	-0.028	-0.011	-0.010	-0.013	0.048
	-(2.64)	-(1.21)	-(0.43)	-(0.41)	-(0.54)	(13.89)
$\Delta VLTY$ (Levels)	-0.145	-0.044	0.000	0.005	0.016	0.162
	-(1.83)	-(0.72)	(0.00)	(0.08)	(0.22)	(10.77)

Panel B: Averages Changes in Idiosyncratic Volatility

	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	High-Low
$\Delta IVOL$	-0.006	-0.001	0.002	0.002	0.005	0.011
	-(0.98)	-(0.17)	(0.49)	(0.63)	(1.03)	(6.63)
$\Delta IVOL$ *(Levels)*	-0.133	-0.066	-0.032	-0.029	-0.043	0.090
	-(3.03)	-(1.50)	-(0.69)	-(0.64)	-(0.96)	(12.06)

Panel C: Averages Changes in Squared Factor Loadings

	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	High-Low
$\Delta(\beta^2_{MKT})$	-0.129	-0.050	-0.038	-0.038	-0.081	0.048
	-(6.35)	-(4.18)	-(2.90)	-(3.07)	-(5.40)	(3.11)
$\Delta(\beta^2_{SMB})$	-0.116	-0.036	-0.021	-0.028	-0.022	0.094
	-(4.69)	-(2.95)	-(1.85)	-(2.16)	-(1.10)	(4.42)
$\Delta(\beta^2_{HML})$	-0.084	-0.017	-0.013	-0.022	-0.012	0.072
	-(1.99)	-(0.72)	-(0.58)	-(0.86)	-(0.37)	(2.93)
$\Delta(\beta^2_{UMD})$	-0.021	0.012	0.026	0.028	0.042	0.063
	-(0.53)	(0.61)	(1.55)	(1.55)	(1.82)	(2.62)

Table 3. Regressions of Changes in Volatility

Panel A contains results from regressions where the dependent variable is the post- versus pre-announcement change in firms' return volatility. $\Delta VLTY$ is the post-announcement change in return volatility, defined as the log of the standard deviation of firm's daily returns over the 252 trading days starting 5 days after the earnings announcement, scaled by the standard deviation of firm's daily returns over the 252 trading days ending 5 days prior to the earnings announcement. $RiskInfo_{30}$ is our proxy for the amount of information about risk contained in a firm's disclosure from 30-day options. *SIZE* is the log of market capitalization, *LBM* is the log of firm's book-to-market ratio, and *SURP* is the firms' analyst-based surprise at their earnings announcement. ΔIV, defined as the change in 30-day implied volatility from standardized options in the three-day window centered on firms' announcement date. *AnnVar* equals the anticipated level of volatility at the earnings announcement derived from option prices following Dubinsky et al. (2018). Firm and year-quarter fixed effects are used throughout. The bottom rows reference indicate the use of a leverage corrected version of our risk information measure as described in Section 3. The parentheses contain t-statistics based on standard errors clustered by firm and quarter. Panel B contains analogous results based on $\Delta VLTY$ *(Level)*, which is defined analogously using the level change in volatility. The sample for this analysis spans 1996 through 2017 and consists of 134,914 quarterly earnings announcements.

Panel A: Regressions of Log Changes in Future Volatility

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$RiskInfo_{30}$	–	–	–	0.044***	0.042***	0.027***	0.032***	0.014***
	–	–	–	(14.24)	(13.74)	(7.51)	(8.74)	(3.52)
ΔIV	0.047***	0.051***	0.049***	–	–	0.031***	–	0.040***
	(13.13)	(13.75)	(13.29)	–	–	(7.31)	–	(9.99)
AnnVar	–	0.015***	0.013***	–	–	–	–	–
	–	(4.48)	(4.08)	–	–	–	–	–
SIZE	–	–	0.087***	–	0.085***	0.086***	–	0.088***
	–	–	(7.71)	–	(7.48)	(7.59)	–	(7.62)
LBM	–	–	-0.002	–	-0.003	-0.003	–	-0.000
	–	–	(-0.29)	–	(-0.33)	(-0.31)	–	(-0.04)
SURP	–	–	-0.023***	–	-0.023***	-0.022***	–	-0.024***
	–	–	(-6.13)	–	(-6.39)	(-6.02)	–	(-6.26)
Obs	133809	133809	133809	133809	133809	133809	130121	130121
Adj. R-sq	0.419	0.419	0.421	0.419	0.420	0.421	0.423	0.426
Firm FE?	Y	Y	Y	Y	Y	Y	Y	Y
YearQtr FE?	Y	Y	Y	Y	Y	Y	Y	Y
Leverage Correction?	N	N	N	N	N	N	Y	Y

Panel B: Regressions of Level Changes in Future Volatility

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$RiskInfo_{30}$	–	–	–	0.001***	0.001***	0.001***	0.001***	0.001***
	–	–	–	(11.65)	(11.38)	(8.53)	(7.36)	(4.69)
ΔIV	0.001***	0.001***	0.001***	–	–	0.001***	–	0.001***
	(9.49)	(9.75)	(9.35)	–	–	(5.63)	–	(7.74)
AnnVar	–	0.000***	0.000***	–	–	–	–	–
	–	(4.04)	(3.58)	–	–	–	–	–
SIZE	–	–	0.003***	–	0.003***	0.003***	–	0.003***
	–	–	(6.66)	–	(6.52)	(6.56)	–	(6.63)
LBM	–	–	0.000	–	0.000	0.000	–	0.000
	–	–	(0.89)	–	(0.86)	(0.87)	–	(1.10)
SURP	–	–	-0.001***	–	-0.001***	-0.001***	–	-0.001***
	–	–	(-5.96)	–	(-6.14)	(-5.89)	–	(-5.98)
Obs	133809	133809	133809	133809	133809	133809	130121	130121
Adj. R-sq	0.401	0.401	0.403	0.401	0.404	0.404	0.406	0.409
Firm FE?	Y	Y	Y	Y	Y	Y	Y	Y
YearQtr FE?	Y	Y	Y	Y	Y	Y	Y	Y
Leverage Correction?	N	N	N	N	N	N	Y	Y

Table 4. Regressions of Implied Costs of Capital

This table contains portfolio averages and regression results where the dependent variable is the post- versus pre-announcement change in firms' implied cost of capital (ICC) using the estimation approach in Gebhardt et al. (2001) that reconciles analysts' forecasts with the current stock price. We calculate the change in ICCs from the month after firms' earnings announcement date relative to the month prior to firms' earnings announcement date. $RiskInfo_{30}$ is our proxy for the amount of information about risk contained in a firm's disclosure from 30-day options. In Panel A, Quintile portfolios are formed on a rolling basis, using the distributional breakpoints of *RiskInfo* from the prior calendar quarter. High-Low denotes the difference between the first and fifth quintile. In Panel B, *SIZE* is the log of market capitalization, *LBM* is the log of firm's book-to-market ratio, and $SURP$ is the firms' analyst-based surprise at their earnings announcement. ΔIV, defined as the change in 30-day implied volatility from standardized options in the three-day window centered on firms' announcement date. Firm and year-quarter fixed effects are used throughout. The bottom rows reference indicate the use of a leverage corrected version of our risk information measure as described in Section 3. The parentheses contain t-statistics based on standard errors clustered by firm and quarter.

Panel A: ICC Changes by $RiskInfo_{30}$ Quintiles

	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	High-Low
ICC (Changes)	-0.091	-0.052	0.003	0.026	0.171	0.262
	-(1.32)	-(1.01)	(0.06)	(0.51)	(2.11)	(7.62)

Panel B: Regressions of Changes in ICC

	(1)	(2)	(3)	(4)	(5)	(6)
$RiskInfo_{30}$	0.218***	0.200***	0.191***	0.173***	0.143***	0.116***
	(11.34)	(10.64)	(9.75)	(8.69)	(6.80)	(4.75)
SIZE	–	0.783***	0.774***	–	0.780***	0.787***
	–	(8.84)	(8.60)	–	(8.63)	(8.33)
LBM	–	-0.665***	-0.675***	–	-0.675***	-0.676***
	–	(-10.55)	(-10.73)	–	(-10.74)	(-10.20)
SURP	–	–	-0.147***	–	-0.143***	-0.153***
	–	–	(-4.24)	–	(-4.09)	(-4.21)
$\Delta IV30$	–	–	–	0.097***	0.105***	0.126***
	–	–	–	(3.82)	(4.09)	(5.10)
Obs	73079	73079	73079	73079	73079	70051
Adj. R-sq	0.180	0.211	0.213	0.181	0.214	0.216
Firm FE?	Y	Y	Y	Y	Y	Y
YearQtr FE?	Y	Y	Y	Y	Y	Y
Leverage Correction?	N	N	N	Y	N	Y

Table 5. Horizon of Volatility

This table contains regression results where the main independent variable is $\Delta RiskInfo$, defined as the difference in risk information derived from 30-day and 182-day options and is defined as $RiskInfo_{30}$ minus $RiskInfo_{182}$. $RiskInfo_{30}$ is our proxy for the amount of information about risk contained in a firm's disclosure from 30-day options, and $RiskInfo_{182}$ is defined analogously for 182 options. $log[VLTY(+5, +26)/VLTY(+27, +182)$ is defined as the log of the standard deviation of firm's daily market-adjusted returns from 5 to 26 trading days after the earnings announcement, scaled by the standard deviation of firm's daily returns from 27 to 182 trading days after the earnings announcement. $STVLTY(+5, +26) - STVLTY(+27, +182)$ is level difference in volatility after standardizing both components each calendar quarter to have a mean zero and unit standard deviation. Year-quarter fixed effects are used throughout. The bottom rows reference indicate the use of a leverage corrected version of our risk information measure as described in Section 3. The parentheses contain t-statistics based on standard errors clustered by firm and quarter.

	log[VLTY(+5,+26)/VLTY(+27,+182)]			SVLTY(+5,+26) - SVLTY(+27,+182)]		
	(1)	(2)	(3)	(4)	(5)	(6)
ΔRiskInfo	0.014***	0.012**	0.014***	0.065***	0.055***	0.070***
	(3.01)	(2.61)	(3.25)	(4.98)	(4.57)	(5.09)
SIZE	–	0.036***	0.039***	–	0.198***	0.202***
	–	(3.58)	(3.82)	–	(8.20)	(8.12)
LBM	–	0.033***	0.035***	–	0.088***	0.089***
	–	(3.18)	(3.29)	–	(3.56)	(3.50)
SURP	–	-0.009*	-0.008	–	-0.008	-0.005
	–	(-1.83)	(-1.64)	–	(-0.63)	(-0.35)
Obs	95499	95499	93303	95499	95499	93303
Adj. R-sq	0.222	0.224	0.228	0.000	0.006	0.006
YearQtr FE?	Y	Y	Y	Y	Y	Y
Leverage Correction?	N	N	N	N	N	Y

Table 6. Fundamental Performance

This table contains regressions that relate $RiskInfo_{30}$ to firms' fundamental performance reported in their subsequent fiscal quarter. $RiskInfo_{30}$ is our proxy for the amount of information about risk contained in a firm's disclosure from 30-day options. In Panel A, the dependent variables reflect proxies for firms' subsequently announced earnings news. $FutureSUE$ is firms' standardized unexplained earnings, defined as the fiscal-quarter adjusted innovations in quarterly earnings, scaled by the standard deviation of earnings innovations over the trailing eight quarters. $FutureSURP$ is firm's analyst-based surprise, defined as earnings per share minus the consensus forecast immediately prior to the announcement. In Panel B, $FutureRND$ is the firm's research and development expenditure scaled by total assets. $FutureDistressRisk$ is the firm's distress risk proxy from Campbell et al. (2008), where higher values indicate a greater likelihood of financing constraints. Firm and year-quarter fixed effects are used as indicated at the bottom of each panel. The parentheses contain t-statistics based on standard errors clustered by firm and quarter. The sample for this analysis spans 1996 through 2017 and consists of 134,914 quarterly earnings announcements.

Panel A: Regressions of Future Earnings

	Future SUE		*Future SURP*	
	(1)	(2)	(3)	(4)
$RiskInfo_{30}$	-0.040***	-0.024*	-0.000***	-0.000**
	(-3.08)	(-1.94)	(-3.84)	(-2.32)
SIZE	-0.148***	-0.194***	-0.001***	-0.001***
	(-2.70)	(-4.30)	(-3.21)	(-2.94)
LBM	-0.784***	-0.564***	-0.001***	-0.001***
	(-9.33)	(-7.09)	(-4.00)	(-3.85)
SUE	–	1.108***	–	–
	–	(29.84)	–	–
SURP	–	–	–	0.001***
	–	–	–	(7.39)
Obs	100276	100276	100276	100276
Adj. R-sq	0.106	0.187	0.103	0.111
Firm FE?	Y	Y	Y	Y
YearQtr FE?	Y	Y	Y	Y

Panel B: Regressions of Future Fundamentals

	Future RND		*Future Distress Risk*	
	(1)	(2)	(3)	(4)
$RiskInfo_{30}$	0.000**	0.000*	0.099**	0.086*
	(2.10)	(1.82)	(2.32)	(1.99)
SIZE	-0.005***	-0.005***	-3.336***	-3.344***
	(-9.81)	(-9.82)	(-8.83)	(-8.80)
LBM	-0.002***	-0.002***	2.935***	2.896***
	(-8.38)	(-8.45)	(12.74)	(12.37)
SUE	–	-0.000	–	-0.135**
	–	(-1.01)	–	(-2.45)
SURP	–	-0.000***	–	-0.206***
	–	(-4.12)	–	(-5.12)
Obs	100276	100276	85351	85351
Adj. R-sq	0.877	0.877	0.669	0.670
Firm FE?	Y	Y	Y	Y
YearQtr FE?	Y	Y	Y	Y

Table 7. Absolute Risk Information

This table contains results from regressing *AbsRiskInfo* on firm-, disclosure, and earnings-characteristics. $AbsRiskInfo_{30}$ is the absolute value of our proxy for the amount of information about risk contained in a firm's disclosure from 30-day options. *SIZE* is the log of market capitalization, *LBM* is the log of firm's book-to-market ratio, and *SURP* is the firms' analyst-based surprise at their earnings announcement. *SUE* is firms' standardized unexplained earnings, defined as the fiscal-quarter adjusted innovations in quarterly earnings, scaled by the standard deviation of earnings innovations over the trailing eight quarters. *EarnVol* is the standard deviation of firms' earnings-per-share over the prior eight quarters. COV is the log of one plus analyst coverage. *Guidance* is the log of one plus the number of times a company has issued guidance over the prior quarter. *DiscQuality* is the level of disclosure quality as proxied by the extent of dissagregation in firms' financial statements. Firm and year-quarter fixed effects are used as indicated at the bottom of the table. The parentheses contain t-statistics based on standard errors clustered by firm and quarter. The sample for this analysis spans 1996 through 2017 and consists of 134,914 quarterly earnings announcements.

	(1)	(2)	(3)	(4)	(5)
SIZE	-0.003***	-0.003***	-0.003***	-0.003***	-0.003***
	(-10.44)	(-10.39)	(-9.44)	(-8.04)	(-8.06)
LBM	0.001**	0.001*	0.001**	0.001*	0.001
	(2.22)	(1.92)	(2.38)	(1.67)	(1.64)
SURP		-0.090***	-0.090***	-0.061***	-0.061***
		(-5.73)	(-5.76)	(-4.56)	(-4.55)
SUE		-0.000*	-0.000**	-0.000**	-0.000**
		(-1.84)	(-2.12)	(-2.12)	(-2.14)
EarnVol			0.014***	0.015***	0.014***
			(3.89)	(3.57)	(3.55)
COV			-0.000	-0.000	-0.000
			(-1.33)	(-0.77)	(-0.79)
Guidance				-0.000***	-0.000**
				(-2.64)	(-2.51)
DiscQuality				-0.003	-0.002
				(-1.16)	(-1.10)
Obs	134914	134914	134913	81093	81079
Adj. R-sq	0.217	0.219	0.220	0.216	0.215
Firm FE?	Y	Y	Y	Y	Y
YearQtr FE?	Y	Y	Y	Y	Y
Fiscal Q FE?	N	N	N	N	Y

Table 8. The 2004 8K Regulation and Absolute Risk Info

This table contains results from a regression of absolute risk information from 30-day options, $AbsRiskInfo_{30}$, on firms' use of material contract filings *not* filed as 8Ks prior to the 2004 SEC Regulation mandating that material contracts be filed on a more timely basis via 8Ks. For this analysis, we limit the sample to firms that have at least one Exhibit 10 *not* filed as an 8K in the pre-period. $AbsRiskInfo_{30}$ is the absolute value of our proxy for the amount of information about risk contained in a firm's disclosure from 30-day options. The sample consists of 4,692 earnings announcements corresponding to firm-quarters in the three years immediately before and after the regulation. *Pre-Period Non-8K Exhibit 10s* is defined as the firm's average number of material contract filings *not* filed as an 8K per pre-regulation quarter scaled by the firm's average number of 8K filings per pre-regulation quarter. Note that *Pre-Period Non-8K Exhibit 10s* and the indicator for *Post* are absorbed by firm-fiscal quarter fixed effects and year-quarter fixed effects, respectively, due to perfect multicollinearity. We estimate and report t-statistics in parentheses based on two-way cluster robust standard errors, clustered by industry and year-quarter.

	(1)	(2)	(3)	(4)	-5
post x Pre-Period Non-8K Exhibit 10s	-0.020*	-0.019*	-0.019*	-0.020*	-0.019*
	(-1.74)	(-1.72)	(-1.73)	(-1.72)	(-1.71)
Log (Material Contract Count)	-0.000	-0.000	-0.000	-0.000	-0.000
	(-0.32)	(-0.48)	(-0.43)	(-0.46)	(-0.32)
SIZE	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***
	(-3.74)	(-3.81)	(-3.80)	(-3.79)	(-3.82)
LBM	0.002	0.002	0.002	0.002	0.002
	(1.04)	(1.14)	(0.99)	(1.07)	(1.07)
SURP		-0.117***	-0.117***	-0.117***	-0.117***
		(-3.63)	(-3.58)	(-3.60)	(-3.55)
SUE		0.000	0.000	0.000	0.000
		(1.31)	(1.08)	(1.21)	(1.20)
COV			-0.002	-0.002	-0.002
			(-1.00)	(-0.76)	(-0.73)
Guidance				0.000	0.000
				(0.21)	(0.24)
DiscQuality				-0.002	-0.002
				(-0.33)	(-0.27)
Obs	4692	4692	4692	4692	4692
Adj. R-sq	0.221	0.224	0.224	0.224	0.225
Firm FE?	Y	Y	Y	Y	Y
YearQtr FE?	Y	Y	Y	Y	Y
Fiscal Q FE?	N	N	N	N	Y

Table 9. Comparison to Text-based Measures of Risk Information

This table reports averages of volatility (and firm size) relative to firms' 10K filing date, across quintiles sorted by $RiskInfo_{30}$, the fraction of uncertainty words in the 10K, and the total number of uncertainty words in the 10K.$RiskInfo_{30}$ is our proxy for the amount of information about risk contained in a firm's 10K from 30-day options. Uncertatinty words come from the Wharton Research Data Services Readability and Sentiment file corresponding to firms' 10K SEC filings. Quintiles are formed on a rolling basis, using the distributional breakpoints from the prior calendar quarter. High-Low denotes the difference between the first and fifth quintile. *SIZE* is the log of market capitalization. *VLTY (Pre-10K)* is the standard deviation of firm's daily returns over the 252 trading days ending 5 days prior to the 10K filing date. *VLTY (Post-10K)* is the standard deviation of firm's daily returns over the 252 trading days beginning 5 days after the 10K filing date. $\Delta VLTY$ is the post-announcement change in return volatility, defined as the log of the ratio of *VLTY (Post-10K)* to *VLTY (Pre-10K)*. Δ*VLTY (Levels)* is defined analogously using the level change in volatility. The parentheses contain t-statistics derived from the quarterly time-series average of each variable. The sample for this analysis consists of 23,715 firm-years from 1996 through 2017.

Panel A: Averages by $RiskInfo_{30}$

	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	High-Low
SIZE	13.614	14.448	14.866	14.630	13.670	0.056
	(252.05)	(280.53)	(244.79)	(226.94)	(232.19)	(0.84)
VLTY (Pre-10K)	0.033	0.024	0.022	0.025	0.033	0.000
	(27.12)	(29.15)	(28.74)	(25.05)	(23.64)	(0.28)
VLTY (Post-10K)	0.032	0.024	0.022	0.025	0.034	0.002
	(24.06)	(27.29)	(23.17)	(21.66)	(17.79)	(1.62)
$\Delta VLTY$	-0.040	-0.021	-0.016	-0.020	-0.010	0.030
	-(1.46)	-(0.80)	-(0.58)	-(0.74)	-(0.37)	(2.71)
Δ*VLTY (Levels)*	0.000	0.000	0.000	0.000	0.001	0.002
	-(0.39)	-(0.27)	(0.24)	(0.03)	(1.02)	(2.14)

Panel B: Averages by Total Number of Uncertainty Words in 10K

	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	High-Low
SIZE	14.481	14.317	14.282	14.159	14.078	-0.403
	(248.20)	(257.68)	(275.11)	(243.57)	(285.31)	-(6.50)
VLTY (Pre-10K)	0.025	0.026	0.028	0.030	0.032	0.007
	(29.28)	(30.51)	(26.88)	(24.35)	(22.78)	(7.91)
VLTY (Post-10K)	0.025	0.026	0.027	0.029	0.032	0.007
	(24.69)	(25.49)	(25.39)	(22.18)	(20.07)	(7.12)
$\Delta VLTY$	-0.034	-0.030	-0.032	-0.036	-0.032	0.002
	-(1.25)	-(1.14)	-(1.26)	-(1.41)	-(1.22)	(0.22)
Δ*VLTY (Levels)*	0.000	0.000	-0.001	0.000	0.000	0.000
	-(0.29)	-(0.26)	-(0.69)	-(0.50)	-(0.32)	-(0.12)

Panel C: Averages by Fraction of Uncertainty Words in 10K

	Q1 (Low)	Q2	Q3	Q4	Q5 (High)	High-Low
SIZE	14.256	14.118	14.174	14.268	14.568	0.312
	(303.36)	(313.20)	(321.78)	(250.64)	(242.00)	(4.07)
VLTY (Pre-10K)	0.025	0.027	0.028	0.029	0.030	0.005
	(31.06)	(28.62)	(27.49)	(22.66)	(24.04)	(7.82)
VLTY (Post-10K)	0.024	0.027	0.028	0.029	0.029	0.005
	(27.81)	(24.35)	(25.13)	(20.36)	(20.27)	(6.19)
$\Delta VLTY$	-0.030	-0.025	-0.022	-0.031	-0.036	-0.006
	-(1.20)	-(0.98)	-(0.85)	-(1.23)	-(1.27)	-(0.44)
Δ*VLTY (Levels)*	0.000	0.000	0.000	0.000	0.000	0.000
	-(0.68)	(0.06)	-(0.04)	-(0.33)	-(0.28)	(0.40)

Table 10. Regressions of Changes in Volatility Around 10Ks

This table reports results from regressions where the dependent variable is the post- versus pre-10K-filing change in firms' return volatility, defined as the log of the standard deviation of firm's daily returns over the 252 trading days starting 5 days after the 10K filing date, scaled by the standard deviation of firm's daily returns over the 252 trading days ending 5 days prior to the 10K filing date. The regression includes the log of the total number of uncertainty words in the 10K, and the fraction of uncertainty words in the 10K. $RiskInfo_{30}$ is our proxy for the amount of information about risk contained in a firm's 10K from 30-day options. Uncertainty words come from the Wharton Research Data Services Readability and Sentiment file corresponding to firms' 10K SEC filings. All independent variables are assigned to quintiles ranging from zero to one, where quintiles are formed on a rolling basis using the distributional breakpoints from the prior calendar quarter. *SIZE* is the log of market capitalization. Firm and year-quarter fixed effects are used throughout. The parentheses contain t-statistics based on standard errors clustered by firm and quarter. The sample for this analysis consists of 23,715 firm-years from 1996 through 2017.

	(1)	(2)	(3)	(4)	(5)	(6)
Log(Uncertainty Word Count)	-0.034***	-0.035***	-0.035***	–	–	–
	(-3.60)	(-3.70)	(-3.73)	–	–	–
Fraction of Uncertainty Words	–	–	–	0.016	0.016	0.016
	–	–	–	(1.10)	(1.09)	(1.10)
SIZE	–	0.066**	0.064**	–	0.063**	0.062**
	–	(2.41)	(2.36)	–	(2.35)	(2.30)
LBM	–	-0.001	-0.001	–	-0.004	-0.003
	–	(-0.07)	(-0.05)	–	(-0.26)	(-0.24)
$RiskInfo_{30}$	–		0.022***	–	–	0.022***
	–		(2.96)	–	–	(2.98)
Obs	23715	23715	23715	23703	23703	23703
Adj. R-sq	0.398	0.399	0.399	0.398	0.398	0.399
Firm FE?	Y	Y	Y	Y	Y	Y
YearQtr FE?	Y	Y	Y	Y	Y	Y