Earnings Surprises and Uncertainty: Theory and Evidence from Option Implied Volatility

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ABSTRACT: We model the effect of information surprise on market uncertainty regarding firm value. Unlike traditional rational expectations models without parametric uncertainty, where information decreases uncertainty by a constant amount, we show that uncertainty regarding information precision results in a V-shaped relation between surprise and uncertainty about firm value. In this model, small absolute surprises decrease uncertainty, while large absolute surprises increase uncertainty. We test our theory by relating analysts’ earnings forecast errors to changes in option implied volatilities around earnings announcements. Our empirical analysis yields evidence consistent with the proposed V-shaped relation. We also find support for a confirmation role of earnings, where uncertainty decreases despite a lack of new information conveyed by the earnings announcement. Our findings contribute to the rational expectations literature, the implied volatility literature, and the literature on the effects of accounting information on the second moment of investors’ beliefs regarding firm value.

Key Words: Uncertainty, higher-order uncertainty, earnings surprise, information precision, implied volatility, confirmation role of earnings

Data Availability: Data are available from public sources identified in the paper.
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1. Introduction

We examine the effect of earnings surprise on market uncertainty regarding firm value. While a large literature studies the effect of earnings information on security prices—which reflects the first moment (conditional expectation) of the market’s beliefs about firm value—the effect of earnings information on market uncertainty—which is the second moment (conditional variance) of the market’s beliefs about firm value—has been relatively less explored. In this paper, we model the relation between public information and market uncertainty under a framework where the precision of the information signal is uncertain. Our model predicts a “V-shaped” relation between information surprise and uncertainty, wherein small magnitude surprises reduce uncertainty but large magnitude surprises could even escalate uncertainty in the market. We test the model predictions by examining the behavior of implied option volatility (our proxy for uncertainty) around earnings announcements. Our empirical results are entirely consistent with our theoretical predictions. Specifically, post-announcement implied volatilities increase in absolute value of earnings surprise, and while small earnings surprises reduce implied volatilities, large surprises escalate implied volatilities.

For our theoretical analysis, we adapt the framework of Subramanyam (1996) where uncertainty regarding the precision of information is allowed. The advantage of using the uncertain precision framework is that it allows us to model uncertainty as a function of information surprise, unlike the traditional constant-precision framework, where uncertainty is a constant (e.g., Holthausen and Verrecchia, 1988). Our theoretical model predicts that the post-announcement market uncertainty is “V-shaped” in information surprise (i.e., increasing in absolute surprise), with uncertainty after receipt of the information decreasing for small
magnitude surprises, but increasing for large magnitude surprises. The predicted relation between uncertainty and information surprise arises from the confluence of two different sources of uncertainty. The first source of uncertainty is the uncertainty about the unknown liquidating dividend that increases monotonically in absolute surprise because investors associate lower precision with higher absolute surprise. The second source of uncertainty is uncertainty regarding price that arises because the market is uncertain about the weight attached to the new information.

To empirically test our predictions, we use option implied volatilities calculated from 91-day option prices. Because uncertainty in our analytical model is the conditional variance regarding firm value, option implied volatilities that capture conditional return variance are an especially appropriate proxy for uncertainty in our setting. Using data from 1996-2011 available via OptionMetrics, we find graphical support for the predicted V-shaped relation between information precision and post-announcement uncertainty when plotting post-announcement implied volatilities ($post-IV$) against analyst forecast errors ($AFE$), our proxy for earnings surprise. While our theoretical model predicts a relation between the level of post-announcement uncertainty and earnings surprise, prior research shows that option prices (see Patell and Wolfson, 1979, 1981; Jin, Livnat, and Zhang, 2012) and option trading volumes (see Amin and Lee, 1997; Roll, Schwartz, and Subrahmanyam, 2010) can (partially) anticipate the direction and magnitude of quarterly earnings information prior to the announcement. Accordingly, we control for the anticipated magnitude of the absolute earnings surprise in our empirical analysis.

To confirm that market uncertainty about firm value increases in the absolute magnitude of earnings surprise, we use multivariate regression analysis to formally test our hypothesis. We regress $post-IV$ on absolute $AFE$ using both linear and quadratic specifications controlling for the
level of pre-IV to examine whether the earnings surprise induces a V-shape in implied volatility. Our findings provide empirical support for our analytical prediction, even after controlling for the leverage effect (Christie, 1982), in which stock price decreases are associated with volatility increases and vice versa, volatility clustering (Bollerslev, Chou, and Kroner, 1992) in which stock price increases are followed by volatility increases, and the effect of equity return variability that is unrelated to the earnings surprise itself (Goyal and Saretto, 2009).

To provide empirical support for our analytical prediction that small (large) earnings surprises reduce (increase) market uncertainty, we first regress expected absolute $AFE$ on the level of pre-IV in order to identify the unexpected component of the absolute $AFE$ ($UAAFE$). In the second stage, we regress the change in implied volatility centered around the earnings announcement on $UAAFE$, controlling for equity returns, squared equity returns, realized pre-announcement equity return volatility, and the staleness of the analyst forecast. Consistent with our theoretical predictions, we find that negative $UAAFE$s (i.e., earnings surprises smaller in magnitude than expected by option markets) significantly reduce implied volatility, suggesting that smaller absolute surprises reduce uncertainty. Likewise, we find that positive $UAAFE$s (i.e., surprises larger in magnitude than expected by option markets) are associated with increases in uncertainty. Thus, we find evidence in support of our hypotheses that market uncertainty following an earnings announcement is an increasing function of the absolute magnitude of surprise and that small earnings surprises reduce market uncertainty while large earnings surprises actually increase market uncertainty despite the release of price-relevant information.

Our study differs from prior research in two major respects. First, our study focuses on theoretically modeling the relation between investor uncertainty and information releases (surprises) to provide a basis for when we would expect surprises to decrease and/or increase
investor uncertainty. Our theoretical predictions contrast with that of traditional rational expectations models, in which information has a constant effect on—and can never increase—investor uncertainty (e.g., Holthausen and Verrecchia, 1988; Kim and Verrecchia, 1991). Our model also contrasts with models of the relation between information asymmetry and information releases. Kim and Verrecchia (1994) argue that a heterogeneous investor base that is able to process public information releases into differing quality private information signals about firm performance will lead to potential increases in information asymmetry around earnings announcements. Similarly, recent theoretical literature in finance has considered differences in higher-order investor beliefs as a determinant of stock price volatility increases, trade, and price drift (Banerjee, Kaniel, and Kremer, 2009; Banerjee, 2011; Kandel and Pearson, 1995; Kondor, 2012). Unlike these models, which rely on heterogeneous investors to drive higher-order disagreement, our model predictions are not dependent on explicitly modeling investor disagreement. With risk-averse investors, it must be noted that stock prices also reflect the second moment of investor beliefs through the pricing of risk. However, the thrust of the extant literature that examines the effects of earnings announcements on stock prices has been on the ability of earnings to revise investors’ expectations of future cash flows (i.e., the first moment of investors’ beliefs). Rare exceptions are Ball, Kothari, and Watts (1993), who examine systematic risk shifts around earnings announcements and the literature examining effects of

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1 Our theoretical approach is broadly similar to that in recent papers in finance that model “parametric uncertainty” (e.g., Brav and Heaton, 2002). Our predictions are broadly consistent with the “uncertainty information hypothesis” predicted by Brown, Harlow, and Tinic (1988). Brown, Harlow and Tinic, however, do not theoretically model their hypothesis and their empirical tests, which are based on stock price drift after periods of extreme stock return volatility, do not directly examine effects of information on uncertainty.

2 Kim and Verrecchia (1997) make a similar prediction for the effect of earnings announcements on investor disagreement by modeling pre-announcement and announcement period private information signals.

3 Empirical work in this area focuses on bid-ask spreads as a measure of information asymmetry. Lee, Mucklow and Ready, 1993 and Krinsky and Lee, 1996 find evidence consistent with an increase in bid-ask spreads that reflects increased information asymmetry around earnings announcements. Perhaps most closely related is work by Affleck-Graves, Callahan, and Chipalkatti (2002) who show that earnings predictability is inversely related to changes in the bid-ask spread around earnings releases.
earnings information on the heterogeneity of investor beliefs (Bamber, Barron, and Stober, 1997; Brown and Han, 1992; Morse, Stephan, and Stice, 1991; Rees and Thomas, 2010; Gallo, 2013)

Second, we utilize option implied volatility to proxy for investor uncertainty in place of analyst forecast dispersion. Existing research relies on analyst forecast dispersion to measure both information asymmetry and uncertainty. Barron et al. (1998) note that error in the mean analyst forecast reflects common information available to analysts, while forecast dispersion reflects analysts’ private information sets after controlling for forecast errors. This insight allows the authors to express uncertainty as a function of analyst forecast dispersion and forecast error. Subsequent empirical work uses the Barron et al. decomposition of analyst forecast dispersion to proxy for investor disagreement. Barron, Byard, and Kim (2002) find that analysts’ private information increases following earnings announcements, consistent with theory in Kim and Verrecchia (1994; 1997) for increases in information asymmetry around earnings announcements. Banerjee (2011) and Gallo (2013) similarly examine the extent of investor disagreement and the resolution of uncertainty around earnings announcements. These studies use analyst forecast dispersion, the presence of speculative traders, and trading volume to proxy for disagreement among investors prior to an earnings release.

Using option implied volatility to measure uncertainty has the advantage of allowing us to examine short-window changes in investor uncertainty around an earnings announcement, without waiting for analysts to revise forecasts following the announcement. In addition, implied volatility avoids issues related to bias and herding in analysts’ forecasts. These features are indeed described as a limitation of models relying on forecast dispersion as a measure of uncertainty (Barron et al., 1998). Similarly, Abarbanell, Lanen, and Verrecchia (1995) conclude

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4 Related work examines analyst forecast dispersion around earnings releases without clearly distinguishing between the information asymmetry and uncertainty components. See Bamber, Barron, and Stober (1997), Brown and Han (1992), and Rees and Thomas (2010) for examples.
that dispersion does not fully capture investor uncertainty absent detailed controls for forecast properties related to analysts’ private vs. common information sets and significance of the earnings announcement.

Our results contribute to several literatures. First, we contribute to the theoretical understanding of the effects of information on market uncertainty. In traditional rational expectations models such as Kim and Verrecchia (1991), information unambiguously reduces uncertainty. While the extent of uncertainty reduction depends on the information precision (which is parametric), it is independent of the signal realization. We extend this research by adapting the uncertain precision framework and demonstrating analytically that uncertainty regarding firm value increases with the magnitude of information surprise, and that while uncertainty decreases after small surprises, large surprises can actually increase investor uncertainty about firm value.

Our second contribution to the literature comes from our empirical analysis examining the effect of earnings information on uncertainty. Predictions of our model are broadly consistent with research documenting a decrease in uncertainty measured by option implied volatility around earnings announcements (Patell and Wolfson, 1979, 1981; Isakov and Perignon, 2001; Truong, Corrado, and Chen, 2012; Billings, Jennings, and Lev, 2013). To the extent that most earnings announcements contain sufficiently small levels of surprise, we show that uncertainty will tend to decrease on average around the earnings announcement. Related work by Rogers, Skinner, and Van Buskirk (2009) and Billings, Jennings, and Lev (2013) examines shifts in option implied volatilities around management earnings guidance, with Rogers et al. (2009) noting an increase in implied volatility around unbundled management guidance and Billings et al. (2013) documenting a decrease in residual implied volatility around guidance bundled with an
earnings announcement. Our empirical results extend our understanding of option implied volatility behavior around information releases by showing that the extent of reduction (or increase) in implied volatility around earnings announcements is directly associated with the magnitude of surprise. As a result, the model’s prediction that investor uncertainty is a function of the surprise component of an information release may reconcile differences across studies of scheduled vs. unscheduled information releases.

Lastly, we contribute to the literature on the confirmation role of earnings. We examine a subset of our data where the earnings announcement does not induce a price reaction (the zero-return sample) and find that there is a significant decrease in option implied volatility for this sample. This evidence is consistent with Ball and Shivakumar's (2008) conjecture that earnings announcements may serve a confirmatory role to the markets despite earnings announcements accounting for a modest amount of the total price-relevant information incorporated in equity prices. We find that even when there is no significant first moment reaction to earnings announcements, there does exist a significant second-moment reaction to the earnings announcement via a decrease in investor uncertainty regarding price. Documenting that earnings information that has no first-order effects (in terms of conveying “new” information) does have significant second-order effects (through a reduction in uncertainty), provides evidence on the important feedback role of accounting information (SFAC No. 1, FASB 1978).

The remainder of the paper is organized as follows. Section 2 presents theoretical considerations and their empirical implications, from which our hypotheses are derived. Section 3 discusses the research design and sample data. Sections 4 and 5 present the empirical results. Section 6 concludes.
2. Theory and Hypothesis Development

We motivate our hypotheses by providing an analytical framework with parametric uncertainty. The vast majority of analytical models assume that agents have perfect knowledge of various parameters, such as the distributional properties of an asset’s return, for example. A smaller set of analytical models in finance and accounting allow for uncertainty regarding parameter values and learning by agents in equilibrium (e.g., Subramanyam, 1996; Brav and Heaton, 2002; Banjeree, Daniel and Kremer, 2009; Bannerjee, 2012). Our theoretical framework allows for uncertainty regarding the precision of information signal as in Subramanyam (1996). Subramanyam examines the market price response to information when there is uncertainty about the precision of the information. In contrast, we use the uncertain precision framework to model the effect of information on uncertainty regarding firm value. We only provide major results and their intuition in this section. All proofs are provided in the stand-alone Appendix.

2.1 Modeling Uncertainty in the presence of Uncertain Precision

Consider a single-period pure-exchange economy with a risk-neutral market maker and a single risky asset that pays off an uncertain liquidating dividend, \( \bar{x} \), at the end of the period. Assume that \( \bar{x} \) is unconditionally normally distributed with mean \( m \) and precision \( v \). During the period, the market receives a noisy signal regarding \( \bar{x} \) (which could be interpreted as an earnings announcement): \( \bar{y} = \bar{x} + \bar{u} \), where \( \bar{u} \) is normally distributed white noise with unknown precision. Accordingly, \( \bar{y} \) could be assumed to be normally distributed with expectation \( m \) and unknown precision \( \bar{w} \). However, assume that the market has knowledge that \( \bar{w} \) is described by the probability density function \( f(\bar{w}) \) with support \((0,v)\).\(^5\) Also, conditional on \( \bar{w} = w \), \( \bar{x} \) and \( \bar{y} \) are bivariate normal.

\(^5\)The support of \( \bar{w} \) is bounded from above by \( v \), since \( \bar{y} \), which is a noisy signal of \( \bar{x} \), cannot be more precise
Theoretically, the market’s uncertainty is represented by $\text{Var}(\bar{x}|\Omega)$, which is the market’s conditional variance regarding $\bar{x}$ given information $\Omega$. Intuitively, this conditional variance denotes the inaccuracy of the market’s estimate of unknown firm value, given the information available to the market at that point in time. Prior to the receipt of the information signal, the market’s uncertainty is simply:

$$\text{Var}(\bar{x}) = \frac{1}{v} \quad (1)$$

In the absence of uncertainty regarding signal precision (i.e., where $w$ is a constant), the standard statistical result for multivariate normality reveals that the market’s post-signal uncertainty is:

$$\text{Var}(\bar{x}|\bar{y} = y) = \frac{1}{v} - \frac{w}{v^2} \quad (2)$$

Inspection of equation 2 reveals that the post-information uncertainty consists of two parts: the original uncertainty, $1/v$, and the reduction in uncertainty due to information, $w/v^2$. The magnitude of reduction in uncertainty is increasing in information precision, $w$, and is bounded between 0 and $1/v$. In the worst case, when $\bar{y}$ is complete noise ($w = 0$), information does not reduce uncertainty, while in the best case, when $\bar{y}$ is perfectly informative ($w = v$), information removes all uncertainty from the market. Thus, information can never increase uncertainty, and, except in the case of infinitely noisy information, decreases uncertainty. This is a standard result that is common to various rational expectations models, such as Holthausen and Verrecchia (1988) and Kim and Verrecchia (1991).

In contrast, when information precision is uncertain, the conditional variance ceases to be independent of signal realization and is statistically represented by:
\[ Var(\bar{x} | \bar{y} = y) = E_{w|y}[Var(\bar{x} | \bar{y} = y, \bar{w} = w)] + Var_{w|y}[E(\bar{x} | \bar{y} = y, \bar{w} = w)] \] (3)

which in turn translates to the following expression in our model:

\[ Var(\bar{x} | \bar{y} = y) = \frac{1}{v} - \frac{1}{v^2} E(\bar{w} | \bar{y} = y) + \frac{s^2}{v^2} Var(\bar{w} | \bar{y} = y) \] (4)

where \( s = y - m \) denotes the information surprise.

Inspecting Equation 4 reveals the following. First, given that \( E(\bar{w} | \bar{y} = y) \) is non-negative and decreasing in \( s^2 \) (see Proposition 1 in Subramanyam, 1996), it is evident that \( Var(\bar{x} | \bar{y} = y) < Var(\bar{x}) \) when \( s = 0 \), i.e., information reduces uncertainty in the neighborhood of zero surprise. Second, no unambiguous inferences can be drawn about whether information reduces uncertainty when \( s \neq 0 \). Unlike the certain precision case where information can never increase uncertainty (see Equation 2), it is possible that information could escalate uncertainty when precision is uncertain over particular ranges of (absolute) surprise.

We next examine the marginal response of \( Var(\bar{x} | \bar{y} = y) \) with respect to absolute surprise. The marginal response is given by:

\[ \frac{\partial Var(\bar{x} | \bar{y} = y)}{\partial s^2} = \frac{1}{2v^2} \left[ 3Var(w | y) - s^2 skew(w | y) \right] \] (5)

where \( skew(\bar{w} | \bar{y} = y) \) denotes conditional skewness.

It is apparent that when \( s = 0 \), the marginal response is positive. This implies that uncertainty is increasing in absolute surprise in the neighborhood of \( s = 0 \). The relation between marginal response and absolute surprise over a larger range of surprise, however, is dependent on the properties of the conditional distribution of precision, in particular its conditional skewness. If \( \bar{w} | \bar{y} = y \) is negatively skewed, then the marginal response is positive over the entire range of surprise, i.e., post-information uncertainty unambiguously increases in absolute surprise. If
\( \tilde{w} | \tilde{y} = y \) is positively skewed, then it can be established that uncertainty is increasing in absolute surprise when the absolute surprise is below the following inflexion point:

\[
s^2 = \frac{3 \text{Var}(\tilde{w} | \tilde{y} = y)}{\text{skew}(\tilde{w} | \tilde{y} = y)}
\]

As long as the above inflexion point is unique, uncertainty is increasing and unimodal in either quadrant. The appendix provides the conditions for the uniqueness of this inflexion point.

The intuition for these results is best explained by first examining Equations 3 and 4. Equation 3 is a statistical result that suggests that post-information uncertainty, i.e., conditional variance of the liquidating dividend based on signal realization or \( \text{Var}(\tilde{x} | \tilde{y} = y) \), is the sum of two components. The first component, \( E_{w|y}[\text{Var}(\tilde{x} | \tilde{y} = y, \tilde{w} = w)] = \frac{1}{v} \cdot \frac{1}{v^2} \cdot E(\tilde{w} | \tilde{y} = y) \), is the expected uncertainty regarding the liquidating dividend for a given signal realization. It is simply the uncertain precision analogue of the constant precision measure of uncertainty (which is reported in Equation 2), wherein the precision, \( v \), is replaced by its conditional expectation, \( E(\tilde{w} | \tilde{y} = y) \). Because \( E(\tilde{w} | \tilde{y} = y) \) is non-negative and increasing in absolute surprise, this component increases in absolute surprise but is bound between zero and \( \frac{1}{v} \). Therefore this component alone can never lead to escalation of uncertainty.

The second component, \( \text{Var}_{w|y}[E(\tilde{x} | \tilde{y} = y, \tilde{w} = w)] = \frac{s^2}{v^2} \cdot \text{Var}(\tilde{w} | \tilde{y} = y) \), represents the uncertainty regarding price for a given signal realization that arises because of uncertainty regarding precision. To understand the evolution of this component, we need to introduce the expression for price in our framework. Note that, when precision is known with certainty, the post-information price is given by \( E(\tilde{x} | \tilde{y} = y, \tilde{w} = w) = m + \frac{w}{v} \cdot s \); this price is equal to the prior \((m)\) plus an update for the new information \((\frac{w}{v} \cdot s)\), which increases in the precision of
information. In the absence of uncertainty about precision, price is exactly determinable upon signal realization. However, in the presence of uncertainty regarding precision, price is given by $E(\tilde{x}|\tilde{y} = y) = m + \frac{E(\tilde{w}|\tilde{y} = y)}{\nu}s$. This price has an element of uncertainty attached to it because the market is uncertain about the exact weight it should attach to the new information in the absence of perfect knowledge about the precision. The extent of this uncertainty is of course increasing in the absolute magnitude of surprise because the magnitude of the price reaction is dependent on the magnitude of the surprise. This uncertainty regarding price adds another layer of uncertainty after the receipt of the signal. The behavior of this component with respect to absolute surprise is somewhat difficult to model without restrictions on the distribution of $\tilde{w}$. However, because this component is non-negative, it results in a net increase in uncertainty, which could result in an escalation in uncertainty upon receipt of the information signal.

To summarize, we have established the following. First, information reduces uncertainty in the neighborhood of zero surprise. For larger magnitudes of surprise, it is possible (but not necessary) that information could escalate uncertainty. Second, uncertainty increases in absolute surprise in the neighborhood of zero surprise. Whether it increases monotonically over the entire range of absolute surprise (i.e., it is concave in absolute surprise) or up to an inflexion point (i.e., it is quasi-concave in absolute surprise) depends on the distribution properties of the conditional precision. The example we provide next shows that under fairly standard distributional assumptions, post-information uncertainty is quasi-concave in absolute surprise and that while information reduces uncertainty for low magnitudes of surprise, information escalates uncertainty for large surprises.
2.2 An Example

We next provide an example where we assume \( \hat{w} \) is distributed in the form of a Truncated Gamma with parameters \((\lambda, r)\) and support \((0, v)\).\(^6\) In this example, the conditional variance is described by the following expression:

\[
Var(\bar{x}|\bar{y} = y) = \frac{1}{v} - \frac{1}{v^2} \frac{\Gamma\left(r + \frac{1}{2}, \phi v\right)}{\Gamma\left(r + \frac{1}{2}, \phi v\right)} \phi^{-1} \\
+ \frac{s^2}{v^2} \left[ \frac{\Gamma\left(r + 2, \phi v\right)}{\Gamma\left(r + \frac{1}{2}, \phi v\right)} - \left( \frac{\Gamma\left(r + 2, \phi v\right)}{\Gamma\left(r + \frac{1}{2}, \phi v\right)} \right)^2 \right] \phi^{-2}
\]

(8)

where \( \phi = \frac{s^2}{2} + \lambda \) and \( \Gamma(\cdot, \phi v) \) represents the Incomplete Gamma integral with support \((0, \phi v)\).

The above expression for \( Var(\bar{x}|\bar{y} = y) \) is analytically intractable. However, it is possible to graphically characterize the above function. Figure 1 graphs \( Var(\bar{x}|\bar{y} = y) \) over a range of surprise.\(^7\) It can be seen that \( Var(\bar{x}|\bar{y} = y) \) attains its global minimum at \( s = 0 \), where it is less than \( Var(\bar{x}) \), and increases in absolute surprise at a decreasing rate up to a threshold, after which it decreases and asymptotes to \( \frac{1}{v} \). That is, \( Var(\bar{x}|\bar{y} = y) \) is increasing in absolute surprise and unimodal (quasi-concave) in either quadrant. It can also be seen that \( Var(\bar{x}|\bar{y} = y) \geq Var(\bar{x}) \) for absolute surprise above some threshold.

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\(^6\)The choice of the Gamma family of distributions for precision is standard practice. In addition to its suitability for modeling precision when the original variable is a normal variable (normal-gamma family of distributions), the Gamma evolves naturally as the posterior distribution of the precision when the prior is degenerate (Zellner, 1971). Our choice of a Truncated Gamma distribution for \( \hat{w} \) is predicated by its finite support \((0, v)\)—gamma distributions usually have a support in the entire positive real line \((0, +\infty)\).

\(^7\)Please refer to the Appendix for details on how the graph is created.
We can also decompose the expression for uncertainty in Equation 5 into its two components—expected uncertainty and uncertainty regarding price—using the assumed distribution for \( \bar{w} \) to separately examine each effect:

\[
Var(\bar{x}|\bar{y} = y) = \left\{ \frac{1}{v} - \frac{1}{v^3} \frac{\Gamma(r + \frac{1}{2}, \phi v)}{\Gamma(r + \frac{1}{2})} \phi^{-1} \right. \\
+ \left. \frac{s^2}{v^2} \left[ \frac{\Gamma(r + 2 + \frac{1}{2}, \phi v)}{\Gamma(r + \frac{1}{2})} \right] - \left( \frac{\Gamma(r + \frac{1}{2}, \phi v)}{\Gamma(r + \frac{1}{2})} \right)^2 \right\} \phi^{-2}
\]

(10)

The first component, expected uncertainty, increases monotonically in absolute surprise. In other words, the magnitude of reduction in uncertainty reduces in absolute surprise. However, this effect alone cannot increase post-information uncertainty beyond the pre-uncertainty level of \( \frac{1}{\nu} \). The second component, uncertainty regarding price, is positive but its relation to absolute surprise is non-monotonic: it increases in absolute magnitude of surprise only up until some level, after which it declines. However, the second effect makes it possible for post-information to exceed the pre-information level at some point. Together, the two components create the “V” shaped relation between post-information uncertainty and information surprise, with the minimum occurring at zero surprise, and uncertainty increasing in the absolute magnitude of surprise up to a threshold, such that it exceeds pre-information uncertainty for larger magnitudes of surprise.

Economically, the unimodal relation between uncertainty and absolute surprise can be explained in the following manner. At zero surprise, new information confirms priors and so the market rationally associates a high precision with the information signal. This in turn results in a
reduction in the level of uncertainty in the market. As the signal realization deviates from the prior, the market rationally begins associating lower precision with the information signal. This reduces the effectiveness of the information in reducing uncertainty. Additionally, the market also becomes more uncertain of its assessment of value (i.e., price), which adds another layer of uncertainty. Together, these two forces increase uncertainty regarding the firm’s liquidating value as the absolute magnitude of surprise increases. At a sufficiently large absolute surprise, the post-information level of uncertainty exceeds that of the pre-information level, resulting in an escalation in uncertainty. As the absolute magnitude of surprise grows very large, the weight that the market attaches to the new information starts to decline significantly and therefore the effects of the information signal on both the price and on uncertainty eventually approaches zero.

2.3 Testable Hypotheses

Following the above theoretical discussion, we formally develop testable hypotheses. As depicted in Figure 1, we expect that for small earnings surprises, the earnings announcement will confirm prior beliefs about firm value and result in a reduction in uncertainty. As the magnitude of the earnings surprise increases, the resolution of uncertainty decreases. For extreme earnings surprises, uncertainty may even increase following the earnings announcement. This predicted relation between investor uncertainty and earnings announcements leads to three empirical predictions:

H1A: Market uncertainty following an earnings announcement increases in the absolute magnitude of surprise.

8 The only other set of models that, to our knowledge, makes a somewhat related prediction are those by Banerjee, Kaniel, and Kremer (2009), Banerjee (2011), and Kondor (2012). Banerjee, Kaniel, and Kremer (2009) and Banerjee (2011) nest rational expectations (RE) models with differences of opinion (DO) models to develop a dynamic heterogeneous beliefs framework. Similarly, Kondor (2012) allows for trading horizon heterogeneity in an otherwise standard differential information model to show that after a public announcement, trading volume increases, more private information is incorporated into prices, and volatility increases. This is due to the public announcement increasing disagreement among short-horizon traders regarding the expected selling price even as it decreases disagreement about the fundamental value of the asset. In contrast, our model does not rely on investor disagreement or trading horizon heterogeneity and only considers public information sets.
H1_B: Small earnings surprises reduce market uncertainty.

H1_C: Large earnings surprises increase market uncertainty.

3. Empirical Design

3.1 Variable Measurement

In the following section we describe the empirical measurement of our dependent variable, investor uncertainty, our primary independent variable of interest, earnings surprises, and key control variables.

3.1.1 Implied Volatility as a Proxy for Investor Uncertainty about Firm Value

We follow recent literature in accounting and finance and use implied volatilities embedded in equity option prices to measure investor uncertainty (e.g., Rogers, Skinner, and Van Buskirk, 2009; Billings and Jennings, 2011; Troung, Corrado, and Chen, 2012).\(^9\) Implied volatility captures investors’ expectations of a firm’s average stock return volatility over the life of the option and is therefore a measure of the average investor’s perceived uncertainty regarding firm value.

Using data from the OptionMetrics database, we calculate implied volatilities from option prices using standardized at-the-money-forward options via interpolation for each underlying series.\(^{10}\) Since earnings announcements occur quarterly and because prior research has shown that 30-day options are dominated by movements in equity returns (Rogers et al., 2009), we

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\(^9\) Early literature in accounting used analyst forecast dispersion as a proxy for uncertainty (e.g., Bamber et al., 1997; Dechow et al., 1996; Ziebart, 1990; Clement, Frankel, and Miller, 2003). However, Abarbanell et al. (1995) show that forecast dispersion is unable to fully capture investor uncertainty. Relatedly, Gallo (2013) refers to analyst forecast dispersion as fundamental uncertainty and refers to the change in implied volatility around earnings announcements as price uncertainty.

\(^{10}\) These options are hypothetical at-the-money options. Using standardized rather than actual maturities has the advantage of eliminating any potential cross-sectional bias that may occur in implied volatility because of differing option maturities. The calculation of these hypothetical options is consistent with prior literature in finance (Patell and Wolfson, 1979; Donders and Vorst, 1996; Ederington and Lee, 1996).
focus our attention on 91-day U.S. equity options to capture the time horizon between earnings announcements.\textsuperscript{11} We measure pre-announcement implied volatility two trading days prior to the quarterly earnings announcement and measure post-announcement implied volatility two trading days after the earnings announcement.\textsuperscript{12} Change in implied volatility ($\Delta IV$) is the difference between $post-IV$ and $pre-IV$.

3.1.2 Analyst Forecast Errors as a Proxy for Earnings Surprise

As in prior research (e.g., Abarbanell and Lehavy, 2003), our proxy for earnings surprise is the analyst forecast error ($AFE$), defined as actual earnings per share minus the most recent consensus analyst forecast prior to the earnings announcement divided by stock price at the beginning of the fiscal quarter.

Prior research finds that option markets are able to anticipate both the magnitude and direction of earnings surprises (Patell and Wolfson, 1979; Patell and Wolfson, 1981; Amin and Lee, 1997; Jin, Livnat, and Zhang, 2012). If the options market successfully anticipates the magnitude of earnings surprises, then absolute forecast errors will be positively associated with pre-announcement implied volatilities. We control for this association by (1) including $pre-IV$ as a control variable in a regression with $post-IV$ as the dependent variable or (2) by controlling for the effect of $pre-IV$ on the absolute value of the $AFE$—through a two-step procedure detailed below—when $\Delta IV$ is the dependent variable.

\textsuperscript{11} Results are unchanged if we use 60-day U.S. equity options instead.
\textsuperscript{12} To be consistent with findings by Amin and Lee (1997) that option trading precedes earnings announcements by several days and with Bollerslev, Chou, and Kroner (1992) and Isakov and Perignon (2001) who find that it takes several days for implied volatilities to return to equilibrium after an earnings announcement, we use a five day trading window around the earnings announcement to measure implied volatility (days -2 to +2). Results hold if we increase this time period to a 7 day window.
3.1.3 Controlling for Returns and Realized Volatility

To control for the impact of equity returns on earnings surprises, we include both equity returns and squared equity returns in our regression analysis. Including these variables controls for the leverage effect (Black, 1976; Christie, 1982)—in which stock price decreases are associated with volatility increases—and volatility clustering (Bollerslev, Chou, and Kroner, 1992)—in which stock price increases are followed by volatility increases. Buy-and-hold equity returns are calculated using daily returns from CRSP during the 5-day window surrounding the earnings announcement.

In addition, we control for realized equity return volatility in the 91-day period ending 2 days prior to the earnings announcement. Controlling for realized return volatility prior to the earnings announcement controls for the effect of equity return variability that is unrelated to the earnings surprise itself (Goyal and Saretto, 2009). In addition, research on management earnings guidance documents evidence that realized volatility prior to an information release influences the decision to release additional information (Waymire, 1985; Billings, Jennings, and Lev, 2013). Realized volatility is obtained from the historical volatility file in OptionMetrics and is calculated as:

\[
vol = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (R_i - \bar{R})^2}
\]  
(12)

where \(R_i\) is the close-to-close daily stock return, \(\bar{R}\) is the average daily stock return over the \(N\) trading day window, and \(vol\) is the realized volatility over \(N\) trading days.\(^{13}\)

3.2 Sample and Descriptive Statistics

We begin with 216,294 firm-quarters during the 1996-2011 period with earnings per share and consensus analyst forecast information available from I/B/E/S. After merging this data

\(^{13}\) Firm-quarters with realized volatility at the two most extreme percentiles of the distribution within each year are deleted to minimize the effects of outliers and remove potential errors in the OptionMetrics data.
with implied volatilities from the standardized option file in *OptionMetrics*, we are left with a sample of 151,506 firm-quarters. To ensure that options are regularly traded, we require option information to be available for the 5-day period centered on the earnings announcement date and at least 7 out of the 13 weeks centered on the earnings announcement week. Since our analyses use the average implied volatilities across call and put options, we require that information regarding both 91-day call and put options is available in the standardized option file. Finally, to minimize the effect of outliers and/or coding errors, we delete firm-quarters with absolute analyst forecast errors at the two most extreme percentiles of the distribution within each year. This leads to our final sample of 104,062 firm-quarters.

Table 1 provides descriptive statistics for *pre-IV, post-IV, ΔIV, AFE*, and control variables for our sample firms. The mean (median) *pre-IV* for our sample of 91-day options is 0.471 (0.423), while the mean (median) *post-IV* falls to 0.464 (0.415). *Post-IV* is lower on average relative to pre-announcement levels, consistent with prior research by Patell and Wolfson (1979; 1981). The mean (median) *ΔIV* around earnings announcements is also significantly negative at -0.007 (-0.006). The average equity return during our window is positive and realized volatility in the period leading up to the earnings announcement is consistent with the magnitude of *pre-IV*. Finally, we note that for our sample of firms, analysts underestimate reported earnings on average, as the mean *AFE* is a positive 0.001. On average, the consensus analyst forecast is reported 23 days prior to the earnings announcement.

### 4. Earnings Surprise and Implied Volatility

In this section, we report our primary results relating to the shape of the relation between implied volatility and earnings surprise. First, we graph the relation between *post-IV* and
earnings surprise. Next, we move to more formal analyses. We use two types of tests to examine the effect of earnings surprise on IV: (1) non-linear regressions of post-IV on AFE after controlling for pre-IV; and (2) analysis of the relation between ΔIV and absolute AFE after controlling for the relation between pre-IV and AFE.

4.1 Graphing the post-IV and AFE relation

To test our hypothesis that market uncertainty after an earnings announcement is an increasing function of the magnitude of the earnings surprise, we begin by graphing option implied volatility to see if it mirrors the functional form implied by our theoretical model. Figure 2 graphs median post-IV on the vertical-axis against median earnings surprise, as a percentage of stock price, on the horizontal-axis for 10 equal-sized surprise portfolios based on the distribution of earnings surprises. Consistent with our theoretical model, we observe a V-shaped relation between AFE and post-IV, with the trough occurring near the zero earnings surprise threshold. We also note that the relation does not appear to be perfectly symmetric for negative and positive earnings surprises.

4.2 Regressing Post-IV on AFE after controlling for Pre-IV

We formally test our hypothesis that market uncertainty after an earnings announcement is an increasing function of the magnitude of the earnings surprise using a multiple regression model where we regress post-IV on the absolute value of AFE after controlling for pre-IV. We estimate the regression using several functional forms to allow for a possible non-linear relation between option implied volatility and earnings surprises as indicated by our graph in Figure 2. To begin, we estimate the following linear regression model:

\[ \text{post}\_IV_{it} = \alpha_0 + \alpha_1 \text{pre}\_IV_{it} + \alpha_2 \text{AbsAFE}_{it} + \text{Controls} + \epsilon_{it} \]  

(13)
where \( post_{IVit} \) is post-announcement implied volatility for firm \( i \) at time \( t \), \( pre_{IVit} \) is pre-announcement implied volatility for firm \( i \) at time \( t \), and \( AbsAFE_{it} \) is the absolute value of the analyst forecast error for firm \( i \) at time \( t \).

Additional control variables include equity returns, squared equity returns, realized equity price volatility prior to the earnings announcement, and a proxy for the “staleness” of the consensus analyst forecast measured by the days between the consensus date and the earnings announcement, consistent with the rationale in Section 3.1.3 above. Results of the regression model detailed by Equation 13 are reported in Panel A of Table 2. Consistent with our prediction that market uncertainty after an earnings announcement is an increasing function of the magnitude of the earnings surprise, we find a positive and significant coefficient on \( AbsAFE \) of 0.291 when we include control variables in the regression.

Next, we allow for curvature in the relation between \( IV \) and \( AFE \). We estimate Equation 13 with a quadratic specification for the absolute value of \( AFE \) as follows:

\[
post_{IVit} = \alpha_0 + \alpha_1 pre_{IVit} + \alpha_2 AbsAFE_{it} + \alpha_3 AbsAFE_{it}^2 + Controls + \epsilon_{it} \tag{14}
\]

Given our theoretical predictions, we expect \( \alpha_2 \) to be positive and \( \alpha_3 \) to be negative, i.e., that the relation between surprise and uncertainty is increasing at a decreasing rate. Panel B of Table 2 shows that our results are consistent with this prediction. We find a positive and significant coefficient on \( AbsAFE \) (0.790) and a negative and significant coefficient on the squared term, \( AbsAFE^2 \) (-10.74), indicating a concave relation between \( post-IV \) and \( AFE \).

Next we explore the possibility that the relation between \( post-IV \) and \( AFE \) may not be symmetric for positive and negative earnings surprises, as indicated in Figure 2. To allow coefficients on positive and negative earnings surprises to vary, we include a separate intercept and an interaction term for observations where \( AFE \) is negative:
\[
\text{post}_{-IV_{it}} = \alpha_0 + \alpha_1 \text{pre}_{-IV_{it}} + \alpha_2 \text{AbsAFE}_{it} + \alpha_3 \text{AbsAFE}^2_{it} + \alpha_4 \text{Neg}_{it} + \\
\alpha_5 \text{Neg}_{it} \text{AbsAFE}_{it} + \alpha_6 \text{Neg}_{it} \text{AbsAFE}^2_{it} + \text{Controls} + \epsilon_{it}
\]

where \(\text{Neg}_{it} = 1\) if the analyst forecast error is negative for firm \(i\) at time \(t\), and 0 otherwise. If \(\text{post}_{-IV_{it}}\) responds asymmetrically to the direction of the earnings surprise, then the coefficients on the \(\text{Neg} \times \text{AbsAFE}\) and \(\text{Neg} \times \text{AbsAFE}^2\) interaction terms should be statistically significant. Panel C of Table 2 shows that the coefficient for \(\text{Neg} \times \text{AbsAFE}\) and \(\text{Neg} \times \text{AbsAFE}^2\) are statistically insignificant, indicating that after controlling for the level of \(\text{pre-IV}\), the relation between \(\text{post-IV}\) and earnings surprise does not differ significantly for negative and positive earnings surprises.\(^\text{14}\)

Figure 3 graphs the predicted value of \(\text{post-IV}\) over the range of earnings surprise (expressed as a percentage of pre-announcement stock price), using the estimated coefficients from Equation 15. Figure 3 shows that the fitted relation between \(\text{post-IV}\) and \(\text{AFE}\) is a V-shape that looks quite similar to Figure 1, which graphs the theoretical relation between uncertainty and earnings surprise, with the trough occurring near the zero-earnings surprise threshold and the predicted increase in uncertainty tailing off for extreme positive and negative earnings surprises.

### 4.3 Change in Implied Volatility and Unexpected Absolute Analyst Forecast Error

The regression analysis suggests that \(\text{post-IV}\) is increasing in the absolute magnitude of earnings surprise. However, this analysis is unable to establish whether small (large) earnings surprises reduce (increase) market uncertainty as predicted by H1B (H1C). In order to test this prediction, we need to use the change in IV around the earnings announcement (\(\Delta IV\)) as the dependent variable. Unfortunately, options markets anticipate the magnitude and direction of earnings surprise (Patell and Wolfson, 1981; Amin and Lee, 1997; Jin, Livnat, and Zhang, 2012),

\(^\text{14}\) When we run Equation 15 without controlling for \(\text{pre-IV}\), we find that there is a statistically significant difference between negative and positive earnings surprises. Specifically, we find that the relation between \(\text{post-IV}\) and negative surprises is steeper and less curved than the relation between \(\text{post-IV}\) and positive surprises. However, this relationship is also present in implied volatility prior to the earnings announcement.
and as a result, we need to measure that portion of earnings surprise that is unanticipated by the options market. In our case, we are only interested in mapping the relation between the absolute earnings surprise and the change in IV. Accordingly, we implement a two-stage procedure. In the first stage, we measure unexpected absolute forecast error (\textit{UAAFE}) as the residual from a regression of \textit{pre-IV} on the absolute forecast error. In the second stage, we examine the shape of the relation between changes in IV and \textit{UAAFE}.

We use three different specifications to model the relation between absolute \textit{AFE} and \textit{pre-IV} in the first stage. We begin with a linear specification:

$$\text{AbsAFE}_{it} = \alpha_0 + \alpha_1 \text{pre-IV}_{it} + \epsilon_{it}$$  \hspace{1cm} (16)$$

where \text{AbsAFE}_{it} is the absolute value of the analyst forecast error for firm \textit{i} at time \textit{t} and \text{pre-IV}_{it} is pre-announcement implied volatility for firm \textit{i} at time \textit{t}. We take the residuals from Equation 16, \(\epsilon_{it}\), as our measure of unexpected absolute \textit{AFE} (\textit{UAAFE}). Positive (negative) values of \textit{UAAFE} represent earnings surprises that are larger (smaller) in magnitude than expected by the option market. Results from this linear specification are reported in Table 3, Panel A. We find a positive and statistically significant coefficient for \textit{pre-IV} of 0.006 and an adjusted \(R^2\) of 6%, consistent with the options market partially anticipating the magnitude of the earnings surprise prior to the announcement. We also estimate Equation 16 separately for negative and positive \textit{AFE} to allow for potential differences in the ability of option traders to anticipate positive and negative surprises. We find a positive and statistically significant coefficient on \textit{pre-IV} of 0.005 (0.010) for the sample of positive (negative) analyst forecast errors. Interestingly, the coefficient for negative surprise is twice as large as that for positive surprise.

To ensure that we are appropriately modeling the relation between pre-announcement implied volatility and the magnitude of earnings surprise, we consider two alternative models.
First, we use a quadratic specification for the relation between \textit{pre-IV} and absolute analyst forecast errors in Table 3, Panel B. While we continue to find a positive and statistically significant coefficient for \textit{pre-IV}, the coefficient for \textit{pre-IV}^2 is not statistically different from zero. This result remains when we split the sample by the sign of \textit{AFE}. Second, we model the anticipated portion of the earnings surprise using a non-parametric approach. We rank \textit{pre-IV} into deciles and calculate mean absolute \textit{AFE} for each decile separately. The anticipated earnings surprise is then the mean absolute \textit{AFE} for each decile, with the unanticipated earnings surprise being the difference between actual absolute \textit{AFE} and mean absolute \textit{AFE} for each decile of \textit{pre-IV}. The mean absolute \textit{AFE} for each decile of \textit{pre-IV} is reported in Panel C of Table 3. Panel C shows a monotonic increase in the mean absolute \textit{AFE} across the deciles of \textit{pre-IV}, consistent with the predicted positive relation between \textit{pre-IV} and the magnitude of surprise.

Using our three different measures of \textit{UAAFE}, we first validate that market uncertainty, measured as \textit{ΔIV}, is an increasing function of the magnitude of the unanticipated absolute earnings surprise using a quadratic specification as follows:

\[
ΔIV_{it} = α_0 + α_1UAAFE_{it} + α_2UAAFE_{it}^2 + Controls + ε_{it}
\]  

(17)

where \textit{ΔIV}_{it} is the change in implied volatility for firm \textit{i} at time \textit{t}, \textit{UAAFE}_{it} (\textit{UAAFE}^2_{it}) is the unanticipated absolute \textit{AFE} (unanticipated absolute \textit{AFE} squared) for firm \textit{i} at time \textit{t}, and control variables are as defined in Equation 13. Consistent with our prediction in H1A, we expect \textit{α}_1 to be positive and \textit{α}_2 to be negative.

Table 4, Panel A presents results using the measure of \textit{UAAFE}_{it} from Equation 16 (linear specification). We find that the coefficient on \textit{UAAFE}_{it} (\textit{UAAFE}^2_{it}) is a positive (negative) and significant 0.958 (-16.611), which is consistent with our prediction that the relationship between market uncertainty and earnings surprise is increasing at a decreasing rate. We also estimate
Equation 17 using our positive (negative) AFE subsamples and find consistent results across these subsamples. In Table 4, Panel B, we use the quadratic measure of $UAAFE_{it}$ from Panel B of Table 3. Again, we find that the coefficient on $UAAFE_{it}$ ($UAAFE_{it}^2$) is positive (negative) and significant with a value of 1.019 (-17.647). Panel C of Table 4 presents regression coefficients for Equation 17 when we use the non-parametric measure of $UAAFE_{it}$ from Panel C of Table 3. We continue to find that the coefficient on $UAAFE_{it}$ ($UAAFE_{it}^2$) is a positive (negative) and significant 0.873 (-15.131). Overall, we find consistent results that suggest that there is an increasing and concave relation between $\Delta IV$ and $UAAFE$.

We next move to testing whether small earnings surprises reduce market uncertainty (H1B), and whether large earnings surprises increase market uncertainty (H1C). To do this we present the mean and median residual $\Delta IV$ for portfolios formed on the level of $UAAFE$.\textsuperscript{15} Residual $\Delta IV$ is measured as the intercept plus the residual estimated from regressing $\Delta IV$ on equity returns, squared equity returns, and pre-announcement realized equity volatility. These are the same control variables included in the regression models in Panels A-C of Table 4. To visualize the evidence in support of H1B and H1C, we first graph residual $\Delta IV$ by decile of $UAAFE$. Panel A of Figure 4 shows residual $\Delta IV$ on the y-axis and $UAAFE$ on the x-axis.\textsuperscript{16} For earnings surprises that are much smaller than anticipated, we see negative residual $\Delta IV$, suggesting that IV decreases around earnings announcements for low unanticipated earnings surprise. As the unanticipated magnitude of earnings surprises become larger, residual $\Delta IV$ increases in value and becomes positive at larger values of $UAAFE$. This suggests that IV

\textsuperscript{15} We measure UAAFE as the residual from the regression based on the linear specification in equation 13. Results are consistent if we use alternate specifications of UAAFE.

\textsuperscript{16} Unlike Figure 2, which graphs IV against the AFE and results in a V-shape, Figure 3 uses the UAAFE which was measured using $|AFE|$, effectively collapsing the graph in Figure 2 around the y-axis. The result is a concave line as opposed to a V-shape.
increases for large magnitudes of unanticipated earnings surprise. Panel B (Panel C) of Figure 4 present the graphs of residual $\Delta IV$ when we examine subsamples for positive AFE (negative AFE) separately. Both graphs are consistent with our findings in Panel A of Figure 4, however, the graph is less smooth for our negative AFE sample, consistent with the smaller number of observations in this subsample.

We next conduct formal tests to ascertain that uncertainty indeed decreases for small $UAAFE$ and increases for large $UAAFE$. Panel D of Table 4 tracks the mean (median) residual $\Delta IV$ ($r\Delta IV$) after controlling for equity returns and realized equity return volatility by quintiles formed on the level of $UAAFE$. For the smallest $UAAFE$ quintile, both mean and median residual $\Delta IV$ are negative and significant, with a mean (median) $r\Delta IV$ of -0.0065 (-0.0025), p-value<0.001 (p<0.001). This result is consistent with H1B and suggests that low magnitudes of earnings surprise decrease market uncertainty. As $UAAFE$ becomes large, residual $\Delta IV$ increases. For all but the smallest $UAAFE$ quintile, both mean and median $r\Delta IV$ are positive and statistically significant with the exception of mean $r\Delta IV$ for quintile 2. This suggests that after controlling for the effect of stock price changes and pre-period realized volatility, uncertainty increases for larger magnitudes of earnings surprise, consistent with H1C.

5. The Confirmation Role of Earnings

Beginning with seminal research by Ball and Brown (1968), researchers have shown that the information content of earnings is modest because much of the earnings surprise is anticipated by the stock market prior to the earnings announcement. This has led many to question whether earnings are useful in providing information to the stock market (Lev, 1989). Consistent with the notion of limited information in earnings announcements, Ball and
Shivakumar (2008, p.976) note that the “low ‘surprise’ content of earnings announcements is to be expected...accounting earnings is low frequency...not discretionary...and primarily backward-looking.” They find that returns earned during earnings announcement windows account for a modest amount of total information incorporated in annual stock returns. Using a simple empirical design and thus eliminating the need to estimate earnings expectations, the authors find that “the average quarterly earnings announcement is associated with abnormal price volatility of only 1% to 2%, approximately, of total annual volatility” (p. 1011). While these authors reject the idea that the primary role of earnings is to provide new information to the market, they do conjecture that earnings may serve a confirmatory role by confirming investors’ prior beliefs about firm value.17

However, there is little direct evidence in support of the confirmatory role of earnings. To shed light on this question, we isolate the subsample of earnings announcements with little to no stock price reaction in the five days around the announcement. We then examine whether there was a significant reduction in IV for this subsample. We examine three separate return bands for determining small price reactions, where the 5-day return around the earnings announcement is between +/- 1%, +/- 0.5% and +/- 0.1%, respectively.

Table 5 presents ΔIV for the various return bands. When we consider the 12,519 observations where the announcement return was between -1% and 1%, we see that almost 64% of our observations result in a decrease in IV and we find that the mean (median) ΔIV is -0.0073 (-0.0046) and is statistically significant at the 99% confidence level. The mean (median) ΔIV represents a 1.35% (1.40%) decrease in ΔIV relative to the level of pre-IV. This result holds

17 The role of earnings as a confirmation of investors’ prior beliefs about firm value, “…enhances the credibility of managers’ disclosure of private information” (Ball, 2013, p.848). For more on the confirmation role of earnings see Gigler and Hemmer (1998), Ball (2001), and Ball, Jayaraman, and Shivakumar (2012).
when we narrow the announcement return to +/- 0.5% and +/- 0.1%. Although our total number of observations decreases to 6,315 (1,608), for the +/- 0.5% (+/- 0.1%) window, we still see a decrease in IV for 63% (62%) of our sample. When the announcement return is between -0.5% and 0.5%, we observe a statistically significant mean (median) $\Delta IV$ of -0.0072 (-0.0045), which represents a percent decrease in $\Delta IV$ of 1.34% (1.39%). Even as we decrease the return band to -0.1% and 0.1%, we continue to observe a statistically significant and negative $\Delta IV$ with a mean (median) $\Delta IV$ of -0.0064 (-0.0041), representing a percent decrease in $\Delta IV$ of 0.99% (1.17%).

These results support the theory that while earnings announcements may not always provide new information to the market, these announcements can serve to confirm market expectations about underlying firm value, resulting in a decrease in market uncertainty.

6. Conclusion

We model the effect of information on uncertainty about firm value when there is uncertainty regarding precision of the information. In traditional rational expectations models without parametric uncertainty, information decreases uncertainty by a constant amount. In contrast, we show that uncertainty regarding information precision results in a V-shaped relation between surprise and uncertainty about firm value. While small absolute surprises decrease uncertainty, large absolute surprises increase uncertainty in the market. Our theoretical model adds to the accounting literature on the effects of information on market uncertainty by modifying the uncertain precision framework to allow uncertainty to vary with signal realization. The outcome of this modification is that we are able to analytically demonstrate that uncertainty regarding firm value increases with the magnitude of information surprise, and that while
uncertainty decreases after small surprises, large surprises can actually increase investor uncertainty about firm value.

We provide empirical evidence to support our model predictions. Consistent with our theory, we find strong evidence of a V-shaped relation between earnings surprises and post-announcement implied volatilities. We show that market uncertainty (measured as 91-day option implied volatility) after an earnings announcement is an increasing function of the magnitude of the earnings surprise (measured as analyst forecast errors). These results hold after controlling for pre-announcement implied volatility, the leverage effect in equity returns, volatility clustering, pre-announcement realized equity return volatility, and the staleness of analyst forecasts.

We also provide empirical evidence that small (large) earnings surprises reduce (increase) market uncertainty. Using the change in implied volatility around the earnings announcement as our measure of market uncertainty and the unanticipated portion of the absolute analyst forecast errors (UAAFE) as our measure of unexpected earnings surprise, we find that for smaller (larger) than expected absolute analyst forecast errors, implied volatility decreases (increases) around the earnings announcement. Our empirical results support our model predictions, which challenge conventional models of information precision. These results add to growing accounting literature on the higher-order effects of earnings announcements, showing that while small surprises can lead to a resolution of uncertainty, large surprises can exacerbate uncertainty about firm value.

Lastly, we add to the literature on the confirmation role of earnings by showing that even when there is no significant first moment reaction to earnings announcements there does exist a higher-order reaction to the earnings announcement. By confirming market expectations about
firm value, the earnings announcement can serve to resolve market uncertainty even when there is no significant first-order response to the announcement.
APPENDIX

Basic Model

1. \( \tilde{x} \sim N\left(m, \frac{1}{\nu}\right) \)

Thus the unconditional variance of \( \tilde{x} \) is \( \text{Var}(\tilde{x}) = \frac{1}{\nu} \), where \( \nu \) represents the precision of \( \tilde{x} \).

2. \( \tilde{y} = \tilde{x} + \tilde{u} \) is a noisy signal about \( \tilde{x} \); \( \tilde{u} \) is normally distributed with mean zero and uncorrelated with \( \tilde{x} \). Let \( \tilde{w} \) represent the uncertain precision of \( \tilde{y} \).

3. Thus, conditional on \( \tilde{w} = w \), \( \begin{pmatrix} \tilde{x} \\ \tilde{y} \end{pmatrix} \) is Bivariate Normal with \( E\left( \begin{pmatrix} \tilde{x} \\ \tilde{y} \end{pmatrix} \right) = \begin{pmatrix} m \\ m \end{pmatrix} \) and

\[
\text{Var}\left( \begin{pmatrix} \tilde{x} \\ \tilde{y} \end{pmatrix} \right) = \begin{pmatrix} \frac{1}{\nu} & \frac{1}{\nu} \\ \frac{1}{\nu} & \frac{1}{w} \end{pmatrix},
\]

where \( \frac{1}{w} \) is \( \text{Var}(\tilde{y}|\tilde{w} = w) = \text{Var}(\tilde{x}) + \text{Var}(\tilde{u}|\tilde{w} = w) \).

4. Using standard results from Bivariate Normality and the above distributional assumptions, conditional on \( \tilde{w} = w \), we get \( E(\tilde{x}|\tilde{y} = y)_{\tilde{w}=w} = m + \frac{w}{\nu} s \) and

\[
\text{Var}(\tilde{x}|\tilde{y} = y)_{\tilde{w}=w} = \frac{1}{\nu} - \frac{w}{\nu^2},
\]

where \( s = y - m \) represents surprise.

5. For obtaining unconditional \( \text{Var}(\tilde{x}|\tilde{y} = y) \) we use the following statistical result:

\[
\text{Var}(\tilde{x}|\tilde{y} = y) = E_{\tilde{w}} \left[ \text{Var}(\tilde{x}|\tilde{y} = y, \tilde{w} = w) \right] + \text{Var}_{\tilde{w}} \left[ E(\tilde{x}|\tilde{y} = y, \tilde{w} = w) \right]
\]

Substituting from (4) we get:

\[
\text{Var}(\tilde{x}|\tilde{y} = y) = E_{\tilde{w}} \left( \frac{1}{\nu} - \frac{w}{\nu^2} \right) + \text{Var}_{\tilde{w}} \left( m + \frac{w}{\nu} s \right)
\]
Marginal Response

6. The marginal response is given by

\[ \frac{\partial \text{Var}(\tilde{x} | \tilde{y} = y)}{\partial s^2} = -\frac{1}{v^2} \left( \frac{\partial E(\tilde{w} | \tilde{y} = y)}{\partial s^2} \right) + \frac{s^2}{v^2} \left( \frac{\partial \text{Var}(\tilde{w} | \tilde{y} = y)}{\partial s^2} \right) + \frac{1}{v^2} \left( \text{Var}(\tilde{w} | \tilde{y} = y) \right). \]

Subramanyam (1996, p.217) shows that \( \frac{\partial E(\tilde{w} | \tilde{y} = y)}{\partial s^2} = -\frac{1}{2} \text{Var}(\tilde{w} | \tilde{y} = y) \). In a similar manner, it can be shown that \( \frac{\partial \text{Var}(\tilde{w} | \tilde{y} = y)}{\partial s^2} = -\frac{1}{2} \text{skew}(\tilde{w} | \tilde{y} = y) \), where skew refers to skewness.

Thus, \[ \frac{\partial \text{Var}(\tilde{x} | \tilde{y} = y)}{\partial s^2} = \frac{1}{2v^2} \left[ 3\text{Var}(\tilde{w} | \tilde{y} = y) - s^2 \text{skew}(\tilde{w} | \tilde{y} = y) \right]. \]

7. When \( s = 0 \), \( \frac{\partial \text{Var}(\tilde{x} | \tilde{y} = y)}{\partial s^2} = \frac{3\text{Var}(\tilde{w} | \tilde{y} = y)}{2v^2} > 0 \).

8. The turning point is at the point where the marginal response is zero:

\[ \frac{1}{2v^2} \left[ 3\text{Var}(\tilde{w} | \tilde{y} = y) - s^2 \text{skew}(\tilde{w} | \tilde{y} = y) \right] = 0 \]

\[ \Rightarrow s^2 = \frac{3\text{Var}(\tilde{w} | \tilde{y} = y)}{\text{skew}(\tilde{w} | \tilde{y} = y)}. \]

8. To establish uniqueness of the turning point (in each quadrant), it must be shown that \( \frac{3\text{Var}(\tilde{w} | \tilde{y} = y)}{\text{skew}(\tilde{w} | \tilde{y} = y)} \) is decreasing in \( s^2 \).
Now, 

\[
\frac{\partial}{\partial s^2} \frac{3 \text{Var} (\tilde{w} | \tilde{y} = y)}{\text{skew} (\tilde{w} | \tilde{y} = y)} = \frac{\text{skew} (\tilde{w} | \tilde{y} = y) \frac{\partial}{\partial s^2} \left(3 \text{Var} (\tilde{w} | \tilde{y} = y)\right) - 3 \text{Var}^2 (\tilde{w} | \tilde{y} = y) \frac{\partial}{\partial s^2} \text{skew} (\tilde{w} | \tilde{y} = y)}{\left(\text{skew} (\tilde{w} | \tilde{y} = y)\right)^2}.
\]

Using the approach adopted by Subramanyam (1996, p.217) it can be shown that 

\[
\frac{\partial}{\partial s^2} \text{skew} (\tilde{w} | \tilde{y} = y) = -\frac{1}{2} \text{kurt} (\tilde{w} | \tilde{y} = y) + \frac{3}{2} \text{Var} (\tilde{w} | \tilde{y} = y) \quad \text{where} \quad \text{kurt} \quad \text{represents kurtosis}.
\]

Thus, 

\[
\frac{\partial}{\partial s^2} \frac{3 \text{Var} (\tilde{w} | \tilde{y} = y)}{\text{skew} (\tilde{w} | \tilde{y} = y)} = \frac{\frac{3}{2} \left[ \text{Var} (\tilde{w} | \tilde{y} = y) \text{kurt} (\tilde{w} | \tilde{y} = y) - \text{skew}^2 (\tilde{w} | \tilde{y} = y) - 3 \text{Var}^3 (\tilde{w} | \tilde{y} = y) \right]}{\text{skew}^2 (\tilde{w} | \tilde{y} = y)}.
\]

For this to be negative, 

\[
\text{kurt} (\tilde{w} | \tilde{y} = y) < \frac{3 \text{Var}^3 (\tilde{w} | \tilde{y} = y) + \text{skew}^2 (\tilde{w} | \tilde{y} = y)}{\text{Var} (\tilde{w} | \tilde{y} = y)}.
\]

**An Example**

9. Assume \( \hat{w} \) is distributed as a Truncated Gamma \((\lambda, r); \lambda, r > 0 \); and \( 0 \leq w \leq v \). Then the pdf of \( \hat{w} \) is given by 

\[
f (w) = \frac{\lambda^r w^{r-1} \exp(-\lambda w)}{\Omega \Gamma (r)}
\]

where 

\[
\Omega \Gamma (r) = \int_0^v \lambda^r w^{r-1} \exp(-\lambda w) dw \quad \text{and} \quad \Gamma (\cdot) \quad \text{denotes the Gamma integral}.
\]
From equation (5) we have:

\[ Var(\tilde{x}|\tilde{y} = y) = \frac{1}{v} - \frac{1}{v^2} E(\tilde{w}|\tilde{y} = y) + \frac{s^2}{v^2} Var(\tilde{w}|\tilde{y} = y) \]

\[ = \frac{1}{v} - \frac{1}{v^2} \int_0^\infty w g(w|y) dw + \frac{s^2}{v^2} \left[ \int_0^\infty w^2 g(w|y) dw - \left( \int_0^\infty w g(w|y) dw \right)^2 \right]. \]

Using Bayes Theorem,

\[ g(w|y) = \frac{g_1(y|w)f(w)}{f_1(y)} = \frac{g_1(y|w)f(w)}{\int g_1(y|w)f(w) dw}. \]

Substituting the above expression for \( g(w|y) \) we get

\[ Var(\tilde{x}|\tilde{y} = y) = \frac{1}{v} - \frac{1}{v^2} \frac{\Gamma\left( r + \frac{1}{2}, \phi v \right)}{\Gamma\left( r + \frac{1}{2}, \phi v \right) \phi^{-1}} \]

\[ + \frac{s^2}{v^2} \phi^{-2} \left[ \frac{\Gamma\left( r + 2 \frac{1}{2}, \phi v \right)}{\Gamma\left( r + \frac{1}{2}, \phi v \right)} - \left( \frac{\Gamma\left( r + \frac{1}{2}, \phi v \right)}{\Gamma\left( r + \frac{1}{2}, \phi v \right)} \right)^2 \right] \]

where \( \phi = \frac{s^2}{v^2} + \lambda \) and \( \Gamma(\cdot, \phi v) \) represents the Incomplete Gamma Integral with support \((0, \phi v)\).

**Graphing Uncertainty-Surprise Relation**

10. Figure 1 graphs \( Var(\tilde{x}|\tilde{y} = y) \) over the surprise range (-10, +10) where all three parameters, \( v, r, \) and \( \lambda \) are set equal to one. Without loss of generality, we set \( v=1 \) and
graphically simulate the shape of \( Var(\bar{x}|y = y) \) over an entire range of parameter values of \( \lambda > 0 \) and \( r > 0 \). We only report the graphs where \( r \) and \( \lambda \) are equal to one.

For this purpose we use the result that \( \Gamma(r, \varphi) = \Gamma(r) \cdot \chi^2_{2\varphi} \), where \( \chi^2_{2\varphi} \) is the cumulative probability distribution of a Chi-squared with \( d \) degrees of freedom.

Using this result, the expression in equation (8) is represented as:

\[
Var(\bar{x}|y = y) = \frac{1}{v} \left[ \left( r + \frac{1}{2} \right) g_1 + \frac{\chi^2_{2\varphi} \left( r + \frac{1}{2} \right) g_2 - \left( r + \frac{1}{2} \right)^2 g_1}{v^2 \phi^2} \right]
\]

where \( g_1 = \frac{x^2_{2\varphi+1}(2\varphi)}{x^2_{2\varphi}(2\varphi)} \) and \( g_2 = \frac{x^2_{2\varphi+1}(2\phi\nu)}{x^2_{2\varphi}(2\phi\nu)} \).

We use Microsoft Excel to conduct our curve fitting simulations. We find that the unimodal shape depicted in Figure 1 applies to the entire range of parameter values examined. The Excel spreadsheet is available from the authors on request.
REFERENCES


Figure 1
Theoretical Relation Between Uncertainty and Surprise

The figure graphs uncertainty, \( Var(\hat{x} | \hat{y} = y) \), when precision \( \tilde{\nu} \) is distributed in the form of a truncated Gamma with parameters \( r \) and \( \lambda \) over a range of surprise (s). The graph has been calibrated for \( v = 1, r = 1, \) and \( \lambda = 1. \)
FIGURE 2
Implied Volatility and Earnings Surprise

Figure 2 plots median implied volatility with median earnings surprise for 10 equal-sized portfolios based on the distribution of earnings surprises. The figure plots post-announcement implied volatility measured as of 2 trading days following the earnings announcement for 91-day standardized options. Earnings surprise is measured using analyst forecast error (AFE), calculated as actual earnings per share from I/B/E/S minus the latest consensus analyst forecast before the earnings announcement, deflated by stock price at the end of the fiscal period.
FIGURE 3
Predicted Post-Announcement Implied Volatility Using Analyst Forecast Error

Figure 3 plots the predicted post-announcement implied volatility for 91-day standardized options as of trading day +2 relative to the earnings announcement against the range of analyst forecast errors (AFE) based on the distribution of AFE. Coefficients for the linear regression are obtained from Table 2, Panel C using the quadratic specification to estimate post-announcement implied volatility. These predicted values come from the estimation of equation 15 using observed implied volatilities for 91-day standardized options:

\[ post_{IV_{it}} = \alpha_0 + \alpha_1 pre_{IV_{it}} + \alpha_2 AbsAFE_{it} + \alpha_3 AbsAFE_{it}^2 + \alpha_4 Neg_{it} + \alpha_5 Neg_{it} AbsAFE_{it} + \alpha_6 Neg_{it} AbsAFE_{it}^2 + Controls + \epsilon_{it} \]  

(15)
FIGURE 4
Residual Change in Implied Volatility and Residual Earnings Surprise

Panel A

91 Day options - All AFE values

Panel B

91 Day options - Positive AFE

Panel C

91 Day options - Negative AFE

Figure 4 plots median residual change in implied volatility for 91-day standardized options from trading days -2 to +2 relative to the earnings announcement with median unexpected absolute analyst forecast errors (UAAFE) for 10 equal-sized portfolios based on the distribution of UAAFE. Residual change in implied volatility ($r\Delta IV$) is measured as the intercept plus the residual estimated from regressing change in implied volatility on RET, RET$^2$, and pre-announcement realized volatility during the announcement period. UAAFE is unexpected absolute analyst forecast error, measured as the residual from regressing absolute AFEs on pre-announcement implied volatility (see Table 3 for details on the linear model for estimating UAAFE). Panel A presents results for the linear model for UAAFE estimated using all values of AFE. Panels B and C present results for the linear model UAAFE estimated using positive and negative values of AFE, respectively.
### TABLE 1
Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>St. Deviation</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-IV</td>
<td>0.471</td>
<td>0.223</td>
<td>0.311</td>
<td>0.423</td>
<td>0.582</td>
<td>104,062</td>
</tr>
<tr>
<td>Post-IV</td>
<td>0.464</td>
<td>0.221</td>
<td>0.306</td>
<td>0.415</td>
<td>0.570</td>
<td>104,062</td>
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<tr>
<td>Change IV</td>
<td>-0.007</td>
<td>0.060</td>
<td>-0.025</td>
<td>-0.006</td>
<td>0.009</td>
<td>104,062</td>
</tr>
<tr>
<td>Realized Vol</td>
<td>0.453</td>
<td>0.245</td>
<td>0.277</td>
<td>0.395</td>
<td>0.566</td>
<td>104,062</td>
</tr>
<tr>
<td>AFE</td>
<td>0.001</td>
<td>0.006</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
<td>104,062</td>
</tr>
<tr>
<td>RET</td>
<td>0.004</td>
<td>0.103</td>
<td>-0.047</td>
<td>0.002</td>
<td>0.053</td>
<td>104,062</td>
</tr>
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<td>RET²</td>
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<td>0.000</td>
<td>0.003</td>
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<td>104,062</td>
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<td>DateDiff</td>
<td>23.163</td>
<td>23.460</td>
<td>6</td>
<td>14</td>
<td>33</td>
<td>104,062</td>
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<tr>
<td>log_DateDiff</td>
<td>2.541</td>
<td>1.228</td>
<td>1.792</td>
<td>2.639</td>
<td>3.497</td>
<td>104,062</td>
</tr>
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</table>

Pre-announcement and post-announcement implied volatilities (IVs) are available from OptionMetrics for 91-day standardized options measured on trading day -2 and +2, respectively relative to the earnings announcement. Changes in IV are the difference between post-IV and pre-IV. AFE is calculated as actual earnings per share minus the latest consensus analyst forecast before the earnings announcement, deflated by stock price at the beginning of the quarter. Realized Vol is realized equity return volatility calculated as the standard deviation of daily equity returns in the 91-day period ending 2 days before the earnings announcement. RET and RET² are calculated using buy-and-hold equity returns in the 5 day window centered on the earnings announcement. DateDiff (log_DateDiff) is the number of days (natural log of the number of days) between the date of the consensus analyst forecast and the earnings announcement. Absolute analyst forecast errors and pre-period volatility are trimmed at the top 2% of their distributions to eliminate potential errors or outlying observations from influencing results.
<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Intercept</th>
<th>Pre-IV</th>
<th>RET</th>
<th>RET^2</th>
<th>Realized VOL</th>
<th>log_DateDiff</th>
<th>AbsAFE</th>
<th>AbsAFE^2</th>
<th>Neg</th>
<th>Neg*</th>
<th>AbsAFE</th>
<th>AbsAFE^2</th>
<th>Adjusted R^2</th>
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<td>Panel A: Absolute AFE—Linear specification</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-IV</td>
<td>0.013***</td>
<td>0.954***</td>
<td>0.289**</td>
<td>92.89%</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>0.0005</td>
<td>&lt;0.0001</td>
<td>0.0471</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Post-IV</td>
<td>0.011***</td>
<td>0.89***</td>
<td>-0.228***</td>
<td>0.261***</td>
<td>0.056***</td>
<td>0.002***</td>
<td>0.291**</td>
<td>94.16%</td>
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<td>&lt;0.0001</td>
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<td>&lt;0.0001</td>
<td>0.0478</td>
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<td>Panel B: Absolute AFE—Quadratic specification</td>
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<tr>
<td>Post-IV</td>
<td>0.013***</td>
<td>0.954***</td>
<td>0.661**</td>
<td>-8.004**</td>
<td>92.90%</td>
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<td>0.0006</td>
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</tr>
<tr>
<td>Post-IV</td>
<td>0.01***</td>
<td>0.889***</td>
<td>-0.228***</td>
<td>0.26***</td>
<td>0.057***</td>
<td>0.002***</td>
<td>0.79***</td>
<td>-10.74***</td>
<td>94.17%</td>
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<tr>
<td></td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0003</td>
<td>0.0009</td>
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<td>Panel C: Incremental slope and curvature for negative AFE values—Quadratic specification</td>
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</tr>
<tr>
<td>Post-IV</td>
<td>0.011***</td>
<td>0.889***</td>
<td>-0.229***</td>
<td>0.26***</td>
<td>0.057***</td>
<td>0.002***</td>
<td>0.815***</td>
<td>-11.224**</td>
<td>-0.001**</td>
<td>0.019</td>
<td>0.202</td>
<td>94.17%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
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<td>0.026</td>
<td>0.9193</td>
<td>0.9595</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Post-announcement implied volatility is measured as of 2 trading days after the earnings announcement for options with a 91-day expiration. Pre-IV is pre-announcement implied volatility measured as of 2 trading days prior to earnings announcement. RET is the buy-and-hold stock return over the announcement period. AFE is calculated as actual earnings per share minus the latest consensus analyst forecast before the earnings announcement, deflated by stock price at the beginning of the quarter. AbsAFE is the absolute value of AFE, and AbsAFE^2 is the square of AbsAFE. log_DateDiff is the natural log of the number of days between the date of the consensus analyst forecast and the earnings announcement. P-values below each coefficient and corresponding t-statistics are calculated using standard errors clustered by year of the fiscal period end. 

*** p<0.01, ** p<0.05, * p<0.1
TABLE 3
Unexpected AFE

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Intercept</th>
<th>Pre-IV</th>
<th>Pre_IV^2</th>
<th>Adj. R^2</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A: Absolute AFE Regressed on Pre-Announcement IV (Linear)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute AFE</td>
<td>0</td>
<td>0.006***</td>
<td>5.98%</td>
<td>104,062</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8646</td>
<td>0.0092</td>
<td>0.8646</td>
<td>0.0092</td>
<td>5.98%</td>
</tr>
<tr>
<td>Absolute AFE^+</td>
<td>0</td>
<td>0.005**</td>
<td>4.42%</td>
<td>77,736</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.6577</td>
<td>0.0127</td>
<td>0.6577</td>
<td>0.0127</td>
<td>4.42%</td>
</tr>
<tr>
<td>Absolute AFE^-</td>
<td>-0.001</td>
<td>0.01***</td>
<td>9.39%</td>
<td>26,866</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5174</td>
<td>0.0021</td>
<td>0.5174</td>
<td>0.0021</td>
<td>9.39%</td>
</tr>
<tr>
<td>Panel B: Absolute AFE Regressed on Pre-Announcement IV and squared Pre-Announcement IV (Quadratic)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute AFE</td>
<td>0</td>
<td>0.005*</td>
<td>0.001</td>
<td>6.01%</td>
<td>104,062</td>
</tr>
<tr>
<td></td>
<td>0.6242</td>
<td>0.0549</td>
<td>0.6272</td>
<td>6.01%</td>
<td>104,062</td>
</tr>
<tr>
<td>Absolute AFE^+</td>
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<td>0.003*</td>
<td>0.001</td>
<td>4.45%</td>
<td>77,736</td>
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<tr>
<td></td>
<td>0.1809</td>
<td>0.0773</td>
<td>0.5942</td>
<td>4.45%</td>
<td>77,736</td>
</tr>
<tr>
<td>Absolute AFE^-</td>
<td>-0.001</td>
<td>0.01***</td>
<td>0</td>
<td>9.38%</td>
<td>26,866</td>
</tr>
<tr>
<td></td>
<td>0.4699</td>
<td>0.0088</td>
<td>0.9569</td>
<td>9.38%</td>
<td>26,866</td>
</tr>
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</table>
### TABLE 3, continued

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Decile 1</th>
<th>Decile 2</th>
<th>Decile 3</th>
<th>Decile 4</th>
<th>Decile 5</th>
<th>Decile 6</th>
<th>Decile 7</th>
<th>Decile 8</th>
<th>Decile 9</th>
<th>Decile 10</th>
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</thead>
<tbody>
<tr>
<td>Absolute AFE</td>
<td>0.0016***</td>
<td>0.0016***</td>
<td>0.0018***</td>
<td>0.0021***</td>
<td>0.0022***</td>
<td>0.0026***</td>
<td>0.0029***</td>
<td>0.0034***</td>
<td>0.0042***</td>
<td>0.0062***</td>
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<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
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<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

In Panels A through C, absolute analyst forecast errors are calculated as the absolute value of actual earnings per share minus the latest consensus analyst forecast before the earnings announcement, deflated by stock price at the beginning of the quarter. In Panels A and B, these forecast errors are regressed on pre-announcement implied volatility measured on trading day -2 relative to the earnings announcement for options with a 91-day expiration. Panel C presents mean absolute analyst forecast errors by decile rank of pre-announcement IV. P-values below each coefficient and corresponding t-statistics are calculated using standard errors clustered by year of the fiscal period end.

*** p<0.01, ** p<0.05, * p<0.1
<table>
<thead>
<tr>
<th>Unexpected AFE Model</th>
<th>Dependent Variable</th>
<th>Intercept</th>
<th>RET</th>
<th>RET$^2$</th>
<th>Realized VOL</th>
<th>log DateDiff</th>
<th>UAAFEE</th>
<th>UAAFEE$^2$</th>
<th>Adj. R$^2$</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A: Change in IV regressed on unexpected absolute AFE (Linear model)</td>
<td>ΔIV</td>
<td>-0.001</td>
<td>-0.227***</td>
<td>0.209***</td>
<td>-0.023***</td>
<td>0.001***</td>
<td>0.958***</td>
<td>-16.611***</td>
<td>16.11%</td>
<td>104,062</td>
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<tr>
<td></td>
<td></td>
<td>0.6198</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0026</td>
<td>&lt;0.0001</td>
<td>0.0006</td>
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</tr>
<tr>
<td></td>
<td>ΔIV</td>
<td>0</td>
<td>-0.221***</td>
<td>0.203***</td>
<td>-0.025***</td>
<td>0.001***</td>
<td>0.965***</td>
<td>-16.583***</td>
<td>14.86%</td>
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<td>&lt;0.0001</td>
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<td>0.0037</td>
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<tr>
<td></td>
<td>ΔIV</td>
<td>-0.004**</td>
<td>-0.25***</td>
<td>0.207***</td>
<td>-0.02***</td>
<td>0.001**</td>
<td>0.821***</td>
<td>-15.123***</td>
<td>17.46%</td>
<td>26,866</td>
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<td>0.0125</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0013</td>
<td>0.0403</td>
<td>0.0007</td>
<td>0.0022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panel B: Change in IV regressed on unexpected absolute AFE (Quadratic model)</td>
<td>ΔIV</td>
<td>-0.001</td>
<td>-0.227***</td>
<td>0.209***</td>
<td>-0.023***</td>
<td>0.001***</td>
<td>1.019***</td>
<td>-17.647***</td>
<td>16.15%</td>
<td>104,062</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6175</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0027</td>
<td>&lt;0.0001</td>
<td>0.0007</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ΔIV</td>
<td>0</td>
<td>-0.221***</td>
<td>0.203***</td>
<td>-0.025***</td>
<td>0.001***</td>
<td>1.034***</td>
<td>-17.736***</td>
<td>14.91%</td>
<td>77,736</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.739</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0038</td>
<td>&lt;0.0001</td>
<td>0.0015</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ΔIV</td>
<td>-0.004**</td>
<td>-0.25***</td>
<td>0.207***</td>
<td>-0.02***</td>
<td>0.001**</td>
<td>0.825***</td>
<td>-15.184***</td>
<td>17.46%</td>
<td>26,866</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0125</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0013</td>
<td>0.0403</td>
<td>0.0007</td>
<td>0.0022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panel C: Change in IV regressed on unexpected absolute AFE (Non-parametric model)</td>
<td>ΔIV</td>
<td>0</td>
<td>-0.227***</td>
<td>0.21***</td>
<td>-0.024***</td>
<td>0.001***</td>
<td>0.873***</td>
<td>-15.131***</td>
<td>16.06%</td>
<td>104,062</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8821</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0021</td>
<td>0.0004</td>
<td>0.0014</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 4, continued
#### Panel D: Mean/Median residual change in IV for quintiles based on unexpected absolute AFE

<table>
<thead>
<tr>
<th>Quintile</th>
<th>Mean</th>
<th>Median</th>
<th>(p-value)</th>
<th>(p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.0065</td>
<td>-0.0025</td>
<td>0.001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>2</td>
<td>0.0020</td>
<td>0.0013</td>
<td>0.129</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>3</td>
<td>0.0044</td>
<td>0.0036</td>
<td>0.002</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>4</td>
<td>0.0057</td>
<td>0.0048</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>5</td>
<td>0.0072</td>
<td>0.0060</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

In Panels A through C, change in IV is the change in implied volatility from OptionMetrics for trading days -2 to +2 relative to the earnings announcement. RET is the buy-and-hold stock return over the announcement period. UAAFE is unexpected absolute analyst forecast error, measured as the residual from regressing absolute AFEs on pre-announcement IV using either a linear model (Panel A), a quadratic model (Panel B), or a non-parametric decile approach (Panel C) when predicting absolute AFE values. Each of the models for unexpected absolute AFE is detailed in Table 3. log_DateDiff is the natural log of the number of days between the date of the consensus analyst forecast and the earnings announcement. P-values below each coefficient and corresponding t-statistics are calculated using standard errors clustered by year of the fiscal period end. In Panel D, residual change in IV ($r\Delta IV$) is calculated as the intercept plus the residual estimated from regressing change in IV on RET, RET$^2$, and pre-announcement realized volatility. For means, p-values and t-statistics are calculated using standard errors clustered by year of the fiscal period end; for medians, p-values are based on signed-rank tests.
TABLE 5
Change in IV for low-absolute return earnings announcements

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Announcement returns (-1% → 1%)</th>
<th>(-0.5% → 0.5%)</th>
<th>(-0.1% → 0.1%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in IV</td>
<td>Mean -0.0073 (p-value) &lt;0.0001</td>
<td>-0.0072 (p-value) &lt;0.0001</td>
<td>-0.0064 (p-value) &lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Median -0.0046 (p-value) &lt;0.0001</td>
<td>-0.0045 (p-value) &lt;0.0001</td>
<td>-0.0041 (p-value) &lt;0.0001</td>
</tr>
<tr>
<td>% Change in IV</td>
<td>Mean -0.0135 (p-value) &lt;0.0001</td>
<td>-0.0134 (p-value) &lt;0.0001</td>
<td>-0.0099 (p-value) 0.0007</td>
</tr>
<tr>
<td></td>
<td>Median -0.0140 (p-value) &lt;0.0001</td>
<td>-0.0139 (p-value) &lt;0.0001</td>
<td>-0.0117 (p-value) &lt;0.0001</td>
</tr>
<tr>
<td>Decreases in IV</td>
<td>7,970</td>
<td>4,007</td>
<td>994</td>
</tr>
<tr>
<td>Increases in IV</td>
<td>4,549</td>
<td>2,308</td>
<td>614</td>
</tr>
<tr>
<td>Total Observations</td>
<td>12,519</td>
<td>6,315</td>
<td>1,608</td>
</tr>
</tbody>
</table>

This table presents analyst forecast errors and changes in implied volatility for earnings announcements with equity returns near zero during the announcement window. AFE is calculated as actual earnings per share minus the latest consensus analyst forecast before the earnings announcement, deflated by stock price at the beginning of the quarter. Change in IV is the change in implied volatility from OptionMetrics for trading days -2 to +2 relative to the earnings announcement. The % Change in IV is the change in implied volatility from OptionMetrics for trading days -2 to +2 relative to the earnings announcement scaled by implied volatility as of trading day -2. For means, p-values and t-statistics are calculated using robust standard errors; for medians, p-values are based on signed-rank tests.