Pricing Event Risk: Evidence from Concave Implied Volatility Curves

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May 2022

Abstract

We document that implied volatility (IV) curves extracted from short-term equity options frequently become concave prior to the earnings announcements day (EAD) reflecting a bimodal risk-neutral distribution for the underlying stock price. Firms with concave IV curves exhibit significantly higher absolute stock returns on EAD and higher realized volatility after the announcement, as compared to firms with non-concave IV curves. Hence, concavity in the IV curve constitutes an ex-ante option-based signal for event risk in the underlying stock. Returns on delta-neutral straddles, delta-neutral strangles, and delta- and vega-neutral calendar straddles are all negative and significantly lower in the presence of concave IV curves, showing that investors pay a substantial premium to hedge against the gamma risk arising due to this event.

Keywords: Earnings announcement, Event risk, Risk-neutral distribution, Implied volatility.

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1 Introduction

Earnings announcements are scheduled corporate events that disseminate substantial fundamental information to investors. A voluminous literature has examined several features, such as the behavior of stock returns (see, for example, Ball and Brown (1968), Ball and Kothari (1991), Beaver (1968), and Frazzini and Lamont (2007)) and systematic risk (see, for example, Patton and Verardo (2012) and Savor and Wilson (2016)) around these earnings announcements days (EADs).

We posit that these scheduled announcements are often viewed as referendums on firm value. On these occasions, investors anticipate that the underlying stock price will, more likely than not, exhibit a large movement in either direction upon the announcement. This anticipated stock price jump induces bimodality in the ex-ante risk-neutral distribution (RND) and concavity in the implied volatility (IV) curve. Using data on very short-term options, we first empirically document that bimodality in the RND and concavity in the IV curve are pervasive features prior to EADs and then study the pricing implications of these phenomena.

The possibility of stock price jumps can also translate into increased volatility around EADs. In fact, Dubinsky, Johannes, Kaeck, and Seeger (2019, DJKS henceforth) and Patell and Wolfson (1979, 1981) document an increase in IV in the runup to EADs and a sharp drop afterwards. However, the bimodality that we document is a fundamentally different concept of risk relative to a more dispersed distribution (volatility), or a negatively skewed distribution (a reflection of tail risk), or a more fat-tailed distribution (kurtosis).

The documented bimodality in the central part of the RND implies that, subject to a relatively minor risk-adjustment due to the very short option expiry, the prevailing stock price is expected to be around either of the two identified modes. This means that the stock price after the announcement will most likely be $x\%$ above or $y\%$ below the current price; each outcome may also be associated with a different volatility level. This feature is, therefore, also different from the common modeling assumption of a low-probability, randomly timed Poisson jump (see, for example, Ball and Torous (1985) and Merton (1976)), which can lead to an IV smirk and a left-tailed RND, capturing tail risk and explaining the expensiveness of OTM puts (Bates (1996, 2000), Pan (2002), and Yan (2011)). We dub this ex-ante bimodality as "event risk" for the underlying stock and argue that a concave IV curve provides an option-based signal for this type of risk.[1]

We show that during our sample period (2013-2020) a large fraction (38.4%) of IV curves

[1]According to Liu, Longstaff, and Pan (2003, p. 231), event risk is defined as "the risk of a major event precipitating a sudden large shock to security prices and volatilities."

extracted from short-expiry equity options become concave prior to EADs. This compares to just 4.8% of IV curves exhibiting concavity on a typical trading day when option expiry does not span an EAD. The concave IV curves that we document are typically inverse U-shaped, S-shaped, or W-shaped. These shapes are in stark contrast with the convex volatility smiles and smirks (or skews) that are commonly observed for equity options, where out-of-the-money (OTM) puts trade at higher volatility relative to at-the-money (ATM) options. Interestingly, the feature of concavity mostly disappears right after the announcement, as the uncertainty surrounding this event is resolved, and the IV curves revert to their standard convex shape.

Concavity appears in short- rather than long-expiry options. This feature arises due to the relative effect between the anticipated jump and the diffusion component of the underlying stock price process. As expiry shrinks, the effect of the anticipated jump dominates the effect of the diffusion component; this renders the underlying RND bimodal and the IV curve concave. On the other hand, as the expiry increases, the diffusion component dominates, the RND reverts to unimodality and the IV curve to convexity. The sparsity of short-term equity options prior to our sample period may explain why this feature has not been previously documented in the literature.

Having documented these novel features of IV curves around EADs, we examine the informational content of concavity. Our analysis reveals that concave IV curves possess significant predictive ability with respect to stock returns on EAD and post-EAD realized volatility. First, we find that, on average, firms exhibiting concave IV curves have an absolute abnormal stock return of 5.88% on EAD, which is 1.65% higher than the corresponding absolute return for firms with non-concave IV curves. Second, we find that firms with concave IV curves exhibit an average realized stock return annualized volatility of 47.5% in the 10-day interval after the announcement, which is 10.43% higher than the corresponding realized volatility of firms with non-concave IV curves.

These findings show that investors are able to identify earnings announcements that trigger larger than average stock price movements and volatility. Anticipating these effects, investors trade accordingly in the option market, giving rise to concave IV curves and bimodal RNDs, which in turn signal ex-ante the impending event risk.

The most obvious way investors could speculate on, or hedge against, large stock price swings on EADs, regardless of their direction, is by purchasing straddles. Delta-neutral ATM straddles have been commonly used to capture the price of volatility risk for the underlying stock returns (Coval and Shumway (2001)). Therefore, we examine whether delta-neutral straddle returns on EADs differ across concave and non-concave IV curves. Interestingly, concave IV curves are followed by a negative and 4.57% lower average delta-neutral straddle return on EAD, as compared to non-concave IV curves. In fact, we find that only in the presence of concave IV curves do investors pay a significant premium to hedge against the uncertainty caused by the forthcoming announcement.

To directly show that ATM straddles are particularly expensive in the presence of concave IV curves, we introduce a simple measure of their expensiveness. Specifically, we compute the ratio of the sum of the ATM put and call prices divided by the underlying stock price. Intuitively, this ratio indicates the required percentage change in the underlying stock price, in either direction, to offset the cost of the ATM straddle. Hence, this ratio is termed as the *implied move* for the underlying stock price. The higher (lower) the value of this ratio, the more (less) expensive it is to purchase an ATM straddle, ceteris paribus.

We find that, on average, the implied move prior to the EAD is 2.21% higher for concave IV curves. This strongly significant differential confirms that ATM straddles are much more expensive prior to EADs in the presence of concave IV curves. This finding can help explain why these straddles yield much lower returns on EADs despite the larger than average absolute stock returns observed following the formation of concave IV curves. This finding also provides an alternative way to illustrate that investors pay a significant premium to hedge against the event risk that is signaled by a concave IV curve prior to the announcement.

Delta-neutral straddles are exposed to both stochastic volatility (vega) and jump (gamma) risk. To identify which of these two sources of risk is priced around earnings announcements, we follow two complementary approaches. First, similar to Dew-Becker, Giglio and Kelly (2021), we construct strangles that yield positive payoffs only when the underlying stock price exhibits a sufficiently large move. Hence, strangle returns can provide direct evidence on the price of gamma risk around EADs. Second, following Cremers, Halling and Weinbaum (2015), we construct delta- and vega-neutral calendar straddles (which expose investors to gamma risk only) and delta- and gamma-neutral calendar straddles (which expose investors to vega risk only).

We find that, on average, concave IV curves are followed by a 8.84% lower strangle return and a 12.71% lower delta- and vega-neutral straddle return on EADs, as compared to non-concave IV curves. In fact, the average returns of these option strategies are negative only in the presence of concave IV curves. On the other hand, delta- and gamma-neutral straddles yield a positive premium across concave and non-concave IV curves. These results show that investors pay a substantial premium to hedge against the gamma risk that arises due to the earnings announcement only in the presence of concave IV curves. They also show that the informational content of concave IV curves is related to gamma rather than vega risk.

Overall, our study shows that large stock price movements are systematically anticipated by investors prior to EAD and can be detected ex-ante because they dramatically affect the pricing of short-expiry options. In the case of concave IV curves, we show that large stock price movements are not just a possibility due to the announcement, but rather a very likely outcome. This feature gives rise to a bimodal short-term RND for the underlying stock price (and return), which is in stark contrast with the established paradigm in asset pricing that relies on unimodal return distributions.

Even though the main objective of our paper is empirical, to better understand the drivers of concave IV curves and bimodal RNDs, we introduce an option pricing model building on DJKS (2019) and Piazzesi (2000). DJKS model EAD jump size to be normally distributed, leading to a large increase in short-term ATM IV and a downward sloping term structure prior to the announcement. In contrast, we allow the jump size to follow a mixture of normal distributions. While seemingly an innocuous modification, our assumption is more consistent with the different conceptual underpinnings of price jump risk and volatility risk. More importantly, our modeling assumption can naturally generate a bimodal RND. In this respect, our model is closer in spirit to the studies that have used mixtures of log-normal distributions to empirically fit the RNDs for various assets prior to geopolitical events or policy decisions (see, for example, Hanke, Poulson, and Weissensteiner (2018), Leahy and Thomas (1996), Melick and Thomas (1997), and Mirkov, Pozdeev, and Söderlind (2016)).

Our study contributes to various strands of the literature. Starting from the early studies of Patell and Wolfson (1979, 1981), there is a growing literature showing that option-based measures embed significant information prior to earnings announcements (see, for example, Amin and Lee (1997), Barth and So (2014), Billings and Jennings (2011), Gao, Xing, and Zhang (2018), Ni, Pan, and Poteshman (2008), and Xing, Zhang, and Zhao (2010)). We add to this literature by showing that the curvature properties of the IV curve contain significant predictive ability over stock returns, realized volatility, straddle and strangle returns around EADs.

Our study is also related to the literature showing that stock prices do jump upon the release of news in the form of pre-scheduled macroeconomic (Savor and Wilson (2013)) or earnings announcements (Lee (2012) and Lee and Mykland (2008)). Contributing to this literature, we show that large stock price movements are systematically anticipated prior to the announcement and they can be detected ex-ante because they dramatically affect the pricing of short-expiry options.

Our setup is closely related to that of DJKS (2019), who also examine the impact of predictably timed EAD stock price jumps on option pricing. However, their focus is on the term structure of ATM IV prior to the announcement, whereas we examine the curvature properties of the IV curve for short-term equity options. Importantly, in their model, the EAD jump size is assumed to be normally distributed and its mean is a transformation of its volatility. As a result, the only effect of this anticipated price jump is a large increase in short-term ATM IV, leading to a downward sloping term structure prior to the announcement. The distribution of stock prices remains unimodal and the jump has no effect on the curvature of the IV curve across moneyness levels. Therefore, the model of DJKS cannot reproduce the novel but pervasive empirical features we document in our study, namely concavity in the IV curve and bimodality in the RND of the underlying stock price prior to the announcement.

2 Data and Methodology

2.1 Option Data and IV Curves

We construct IV curves using option data from OptionMetrics during the period 2013 to 2020. For each calendar year, we select 100 firms with the highest option trading volume, requiring the underlying to be common stock (share codes 10 or 11) with share price higher than \$5. This yields a total sample of 194 firms during the entire period. The choice of the sample period and the cross-section of firms are dictated by the availability of short-term option data. Weekly equity options have been actively traded for a range of strikes only in the last decade. Hence, OptionMetrics provides very sparse data for short expiries prior to 2013.

Our primary focus is on option-implied information related to earnings announcements, so we utilize short-term options whose expiry spans the EAD. In particular, we keep options with expiry between 3 and 13 calendar days ahead. We obtain information on the timing of quarterly EADs from I/B/E/S. Following common practice in the literature (see Barth and So (2014) and Michaely, Rubin, and Vedrashko (2014)), if the announcement is made after the market close, the next trading day is defined as the EAD.

To ensure that the information embedded in IV curves is meaningful, we apply a number of standard filters to the option data. Specifically, we discard options with zero open interest, zero trading volume, zero bid price, mid-quote price less than \$0.125, non-standard settlement, or missing implied volatility. We also discard options that violate standard arbitrage bounds or when the bid is higher than the ask price. To ensure that our findings are not driven by particularly illiquid options, we also discard options when the bid-ask spread is higher than 20% of the mid-quote price.

To construct the IV curve, we utilize the annualized IVs of ATM and OTM options provided by OptionMetrics. To avoid an artificial jump at the ATM region, which could arise from ATM puts potentially trading at higher IV relative to ATM calls, we follow the blending approach of Figlewski (2010). Specifically, we blend the IVs of puts (IV_P) and calls (IV_C) whose strike price K lies within $\pm 2\%$ of the underlying spot price, S, into a single point as follows:

$$IV(K) = wIV_P(K) + (1-w)IV_C(K), \tag{1}$$

where $w = (K_{high} - K)/(K_{high} - K_{low})$ and K_{high} (K_{low}) is the highest (lowest) strike in this $\pm 2\%$ range. To ensure a good coverage of the moneyness range, after the blending we require at least six options for a given expiry, with at least two puts and two calls.

Equipped with these IV points, we fit a quintic spline using the function `spaps` in MATLAB.[2] This yields the smoothest IV curve in the moneyness space K/S, subject to a tolerance level for the sum of squared errors between the actual and the fitted IVs. In the spirit of Bliss and Panigirtzoglou (2002, 2004), the quintic spline minimizes the following objective function:

$$\rho \sum_{i=1}^{N} \left[IV(K_i) - \widehat{IV}(K_i;\theta) \right]^2 + \int_{-\infty}^{\infty} S^{(3)}(x;\theta)^2 dx, \tag{2}$$

where $IV(K_i)$ is the actual implied volatility for strike K_i, $\widehat{IV}(K_i;\theta)$ is the corresponding fitted implied volatility, which is a function of the parameter set θ that defines the quintic spline $S(\theta)$, and ρ is a smoothing parameter that is optimally selected to ensure that the sum of squared IV errors does not exceed a given tolerance level.[3]

To compute the RND corresponding to the fitted IV curve, we use the standard result of Breeden and Litzenberger (1978). The density function is given by $f(K) = e^{rT}\partial^2 C/\partial K^2$, where r is the interest rate and C is the call option price as a function of the strike price K. The fitted IV curve contains 1,001 points. These IVs are converted to call option prices using the Black-Scholes formula. In the absence of a continuum of strikes, we compute the second partial derivative in the above formula using finite differences and derive the RND for the range of the available moneyness levels.

Having imposed a number of strict filters on the option data, we seek to fit well the actual IV points, and hence we opt for a low tolerance level. This tolerance level corresponds to a

[2] A quintic spline ensures that the third derivative of the IV curve (and hence the option price function) is continuous, yielding a well-behaved RND (see Figlewski (2010)).

[3] Parameter ρ controls the tradeoff between the goodness-of-fit and the smoothness of the spline function; the latter is captured by its integrated squared third derivative. Setting a low tolerance level ensures that the spline fits well the actual IV points at the expense of smoothness. To the contrary, setting a high tolerance level yields a rather smooth spline that may not fit well the actual IV points.

0.01% mean squared error between the actual and the fitted IVs. However, to ensure that the fitted IV curve is not too erratic and does not correspond to an ill-behaved RND, we impose further conditions. We require that no interpolated IV point is negative and that the corresponding RND does not exhibit a negative density point or more than two modes. If any of these conditions is violated, we increase the upper bound of the mean squared error in steps of 0.005% until the conditions are met. Our final sample consists of 2,229 IV curves on the trading day prior to EAD for the firms in our sample.

2.2 Definition of Concave IV Curve

We introduce a definition of concavity based on the first and second derivatives of the fitted IV curve with respect to moneyness.[4] Specifically, we define an IV curve to be concave when the following three conditions hold. First, the second derivative of the fitted IV curve is negative for a continuous moneyness (K/S) range of at least 0.03 points, i.e., for a continuous range of strikes that amount to at least 3% of the underlying spot price. Second, we require that the fitted IV curve exhibits a stationary point within the moneyness range where it exhibits concavity. Third, this stationary point is located between the second lowest ($K_{\min+1}$) and the second highest ($K_{\max-1}$) strikes of the actual IV points used to fit the smooth IV curve.

These conditions address the potential concern that the documented concavity may be an artefact of outliers or the employed smoothing spline. In particular, they ensure that our definition does not simply capture very local infection points or marginally concave parts of the IV curve. They also ensure that the concavity does not arise from the lowest or highest actual strikes, which typically correspond to deep OTM options.

This definition is sufficiently general to capture various shapes of concavity, such as the inverse U-shape, W-shape, and S-shape IV curves illustrated in Figure 1. Using this definition, we define the dummy variable `CONCAVE`, which takes the value one when the IV curve is concave and zero otherwise.

2.3 Other Variables and Data Sources

In addition to `CONCAVE`, we use a number of other variables in the subsequent empirical analysis. The definition of these variables is provided in Appendix A. For each firm, we compute at the daily frequency its market beta (`BETA`), the natural logarithm of market capitalization (`Ln(SIZE)`) and stock price (`Ln(PRICE)`), five-day cumulative stock return

[4]First and second derivatives of the fitted IV curve are computed using finite differences.

(RUNUP), momentum return (MOM), and stock turnover ratio (STOCKTR). The source of stock prices, trading volumes and number of outstanding shares is CRSP. We compute the book-to-market ratio (B/M) using quarterly data from COMPUSTAT. We also use the number of analysts providing earnings forecasts (NUMEST), the standard deviation of these forecasts (DISP), and the differential stock beta around EADs (ANNBETA) as in Barth and So (2014). Analysts forecast data are obtained from I/B/E/S.

We also use a number of option-based variables. Specifically, we compute the ATM implied volatility (ATMIV) and the difference (RVIV) between the realized volatility and ATMIV of Goyal and Saretto (2009). Since our focus is on short-expiry options, we construct ATMIV and RVIV utilizing the 10-day volatility surfaces that have been recently introduced by OptionMetrics. In addition, we compute the Risk-Neutral Skewness (RNS) and Risk-Neutral Kurtosis (RNK), following the approach of Bakshi, Kapadia, and Madan (2003). We also use the option-to-stock trading volume ratio (O/S) of Roll, Schwartz, and Subrahmanyam (2010). Finally, we compute the term structure estimate of ATM implied volatility (TSIV) proposed by DJKS (2019).

2.4 Summary Statistics

Table 1 presents the summary statistics for the variables used in our analysis. Their values are computed on the day prior to EAD and they are winsorized at the 1% and 99% levels. We find that 38.4% of the IV curves extracted prior to the EAD exhibit concavity. These IV curves are computed from short-term options, with an average EXPIRY of 6.46 calendar days and a large number of strikes (average STRIKES =17.88). The latter feature is consistent with the fact that our sample consists of very large firms, with an average (median) market capitalization of $57,526 ($68,186) million. As a result, these firms trade at a much higher price (average = $77.48), they exhibit low B/M (average = 0.35), and they are followed by a very large number of analysts (average NUMEST = 23.95), as compared to the corresponding values typically encountered in studies that utilize the entire CRSP universe.

Regarding option-based variables, the median RNS (RNK) is −0.25 (3.46). In line with the arguments of Patell and Wolfson (1979, 1981), ATMIV is substantially higher prior to EADs, with an average value of 45.04%. As a consequence, RVIV takes very large negative values, with an average of −16.62%. Moreover, TSIV is almost always positive, with an average value of 6.8%. This confirms the findings of DJKS (2019) that the term structure of ATM implied volatility is downward sloping prior to EADs. Lastly, we also find substantial stock trading activity prior to the EAD, with an average daily STOCKTR of 2.4%, and an even higher trading activity in the option market, with an average O/S of 28.43%.

Table 2 reports the pairwise correlations among these variables. Our main focus is on the correlation properties of the newly proposed variable `CONCAVE`. Most notably, we find that `CONCAVE` is positively correlated with `ATMIV`, `RNS`, and `TSIV`, but negatively correlated with `RNK` and `RVIV`. Hence, concave IV curves are associated with higher levels of ATM implied volatility and a steeper downward sloping IV term structure prior to EAD. Moreover, `CONCAVE` exhibits a positive correlation with `STOCKTR`, `O/S`, and `NUMEST`, which indicates that concave IV curves more often appear when there is substantial coverage by financial analysts as well as high trading activity by investors prior to the announcement.

However, it should be noted that the reported correlations for `CONCAVE` are not particularly high (much less than 0.40 in absolute value), alleviating the potential concern that `CONCAVE` may simply mimic another firm characteristic. To the contrary, Table 2 illustrates the very high pairwise correlations between `ATMIV`, `RVIV`, `TSIV`, and `Ln(SIZE)` prior to EADs.

Table 3 compares the average values of these variables across observations of concave and non-concave IV curves on the day prior to EAD. We find that concave IV curves are extracted from sets of options with a somewhat shorter average expiry and a higher average number of available strikes. We also find that concave IV curves are associated with firms that, on average, are followed by more analysts, they are relatively smaller, and they have lower `B/M`.

Moreover, we observe that concave IV curves are associated with significantly higher average values of `BETA`, `STOCKTR`, and `O/S` as well as higher average stock prices and returns (`Ln(PRICE)`, `RUNUP`, `MOM`) prior to the EAD. Consistent with the pairwise correlations presented in Table 2, we also report that concave IV curves are accompanied, on average, by significantly higher `ATMIV`, `RNS`, and `TSIV` values and significantly lower `RNK` and `RVIV` values relative to non-concave IV curves.

3 Features of Concave IV Curves and Empirical RNDs

3.1 Features of Concave IV Curves

IV curves for equity options typically exhibit a smile or a smirk (see, for example, Rubinstein (1994), Toft and Prucyk (1997), and the review of the early literature in Jackwerth (2004)), which corresponds to a convex IV curve where OTM puts trade at higher IV than ATM options. This pattern corresponds to an important deviation from the Black and Scholes (1973) model, where implied volatility should be constant across moneyness levels. In sharp contrast to the commonly documented convex IV curves for equity options, as shown in the summary statistics, we often observe concave IV curves prior to EADs. This section illustrates the main features of concave IV curves observed in the data.

Figure 1 provides examples of the three main types of concavity we encounter in our sample. In this figure, circles indicate implied volatilities corresponding to actual traded strikes, whereas the curve is fitted using a quintic spline. Panel A shows an inverse U-shape IV curve for Twitter, computed from options with three days to expiry on 29th July, 2014. Here the IV of OTM calls and puts is substantially lower than the IV of ATM options.

Panel B of Figure 1 illustrates an S-shape curve for Ebay, computed from options with three days to expiry on 29th April, 2014. This curve exhibits two stationary points. In this particular example, the concave part of the curve is located in the OTM calls region, whereas the OTM puts region exhibits a typical convex shape. An interpretation of this shape is that concavity arises in a specific moneyness range, where options are trading at higher volatility relatively to neighboring strikes.

Panels C and D provide examples of an even more intriguing type of concavity, for Google and Netflix, respectively, computed from options with four days to expiry on 23rd April and 16th July 2018, respectively. This W-shaped IV curve exhibits three stationary points, with a U-shape curve followed by an inverse-U shape curve, which is in turn followed by another U-shape curve. Here, concavity arises in specific ranges of moneyness, with near-the-money options trading at volatility levels as high as, or even higher than, deep OTM options.

The above shapes of concavity systematically appear in short-expiry equity options just before EADs. We find that these shapes typically disappear right after the announcement, with the IV curve reverting to a standard convex shape. Figure 2 illustrates this pattern using as example the earnings announcement of Apple that took place right after the market close on 28th October, 2013. Whereas the IV curve extracted just before the announcement from options with four days to expiry exhibits a clear W-shape, it reverts to a smile on the following day using options with the same expiry date.

Figure 3 further illustrates that IV curves often become concave in the runup to the EAD but they subsequently revert to their standard convex shape. Specifically, Figure 3 reports the fraction of concave IV curves for the firms in our sample on trading days around the EAD d. We observe that the fraction of concave IV curves gradually increases from 20% on day $d-5$ to 26.9% on day $d-2$, reaching the peak of 38.4% on the trading day prior to EAD. Right after the announcement, there is a sharp drop in the fraction of IV curves exhibiting concavity to only 8.7% on day d. This fraction subsequently drops further and hovers around 5% from day $d+1$ onwards.

To emphasize how uncommon it is to find a large fraction of concave IV curves using options whose expiry does not span an EAD, we perform the following analysis. For the firms in our sample, we impose the same data filters and follow the same steps of the methodology described in Section 2 to compute `CONCAVE` on all trading days during the period 2013-2020. We extract 90,464 firm-day IV curves from very short-term options whose expiry does not span an EAD. We find that only 4.8% out of these observations exhibit a concave IV curve. This finding further alleviates the potential concern that the large faction of concave IV curves we identify in the runup to the EAD may be an artefact of our methodology or the use of very short-expiry options.

3.2 Bimodality in RND

The main variable of interest in our analysis (`CONCAVE`) is defined with respect to the properties of the IV curve. The shape of the IV curve is a reflection of the properties of the RND for the underlying stock price. For example, a symmetric volatility smile corresponds to a leptokurtic RND, whereas a volatility smirk (or skew) is associated with a negatively skewed RND (see the related discussion in Jackwerth (2004) and Hull (2009, chapter 18)).

Figure 4 illustrates that a concave IV curve reflects a bimodal RND for the underlying stock price. This is a rather unusual feature. RND bimodality implies that at option expiry, the underlying stock will most likely trade around either of the two identified price modes.[5] The right Panel of Figure 4 illustrates the RND for the stock price of Amazon, extracted from options with eight days to expiry on April 26, 2018, i.e., just before the earnings announcement that took place right after the market close. The closing stock price was $1,517.96 on that day. The 8-day RND reveals two price modes at expiry; one at $1,444.80 (i.e., 4.8% lower) and the other one at $1,602.00 (i.e., 5.5% higher). Following the announcement, Amazon's stock price had a positive return of 3.6% on April 27 and closed at $1,580.95 (i.e., 4.15% higher) on May 4, at option expiry.

Another interpretation of RND bimodality prior to an EAD, as illustrated in Figure 4, is that a discrete price movement or jump is anticipated due to the forthcoming announcement. Hull (2009, p. 398) describes a concave inverse U-shape IV curve as a "frown" and argues that it reflects a bimodal RND for the underlying asset price, which in turn arises "when a single large jump is anticipated." Therefore, we argue that a bimodal RND and a concave IV curve provide option-based signals of impending event risk in the underlying stock. Our analysis reveals that earnings announcements frequently give rise to event risk, which is

[5] It should be noted that the RND indicates risk-neutral probabilities rather than physical probabilities. However, since we utilize firm-level options with very short expirations, the adjustment from risk-neutral to physical probabilities is expected to have a relatively minor effect.

priced in the option market, and hence can be detected *ex-ante*.

RND bimodality is an important feature that distinguishes our study from DJKS (2019). DJKS's model allows for predictably timed price jumps on EADs. However, by assuming a normally distributed EAD jump size, their implied RND remains unimodal, and hence their model cannot reproduce the concave IV curves observed in the data.

We emphasize that concave IV curves predominantly appear in short expiry options. Figure 5 illustrates an example of fitted IV curves for Amazon across different expirations (8, 22, 36, and 50 days) on April 26, 2018. The figure shows that, while the IV curve for the 8-day expiry clearly exhibits a W-shape type of concavity, this feature is much less obvious for the 22-day expiry and disappears for longer expiries.[6]

Intuitively, these patterns arise due to the relative effect of the anticipated stock price jump on EAD versus the diffusion component of the underlying process. As expiry shrinks, the effect of the anticipated price jump dominates the effect of the diffusion component, rendering the underlying RND bimodal and the IV curve concave. To the contrary, as time to expiry increases, the effect of the diffusion component dominates the effect of the anticipated price jump, the RND reverts to unimodality, and the IV curve becomes convex. Finally, while our focus is on the shape of the entire IV curve extracted from short-expiry options, Figure 4 also shows that ATM IV is downward sloping prior to EADs, consistent with the findings of DJKS (2019).

3.3 Forecasting Ability of Empirical RNDs

A natural question that arises is whether the fitted IV curves and the corresponding empirical RNDs prior to EAD have forecasting ability with respect to future stock prices. This question becomes particularly interesting in the case of concave IV curves and bimodal RNDs. If the empirical bimodal RNDs do not forecast future realized densities, these non-standard shapes could simply reflect biases in the beliefs or preferences of option market participants, undermining their importance.

To evaluate the forecasting ability of empirical RNDs, we employ the test statistic of Amisano and Giacomini (2007). This statistic, AG, compares the out-of-sample accuracy of competing density forecasts. In our context, all densities are computed on the day prior to the EAD, i.e., on day $d-1$. Let $\widehat{f}(S_T)$ denote the empirical RND forecast for the underlying stock price S_T at option expiry T, which is extracted from the fitted IV curve, as described in Section 2.1. Similarly, let $\widehat{g}(S_T)$ denote a competing RND forecast with respect to S_T.

[6] Data on short-expiry equity options are sparsely available prior to 2013. This may be one reason why this feature has not been documented in the prior literature.

The Amisano and Giacomini test uses a logarithmic scoring rule to compare the accuracy of the competing densities with respect to the realization of S_T at T, $\widetilde{S}_T$. Assuming equal weights for all observations, we compute the following statistic:

$$AG = \frac{N^{-1}\sum_{j=1}^{N}\left(\log\widehat{f}\left(\widetilde{S}_{j,T}\right) - \log\widehat{g}\left(\widetilde{S}_{j,T}\right)\right)}{\widehat{\sigma}_N/\sqrt{N}}, \tag{3}$$

where $\widehat{\sigma}_N$ is the sample standard deviation of $\left(\log\widehat{f}\left(\widetilde{S}_{j,T}\right) - \log\widehat{g}\left(\widetilde{S}_{j,T}\right)\right)$ and N denotes the number of observations. Under the null hypothesis of equal performance of density forecasts, the AG statistic is asymptotically distributed as $N(0,1)$. If the null is rejected, $\widehat{f}(S_T)$ has superior forecasting ability to $\widehat{g}(S_T)$ if $AG > 0$ and vice versa if $AG < 0$.

We compare the empirical RNDs with three alternative sets of unimodal, log-normal RNDs that are computed from Black-Scholes option prices using different volatility parameters as inputs. The first competing approach (RV30 RND) is based on RNDs that uses as volatility parameter the 30-day realized volatility of the underlying stock on day $d-1$, sourced from the Historical Volatility File of OptionMetrics.

Panel A of Table 4 presents the results from this forecasting comparison.[7] Across all observations, we find strong evidence that the empirical RNDs possess superior forecasting ability with respect to stock prices at option expiry. We also examine subsamples where the fitted IV curve is concave (`CONCAVE`=1) and the realized absolute log stock return at expiry is greater than one or two standard deviations (scaled by time), respectively.[8] We find that in the presence of concave IV curves, which largely reflect bimodal RNDs, the outperformance of empirical RNDs becomes stronger. Hence, bimodal RNDs can better forecast future stock prices, highlighting the informational content of this feature prior to earnings announcements. This superior forecasting performance becomes even more impressive when the underlying stock price subsequently exhibits a large move. This finding leads to the conclusion that bimodal RNDs are able to better forecast stock prices that substantially deviate from their pre-EAD levels.

A potential reason for the above finding could be that the unimodal RNDs use a volatility parameter that is too backward-looking. To address this issue, the second competing approach (RV10 RND) alternatively uses as volatility parameter the 10-day realized volatility computed on day $d-1$. Panel B of Table 4 presents the corresponding comparisons. The rel-

[7]Empirical RNDs are extracted from the available moneyness range without extrapolating or fitting their tails that could artificially improve their performance. Thus, for fairness, these comparisons only consider observations where the empirical RND yields a cumulative probability of at least 70% or 80%, respectively.

[8]To identify these observations, we use the 30-day realized volatility on day $d-1$ from the Historical Volatility File.

ative outperformance of empirical RNDs across all subsamples becomes even stronger in this case. We conclude that empirical RNDs have superior forecasting ability prior to earnings announcements relative to unimodal RNDs that are based on realized volatility.

We also compare empirical RNDs with unimodal RNDs that make use of option-implied volatility. To this end, the third competing approach (ATM RND) uses as volatility parameter the ATM volatility on day $d-1$ for the same expiry as the one used to compute the empirical RND. Hence, this approach equips the competing RNDs with forward-looking information embedded in option prices but still imposes unimodality.

Panel C of Table 4 presents the corresponding results. Here, we cannot reject the null hypothesis of equal forecasting performance across all observations or for observations with concave IV curves.[9] However, in the presence of concave IV curves, empirical RNDs possess superior forecasting ability relative to ATM RNDs when large stock returns are observed at expiry. This finding is consistent with the distinct feature of bimodal RNDs. As they shift probability mass away from the prevailing stock price at $d-1$, bimodal RNDs are better suited to capture large price moves relative to unimodal RNDs. Since earnings announcements are often followed by large stock price moves, this result underlines the informational advantage of a bimodal RND relative to a disperse but still unimodal RND.

In sum, we conclude that empirical RNDs possess significant forecasting ability with respect to future stock prices. This ability is stronger in the presence of concave IV curves where bimodal RNDs can better forecast large stock price moves.

4 Model

Motivated by the empirical findings in the previous section, we build an option pricing model that can generate the novel features that we document, namely concavity in the IV curve and bimodality in the RND of the underlying stock price prior to the EAD. The model builds upon the continuous-time model of Bates (1996), which features stochastic volatility and random jumps. We note that it is straightforward to generalize our modeling structure using more complicated continuous-time stochastic volatility models.

The most common modeling assumption for large stock price changes is that of a low-probability, randomly timed Poisson jump (see, for example, Ball and Torous (1985) and Merton (1976)). While random jumps, for example, can lead to an IV smirk and a left-tailed

[9] The improved performance of ATM RNDs relative to RV10 and RV30 RNDs is due to the fact that ATM volatility is typically much higher than realized volatility at $d-1$. This feature leads to much more disperse ATM RNDs relative to RV30 and RV10 RNDs, enabling the former to better forecast the larger than average stock returns that are observed around earnings announcements.

RND, capturing tail risk and explaining the expensiveness of OTM puts (Bates (1996, 2000), Pan (2002), and Yan (2011)), neither these jumps nor stochastic volatility typically generate concave IV curves.

DJKS (2019) and Piazzesi (2000) introduce deterministically timed jumps in the continuous-time path of the underlying stock price. Our model builds upon their insights. Let N_t^d count EADs prior to time t so that $N_t^d = \sum_j \mathbf{1}_{\tau_j \le t}$, where τ_j is an increasing sequence of predictable stopping times representing an EAD. Different from DJKS (2019), the jump size occuring on EAD τ_j, $Z_j = \ln\left(S_{\tau_j}/S_{\tau_j -}\right)$, is assumed to follow a mixture of normal distributions. Specifically, $Z_j = \pi_j X_j^{(-)} + (1-\pi_j) X_j^{(+)}$, where π_j is a Bernoulli distribution with $P(\pi_j = 1) = p_j$ and $P(\pi_j = 0) = 1 - p_j$, $X_j^{(-)} \left| \mathcal{F}_{\tau_j -} \sim N\left(\mu_j^{(-)}, \left(\sigma_j^{(-)}\right)^2\right)\right.$ and $X_j^{(+)} \left| \mathcal{F}_{\tau_j -} \sim N\left(\mu_j^{(+)}, \left(\sigma_j^{(+)}\right)^2\right)\right.$.

This parsimonious modeling stucture introduces event risk, which is captured by the anticipated upside and downside jumps, in the continuous-time stochastic volatility model. It implies that on EAD, the stock price will exhibit either a "negative" jump $X_j^{(-)}$ with probability p_j or a "positive" one $X_j^{(+)}$ with probability $1-p_j$. Since EADs are predictably timed, the martingale restriction (see Piazzesi (2000)) requires that $E\left[S_{\tau_j} \left| \mathcal{F}_{\tau_j -}\right.\right] = S_{\tau_j -}$, imposing the following restriction upon the parameters of the Z_j distribution: $p_j \exp\left(\mu_j^{(-)} + 0.5\left(\sigma_j^{(-)}\right)^2\right) + (1-p_j)\exp\left(\mu_j^{(+)} + 0.5\left(\sigma_j^{(+)}\right)^2\right) = 1$.

According to our model, under the risk-neutral measure $\mathbb{Q}$, the stock price and variance processes solve the following stochastic differential equations:

$$\begin{aligned} dS_t &= (r - \lambda_J \overline{\mu}_J) S_t dt + \sqrt{V_t} S_t dW_t^S + d\left(\sum_{j=1}^{N_t^d} S_{\tau_j -}\left(e^{Z_j} - 1\right)\right) + d\left(\sum_{j=1}^{N_t} S_{\overline{\tau}_j -}\left(e^{\overline{Z}_j} - 1\right)\right) \\ dV_t &= \kappa_v\left(\theta_v - V_t\right) dt + \sigma_v \sqrt{V_t} dW_t^v, \end{aligned} \tag{4}$$

where r is the risk-free rate and W_t^S, W_t^v are two standard Brownian motions with correlation ρdt. Price jumps may also occur at random times $\overline{\tau}_j$ according to a Poisson process N_t with intensity parameter λ_J and jump size $\overline{Z}_j$ that is normally distributed, i.e., $\overline{Z}_j \left| \mathcal{F}_{\overline{\tau}_j -} \sim N\left(\mu_J, \sigma_J^2\right)\right.$; $\overline{\mu}_J$ denotes the random jump compensator given by $\overline{\mu}_J = \exp\left(\mu_J + \frac{1}{2}\sigma_J^2\right) - 1$. Finally, θ_v is the long-run mean of variance, κ_v determines the mean-reversion rate and σ_v is the volatility-of-volatility parameter.

Note that if $p_j = 1$, the model collapses to the one of DJKS (2019). However, in this case, the martingale restriction on Z_j implies that $\mu_j^{(-)} = -0.5\left(\sigma_j^{(-)}\right)^2$, and hence only a negative-mean jump can occur on EAD. Thus, our model is more general, allowing us to capture the impact of both upside and downside anticipated jumps on the stock price process. In the absence of EADs prior to time t (i.e., $N_t^d = 0$), the model collapses to the one of Bates (1996).

The model specified in equation (4) generates a conditional probability density function (pdf) for the log-return of the underlying stock that is a mixture of three constituent pdfs. The first one is derived by the diffusion and random jumps component of the model. The second and third pdfs are those of the two normally distributed upside and downside jumps that are anticipated to occur on EAD. The mixture of these three pdfs can generate a plethora of different distributions. These include asymmetric distributions, distributions with fat tails and most importantly for our analysis, multi-modal distributions. To this end, this parametric model is sufficiently flexible to reproduce RNDs that prior studies have empirically recovered from option prices by fitting mixtures of log-normal distributions or smoothing splines in the IV space (see, for example, Birru and Figlewski (2012), Hanke, Poulson, and Weissensteiner (2018), Leahy and Thomas (1996), Melick and Thomas (1997), and Mirkov, Pozdeev, and Söderlind (2016)).

The proposed model captures the increase in IV in the run up to the earnings announcement and its sharp fall right after (Patell and Wolfson, 1979, 1981). In addition, similar to DJKS (2019), the model can generate a downward sloping IV term structure prior to scheduled announcements due to the anticipated price jump. Different from the prior literature, however, the model can also generate concave IV curves and bimodal RNDs, revealing the pricing of event risk. Hence, it disentangles the effect of a scheduled event on the overall level of IV from the corresponding effects across different levels of moneyness. As a result, the model can provide estimates of the probability, direction, expected magnitude and dispersion of price jumps that are anticipated to occur. This rich set of information can help us infer investor expectations regarding the impending event as well as the pricing of the arising event risk.

In our model, the stock price is defined by the product of an affine component and a discrete jump on EADs. Therefore, option pricing proceeds in a similar fashion to standard affine models, using the closed-form solution of the conditional characteristic function of the log stock price (see, Duffie, Pan, and Singleton (2000) and Bates (1996)). The characteristic function is presented in Appendix B.

Full-scale estimation of the proposed model is not the main goal of our paper. Nevertheless, to showcase the ability of the model to generate concave IV curves and bimodal RNDs prior to EADs, we consider the example of Apple on October 28, 2013. Recall that in this case, a single EAD occurs prior to option expiry. The corresponding empirical IV curve derived from fitting a quintic spline to the actual IVs is illustrated in Panel A of Figure 2.

Here, we fit our model to the actual option prices by minimizing the root mean squared error (RMSE) between the actual and the model-implied IVs. The parameter values that minimize the RMSE are: $\theta_v = 0.42$, $\kappa_v = 2.44$, $\sigma_v = 4.74$, $\rho = -0.01$, $\lambda_J = 14.5$, $\mu_J = -0.007$, $\sigma_J = 0.078$, $p_j = 0.444$, $\mu_j^{(-)} = -0.056$, $\sigma_j^{(-)} = 0.006$, $\mu_j^{(+)} = 0.043$, $\sigma_j^{(+)} = 0.007$. Apart from pronounced stochastic volatility and a random price jump whose size has a small mean but is rather disperse, these parameter values indicate that investors anticipate with risk-neutral probability 44.4% (55.6%), a downside (upside) price jump on EAD with mean size -5.6% (4.3%) and low volatility.

Figure 6 shows that these parameter values generate a W-shape IV curve that fits extremely well the actual IVs. We repeat the same process fitting the DJKS (2019) model to the actual option prices. As illustrated in Figure 6, the latter model yields a poor fit because it cannot generate concavity in the IV curve.

Figure 7 presents the RND for Apple's log stock return on October 28, 2013. This RND is derived from call option prices implied by our model for the parameter values estimated above. It is evident that our model gives rise to a bimodal RND, which is very similar to the empirical RND corresponding to the fitted IV curve presented in Panel A of Figure 2.

5 Implications of Concave IV Curves

5.1 Absolute Stock Returns on EAD

We now turn our focus on the informational content of `CONCAVE`. We first examine whether concave IV curves can predict higher or lower absolute stock returns on EAD relative to non-concave IV curves. To ensure that our results are not affected by market-wide price movements or systematic factor-related returns, we use the absolute abnormal stock return on EAD (`ABSEADABRET`) with respect to the Fama-French-Carhart (FFC) 4-factor model.

Specifically, we compute the abnormal stock return on EAD as the realized minus the expected return. The expected return is calculated on the basis of pre-estimated factor loadings for each firm. For this estimation, we use daily returns from $d-250$ to $d-25$, where d is the EAD, requiring at least 200 observations. This choice ensures that the estimated factor loadings are not affected by stock returns observed in the runup to the EAD.

The summary statistics reported in Table 1 show that the average `ABSEADABRET` is 4.86%, whereas the median is 3.41%. These statistics are consistent with the finding in prior literature that stock prices often exhibit very large movements around earnings announcements (see Kapadia and Zekhnini (2019), Lee (2012), and Lee and Mykland (2008)). This feature becomes even more striking if one takes into account that our sample consists of very big capitalization firms. Table 3 shows that the average ABSEADABRET is 5.88% when CONCAVE=1 and 4.24% when CONCAVE=0. The differential return of 1.64% is strongly significant (t-statistic = 7.71). As a result, we argue that concave IV curves can signal higher than average absolute stock returns on EADs.

To examine this predictive relationship more formally, Table 5 presents estimates from panel regressions of ABSEADABRET on CONCAVE plus a number of firm characteristics measured on the day prior to the EAD.[10] Columns (1) to (4) report t-statistics based on two-way clustered standard errors, at the firm- and quarter-level, whereas column (5) includes quarterly fixed effects to ensure that our results are not purely driven by specific quarters in our sample period.

Column (1) shows that, on average, concave IV curves are followed by a 1.65% (t-statistic = 5.45) higher absolute abnormal stock return on EAD relative to non-concave IV curves. This differential return remains significant when we additionally control in columns (2) to (4) for a number of firm characteristics that may be related to future stock returns and quarterly fixed effects in column (5).[11] Overall, the results in Table 5 show that concave IV curves observed prior to EADs predict significantly higher ABSEADABRET values.

One interpretation of this predictive relationship is that investors are able to ex-ante identify earnings announcements where larger than average stock price movements are observed, and they trade accordingly in the option market. On these occasions, IV curves become concave and the corresponding RNDs for the underlying stock price become clearly bimodal, indicating that a very large stock price movement is likely to be observed on EAD. Thus, the occurrence of larger than average absolute stock returns upon these announcements verifies the informational content of CONCAVE.

5.2 Post-EAD Stock Return Volatility

Next, we examine the informational content of CONCAVE with respect to the post-EAD stock return volatility (POSTEADVOL). We compute the (annualized) 10-day stock return volatility

[10] After March 5, 2008, OptionMetrics records bid and ask option prices at 15:59 EST. This ensures that the criticism of Battalio and Schulz (2006) on non-synchronicity bias does not apply during our sample period.

[11] Unreported results, which are available upon request, yield very similar conclusions when we alternatively use gross, rather than abnormal, absolute stock returns on EAD.

from d to $d+9$, according to the standard formula:

$$\texttt{POSTEADVOL} = \sqrt{\frac{252}{10}\sum_{t=d}^{d+9} r_t^2}, \tag{5}$$

where r_t is the daily log-return.

Note that while POSTEADVOL is naturally affected by the magnitude of ABSEADABRET, nevertheless the former is conceptually different from the latter because POSTEADVOL also captures the stock price fluctuations occurring after the EAD. We opt for a 10-day measurement window in our benchmark results to be consistent with the range of expirations observed in our option sample.[12]

The mean (median) POSTEADVOL reported in Table 1 is 41.09% (33.39%). Even though we mainly include large capitalization stocks in our sample, we still find that their returns exhibit a high degree of volatility in the 10-day interval right after the earnings announcement. More notably, Table 3 shows that the average POSTEADVOL following concave IV curves is 47.49%, whereas the corresponding average value following non-concave IV curves is 37.11%, with their difference being highly significant (t-statistic = 8.82). Hence, concave IV curves also signal much higher post-announcement stock volatility.

Table 6 presents estimates from panel regressions of POSTEADVOL on CONCAVE plus a number of firm characteristics measured on the day prior to the EAD. We confirm that CONCAVE possesses significant predictive ability over POSTEADVOL. Column (1) indicates that concave IV curves are followed by an average POSTEADVOL of 47.50%, whereas non-concave IV curves are followed by an average POSTEADVOL of 37.07%, yielding a highly significant differential of 10.43% (t-statistic = 5.30). This predictive relationship remains significant when we additionally control in columns (2) to (4) for a number of firm characteristics that may also be related to stock volatility. Column (5) also confirms that this differential is not purely driven by volatility episodes in certain quarters.

In sum, the reported predictive ability of CONCAVE indicates that investors can identify the announcements that cause a significant increase in post-EAD volatility. As a consequence, they trade in the option market to hedge against this feature, determining prices that correspond to a bimodal RND for the underlying stock return. In turn, an RND that features bimodality in its central part implies, ceteris paribus, a higher degree of stock volatility over the remaining life of the option. Observing higher than average POSTEADVOL for concave IV curves verifies the informational content of CONCAVE.

[12] We repeat the subsequent analysis using alternatively the 5-day and the 21-day post-EAD stock return volatility. The results are very similar to the ones presented in Table 6.

5.3 Straddle Returns Around EADs

Having established that concave IV curves are typically associated with significantly higher absolute stock returns on EADs and post-EAD realized volatility, as compared to non-concave IV curves, we further examine the behavior of straddle returns around EADs. Anticipating these stock return characteristics, investors could take long positions in ATM straddles to either speculate on or hedge against these large price swings regardless of their direction. Delta-neutral ATM straddle returns have been used to measure the price of volatility risk for the underlying stock returns (see, for example, Coval and Shumway (2001)).

We compute the returns of delta-neutral ATM straddles (`STRADDLE`) on EAD. Similar to prior literature, we use the nearest-to-the-money pair of call and put options within the moneyness (K/S) range of 0.98–1.02. We buy the straddle at the close of the trading day prior to the EAD and we sell it at the close after the announcement. We use the shortest available options, with expiry between 4 and 13 days. The return of the delta-neutral straddle on EAD is given by:

$$\texttt{STRADDLE} = wR_c + (1-w)R_p, \tag{6}$$

where R_c (R_p) is the return of the call (put) option on EAD. The weight w is given by:

$$w = -\frac{\Delta_P/P}{\Delta_C/C - \Delta_P/P}, \tag{7}$$

where Δ_C (Δ_P) is the delta of the call (put) provided by OptionMetrics and C (P) is the corresponding call (put) price at straddle formation. This weight ensures that the straddle is delta-neutral at formation.

The summary statistics reported in Table 1 show that the median `STRADDLE` on EAD is −15.43%. This finding provides support for the argument that investors most often pay a substantial price to be hedged against the increased volatility and large stock price swings observed around EADs. Moreover, `STRADDLE` exhibits a positively skewed distribution in our sample and its average is −0.86%. Interestingly, Table 3 shows that the average `STRADDLE` return is −3.74% when `CONCAVE`=1 and 0.91% when `CONCAVE`=0, with a significant differential return of −4.65%. This evidence suggests that investors pay a significant premium to hedge against the volatility risk that arises due to earnings announcements only when IV curves become concave.

Table 7 presents estimates from predictive panel regressions of `STRADDLE` on `CONCAVE` as well as a number of firm characteristics measured on the day prior to the EAD.[13] Here,

[13]We have repeated the analysis reported in Table 7 using simple instead of delta-neutral ATM straddle returns. The results, which are readily available upon request, are very similar to the ones reported in

we also control for the expiry and the average moneyness of the pair of options used to construct this straddle strategy, ensuring that our results are not driven by these features. Column (1) shows that concave IV curves are followed by a 4.57% (t-statistic $= -2.4$) lower average straddle return, as compared to non-concave IV curves. This predictive relationship becomes even stronger when we additionally control in columns (2) to (4) for a number of firm characteristics. Column (5) confirms that the significance of this finding is not driven by specific quarters in our sample period. Overall, we find that concave IV curves predict a significantly lower straddle return on EAD.

The main conclusion from this analysis is that when IV curves become concave, investors pay a substantial premium to hedge against the larger than average stock price swings that are typically observed on these EADs. In fact, even though larger than average stock price movements do occur on EADs following the formation of concave IV curves (as shown in Table 5), these price swings are not large enough to offset the substantial cost of purchasing straddles on these occasions. As a corollary, whereas it is known to be typically profitable to write straddles at the firm level (see Gao, Xing, and Zhang (2018) and DJKS (2019)), we document that it is more profitable to do so when concave IV curves are observed prior to EADs.

To provide direct evidence that ATM straddles are particularly costly in the presence of concave IV curves, we introduce an intuitive measure of their expensiveness. Specifically, we calculate the following ratio:

$$\texttt{IMPMOVE} = \frac{C + P}{S}, \tag{8}$$

where, as above, C (P) is the ATM call (put) price at straddle formation, i.e., on the day prior to EAD, and S is the corresponding price of the underlying stock. This measure roughly indicates how much the underlying stock price should move in either direction to offset the cost of a symmetric ATM straddle, and hence it is termed as the implied stock price move (IMPMOVE). Higher (lower) IMPMOVE is, more (less) expensive it is to purchase an ATM straddle, ceteris paribus.

To construct this measure, we use the same pair of nearest-to-the-money call and put options that we used above to construct the delta-neutral straddle. The summary statistics reported in Table 1 indicate an average (median) IMPMOVE of 6.53% (5.55%). Taking into account that we utilize very short-expiry options, these statistics indicate that straddles are quite expensive prior to EADs, as they require a substantial stock price move in either direction to offset their cost. Table 3 shows that the average IMPMOVE is 7.89% when CONCAVE=1 and 5.69% when CONCAVE=0, yielding a highly significant differential. This finding sup-

Table 7.

ports the argument that straddles are significantly more costly in the presence of concave IV curves.

Table 8 presents estimates from contemporaneous panel regressions of `IMPMOVE` on `CONCAVE` and a number of firm characteristics measured on the day prior to EAD.[14] Column (1) indicates that, on average, concave IV curves are associated with a 2.21% (t-statistic = 7.61) higher `IMPMOVE` relative to non-concave IV curves. This significant differential is not subsumed when we control for additional firm characteristics and quarterly fixed effects in columns (2) to (5). Overall, we find strong evidence that straddles are much more expensive in the presence of concave IV curves.

These findings show that in the presence of concave IV curves, the underlying stock price should exhibit a substantially larger move after the announcement to offset the cost of purchasing the straddle. This evidence rationalizes why despite the larger than average absolute stock returns realized on EADs following the formation of concave IV curves, the corresponding straddle returns are still negative and much lower relative to those following non-concave IV curves. The straddles following concave IV curves are substantially more expensive to purchase in the first place, and hence the realized price jumps on EADs are not sufficient to offset their cost.

The significantly higher cost of buying straddles in the presence of concave IV curves provides an alternative way to illustrate that investors pay a significantly higher price to hedge against the event risk that arises on these occasions due to the impending announcement. This corroborates the argument that concave IV curves provide an ex-ante signal of event risk. Based on these findings, we conclude that investors can ex-ante identify the announcements that trigger large stock price moves and they pay a substantially higher premium to hedge against them, most obviously by purchasing straddles. As a result of this hedging activity, the corresponding ATM options become very expensive, trading at higher volatility, and hence the corresponding IV curves turn concave prior to EADs.

5.4 Gamma or Vega Risk?

Delta-neutral straddle returns have been often used to capture the price of volatility risk. However, this interpretation holds true only in the case of small diffusive shocks. In the presence of jumps, delta-neutral straddles expose investors to both stochastic volatility (vega) and jump (gamma) risk and they cannot distinguish between these two sources of risk (see Cremers, Halling, and Weinbaum (2015)). This is particularly important around EADs as

[14] In unreported results, we have additionally controlled for the expiry and the average moneyness of the pair of options used to compute `IMPMOVE`; the results are very similar to the ones presented in Table 8.

stock prices often jump upon the announcement.

We disentangle these two effects in this section by examining whether gamma or vega risk is priced around earnings announcements and to which source of risk concave IV curves are related to. We follow two complementary approaches. First, similar to Dew-Becker, Giglio, and Kelly (2021), we construct strangles and compute their returns around EADs. Strangles yield positive payoffs only when the underlying price exhibits a sufficiently large move. Hence, strangle returns can provide direct evidence on the price of gamma risk around EADs. Second, following Cremers, Halling, and Weinbaum (2015), we compute the EAD returns of delta- and vega-neutral ATM straddles, which expose investors to gamma risk only, as well as the corresponding returns of delta- and gamma-neutral ATM straddles, which expose investors to vega risk only. Since these calendar straddle strategies can isolate each dimension of risk, their returns can be directly attributed to gamma and vega risk exposure, respectively.

5.4.1 Strangle Returns

Different from straddles, a strangle is a portfolio of long positions in an OTM call and an OTM put. Therefore, its payoff is typically negative unless a sufficiently large movement in the price of the underlying asset occurs. We form delta-neutral strangles at the end of the trading day prior to EAD and unwind the position at the close of EAD. As with straddles, we use the shortest available options, with expiry between 4 and 13 days. Similar to Dew-Becker, Giglio, and Kelly (2021), we use strikes that are nearest to one standard deviation (scaled by time to expiry) away from the underlying stock price at formation.[15] We require that the absolute difference between the available (i.e., traded) and the desired moneyness (K/S) for the OTM options does not exceed 0.01, but we typically have a very close match. The `STRANGLE` return on EAD is computed in a similar fashion to equation (6), with the relevant weights assigned to OTM options ensuring that the strangle is delta-neutral at formation.

Table 1 reports that the median `STRANGLE` return on EAD is -28.78%. This is almost twice as large as the median `STRADDLE` return and indicates that investors most often pay a substantial premium to hedge against the gamma risk that arises due to earnings announcements. As expected, `STRANGLE` exhibits a positively skewed distribution and its average is -2.32%, revealing a negative price for gamma risk around EADs. More interestingly, Table 3 shows that the average `STRANGLE` return is -7.94% when `CONCAVE`=1 and 1.12% when `CONCAVE`=0, with differential return of -9.05% (t-statistic = -2.45). Hence, investors pay

[15] We use the 30-day realized volatility that is available at $d-1$ from the Historical Volatility File of OptionMetrics.

a substantial premium to hedge against gamma risk only when IV curves become concave prior to the EAD. In fact, the cost of purchasing a strangle in the presence of a concave IV curve is so high, on average, that it cannot be offset by the large stock returns that are often observed on EADs.

Table 9 confirms this finding in a panel regression setup. Here, we also control for the expiry of the options used to construct the strangle and the absolute difference in the moneyness levels between the available and the desired strikes, to ensure that the reported return differential is not driven by these features. Column (1) shows that concave IV curves are followed by a 8.84% (t-statistic $= -2.41$) lower average strangle return relative to non-concave IV curves. Columns (2) to (4) show that this differential becomes even larger as we control for other firm characteristics, whereas column (5) shows that it remains intact in the presence of quarterly fixed effects. In sum, we find strong evidence that in the presence of concave IV curves, investors pay a substantial premium to hedge against the large stock price moves observed on EADs. This finding corroborates the argument that concavity in the IV curve is an ex-ante signal for event risk.

5.4.2 Delta- and Vega-Neutral Straddle Returns

An alternative way to isolate the effects of vega and gamma risk is to examine calendar straddles that combine a short- and a longer-maturity delta-neutral ATM straddle. First, we construct a delta- and vega-neutral ATM straddle (`JUMPSTRADDLE`), which exposes investors to gamma risk only. We form this strategy at $d-1$ and unwind it at d. The strategy consists of two legs. The first leg is a long position in a delta-neutral straddle constructed from the nearest-to-the-money options with the shortest available expiry between 4 and 13 days. The second leg is a short position in $\mathcal{V}_S/\mathcal{V}_L$ delta-neutral straddles using the nearest-to-the-money options with the longest available expiry between 100 and 180 days, where $\mathcal{V}_S$ ($\mathcal{V}_L$) denotes the vega of the shorter- (longer-) maturity straddle.[16] This position ensures that this calendar strategy is vega-neutral at formation. The `JUMPSTRADDLE` return on EAD is given by:

$$\texttt{JUMPSTRADDLE} = wR_S + (1-w)R_L, \tag{9}$$

where R_S (R_L) is the return of the shorter- (longer-) maturity delta-neutral straddle on EAD and $w = -\mathcal{V}_L/V_L/(\mathcal{V}_S/V_S - \mathcal{V}_L/V_L)$, with V_S (V_L) denoting the value (i.e., cost) of the shorter- (longer-) maturity straddle at formation.

Table 1 shows that the average `JUMPSTRADDLE` return on EAD is -2.82%, indicating

[16] We require the moneyness of the utilized calls and puts to lie within the range 0.98-1.02 for the short-maturity straddle and 0.96-1.04 for the longer-maturity straddle, but it is typically very close to 1.

again a negative price for gamma risk. The median return of this strategy is highly negative (-39.74%), revealing that investors typically pay a substantial premium to hedge against the gamma risk that arises due to earnings announcements. Table 3 further shows that this negative premium accrues from observations with a concave IV curve. The average `JUMPSTRADDLE` return is -10.69% when `CONCAVE`=1 and 2.29% when `CONCAVE`=0, yielding a significant differential return of -12.98% (t-statistic = -2.12). This finding supports the argument that investors pay a substantial premium to hedge against gamma risk only in the presence of concave IV curves.

Table 10 presents estimates from predictive panel regressions of `JUMPSTRADDLE` on `CONCAVE` and a number of firm characteristics. These regressions also control for the expiry and the average moneyness of each pair of options used to construct this calendar strategy, ensuring that the reported differential return is not driven by these features. Column (1) shows that `CONCAVE` possesses significant predictive ability over `JUMPSTRADDLE` returns. Specifically, concave IV curves are followed by a 12.71% lower average `JUMPSTRADDLE` return on EADs, as compared to non-concave IV curves. This significant differential return is not subsumed when we control for additional firm characteristics in columns (2) to (4) and quarterly fixed effects in column (5). In sum, concave IV curves signal the substantial premium investors are willing to pay to hedge against the gamma risk that arises due to earnings announcements.

5.4.3 Delta- and Gamma-Neutral Straddle Returns

To reinforce the argument that the informational content of concave IV curves is related to gamma rather than vega risk, we also constuct delta- and gamma-neutral ATM straddles (`VOLSTRADDLE`) in a similar fashion. The first leg of this strategy is a long position in a delta-neutral ATM straddle constructed from options with the longest available expiry between 100 and 180 days. The second leg is a short position in Γ_L/Γ_S delta-neutral ATM straddles constructed from options with the shortest available expiry between 4 and 13 days, where Γ_S (Γ_L) denotes the gamma of the shorter- (longer-) maturity straddle. This position ensures that this calendar strategy is gamma-neutral at formation. The `VOLSTRADDLE` return on EAD is given by:

$$\texttt{VOLSTRADDLE} = (1-w)R_S + wR_L, \tag{10}$$

where R_S (R_L) is the return of the shorter- (longer-) maturity delta-neutral straddle on EAD and $w = -\Gamma_S/V_S/(\Gamma_L/V_L - \Gamma_S/V_S)$, with V_S (V_L) denoting the value of the shortrt- (longer-) maturity straddle at formation.

The average (median) `VOLSTRADDLE` return reported in Table 1 is 1.17% (0.81%). Distinguishing between concave and non-concave IV curves, Table 3 shows that the average

VOLSTRADDLE return remains positive in both cases and the differential is insignificant. Hence, we conclude that investors do not pay a premium to hedge against the vega risk that may arise due to earnings announcements.

Table 11 confirms this finding in a panel regression setup, controlling also for the expiry and the average moneyness of each pair of options used to construct this calendar strategy. Column (1) shows that concave IV curves are actually followed by a marginally higher, not lower, average VOLSTRADDLE return relative to non-concave IV curves, but this differential is insignificant. We get similar results when we control for other firm characteristics in Columns (2) to (4) and quarterly fixed effects in Column (5). Overall, we conclude that vega risk is not significantly priced on EADs and that the observed concavity in IV curves is not related to this dimension of risk.

Summarizing the results of this subsection, we conclude that the negative STRADDLE returns that are typically observed on EADs reflect the premium investors pay to hedge against gamma, not vega, risk. Moreover, this evidence shows that gamma risk is significantly priced only in the presence of concave IV curves, confirming that this feature is a valid signal for the event risk arising due to the impending earnings announcement.

6 Conclusions

We documents that the IV curves of equity options frequently exhibit concavity prior to the EAD. This shape is in stark contrast with the convex volatility smiles or smirks that are commonly observed for equity options. Concavity is most obvious in short-expiry options, it reflects a bimodal RND for the underlying stock price, and quickly disappears after the announcement, as the uncertainty surrounding this event is resolved.

We report evidence that firms with concave IV curves exhibit higher absolute abnormal stock returns on EAD and higher realized volatility after the announcement. Despite the larger than average stock price moves on EAD following the formation of concave IV curves, we still find that the corresponding delta-neutral straddle returns are significantly lower than those for non-concave IV curves. To rationalize this finding, we show that ATM straddles are significantly more expensive in the presence of concave IV curves, and hence the realized stock price jumps are not sufficient to offset the substantial cost of these straddles. We further show that concave IV curves are followed by large negative strangle and delta- and vega-neutral straddle returns on EADs, revealing that investors seek to hedge the gamma, rather than vega risk that arises due to this corporate event.

Overall, we show that investors can ex-ante identify the announcements that trigger larger than average stock price moves and they pay a substantial premium to hedge against this event risk. This hedging activity impacts on option prices, leading to the formation of a concave IV curve. We conclude that concavity in the IV curve constitutes an ex-ante option-implied signal for event risk in the underlying stock arising due to the impending announcement.

The focus of our study is on scheduled corporate earnings announcements. However, it would be interesting to examine the features and the informational content of IV curves around other non-corporate events that may also trigger large asset price moves. Prior studies have argued that macroeconomic announcements and geopolitical events can give rise to substantial risk, which can be ex-ante reflected in option prices (see Savor and Wilson (2013), Leahy and Thomas (1996), Melick and Thomas (1997), Kelly, Pástor, and Veronesi (2016), and Hanke, Poulsen, and Weissensteiner (2018)). We anticipate that the curvature properties of the IV curve around these events can reveal substantial information with respect to the pricing of event risk and the subsequent behavior of asset prices. We leave the explorations of these effects to future research.

Appendix A: Definition of Variables

ANNBETA: Following Barth and So (2014), announcement beta is the estimate of coefficient β_3 from the following firm-level regression model:

$$xr_{i,t} = \alpha_i + \beta_{1,i} MKT_t + \beta_{2,i} AnnDay_{i,t} + \beta_{3,i}(MKT_t \times AnnDay_{i,t}) + \varepsilon_{i,t}, \qquad \text{(A1)}$$

where $xr_{i,t}$ is the excess daily return of stock i on day t, MKT denotes the excess market return, and $AnnDay_{i,t}$ is a dummy variable that takes the value 1 on trading days $(d-1, d, d+1)$, where d is the EAD, and 0 otherwise. We estimate this model using daily data during the past 12 quarters. We require at least 8 EADs and at least 451 observations.

ATMIV: The average of the annualized call implied volatility with $\Delta_{CALL} = 0.5$ and the annualized put implied volatility with $\Delta_{PUT} = -0.5$. Annualized implied volatilities are sourced from the 10-day Volatility Surface File of OptionMetrics.

B/M: The ratio of firm book value of equity (CEQ) to market capitalization. Market capitalization is defined as the product of share price (PRC) times the number of shares outstanding (SHROUT). We drop observations with negative book value. We use the B/M computed at the end of the previous fiscal quarter.

BETA: The market beta estimated from the FFC 4-factor regression model. We estimate this model at t using daily data from $t-250$ to $t-25$ and requiring at least 200 observations. MKT, SMB, HML, and WML returns are from Kenneth French's online data library.

DISP: The standard deviation of the earnings per share (EPS) forecasts for the next quarterly earnings announcement scaled by the absolute value of the mean EPS forecast. EPS forecasts are sourced from I/B/E/S.

Ln(PRICE): The natural logarithm of the share price (PRC).

Ln(SIZE): The natural logarithm of the firm's market capitalization (in million \$). Market capitalization is defined as the product of share price (PRC) times the number of shares outstanding (SHROUT). We use the market capitalization computed at the end of the previous fiscal quarter.

MOM: The cumulative stock return from day $t-250$ to day $t-25$. We require at least 200 daily observations.

NUMEST: The number of analysts providing EPS forecasts for the next quarterly earnings announcement sourced from I/B/E/S.

O/S: The ratio of daily option trading volume to daily stock trading volume. Option trading volume is multiplied by 100, as each option contract corresponds to a 100-share lot. We sum up the trading volume of all call and put options with the same expiry as the one used to define the indicator `CONCAVE`.

`RVIV`: The difference between the annualized realized (historical) volatility and `ATMIV`. Realized volatility is from the 10-day Historical Volatility File provided by OptionMetrics.

`RUNUP`: The cumulative stock return from day $t-4$ to day t. We require all 5 daily observations.

`RNK`: The Risk-Neutral Kurtosis computed as per the definition of Bakshi, Kapadia, and Madan (2003). We use prices of OTM and ATM options with the same expiry as the one used to define the indicator `CONCAVE`. We require at least 4 options, with at least 2 calls and 2 puts. Option prices are converted to implied volatilities and vice versa via the Black-Scholes formula. We use a cubic spline to interpolate implied volatilities between the lowest and the highest available strikes and perform a constant extrapolation outside this range, with lower bound $K/S = 1/3$ and upper bound $K/S = 3$.

`RNS`: The Risk-Neutral Skewness computed as per the definition of Bakshi, Kapadia, and Madan (2003). We use prices of OTM and ATM options with the same expiry as the one used to define the indicator `CONCAVE`. We require at least 4 options, with at least 2 calls and 2 puts. Option prices are converted to implied volatilities and vice versa via the Black-Scholes formula. We use a cubic spline to interpolate implied volatilities between the lowest and the highest available strikes and perform a constant extrapolation outside this range, with lower bound $K/S = 1/3$ and upper bound $K/S = 3$.

`STOCKTR`: The ratio of daily stock trading volume to shares outstanding.

`TSIV`: The term structure estimator of ATM implied volatility proposed by DJKS (2019) and defined as the square root of the following expression:

$$\left(\sigma^{Q}_{i,term}\right)^2 = \frac{\sigma^2_{t,T_1} - \sigma^2_{t,T_2}}{T_1^{-1} - T_2^{-1}}, \tag{A2}$$

where σ^2_{t,T_1} is the squared annualized ATM implied volatility corresponding to the nearest expiry T_1 and σ^2_{t,T_2} is the squared annualized ATM implied volatility corresponding to the second nearest expiry T_2. T_1 is the same as the maturity of the options used to define the indicator `CONCAVE`. We use the nearest-to-the-money option to compute the ATM implied volatility, with moneyness defined as the strike price divided by the forward price. `TSIV` is not defined when $\sigma^2_{t,T_1} < \sigma^2_{t,T_2}$.

Appendix B: Characteristic Function

Let $\varphi(u;t,T,S_t,V_t)$ with $u \in \mathbb{R}$ be the characteristic function of $\log S_T$ conditional on $\mathcal{F}_t$ under risk-neutral measure $\mathbb{Q}$. According to our model, the log stock price is the sum of two independent components. The first component is an affine process for which the characteristic function, denoted as $\varphi_{af}(u;t,T,S_t,V_t)$, is known in closed-form (see Bates (1996)) and it is given by:

$$\varphi_{af}(u;t,T,S_t,V_t) = \exp\left(iu \ln S_t + \alpha(u;t,T) + \beta(u;t,T)V_t\right), \tag{B1}$$

where

$$\alpha(u;t,T) = \left(r - \lambda_J \overline{\mu}_J\right)\tau iu + \frac{\kappa_v \theta_v}{\sigma_v^2}\left(q_1 \tau - 2\log\left(\frac{1-ge^{\Delta\tau}}{1-g}\right)\right) + \lambda_J \tau\left(\left(1+\overline{\mu}_J\right)^{iu} e^{\frac{\sigma_J^2}{2}iu(iu-1)} - 1\right), \tag{B2}$$

$$\beta(u;t,T) = \frac{q_1}{\sigma_v^2}\left(\frac{1-e^{\Delta\tau}}{1-ge^{\Delta\tau}}\right), \tag{B3}$$

with $\tau = T-t$, $\Delta = \sqrt{(\kappa_v - \rho\sigma_v iu)^2 - 2\sigma_v^2 iu(iu-1)}$, $q_1 = \kappa_v - \rho\sigma_v iu + \Delta$, $q_2 = \kappa_v - \rho\sigma_v iu - \Delta$ and $g = q_1/q_2$.

The second component is a discrete process with independent deterministic jumps at known times. Its characteristic function, also known in closed-form, is given by:

$$\varphi_{dis}(u;t,T) = \prod_{j=N_t^d+1}^{N_T^d} \varphi_j(u), \tag{B4}$$

where

$$\varphi_j(u) = p_j M_j^{(-)}(u) + (1-p_j) M_j^{(+)}(u), \tag{B5}$$

where $M_j^{(-)}(u) = \exp\left(iu\mu_j^{(-)} + \frac{(iu)^2}{2}\left(\sigma_j^{(-)}\right)^2\right)$ and $M_j^{(+)}(u) = \exp\left(iu\mu_j^{(+)} + \frac{(iu)^2}{2}\left(\sigma_j^{(+)}\right)^2\right)$.

As the two components are independent, $\varphi(u;t,T,S_t,V_t)$ is given by the product of the characteristic functions (B1) and (B4):

$$\varphi(u;t,T,S_t,V_t) = \varphi_{af}(u;t,T,S_t,V_t)\varphi_{dis}(u;t,T). \tag{B6}$$

Knowledge of the characteristic function of the log stock price in closed-form enables us to price options. In particular, the price at time t of a European call option with strike price K and expiry T, denoted as $C_t(K,T)$, is given by (see Heston and Nandi (2000)):

$$\begin{aligned} C_t(K,T) &= \frac{1}{2}S_t + \frac{e^{-r(t-t)}}{\pi}\int_0^\infty \mathrm{Re}\left[\frac{K^{-iu}\varphi(u-i;t,T,S_t,V_t)}{iu}\right]du \\ &\quad - Ke^{-r(T-t)}\left(\frac{1}{2} + \frac{1}{\pi}\int_0^\infty \mathrm{Re}\left[\frac{K^{-iu}\varphi(u;t,T,S_t,V_t)}{iu}\right]du\right). \end{aligned} \tag{B7}$$

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Figure 1: Types of concave IV curves

This figure shows different types of concave IV curves computed on the day prior to the EAD. Panel A presents an example of an inverse U-shape IV curve for Twitter, computed from options with 3 days to expiry on July 29, 2014. Panel B presents an example of an S-shape IV curve for Ebay, computed from options with 3 days to expiry on April 29, 2014. Panels C and D present examples of W-shape IV curves for Google and Netflix, respectively, computed from options with 4 days to expiry on April 23 and July 16, 2018, respectively. Circles indicate implied volatilities corresponding to actual traded strikes, whereas the curve is fitted using a quintic spline.

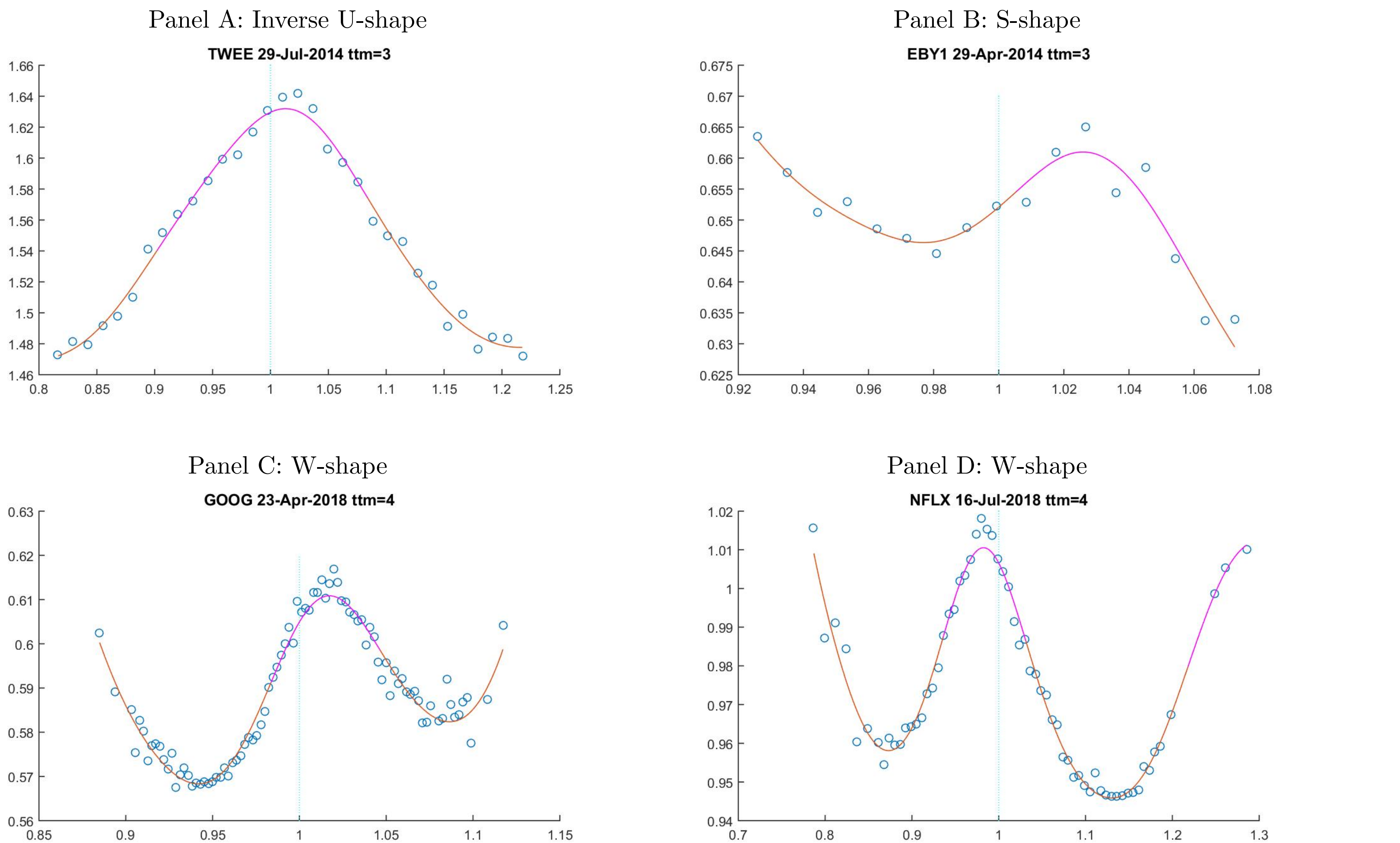
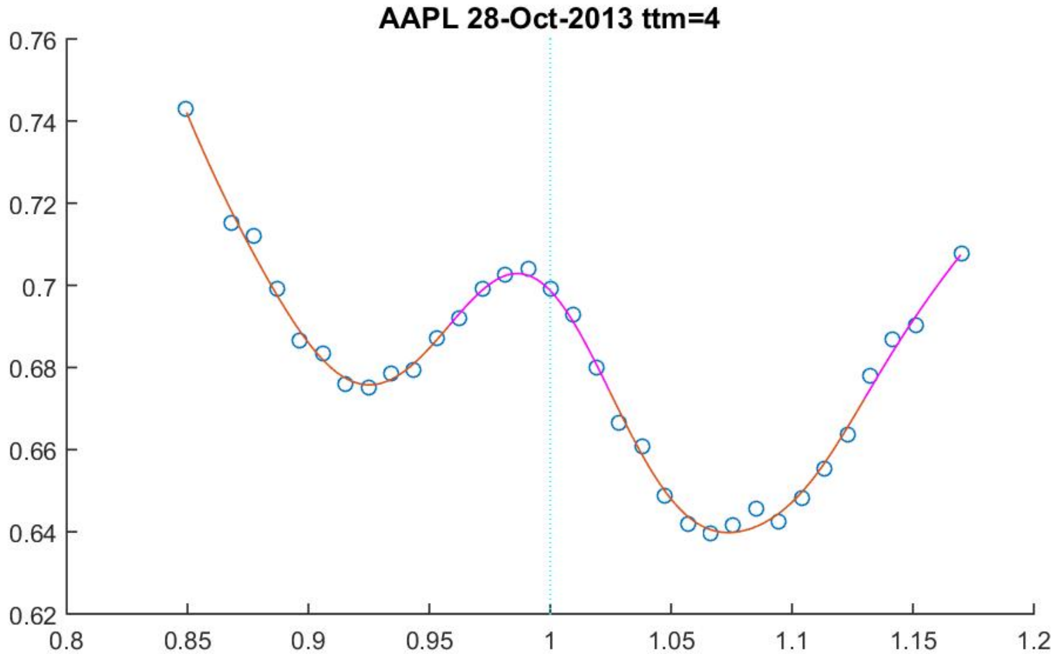


Figure 2: Concave IV curves around EAD

This figure illustrates how a concave IV curve prior to the EAD becomes convex after the announcement. Panel A presents a concave IV curve for Apple, computed from options with 4 days to expiry on October 28, 2013, i.e., prior to its quarterly earnings announcement. Panel B presents a convex IV curve for the same firm, computed from options with 3 days to expiry on October 29, 2013, i.e., right after the announcement.

Panel A: Prior to EAD



Panel B: After the announcement

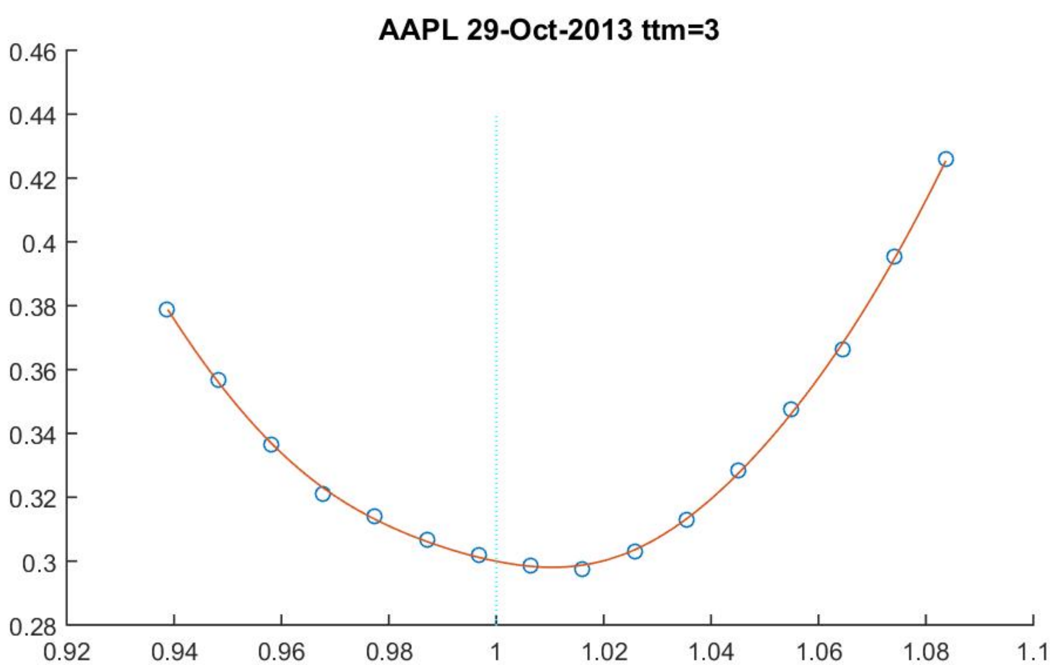


Figure 3: Fraction of concave IV curves around EAD

This figure shows the fraction of firms exhibiting a concave IV curve on each trading day from $d-5$ to $d+5$, where d is the quarterly EAD. The definition of a concave IV curve is provided in Section 2.2. IV curves are computed for the 100 firms with the highest option trading activity per year during the period 2013-2020.

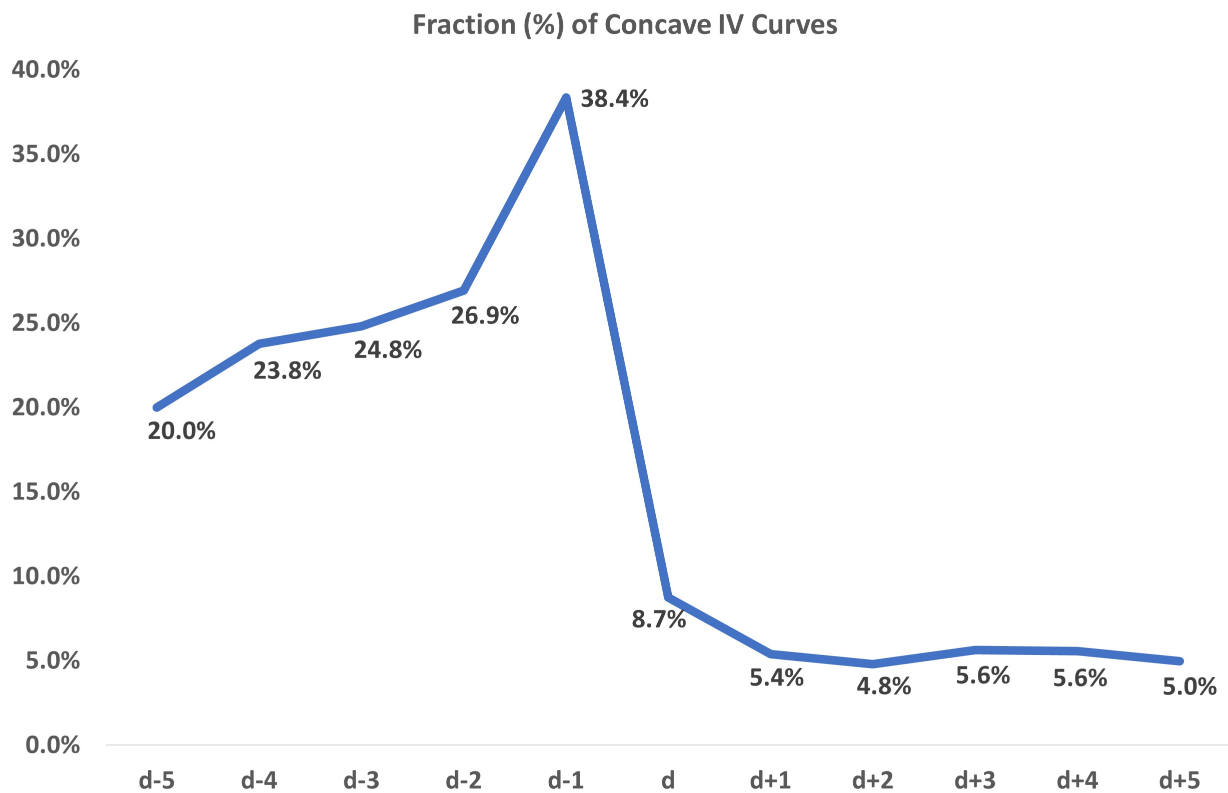
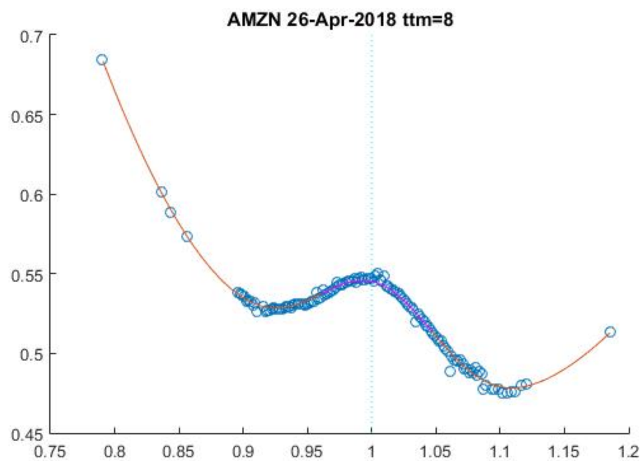


Figure 4: Concave IV curves and RND bimodality

This figure illustrates the correspondence between a concave IV curve and the RND for the underlying stock price. The left panel presents the IV curve for Amazon, computed from options with 8 days to expiry on April 26, 2018, i.e., just before its quarterly earnings announcement. Circles indicate implied volatilities corresponding to actual traded strikes, whereas the curve is fitted using a quintic spline. The right panel presents the corresponding RND for Amazon on the same day. The RND is computed for the range of available strikes using the non-parametric methodology of Figlewski (2010).



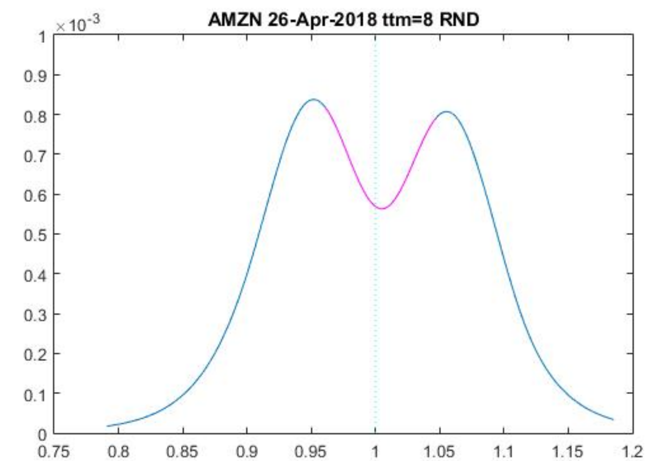


Figure 5: IV curves for short- vs. longer-expiry options

This figure shows the shape of IV curves for Amazon, computed from options with different expiries (8, 22, 36, and 50 days to expiry) on April 26, 2018, i.e., just before its quarterly earnings announcement. The IV curves are fitted using a quintic spline.

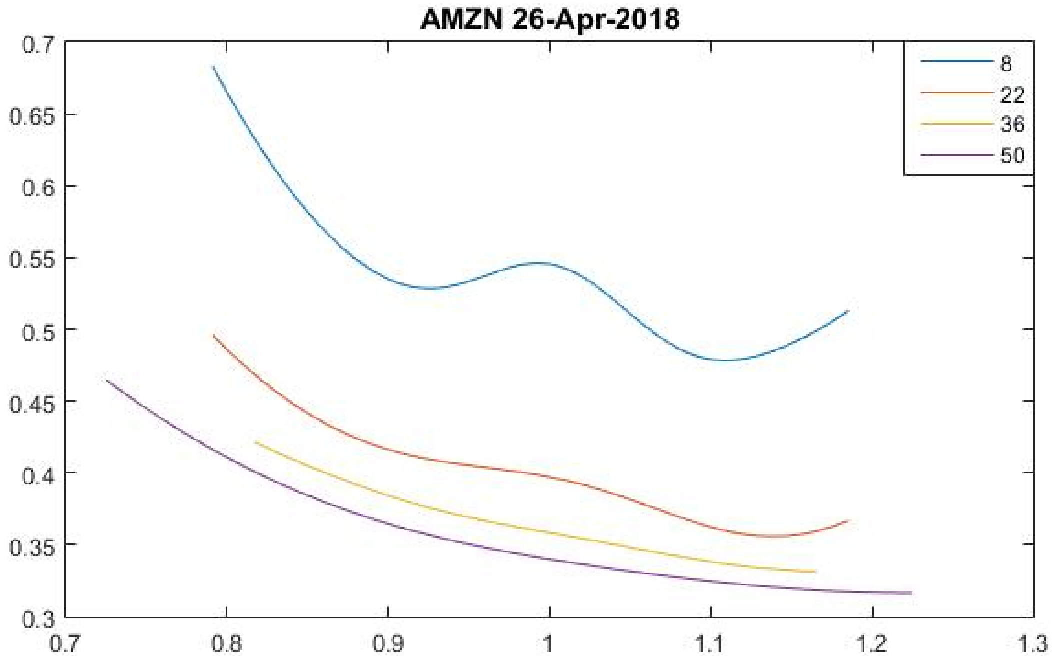


Figure 6: Model-implied IV curve

This figure shows the fit of the model-implied IV curve (solid curve) relative to the actual IVs (circles). Actual IVs are computed for Apple from options with 4 days to expiry on October 28, 2013, i.e., prior to its quarterly earnings announcement. The model-implied IV curve is computed using the corresponding estimated parameter values for the model specified in Section 4. Model parameter values are estimated by minimizing the RMSE between the actual and the model-implied IVs. The Figure also shows the corresponding IV curve (dashed curve) implied by fitting the DJKS (2019) model to the actual IVs.

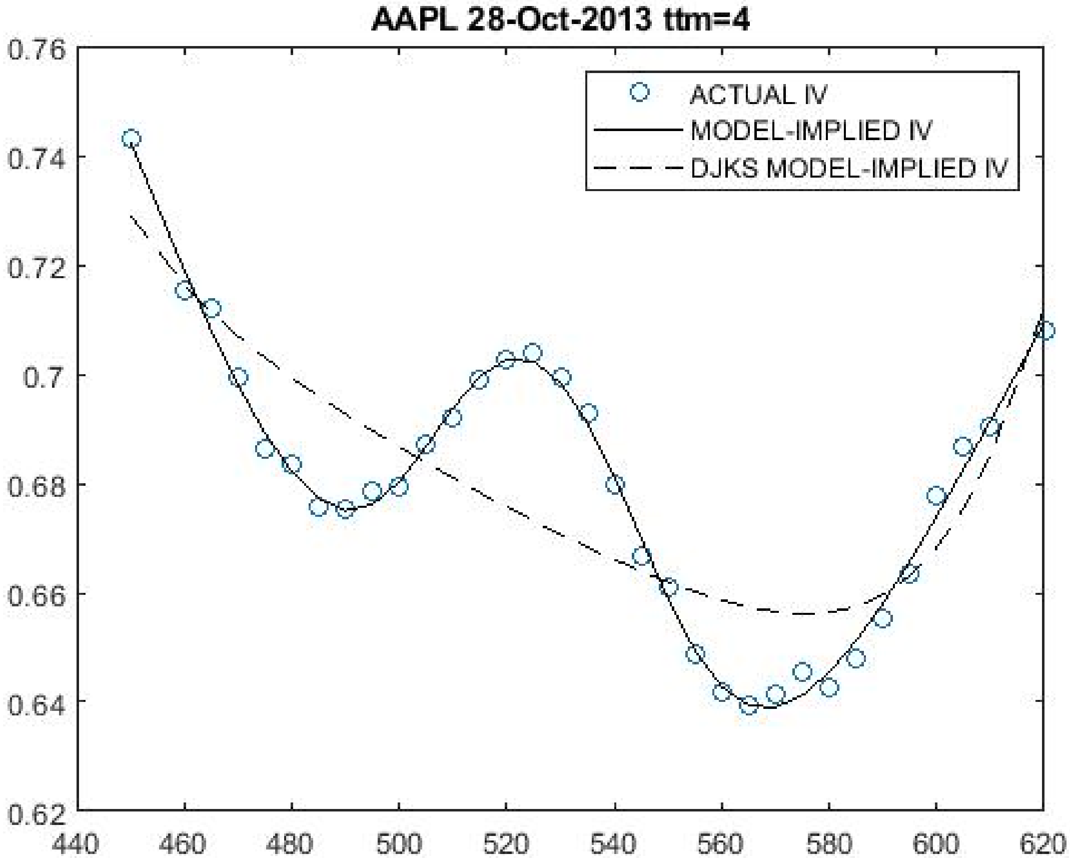


Figure 7: Model-implied RND

This figure shows the empirical RND (solid curve) together with the model-implied RND (dashed curve) for Apple's log stock return, derived from options with 4 days to expiry on October 28, 2013, i.e., prior to its quarterly earnings announcement. The empirical RND corresponds to the empirical IV curve, which is derived from fitting a quintic spline to the actual IVs. The model-implied RND is computed using the corresponding estimated parameter values for the model specified in Section 4. Model parameter values are estimated by minimizing the RMSE between the actual and the model-implied IVs.

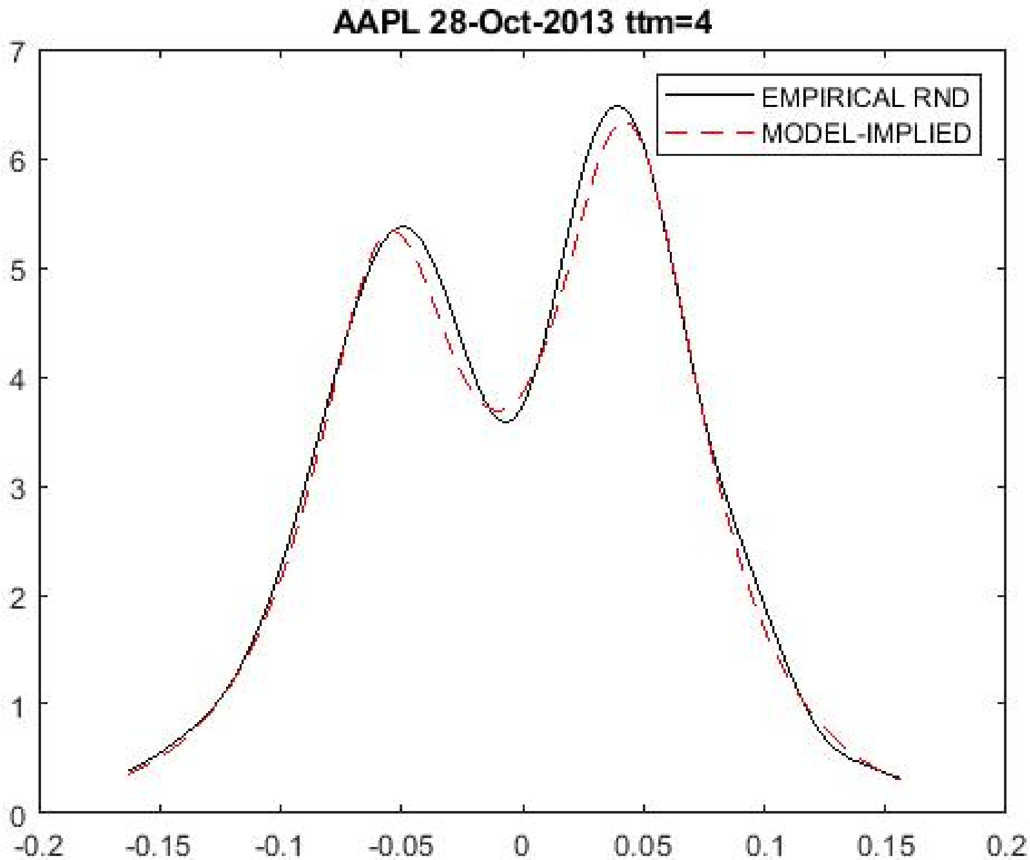


Table 1: Summary statistics

This table presents summary statistics for selected variables. CONCAVE is an indicator variable that takes the value one when the IV curve is concave on the day prior to the EAD and zero otherwise. ABSEADABRET is the absolute abnormal stock return on EAD, measured with respect to the 4-factor FFC model. POSTEADVOL is the 10-day post-EAD annualized realized stock return volatility. STRADDLE denotes the return of the delta-neutral ATM straddle strategy on EAD. IMPMOVE denotes the ratio of the sum of the ATM put and call prices divided by the underlying stock price. STRANGLE denotes the return of the delta-neutral strangle strategy on EAD. JUMPSTRADDLE denotes the return of the delta- and vega-neutral ATM straddle strategy on EAD. VOLSTRADDLE denotes the return of the delta- and gamma-neutral ATM straddle strategy on EAD. The definition of the rest of the variables is provided in Appendix A. These summary statistics are computed for a sample of quarterly earnings announcements during the period 2013-2020.

Variable	Mean	St. Dev.	25th pctl	Median	75th pctl	Obs.
CONCAVE	0.384	0.49	0	0	1	2,229
EXPIRY	6.46	2.60	4	8	9	2,229
STRIKES	17.88	12.85	9	14	22	2,229
BETA	1.09	0.31	0.89	1.09	1.27	2,188
Ln(SIZE)	10.96	1.33	10.07	11.13	12.00	2,220
B/M	0.35	0.33	0.12	0.25	0.46	2,085
RUNUP	0.68	4.36	−1.63	0.64	2.85	2,229
MOM	18.73	46.80	−6.89	12.00	32.29	2,188
Ln(PRICE)	4.35	0.92	3.75	4.22	4.83	2,229
ATMIV	45.04	22.41	29.24	37.74	55.33	2,177
RNS	−0.25	0.28	−0.42	−0.25	−0.09	2,229
RNK	3.63	0.65	3.24	3.46	3.81	2,229
RVIV	−16.62	15.03	23.61	14.72	7.39	2,177
TSIV	6.80	3.79	4.02	5.73	8.65	2,217
NUMEST	23.95	7.66	18	23	29	2,219
DISP	14.70	30.21	2.56	4.84	12.00	2,209
ANNBETA	0.10	0.78	−0.29	0.07	0.49	2,112
STOCKTR	2.40	3.20	0.66	1.16	2.74	2,229
O/S	28.43	32.75	6.13	16.55	37.26	2,229
ABSEADABRET	4.86	4.72	1.60	3.41	6.36	2,188
POSTEADVOL	41.09	26.71	22.48	33.39	51.65	2,227
STRADDLE	−0.86	49.00	−33.65	−15.43	18.37	2,181
IMPMOVE	6.53	3.38	4.08	5.55	8.12	2,181
STRANGLE	−2.32	80.22	−55.71	−28.78	25.54	1,909
JUMPSTRADDLE	−2.82	137.08	−89.79	−39.74	47.69	1,888
VOLSTRADDLE	1.17	4.35	−1.41	0.81	3.38	1,895

Table 2: Pairwise correlations of firm characteristics

This table presents pairwise correlation coefficients among selected variables. CONCAVE is an indicator variable that takes the value one when the IV curve is concave on the day prior to the EAD and zero otherwise. The definition of the rest of the variables is provided in Appendix A. These correlations are based on the values of the variables measured on the day prior to the EAD and they are computed for a sample of quarterly earnings announcements during the period 2013-2020.

	CONCAVE	BETA	Ln(SIZE)	B/M	RUNUP	MOM	Ln(PRICE)	ATMIV	RNS	RNK	RVIV	TSIV	NUMEST	DISP	ANNBETA	STOCKTR
BETA	0.09															
Ln(SIZE)	−0.18	−0.26														
B/M	−0.11	0.18	−0.13													
RUNUP	0.02	0.04	−0.02	0.04												
MOM	0.11	0.11	−0.03	−0.24	0.06											
Ln(PRICE)	0.10	−0.10	0.42	−0.35	0.07	0.22										
ATMIV	0.31	0.29	−0.63	−0.03	0.02	0.14	−0.19									
RNS	0.33	0.04	−0.17	0.02	0.08	0.10	0.02	0.13								
RNK	−0.31	−0.07	0.30	0.04	0.06	−0.02	0.15	−0.13	−0.27							
RVIV	−0.30	−0.12	0.41	0.09	0.04	−0.11	0.09	−0.54	−0.18	0.22						
TSIV	0.36	0.24	−0.59	−0.14	0.02	0.18	−0.13	0.92	0.13	−0.24	−0.61					
NUMEST	0.19	0.04	0.23	−0.25	0.02	0.06	0.28	0.05	0.05	−0.10	−0.15	0.17				
DISP	0.01	0.15	−0.23	0.10	0.02	0.02	−0.03	0.32	0.01	0.07	−0.14	0.24	−0.12			
ANNBETA	0.05	0.12	−0.09	0.00	0.02	0.09	0.02	0.13	0.01	−0.02	−0.10	0.14	−0.04	0.05		
STOCKTR	0.25	0.27	−0.62	−0.01	0.10	0.24	−0.08	0.74	0.11	−0.13	−0.41	0.73	−0.00	0.26	0.14	
O/S	0.24	−0.07	0.05	−0.13	0.07	0.09	0.50	0.03	0.12	0.06	−0.12	0.08	0.14	−0.03	0.05	0.08

Table 3: Characteristics of firms with concave vs. non-concave IV curves

This table presents the average values of selected variables for firms when they exhibit a concave IV curve on the day prior to the EAD (CONCAVE=1) versus the corresponding average values when they do not exhibit a concave IV curve (CONCAVE=0). ABSEADABRETis the absolute abnormal stock return on EAD, measured with respect to the 4-factor FFC model. POSTEADVOLis the 10-day post-EAD annualized realized stock return volatility. STRADDLEdenotes the return of the delta-neutral ATM straddle strategy on EAD. IMPMOVEdenotes the ratio of the sum of the ATM put and call prices divided by the underlying stock price. STRANGLEdenotes the return of the delta-neutral strangle strategy on EAD. JUMPSTRADDLEdenotes the return of the delta- and vega-neutral ATM straddle strategy on EAD. VOLSTRADDLEdenotes the return of the delta- and gamma-neutral ATM straddle strategy on EAD. The definition of the rest of the variables is provided in Appendix A. These average values are computed for a sample of quarterly earnings announcements during the period 2013-2020. The last column contains the difference in the average values with the corresponding t-statistic (under the null hypothesis of equal means) in parenthesis.

Variable	CONCAVE=1	CONCAVE=0	Difference
EXPIRY	6.14	6.65	−0.52 (4.54)
STRIKES	22.15	15.22	6.93 (11.88)
BETA	1.12	1.07	0.05 (3.51)
Ln(SIZE)	10.67	11.14	−0.47 (−7.90)
B/M	0.31	0.38	−0.08 (−5.33)
RUNUP	0.94	0.52	0.42 (2.19)
MOM	24.95	14.93	10.02 (4.55)
Ln(PRICE)	4.45	4.29	0.16 (3.68)
ATMIV	53.41	39.85	13.56 (14.07)
RNS	−0.14	−0.32	0.19 (17.72)
RNK	3.37	3.80	−0.43 (−17.21)
RVIV	−22.24	−13.13	−9.11 (−13.61)
TSIV	8.42	5.79	2.63 (16.42)
NUMEST	25.57	22.94	2.62 (7.68)
DISP	15.31	14.31	1.00 (0.78)
ANNBETA	0.14	0.08	0.06 (1.54)
STOCKTR	3.24	1.88	1.36 (9.40)
O/S	37.84	22.58	15.27 (10.10)
ABSEADABRET	5.88	4.24	1.64 (7.71)
POSTEADVOL	47.49	37.11	10.38 (8.82)
STRADDLE	−3.74	0.91	−4.65 (−2.16)
IMPMOVE	7.89	5.69	2.20 (15.24)
STRANGLE	−7.94	1.12	−9.05 (−2.45)
JUMPSTRADDLE	−10.69	2.29	−12.98 (−2.12)
VOLSTRADDLE	1.32	1.08	0.25 (1.19)

Table 4: Forecasting power of empirical RNDs

This table presents results from forecasting power comparisons of alternative RNDs with respect to the actual stock price at option expiry, using the Amisano and Giacomini (2007) (AG) test statistic. Panel A compares the forecasting power of the empirical RND, which is extracted using the non-parametric methodology described in Section 2.1, with that of a unimodal RND (RV30 RND) extracted from Black-Scholes option prices using as volatility parameter the 30-day realized volatility of the underlying stock computed on the day prior to the earnings announcement, i.e., $d-1$. Panel B compares the forecasting power of the empirical RND with that of a unimodal RND (RV10 RND) extracted from Black-Scholes option prices using as volatility parameter the 10-day realized volatility of the underlying stock computed on $d-1$. Panel C compares the forecasting power of the empirical RND with that of a unimodal RND (ATM RND) extracted from Black-Scholes option prices using as volatility parameter the ATM implied volatility prevailing on $d-1$ for the same expiry as the one of the empirical RND. All RNDs are computed on $d-1$ for a sample of quarterly earnings announcements during the period 2013-2020. Results are presented for observations where the empirical RND extracted from the available moneyness range yields a cumulative probability of at least 70% or 80%, respectively. The table reports the numerator values of the AG test statistic. Positive (negative) values indicate that the empirical RND has superior (inferior) forecasting power relative to the corresponding unimodal RND. Results are also presented for subsamples where the IV curve is concave on $d-1$ (`CONCAVE`=1) and the realized absolute log stock return at expiry, $|ret|$, is greater than one or two standard deviations (scaled by time), respectively. p-values are provided in parentheses. N denotes the number of observations.

	Cum. Probability = 70%		Cum. Probability = 80%	
	Num. AG (p-value)	N	Num. AG (p-value)	N
Panel A: Empirical RND vs. RV30 RND				
All observations	0.619 (0.00)	1,183	0.830 (0.00)	731
CONCAVE=1	0.728 (0.00)	520	0.930 (0.00)	337
CONCAVE=1 and |ret| > 1×stdev	1.799 (0.00)	300	2.104 (0.00)	199
CONCAVE=1 and |ret| > 2×stdev	3.630 (0.00)	148	3.972 (0.00)	104
Panel B: Empirical RND vs. RV10 RND				
All observations	0.972 (0.00)	1,180	1.303 (0.00)	728
CONCAVE=1	1.046 (0.00)	518	1.366 (0.00)	335
CONCAVE=1 and |ret| > 1×stdev	2.372 (0.00)	298	2.878 (0.00)	197
CONCAVE=1 and |ret| > 2×stdev	4.493 (0.00)	146	5.139 (0.00)	102
Panel C: Empirical RND vs. ATM RND				
All observations	0.000 (0.97)	1,183	−0.003 (0.79)	731
CONCAVE=1	−0.023 (0.13)	520	−0.021 (0.27)	337
CONCAVE=1 and |ret| > 1×stdev	0.037 (0.04)	300	0.052 (0.02)	199
CONCAVE=1 and |ret| > 2×stdev	0.068 (0.00)	148	0.086 (0.00)	104

Table 5: Concave IV curves and absolute abnormal stock returns on EAD

This table presents results from predictive panel regressions of the absolute abnormal stock return on EAD (`ABSEADABRET`) on `CONCAVE` and a set of firm-level characteristics measured on the day prior to the EAD. The abnormal stock return is computed with respect to the 4-factor Fama-French-Carhart model. `CONCAVE` is an indicator variable that takes the value one when the IV curve is concave on the day prior to the EAD and zero otherwise. The definition of the rest of the variables is provided in Appendix A. The sample consists of quarterly earnings announcements during the period 2013-2020. Columns (1) to (4) use two-way clustered standard errors at the firm- and quarter-level. Column (5) includes quarterly fixed effects. t-statistics are provided in parenthesis.

	(1)	(2)	(3)	(4)	(5)
`CONCAVE`	1.65	0.76	0.73	0.73	0.76
	(5.45)	(2.82)	(2.75)	(2.94)	(3.84)
`BETA`		0.55	0.53	0.40	0.36
		(1.59)	(1.47)	(1.14)	(1.12)
`Ln(SIZE)`		−1.53	−1.55	−1.40	−1.40
		(−9.93)	(−9.80)	(−8.62)	(−15.90)
`B/M`		−2.09	−2.01	−1.84	−1.78
		(−4.78)	(−4.22)	(−4.00)	(−5.76)
`RUNUP`			2.58	1.98	2.25
			(1.50)	(1.19)	(0.97)
`MOM`			0.00	0.00	0.24
			(−0.01)	(0.00)	(1.03)
`Ln(PRICE)`			0.11	0.07	0.05
			(0.43)	(0.30)	(0.44)
`DISP`				0.63	0.67
				(1.04)	(2.09)
`ANNBETA`				0.29	0.29
				(1.70)	(2.40)
`CNST`	4.23	21.51	21.35	19.64	—
	(17.43)	(11.51)	(11.16)	(9.36)	
Clustered SE	Quarter/Firm	Quarter/Firm	Quarter/Firm	Quarter/Firm	No
Fixed Effects	No	No	No	No	Quarter
# observations	2,182	2,050	2,050	1,971	1,971
R^2	2.89	21.26	21.35	19.89	21.67

Table 6: Concave IV curves and 10-day post-EAD stock return volatility

This table presents results from predictive panel regressions of the post-EAD realized stock return volatility (POSTEADVOL) on CONCAVE and a set of firm-level characteristics measured on the day prior to the EAD. Post-EAD volatility is computed using stock returns from d to $d+9$, where d is the EAD, and it is annualized. CONCAVE is an indicator variable that takes the value one when the IV curve is concave on the day prior to the EAD and zero otherwise. The definition of the rest of the variables is provided in Appendix A. The sample consists of quarterly earnings announcements during the period 2013-2020. Columns (1) to (4) use two-way clustered standard errors at the firm- and quarter-level. Column (5) includes quarterly fixed effects. t-statistics are provided in parenthesis.

	(1)	(2)	(3)	(4)	(5)
CONCAVE	10.43	4.26	4.11	4.44	3.61
	(5.30)	(2.85)	(2.82)	(3.25)	(3.72)
BETA		8.76	8.25	8.70	8.82
		(4.15)	(4.00)	(4.24)	(5.59)
Ln(SIZE)		−9.71	−9.62	−8.01	−8.83
		(−12.22)	(−12.49)	(−10.55)	(−20.57)
B/M		−9.09	−8.03	−7.61	−6.97
		(−4.29)	(−3.76)	(−3.73)	(−4.62)
RUNUP			7.32	−0.11	−2.16
			(0.39)	(−0.01)	(−0.19)
MOM			3.03	1.67	4.15
			(1.17)	(0.70)	(3.60)
Ln(PRICE)			−0.05	−0.34	−0.32
			(−0.04)	(−0.30)	(−0.54)
DISP				11.26	9.02
				(3.78)	(5.74)
ANNBETA				1.04	0.23
				(1.35)	(0.39)
CNST	37.07	139.14	137.99	118.61	—
	(18.37)	(14.36)	(13.27)	(12.06)	
Clustered SE	Quarter/Firm	Quarter/Firm	Quarter/Firm	Quarter/Firm	No
Fixed Effects	No	No	No	No	Quarter
# observations	2,221	2,048	2,048	1,969	1,969
R^2	3.61	29.53	29.82	28.75	37.49

Table 7: Concave IV curves and delta-neutral straddle returns on EAD

This table presents results from predictive panel regressions of delta-neutral ATM straddle returns computed on EAD (`STRADDLE`) on `CONCAVE` and a set of firm-level characteristics measured on the day prior to the EAD. `CONCAVE` is an indicator variable that takes the value one when the IV curve is concave on the day prior to the EAD and zero otherwise. The definition of the rest of the variables is provided in Appendix A. Option controls include the expiry and the average moneyness of the options used to construct the straddle strategy. The sample consists of quarterly earnings announcements during the period 2013-2020. Columns (1) to (4) use two-way clustered standard errors at the firm- and quarter-level. Column (5) includes quarterly fixed effects. *t*-statistics are provided in parenthesis.

	(1)	(2)	(3)	(4)	(5)
CONCAVE	−4.57	−6.80	−6.86	−7.60	−6.77
	(−2.40)	(−3.32)	(−3.34)	(−3.49)	(−2.81)
BETA		−2.80	−2.45	−2.70	−3.05
		(−0.89)	(−0.77)	(−0.78)	(−0.77)
Ln(SIZE)		−3.59	−3.79	−3.70	−3.31
		(−3.37)	(−3.72)	(−3.52)	(−3.08)
B/M		−3.73	−4.42	−3.75	−3.43
		(−1.27)	(−1.39)	(−1.12)	(−0.90)
RUNUP			27.80	27.54	36.57
			(1.77)	(1.48)	(1.29)
MOM			−3.04	−3.34	−3.76
			(−1.03)	(−0.96)	(−1.30)
Ln(PRICE)			0.52	0.58	0.55
			(0.44)	(0.51)	(0.37)
DISP				−2.44	−0.26
				(−0.47)	(−0.07)
ANNBETA				0.81	1.86
				(0.68)	(1.27)
CNST	195.02	211.45	205.27	298.15	—
	(0.86)	(0.87)	(0.84)	(1.22)	
Clustered SE	Quarter/Firm	Quarter/Firm	Quarter/Firm	Quarter/Firm	No
Fixed Effects	No	No	No	No	Quarter
Option Controls	Yes	Yes	Yes	Yes	Yes
# observations	2,175	2,006	2,006	1,930	1,930
R^2	0.27	1.13	1.26	1.34	3.24

Table 8: Concave IV curves and straddle-implied stock price moves prior to EAD

This table presents results from contemporaneous panel regressions of the implied move of the underlying stock price prior to the EAD (`IMPMOVE`) on `CONCAVE` and a set of firm-level characteristics measured on the day prior to the EAD. `IMPMOVE` denotes the ratio of the sum of the ATM put and call prices divided by the underlying stock price. `CONCAVE` is an indicator variable that takes the value one when the IV curve is concave on the day prior to the EAD and zero otherwise. The definition of the rest of the variables is provided in Appendix A. The sample consists of quarterly earnings announcements during the period 2013-2020. Columns (1) to (4) use two-way clustered standard errors at the firm- and quarter-level. Column (5) includes quarterly fixed effects. *t*-statistics are provided in parenthesis.

	(1)	(2)	(3)	(4)	(5)
`CONCAVE`	2.21	1.28	1.26	1.29	1.15
	(7.61)	(6.36)	(6.19)	(7.33)	(12.38)
`BETA`		1.13	1.04	1.09	1.17
		(2.96)	(2.77)	(3.20)	(7.73)
`Ln(SIZE)`		−1.49	−1.47	−1.21	−1.32
		(−11.83)	(−11.23)	(−10.37)	(−31.86)
`B/M`		−1.72	−1.55	−1.48	−1.40
		(−4.96)	(−4.21)	(−4.29)	(−9.60)
`RUNUP`			−0.25	−1.13	−2.78
			(−0.07)	(−0.36)	(−2.55)
`MOM`			0.58	0.48	0.97
			(1.63)	(1.66)	(8.75)
`Ln(PRICE)`			−0.05	−0.09	−0.07
			(−0.22)	(−0.47)	(−1.29)
`DISP`				1.70	1.26
				(4.03)	(8.32)
`ANNBETA`				0.22	0.08
				(1.77)	(1.46)
`CNST`	5.68	21.74	21.59	18.46	—
	(18.34)	(13.19)	(12.42)	(12.18)	
Clustered SE	Quarter/Firm	Quarter/Firm	Quarter/Firm	Quarter/Firm	No
Fixed Effects	No	No	No	No	Quarter
# observations	2,175	2,006	2,006	1,930	1,930
R^2	10.06	49.81	50.43	50.58	61.96

Table 9: Concave IV curves and delta-neutral strangle returns on EAD

This table presents results from predictive panel regressions of delta-neutral strangle returns (STRANGLE) computed on EAD on CONCAVE and a set of firm-level characteristics measured on the day prior to the EAD. The strangle strategy consists of an OTM call and an OTM put, with strikes set at one standard deviation (scaled by time to expiry) from the underlying stock price at formation. CONCAVE is an indicator variable that takes the value one when the IV curve is concave on the day prior to the EAD and zero otherwise. The definition of the rest of the variables is provided in Appendix A. Option controls include the expiry and the absolute difference between the required and the available moneyness levels of the call and put options used to construct the strangle strategy. The sample consists of quarterly earnings announcements during the period 2013-2020. Columns (1) to (4) use two-way clustered standard errors at the firm- and quarter-level. Column (5) includes quarterly fixed effects. t-statistics are provided in parenthesis.

	(1)	(2)	(3)	(4)	(5)
CONCAVE	−8.84	−11.58	−11.19	−12.92	−10.96
	(−2.41)	(−2.91)	(−2.88)	(−3.29)	(−2.62)
BETA		−11.72	−10.71	−9.24	−10.22
		(−2.54)	(−2.34)	(−1.65)	(−1.49)
Ln(SIZE)		−6.77	−6.68	−7.05	−5.94
		(−3.50)	(−3.95)	(−3.69)	(−3.13)
B/M		−3.80	−6.63	−5.82	−6.52
		(−0.86)	(−1.39)	(−1.18)	(−0.97)
RUNUP			66.24	59.74	92.74
			(1.56)	(1.40)	(1.71)
MOM			−6.90	−8.29	−8.72
			(−1.43)	(−1.54)	(−1.57)
Ln(PRICE)			−1.34	−0.82	−0.87
			(−0.65)	(−0.44)	(−0.32)
DISP				−3.72	0.01
				(−0.41)	(0.00)
ANNBETA				−0.44	1.72
				(−0.25)	(0.66)
CNST	−1.06	93.7	100.08	100.86	—
	(−0.12)	(3.00)	(3.00)	(2.75)	
Clustered SE	Quarter/Firm	Quarter/Firm	Quarter/Firm	Quarter/Firm	No
Fixed Effects	No	No	No	No	Quarter
Option Controls	Yes	Yes	Yes	Yes	Yes
# observations	1,903	1,768	1,768	1,710	1,710
R^2	0.40	1.48	1.7	1.95	4.50

Table 10: Concave IV curves and delta- and vega-neutral straddle returns on EAD

This table presents results from predictive panel regressions of delta- and vega-neutral ATM straddle returns computed on EAD (JUMPSTRADDLE) on CONCAVE and a set of firm-level characteristics measured on the day prior to the EAD. CONCAVE is an indicator variable that takes the value one when the IV curve is concave on the day prior to the EAD and zero otherwise. The definition of the rest of the variables is provided in Appendix A. Option controls include the expiry and the average moneyness of each pair of options used to construct this calendar straddle strategy. The sample consists of quarterly earnings announcements during the period 2013-2020. Columns (1) to (4) use two-way clustered standard errors at the firm- and quarter-level. Column (5) includes quarterly fixed effects. t-statistics are provided in parenthesis.

	(1)	(2)	(3)	(4)	(5)
CONCAVE	−12.71	−17.82	−17.34	−18.92	−15.59
	(−2.19)	(−3.03)	(−2.95)	(−3.10)	(−2.12)
BETA		−1.26	0.70	2.31	0.18
		(−0.14)	(0.07)	(0.22)	(0.02)
Ln(SIZE)		−7.53	−7.61	−7.52	−6.54
		(−2.46)	(−2.32)	(−2.33)	(−1.96)
B/M		−9.14	−14.26	−12.73	−9.54
		(−0.67)	(−1.00)	(−0.81)	(−0.81)
RUNUP			110.47	112.46	141.79
			(2.10)	(1.90)	(1.61)
MOM			−13.03	−13.91	−11.57
			(−1.61)	(−1.61)	(−1.37)
Ln(PRICE)			−0.55	−0.52	−0.23
			(−0.17)	(−0.16)	(−0.05)
DISP				−8.92	−3.67
				(−0.70)	(−0.32)
ANNBETA				0.64	3.98
				(0.20)	(0.92)
CNST	−217.4	−345.86	−376.0	85.83	—
	(−0.31)	(−0.45)	(−0.50)	(0.11)	
Clustered SE	Quarter/Firm	Quarter/Firm	Quarter/Firm	Quarter/Firm	No
Fixed Effects	No	No	No	No	Quarter
Option Controls	Yes	Yes	Yes	Yes	Yes
# observations	1,882	1,726	1,726	1,660	1,660
R^2	0.42	0.89	1.19	1.21	3.33

Table 11: Concave IV curves and delta- and gamma-neutral straddle returns on EAD

This table presents results from predictive panel regressions of delta- and gamma-neutral ATM straddle returns computed on EAD (`VOLSTRADDLE`) on `CONCAVE` and a set of firm-level characteristics measured on the day prior to the EAD. `CONCAVE` is an indicator variable that takes the value 1 when the IV curve is concave on the day prior to the EAD and zero otherwise. The definition of the rest of the variables is provided in Appendix A. Option controls include the expiry and the average moneyness of each pair of options used to construct this calendar straddle strategy. The sample consists of quarterly earnings announcements during the period 2013-2020. Columns (1) to (4) use two-way clustered standard errors at the firm- and quarter-level. Column (5) includes quarterly fixed effects. t-statistics are provided in parenthesis.

	(1)	(2)	(3)	(4)	(5)
`CONCAVE`	0.22	0.27	0.32	0.25	0.17
	(1.44)	(1.64)	(1.99)	(1.64)	(0.76)
`BETA`		−0.69	−0.61	−0.51	−0.55
		(−1.58)	(−1.39)	(−1.14)	(−1.49)
`Ln(SIZE)`		−0.20	−0.18	−0.14	−0.15
		(−1.68)	(−1.34)	(−1.02)	(−1.49)
`B/M`		−0.53	−0.79	−0.91	−0.91
		(−1.70)	(−2.21)	(−2.36)	(−2.49)
`RUNUP`			−0.99	−0.85	−0.74
			(−0.32)	(−0.27)	(−0.27)
`MOM`			−0.37	−0.34	−0.31
			(−1.52)	(−1.17)	(−1.17)
`Ln(PRICE)`			−0.13	−0.15	−0.13
			(−0.97)	(−1.10)	(−0.89)
`DISP`				0.25	0.20
				(0.74)	(0.57)
`ANNBETA`				−0.09	−0.05
				(−0.54)	(−0.34)
`CNST`	−4.16	−5.83	−4.76	9.20	—
	(−0.12)	(−0.16)	(−0.13)	(0.28)	
Clustered SE	Quarter/Firm	Quarter/Firm	Quarter/Firm	Quarter/Firm	No
Fixed Effects	No	No	No	No	Quarter
Option Controls	Yes	Yes	Yes	Yes	Yes
# observations	1,889	1,732	1,732	1,665	1,665
R^2	0.45	1.17	1.44	1.37	3.16