Pricing Event Risk: Evidence from Concave Implied Volatility Curves

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First version: April 2021
This version: July 2023

Abstract

We document that implied volatility (IV) curves of short-term equity options frequently become concave prior to the earnings announcements day (EAD), typically 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, rendering concavity an ex-ante signal for event risk. Returns on delta-neutral straddles, delta-neutral strangles, and delta- and vega-neutral calendar straddles are 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 from 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 may induce bimodality in the *central part* of 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 concavity in the IV curve is a pervasive feature prior to EADs and then study the pricing implications of this phenomenon.

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, bimodality 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).

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%) of IV curves extracted from short-expiry equity options become concave prior to EADs. This compares

[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."

to just 5% 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.

We document that concavity in the IV curve is typically associated with bimodality in the central part of the corresponding RND. Specifically, we find that 86% of the observations with concave IV curves exhibit a bimodal RND. Whereas concavity does not axiomatically reflect a bimodal distribution, we show that a concave IV curve provides an option-based signal of impending event risk in the underlying stock.

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.[2]

To rule out the alternative hypothesis that bimodal RNDs are driven by a behavioural mispricing by option traders understating the probability of no news, we examine the distribution of realized stock returns on EAD. We find that the distribution of daily EAD returns following a non-concave IV curve is unimodal (with mode around 0%)—similar to the distribution of daily stock returns on typical trading days. In contrast, following the formation of concave IV curves, the central part of the corresponding stock return distribution exhibits bimodality, with two distinct modes away from 0%. This finding confirms that bimodal RNDs primarily arise because large stock returns in either direction are highly likely to occur on EADs and investors price these anticipated outcomes in the option market.

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

[2] Our analysis uses options with expiry between 3 and 13 calendar days ahead. 80% (20%) of our observations are constructed using weekly (regular) options. 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.

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, 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.

As mentioned above, prior literature (DJKS (2019), Patell and Wolfson (1979, 1981)) shows that in the run up to EAD, implied volatility increases, the difference between realized volatility and implied volatility decreases, and the term structure of volatility becomes downward sloping. Thus, these variables could also be perceived as alternative proxies for event/jump risk, with the term structure of volatility explicitly suggested as such by DJKS (2019). However, we find that concavity contains significant predictive ability with respect to straddle, strangle and vega-neutral calendar straddle premia over and above the informational content of these option-based risk measures.

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 often 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, 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)).

We contribute 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 that uses option prices to extract information regarding firm value following corporate announcements, such as proposed merger and acquisition transactions (see, for example, Barraclough, Robinson, Smith, and Whaley (2013), Borochin (2014), and van Tassel (2016)). However, the timing of these announcements and the successful completion of the proposed transactions are typically uncertain. To the contrary, there is no uncertainty about the timing of the scheduled earnings announcements, allowing us to model their impact via deterministically timed jumps.

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.

We also build upon the literature showing that stock prices do jump upon the release of news in the form of scheduled macroeconomic (Savor and Wilson (2013)) or earnings announcements (Kapadia and Zekhnini (2019), Lee (2012), Lee and Mykland (2008), and Todorov and Zhang (2023)). This is because upon the announcement, a discrete amount of information is released over a vanishingly small period of time. When this information signals a shift in firm profitability or risk, the announcement can substantially impact its valuation. This is similar to the effect of macroeconomic announcements that convey information regarding the state of the economy (see Ai, Han, Pan, and Xu (2022) and Wachter and Zhu (2022)) and the effect of political events that lead to a shift in government policy (see, for example, Kelly, Pástor, and Veronesi (2016) and Pástor and Veronesi (2013)). Contributing to this literature, we show that investors are averse to gamma risk and pay a significant premium to hedge it when they anticipate large stock price moves. In fact, we show that investors can ex-ante identify those announcements that trigger larger than average jumps and they price short-expiry options accordingly, leading to the formation of concave IV curves.

The formation of concave IV curves is also consistent with the demand-based option pricing framework of Gârleanu, Pedersen, and Poteshman (2009) and the related evidence in Ni, Pan, and Poteshman (2008). Anticipating stock price jumps due to the impending announcement, gamma risk averse investors trade options in certain range of strikes (for example, buying ATM straddles or strangles) to hedge against this aspect of risk. Since jump risk cannot be perfectly hedged, market makers would require a premium to be counterparties in these trades (see Figlewski (1989), Gârleanu, Pedersen, and Poteshman (2009), and Green and Figlewski (1999)). This hedging activity leads to higher option prices and implied volatilities for the relevant range of strikes, giving rise to a concave IV curve.

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 and liquidity of short-term options data that we require for our analysis.[3] Weekly equity options have been actively traded for a range of strikes only in the last decade. Hence, OptionMetrics provides

[3]Our sample firms represent, on average, 44% of the total market value across all US common stocks. This is not a surprise because we select the firms with the highest option trading volume per year, which are usually the largest capitalization firms. An added advantage of our (relatively small) cross-section is that our results are not driven by small-capitalization firms.

very sparse data for short expiries with a sufficient number of strikes prior to 2013.[4]

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. Although our sample predominantly consists of weekly options, we also keep regular options as long as they expire between 3 and 13 calendar days ahead. The short expiry options we employ are very liquid on the trading day prior to EAD. Specifically, the total trading volume across all strikes is on average (median) 36,555 (18,096) contracts. To put this figure into perspective, we compare it with the corresponding total trading volume on the same day of the 'next' option with at least 30 days to expiry. We find that the total trading volume of the short expiry we use is on average (median) 4.0 (2.5) times higher than the corresponding volume of the expiry with at least 30 days. Therefore, the short expiry options we use are more liquid prior to the EAD relative to the options with standard expiration often used in the literature.

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 make sure that our findings are not driven by particularly illiquid strikes, we also discard options when the bid-ask spread is higher than 20% of the mid-quote price.

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 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

[4]For example, after imposing liquidity filters and minimum number of strikes (to be described below) we have 2 firm-quarter observations in 2006, and still only 59 observations in 2012.

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.[5] 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.[6]

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 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. 80% (20%) of these observations are constructed using weekly (regular) options.

[5] 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)).

[6] 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.

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.[7] 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 (`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

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

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

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 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.

A potential concern is that concavity might be an artefact of blending OTM puts and calls around the ATM region, following the approach of Figlewski (2010). To alleviate this potential concern, we alternatively compute IV curves of puts and calls (using OTM, ATM, and ITM options) separately. We find that concavity is present in the IV curves computed from puts and calls separately. Therefore, the concavity feature does not arise due to our blending approach.

Since we use American-style equity options, another potential concern is that concavity might be an artefact of an early exercise premium. However, our dataset consists of very short-expiry OTM and ATM options. As shown in prior literature (see Bakshi, Kapadia and Madan (2003)), the combination of these two characteristics ensures that the early exercise premium, and hence its impact on IVs, would be very small, if any. Nevertheless, we additionally filter out firms that pay dividends during the life of the options. Under standard assumptions, calls on non-dividend paying stocks should not be exercised early, and hence there should be no premium. Moreover, the risk-free rate during our sample period is very low, so the early exercise premium for puts should also be negligible. As expected, only 3.5% of the firms in our sample pay dividends during the life of these options. Excluding these firms, we still find that 38.9% of the IV curves exhibit concavity on the day prior to EAD.

Yet another potential concern is that concavity might be an artefact of high stock borrow fees. Muravyev, Pearson, and Pollet (2022) argue that in the presence of high stock borrow fees, IVs provided by OptionMetrics may be misleading because they are computed as if this fee is zero. This is unlikely to be an issue in our study because our sample consists of very large capitalization firms, which typically have low stock borrow fees. To address this concern, we additionally filter out firms with high stock borrow fees. Specifically, we utilise the categorical variable Daily Cost of Borrowing Score (DCBS) provided by Markit. This variable takes values from 1 to 10, where 1 (10) indicates that a stock has the lowest (highest) borrow fee. Blocher and Whaley (2015) show that stocks with DCBS of 1 have a mean (median) fee of just 36 (27) bps per annum. Equipped with this variable, we drop firms with DCBS greater than 1 on the day prior to EAD. Hence, we are only left with firms exhibiting a negligible borrow fee. As expected, only 5% of the firms in our sample have a DCBS greater than 1. Excluding this small fraction of firms, we still find that 37.7% of the IV curves exhibit concavity on the day prior to EAD.

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 2.1 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 fraction of concave IV curves we identify in the run up to the EAD may be an artefact of our methodology or the use of very short-expiry options.

3.1 Bimodality in RND

The main variable of interest in our analysis (`CONCAVE`) is defined with respect to the properties of the IV curve. To an extent, the shape of the IV curve reflects 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 typically associated with a negatively skewed RND (see the related discussion in Jackwerth (2004) and Hull (2009, chapter 18)).

Figure 4 presents an example of a concave IV curve reflecting 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 (under the risk-neutral measure) trade around either of the two identified price modes. 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.

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

Although concavity in the IV curve does not axiomatically reflect RND bimodality, we find that 86% of the observations with `CONCAVE` = 1 prior to EAD exhibit a bimodal RND.[8] To ensure that this bimodality feature captures distinct modes rather than local wiggles in the RND, we further require that the identified modes are located at least 5% apart in terms of moneyness. Using this stricter definition of bimodality, we find that 80% of the observations with `CONCAVE` = 1 still exhibit a bimodal RND. To even further ensure that the documented bimodality feature is not driven by the tails of the RND, we additionally require that neither of the identified modes is located outside the (0.85, 1.15) moneyness range. Imposing this additional requirement, we still find that 79% of the observations with `CONCAVE` = 1 exhibit a bimodal RND.[9]

RND bimodality is an important feature that distinguishes our study from DJKS (2019).

[8] When we restrict our sample to RNDs that yield a cumulative probability of at least 70%, we find that 91% of the observations with `CONCAVE` = 1 exhibit a bimodal RND.

[9] Recall that we extract RNDs using only the available range of traded strikes, without fitting the tails of the RND. Our procedure ensures that no mode artificially appears in the tails of the distribution due to fitting.

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.

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 5 also shows that ATM IV is downward sloping prior to EADs, consistent with the findings of DJKS (2019).

3.2 Bimodality in physical return distribution

We posit that the documented bimodality in the RND primarily reflects the sizeable probability of large stock price moves in either direction occurring on EADs. In other words, we argue that prior to EAD, the distribution of short-term ahead stock returns can become bimodal under the physical measure $\mathbb{P}$, with modes away from 0%.[10]

An alternative hypothesis to explain RND bimodality is that option traders understate the probability of no news on EAD, and hence they systematically misprice options. This conjecture assumes that the probability distribution of stock returns on EAD is unimodal under $\mathbb{P}$ and a behavioural mispricing by option traders would systematically render the return distribution bimodal as we move from $\mathbb{P}$ to $\mathbb{Q}$.

To rule out this alternative hypothesis, we examine the distribution of stock returns on EADs. Figure 6 shows two such histograms. Panel A presents the histogram of realized stock returns on EADs following the formation of non-concave IV curves on $d-1$ ($\texttt{CONCAVE} = 0$), whereas Panel B presents the corresponding histogram following the formation of concave IV curves on $d-1$ ($\texttt{CONCAVE} = 1$). For both histograms, each bin has a 1% width, centred

[10] Of course, we do not argue that the return distributions under $\mathbb{P}$ and $\mathbb{Q}$ coincide.

around the label on the x-axis. For example, the 0% bin contains the observations with EAD returns between -0.5% and 0.5%. For each histogram, we also plot the corresponding density using an Epanechnikov kernel.

For `CONCAVE` $= 0$, Panel A of Figure 6 shows that the distribution of the realized stock returns on EADs exhibits unimodality in its central part, with the mode of the distribution located at the 0% bin. These features are similar to the ones found in the distribution of daily stock returns on typical trading days. To the contrary, the corresponding distribution when `CONCAVE` $= 1$ in Panel B is strikingly different. We find that the central part of the distribution exhibits bimodality, with two distinct modes away from 0%. In fact, the left mode is located at the -2% bin and the right mode is located at the 2% bin. Moreover, the histogram shows that there are 9 bins with higher frequency than the frequency of the 0% bin. Interestingly, for `CONCAVE` $= 1$, EAD returns as high as around 4% or as low as around -4% are more likely to occur than returns around 0%.

This evidence confirms that the formation of bimodal RNDs prior to EADs when `CONCAVE` $=$ 1 does not simply derive from a behavioural mispricing by option traders who systematically understate the probability of no news. To the contrary, these bimodal RNDs primarily arise because large stock returns in either direction are highly likely to occur on EADs and investors price these anticipated outcomes in the option market.

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 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.[11] Let N_t^d count EADs prior to time t so that $N_t^d = \sum_j \mathbf{1}_{\tau_j \leq t}$, 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 $P(\pi_j = 0) = 1 - p_j$, $X_j^{(-)}\left|\mathcal{F}_{\tau_j -}\right. \sim N\left(\mu_j^{(-)}, \left(\sigma_j^{(-)}\right)^2\right)$ and $X_j^{(+)}\left|\mathcal{F}_{\tau_j -}\right. \sim N\left(\mu_j^{(+)}, \left(\sigma_j^{(+)}\right)^2\right)$.

This parsimonious modeling stucture introduces event risk, which is captured by the anticipated upside and downside jumps, in the continuous-time stochastic volatility model. The model 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:

$$\begin{aligned} dS_t &= (r - \lambda_J \overline{\mu}_J) S_t dt + \sqrt{V_t} S_t dW_t^S + d\left(\sum_{j=1}^{N_t^d} S_{\tau_j -}\left(e^{Z_j} - 1\right)\right) + d\left(\sum_{j=1}^{N_t} S_{\overline{\tau}_j -}\left(e^{\overline{Z}_j} - 1\right)\right) \\ dV_t &= \kappa_v\left(\theta_v - V_t\right)dt + \sigma_v\sqrt{V_t}dW_t^v, \end{aligned} \tag{3}$$

where r is the risk-free rate, and W_t^S and 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., $\overline{Z}_j\left|\mathcal{F}_{\overline{\tau}_j -}\right. \sim N\left(\mu_J, \sigma_J^2\right)$; $\overline{\mu}_J$ 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

[11] Todorov (2020) develops a nonparametric test that makes use of options with different expirations to detect the possibility of a jump in the underlying asset price at a given point in time and recover the corresponding jump distribution.

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 (3) 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.

We emphasize that we do not claim that our model is the only one that can generate a bimodal RND. For example, in the case of the classic jump-diffusion model, a sufficiently high probability of jump whose size exhibits a large mean but relatively low variance can give rise to a mode in the tail of the distribution, leading to bimodality. However, our focus is on bimodality in the *central part* of the RND and concavity in the IV curve; introducing both upside and downside anticipated jumps, our model can more naturally capture these phenomena.

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 Bates (1996) and Duffie, Pan, and Singleton (2000)). 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 7 shows that these parameter values generate a W-shape IV curve that fits the actual IVs extremely well. We repeat the same process fitting the DJKS (2019) model to the actual option prices. As illustrated in Figure 7, the latter model yields a poor fit because it cannot generate concavity in the IV curve.

Figure 8 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 4 presents estimates from panel regressions of `ABSEADABRET` on `CONCAVE` plus a number of firm characteristics measured on the day prior to the EAD.[12] 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).[13] Overall, the results in Table 4 show that concave IV curves observed prior to EADs predict significantly higher `ABSEADABRET` values.

An 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`.

[12] After July 30, 2009, 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.

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

The magnitude of absolute stock returns observed on EADs following concave IV curves is so large that it is indicative of stock price jumps. However, stocks exhibiting a higher degree of volatility are also more likely to yield larger price moves relative to stocks characterised by a lower degree of volatility. To address the potential concern that the documented differential in absolute stock returns between concave and non-concave IV curves simply reflects differences in volatilities, we additionally examine ratios of absolute stock returns to realized volatilities. Such ratios have been used in prior literature as measures of stock price jumps (see, for example, Kapadia and Zekhnini (2019)).

Specifically, we compute the ratio of `ABSEADABRET` to idiosyncratic volatility, which is measured from $d - 250$ to $d - 25$ using the FFC 4-factor model. We find that the average ratio following concave IV curves is 3.35 whereas the corresponding average ratio following non-concave IV curves is 3.07, with their difference being significant (t-statistic = 2.44). Similar is the conclusion if we instead compute the ratio of gross stock returns on EAD to total realized volatility measured from $d-250$ to $d-25$. These results confirm that concave IV curves genuinely signal stock price jumps on EADs that are not simply driven by higher volatility.

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

$$\texttt{POSTEADVOL} = \sqrt{\frac{252}{10}\sum_{t=d}^{d+9} r_t^2}, \tag{4}$$

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.[14]

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

[14] 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 5.

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 5 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.

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.

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 to 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:

$$\texttt{STRADDLE} = wR_c + (1-w)R_p, \tag{5}$$

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

$$w = -\frac{\Delta_P/P}{\Delta_C/C - \Delta_P/P}, \tag{6}$$

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 large price swings that arise due to earnings announcements only when IV curves become concave.

Table 6 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.[15] Here, 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 $= -2.40$) lower average straddle return, as compared to non-concave IV curves.[16] This predictive relationship becomes even stronger when we additionally control in columns (2) to (4) for a

[15] We have repeated the analysis reported in Table 6 using simple instead of delta-neutral ATM straddle returns. The results, available upon request, are very similar to the ones reported in Table 6.

[16] This differential straddle return is computed using mid-point option prices. To alleviate the potential concern that this might be driven by options' bid-ask spread, we alternatively compute straddle returns taking this spread into account. In the most stringent version, we compute returns using bid prices to buy the straddle at $d-1$ and ask prices to sell the straddle at d. Alternatively, in the spirit of Muravyev and Pearson (2020), who argue that the effective option trading costs are lower than what the conventionally quoted bid-ask spreads indicate, we also compute straddle returns using adjusted bid-ask spreads. Specifically, we assume that the effective bid-ask spread on a given day is 75% or 50%, respectively, of the quoted spread. Using these effective bid-ask spreads, we compute the corresponding bid and ask prices. Naturally, the straddle returns are overall substantially lower when we take transaction costs into account. Nevertheless, the differential straddle return on EAD following concave versus non-concave IV curves remains intact and significant, similar to the one reported in Table 6. Hence, we conclude that the sign and the magnitude of this return differential is not affected by options' bid-ask spread.

number of firm characteristics. Column (5) confirms that the significance of this finding is not driven by specific quarters in our sample period.

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 4), 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:

$$\texttt{IMPMOVE} = \frac{C + P}{S}, \tag{7}$$

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`). The higher (lower) the `IMPMOVE` is, the 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 supports the argument that straddles are significantly more costly in the presence of concave IV curves.

Table 7 presents estimates from contemporaneous panel regressions of `IMPMOVE` on `CONCAVE` and a number of firm characteristics measured on the day prior to EAD.[17] Column (1) indicates that, on average, concave IV curves are associated with a 2.21% (t-statistic = 7.61)

[17] In unreported results, we additionally control 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 7.

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 (see, for example, Coval and Shumway (2001)). 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 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.[18] 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 (5), 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 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 8 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

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

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.[19] This position ensures that this calendar strategy is vega-neutral at formation. The `JUMPSTRADDLE` return on EAD is given by:

$$\texttt{JUMPSTRADDLE} = wR_S + (1-w)R_L, \tag{8}$$

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 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

[19] 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.

presence of concave IV curves.

Table 9 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:

$$\texttt{VOLSTRADDLE} = (1 - w)R_S + wR_L, \tag{9}$$

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 shorter- (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 10 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.

5.5 Other Option-Based Risk Measures

We have shown that straddle, strangle, and vega-neutral straddle returns are significantly negative in the presence of concavity observed prior to EADs. However, it is well-known that implied volatility also increases in the run up to EADs (Patell and Wolfson (1979, 1981)). Indeed, Table 3 shows that ATMIV is higher for firms that exhibit concavity versus those that do not. In addition, we know from DJKS (2019) that TSIV typically becomes positive as we approach the EAD, whereas RVIV substantially decreases as ATMIV increases. Again, the descriptive statistics in Table 3 confirm that concave IV curves are associated with significantly lower RVIV and significantly higher TSIV values. Hence, these three variables could be perceived as alternative proxies for event/jump risk, with TSIV explicitly suggested as such by DJKS (2019). Therefore, a natural question that arises is whether the negative straddle and strangle premia we document are just a manifestation of increased short-term volatility prior to EAD, as captured by ATMIV, RVIV, and TSIV, rather than of concavity per se.

To address this question, we include ATMIV, RVIV, and TSIV as additional controls in our regressions of STRADDLE, STRANGLE, and JUMPSTRADDLE returns. Table 11 shows that the coefficient on CONCAVE remains negative and strongly significant. For example, in specification (4), the coefficient on CONCAVE is equal to -6.77 (t-statistic $= -3.12$) for STRADDLE returns (versus -4.57, t-statistic $= -2.40$ in specification (1) of Table 6); equal to -11.83 (t-statistic $= -2.91$) for STRANGLE returns (versus -8.84, t-statistic $= -2.41$ in specification (1) of Table 8); and equal to -18.44 (t-statistic $= -3.03$) for JUMPSTRADDLE returns (versus -12.71, t-statistic $= -2.19$ in specification (1) of Table 9), in Panels A, B, and C, respectively.[20] This evidence confirms that concavity contains significant predictive ability with respect to straddle, strangle and vega-neutral straddle premia over an above the informational content of ATMIV, RVIV, and TSIV.

Summarizing the results of this section, we conclude that the negative STRADDLE, STRANGLE,

[20] We also estimate all other specifications (columns (2)-(5) of the Tables 6, 8, and 9), alternatively including ATMIV, RVIV, TSIV, and all three variables jointly. The significance of CONCAVE remains intact in the presence of these option-based risk measures.

and JUMPSTRADDLE 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 document 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 typically 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 Hanke, Poulsen, and Weissensteiner (2018), Leahy and Thomas (1996), Melick and Thomas (1997), Kelly, Pástor, and Veronesi (2016), and Savor and Wilson (2013)). 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:

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

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

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

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:

$$\varphi_{dis}(u;t,T) = \prod_{j=N_t^d+1}^{N_T^d} \varphi_j(u), \tag{B3}$$

where

$$\varphi_j(u) = p_j M_j^{(-)}(u) + (1-p_j) M_j^{(+)}(u), \tag{B4}$$

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 (B3):

$$\varphi(u;t,T,S_t,V_t) = \varphi_{af}(u;t,T,S_t,V_t)\varphi_{dis}(u;t,T). \tag{B5}$$

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)):

$$\begin{aligned}
C_t(K,T) &= \frac{1}{2}S_t + \frac{e^{-r(t-t)}}{\pi}\int_0^\infty \mathrm{Re}\left[\frac{K^{-iu}\varphi(u-i;t,T,S_t,V_t)}{iu}\right]du \\
&\quad - Ke^{-r(T-t)}\left(\frac{1}{2} + \frac{1}{\pi}\int_0^\infty \mathrm{Re}\left[\frac{K^{-iu}\varphi(u;t,T,S_t,V_t)}{iu}\right]du\right).
\end{aligned} \tag{B6}$$

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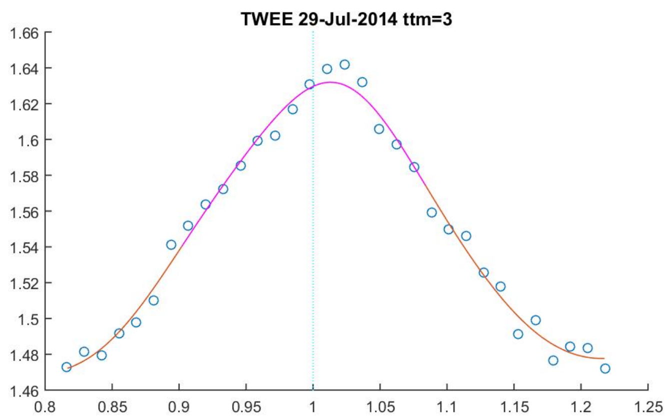
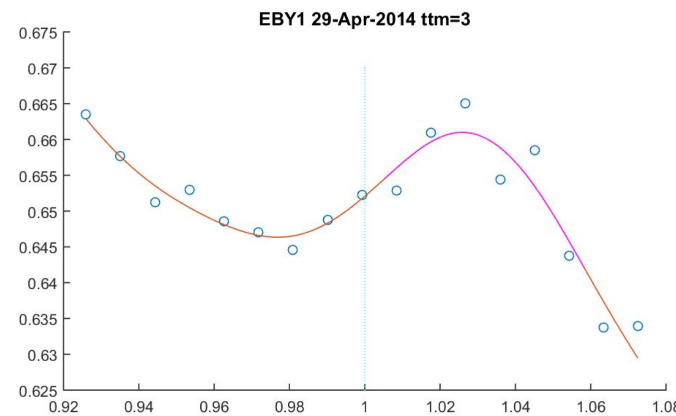
Figure 1: Types of concave IV curves

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.

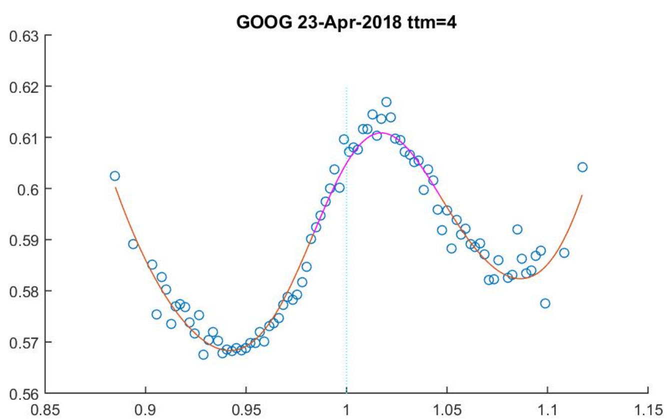
Panel A: Inverse U-shape



Panel B: S-shape



Panel C: W-shape



Panel D: W-shape

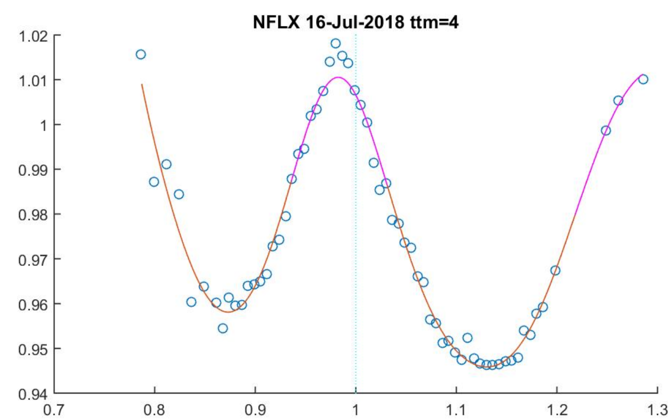
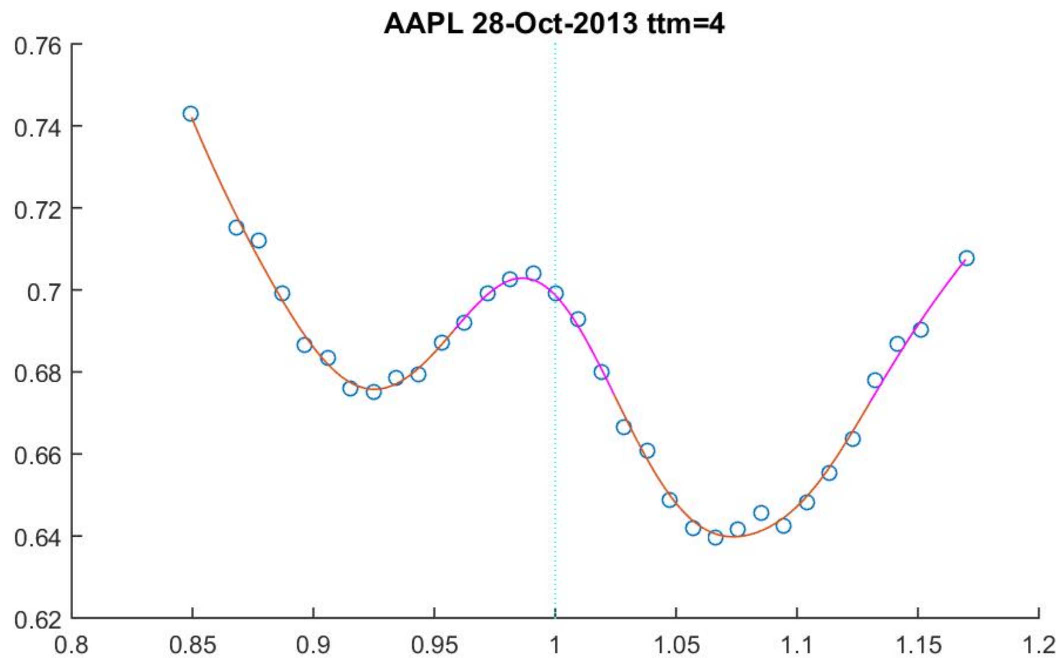


Figure 2: Concave IV curves around EAD

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

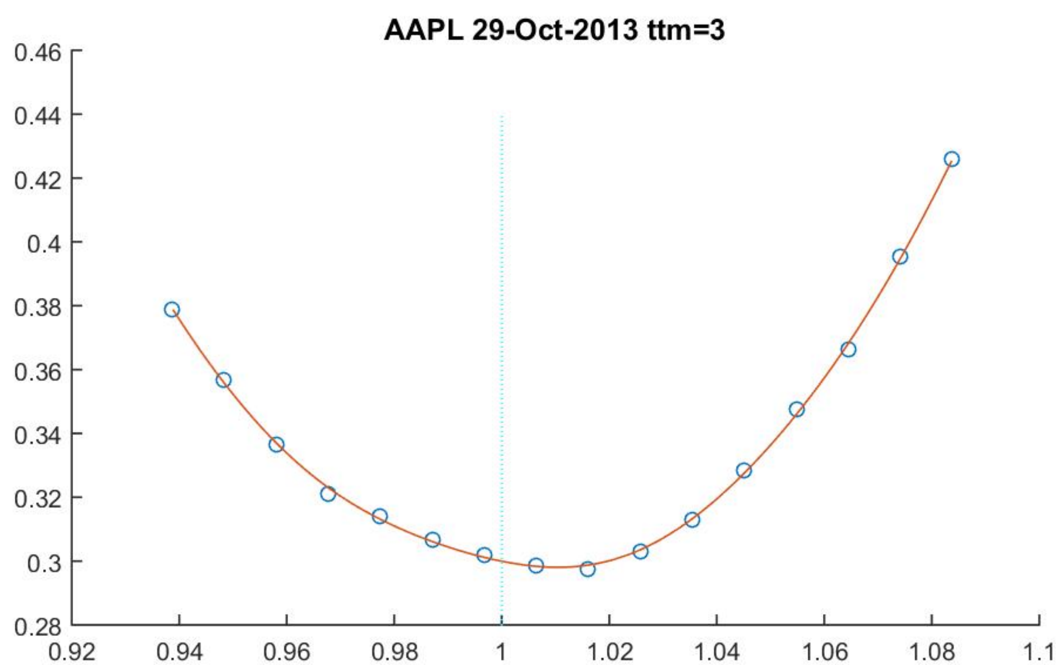


Figure 3: Fraction of concave IV curves around EAD

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.

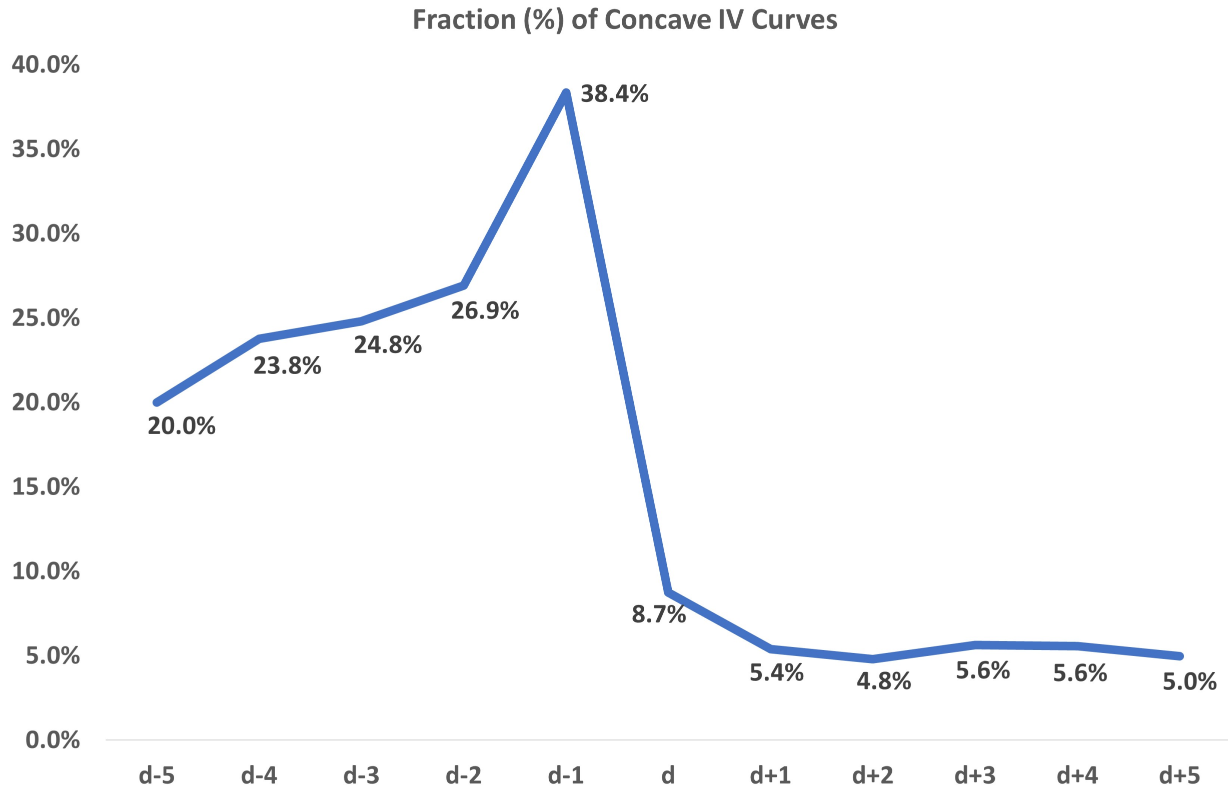
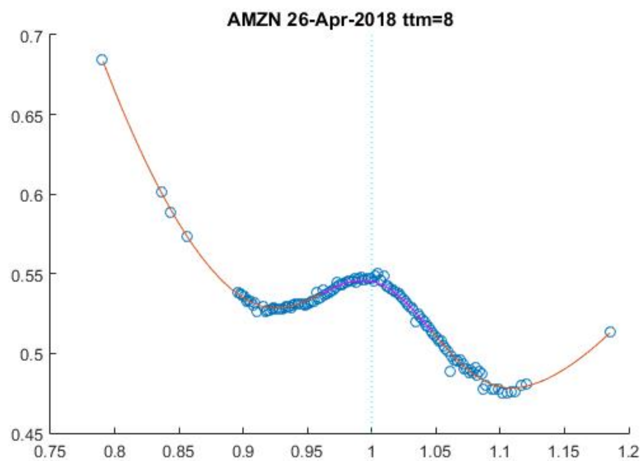


Figure 4: Concave IV curves and RND bimodality

This figure presents an example illustrating 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).



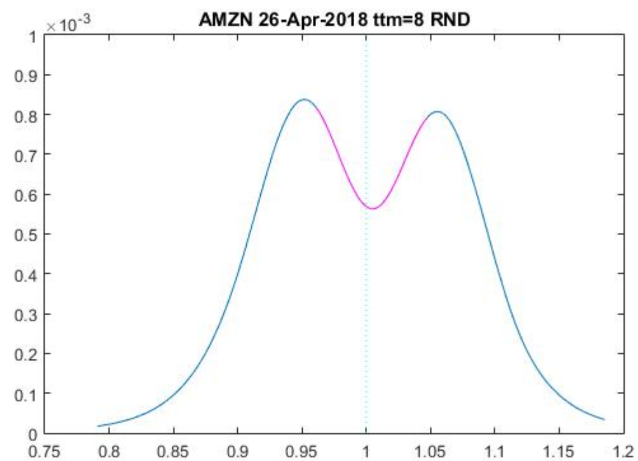


Figure 5: IV curves for short- vs. longer-expiry options

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.

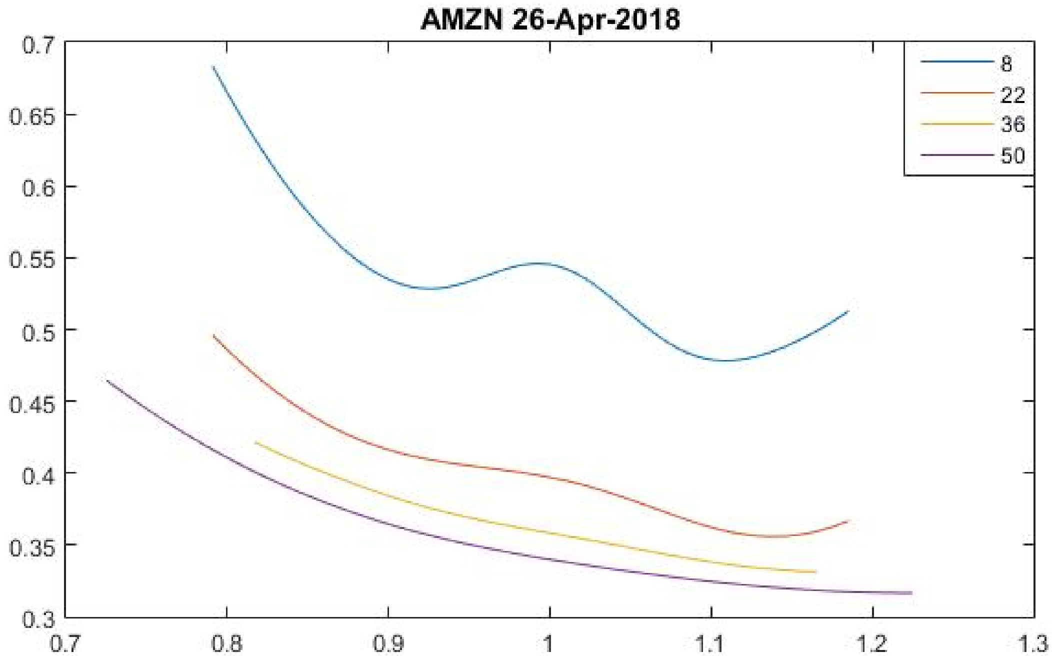
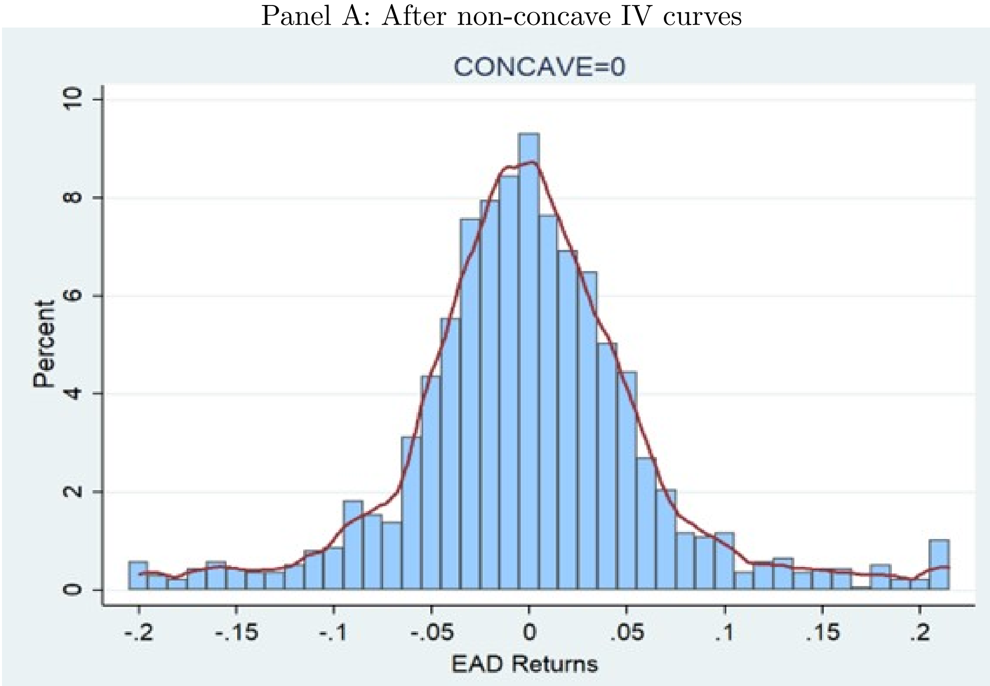


Figure 6: Distribution of realized stock returns on EAD

This figure shows histograms of realized stock returns on EADs. Panel A illustrates the histogram for the observations associated with a non-concave (`CONCAVE` = 0) IV curve observed on the day prior to EAD. Panel B illustrates the corresponding histogram for the observations associated with a concave (`CONCAVE` = 1) IV curve. Each bin in the histogram has a 1% width, centred around the label on the x-axis. The corresponding density derived using an Epanechnikov kernel is also plotted in each Panel. The sample consists of quarterly EADs during the period 2013-2020.

Panel A: After non-concave IV curves



Panel B: After concave IV curves

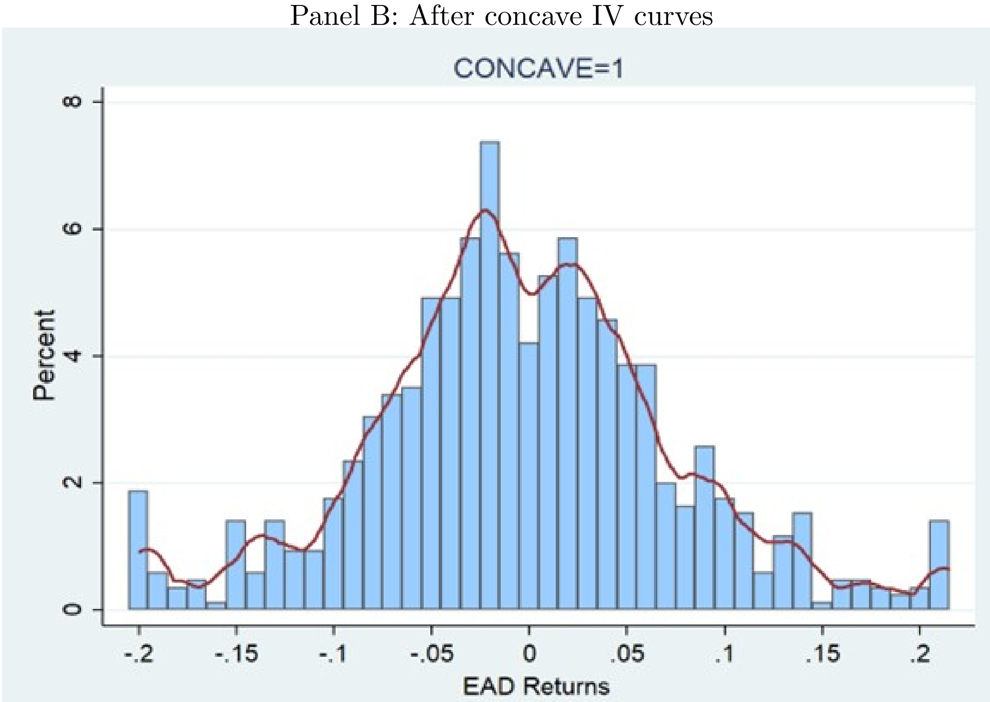


Figure 7: Model-implied IV curve

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.

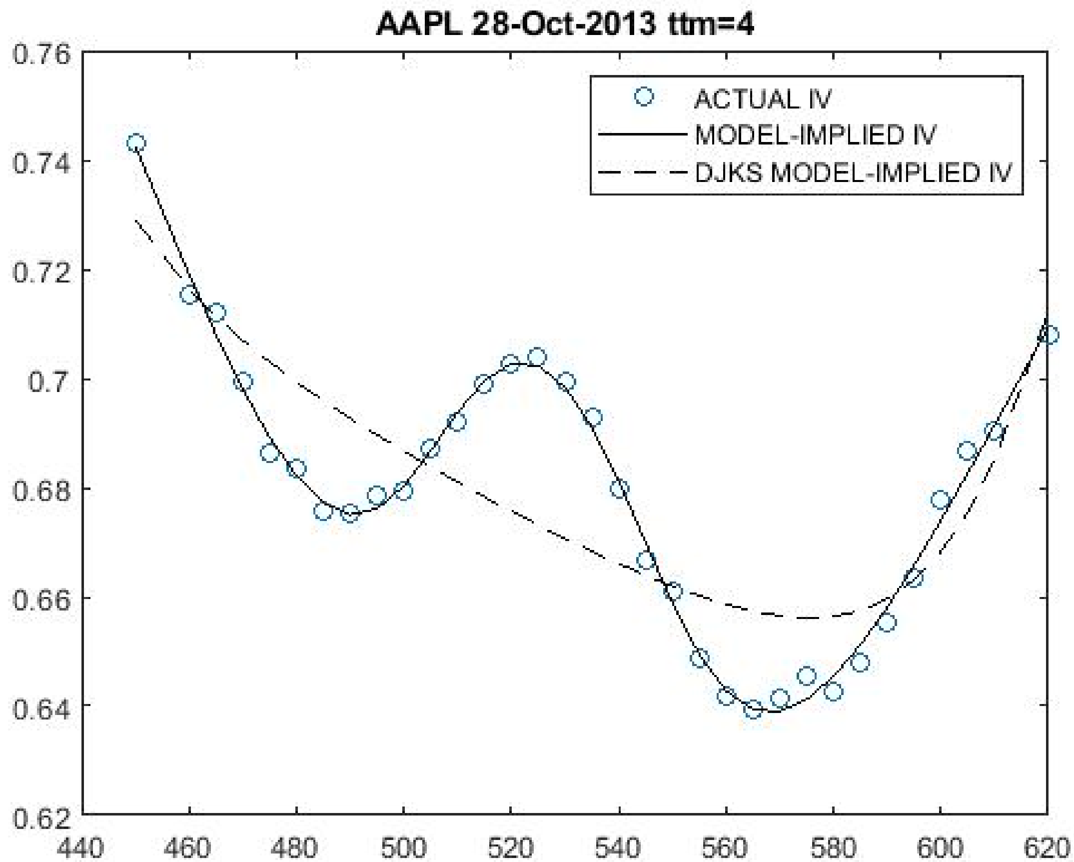


Figure 8: Model-implied RND

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.

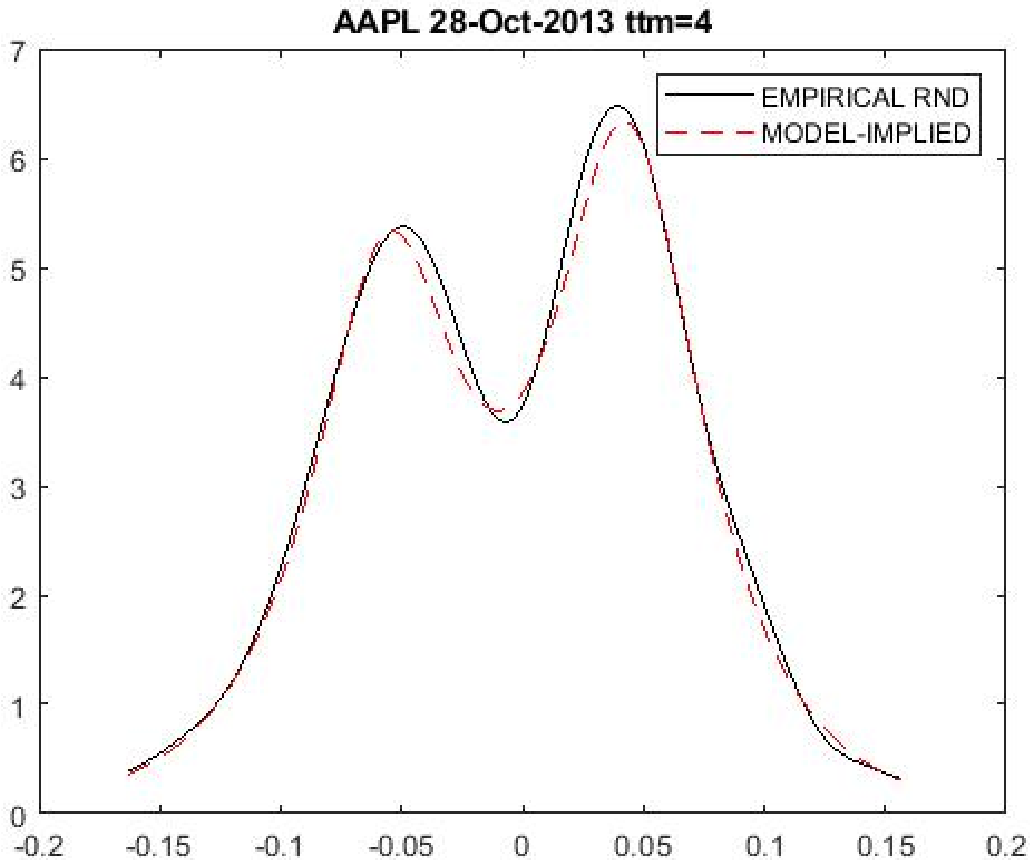


Table 1: Summary statistics

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). 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 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: 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 5: 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 6: Concave IV curves and delta-neutral straddle returns on EAD

This table presents results from predictive panel regressions of delta-neutral ATM straddle returns (`STRADDLE`) computed on EAD 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 7: 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 (IMPMOVE) prior to the EAD 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 8: 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 9: 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 (`JUMPSTRADDLE`) computed on EAD 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 10: 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 (`VOLSTRADDLE`) computed on EAD 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

Table 11: The effect of concave IV curves controlling for other option-based risk measures

This table presents results from predictive panel regressions of delta-neutral ATM straddle returns computed on EAD (STRADDLE, as in Table 6) in Panel A, delta-neutral strangle returns (STRANGLE, as in Table 8) in Panel B, and delta- and vega-neutral ATM straddle returns (JUMPSTRADDLE, as in Table 9) in Panel C on CONCAVE, ATMIV, RVIV, and TSIV. 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. ATMIV, RVIV, and TSIV are defined in Appendix A. Option controls for each specification are included and are defined in the corresponding table (Table 6 for Panel A specifications, Table 8 for Panel B specifications, and Table 9 for Panel C specifications). All specifications also include an intercept (CNST), but its coefficient estimates are not tabulated. t-statistics using two-way clustered standard errors at the firm- and quarter-level are provided in parenthesis. The sample consists of quarterly earnings announcements during the period 2013-2020.

	(1)	(2)	(3)	(4)
Panel A: Delta-neutral straddles, STRADDLE				
CONCAVE	−5.27	−6.65	−5.49	−6.77
	(−2.78)	(−3.19)	(−2.65)	(−3.12)
ATMIV	−0.14			−26.69
	(−0.03)			(−2.38)
RVIV		−14.73		−16.16
		(−2.51)		(−2.77)
TSIV			32.12	133.86
			(1.29)	(2.06)
# observations	2,151	2,151	2,163	2,139
R^2	0.32	0.51	0.33	0.74
Panel B: Delta-neutral strangles, STRANGLE				
CONCAVE	−10.06	−12.35	−10.38	−11.83
	(−2.70)	(−3.13)	(−2.53)	(−2.91)
ATMIV	2.72			−42.65
	(0.28)			(−1.91)
RVIV		−31.98		−38.74
		(−2.74)		(−2.46)
TSIV			55.65	182.88
			(1.09)	(1.45)
# observations	1,883	1,883	1,894	1,874
R^2	0.50	0.76	0.45	0.92

	(1)	(2)	(3)	(4)
	Panel C: Delta- and vega-neutral straddles, JUMPSTRADDLE			
CONCAVE	−14.04	−17.28	−15.39	−18.44
	(−2.54)	(−2.82)	(−2.66)	(−3.03)
ATMIV	−1.54			−92.35
	(−0.10)			(−1.74)
RVIV		−33.32		−30.47
		(−1.79)		(−1.26)
TSIV			98.27	512.65
			(1.26)	(1.56)
# observations	1,862	1,862	1,872	1,852
R^2	0.48	0.60	0.45	0.88