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Abstract

Option prices embed predictive content for the outcomes of pending mergers and acquisitions. This is particularly important in merger arbitrage, where deal failure is a key risk. In this paper, I propose a dynamic asset pricing model that exploits the joint information in target stock and option prices to forecast deal outcomes. By analyzing how deal announcements affect the level and higher moments of target stock prices, the model yields better forecasts than existing methods. In addition, the model accurately predicts that merger arbitrage exhibits low volatility and a large Sharpe ratio when deals are likely to succeed.

Key words: financial economics, option pricing, mergers and acquisitions

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Deal failure is a key risk in mergers and acquisitions. As many as one in five deals fails.[1] In merger arbitrage, arbitrageurs earn a small gain when deals succeed but suffer a large loss when deals fail. As compensation for their liquidity provision and nonlinear risk profile, arbitrageurs earn excess returns relative to standard risk models. More broadly, mergers and acquisitions are an important source of capital reallocation in the economy. As deals may create or destroy value, deal failure can have a detrimental or beneficial impact on economic growth.

In this paper, I build a dynamic asset pricing model that exploits the joint information in target stock and option prices to estimate the risk-neutral probability of deal success in individual deals. The estimated risk-neutral probabilities deliver significant forecasts for deal outcomes and provide evidence that deal risk is priced. Furthermore, the analysis highlights how the combination of priced deal risk and a nonlinear payoff profile can explain various features of merger arbitrage returns.

Merger arbitrage refers to an event-driven trading strategy that provides systematic insurance against deal risk.[2] In a typical situation, a deal is announced, and the target stock price jumps up to trade at a discount to the acquirer's offer, known as the arbitrage spread.[3] Merger arbitrageurs provide liquidity after the announcement by purchasing target stocks. This allows other market participants to avoid deal risk by selling target stocks. Of course, the term arbitrage is a misnomer in this setting. When deals succeed, arbitrageurs can earn the arbitrage spread. When deals fail, the target stock price may fall back to a level closer to the preannouncement price, resulting in a loss.

In addition to the stock market reaction, target option prices react to the changes in the level and higher moments of the target stock price when deals are announced. To analyze how the joint reaction of stock and option prices reflects information about deal risk and the likelihood of deal success, I build a dynamic asset pricing model. The model captures the jump in the target stock price at the announcement, and the varied response of target

[1]In my sample, the probability of deal failure is 22% in 1,094 deals with listed target options and 19% in the full sample of 3,836 deals from 1996 to 2012. Similarly, Baker et al. (2012) find that 25% of deals fail in a sample of 6,462 deals from 1984 to 2007 while Giglio and Shue (2014) report that 21% of deals fail, 6% remain pending, and 73% succeed within one year of the announcement in a sample of 5,377 deals from 1970 to 2010.

[2]For a detailed description of merger arbitrage investments, see Mitchell and Pulvino (2001). As John Paulson puts it in Pedersen (2015), "To play this game, you need a lot of expertise related to the issues that affect deal completion." According to Pedersen (2015), key determinants of deal completion include target shareholder and board approval, regulatory approval, the acquirer's commitment to the offer after due diligence, and the acquirer's ability to finance the offer.

[3]The median target stock price jumps 27% after the announcement and trades at a 3.5% spread to the offer in my sample. This is consistent with Jetley and Ji (2010), who find that arbitrage spreads have decreased since the early 2000s in part due to increased assets under management dedicated to merger arbitrage strategies.

option prices in cash and stock deals. I estimate the model in individual deals. To do this, I use the target stock price to infer the fundamental value of dividends in the model. I then use target option prices as the additional restrictions that identify the model parameters, including the risk-neutral probability of deal success. Empirically, I find the estimated risk-neutral probability delivers significant forecasts of deal outcomes. For example, in cash deals, the estimated probability obtains an R^2_{adj} of 34% in linear-probability regressions, which increases to an R^2_{adj} above 50% in the subset of deals with low standard errors on the estimated probability. To put these numbers in context, the estimated probability represents a substantial improvement over the share-implied probability, which obtains an R^2_{adj} of 14% by using only the information in target stock prices.[4]

To understand why the joint information in target stock and option prices is more informative about deal outcomes than the isolated information in target stock prices, consider what happens when a cash deal is announced. At the announcement, the jump in the target stock price and the arbitrage spread are directly informative about the probability of deal success. After the announcement, the target stock price is a weighted average of the cash offer and the fundamental value of target dividends. Deal announcements shift weight in the target stock price from dividends to cash. This shift decreases the volatility of the target stock price because cash has zero volatility. At the same time, there is a risk the deal will fail after the announcement, in which case the target stock price will fall back to a level closer to the preannouncement price, increasing the skewness and kurtosis of the target stock price.

Target option prices reflect the changes in the higher moments of the target stock price immediately after the announcement. When markets are incomplete, target stock prices do not reveal the same information. In particular, a decrease in at-the-money implied volatility and the emergence of a volatility smile embed predictive content for deal outcomes. Since the weight on cash increases with the probability of deal success, deals with a high probability of success exhibit a larger decrease in implied volatility and a larger increase in skewness. In stock deals, target option prices have a similar reaction when the acquirer stock is less volatile than the target stock. In both cases, target option prices provide complementary information to the information in target stock prices that is useful in forecasting deal outcomes.[5]

[4] I define the share-implied probability of success following Brown and Raymond (1986) and Samuelson and Rosenthal (1986). It is implied directly from the target stock price, the offer, and a fallback price under the assumption the target stock price equals the offer in the event of success and a fallback price in the event of failure, which is often taken to be the value of the target stock a day or a week before the deal was announced.

[5] In principle, target option prices provide a model-free estimate for the risk-neutral probability of success. In cash deals, target shareholders receive a fixed payment when deals succeed, which creates a discontinuity in the cumulative distribution function of the target stock price at the value of the offer. Following Breeden and Litzenberger (1978), target option prices reveal the size of the discontinuity, which equals the risk-neutral probability of success prior to a particular maturity. This information cannot be recovered from the target

In addition to forecasting deal outcomes and pricing target options, I also apply the model to study merger arbitrage investments. Of course, these topics are closely related. The probability of deal success is a key determinant of the risk-return trade-off in merger arbitrage. In the model, I find that merger arbitrage volatility decreases when the probability of deal success increases. This occurs because merger arbitrage places more weight on the fixed arbitrage spread and less weight on volatile target dividends and acquirer stock prices when deals are likely to succeed. At the same time, expected returns have a three factor structure that compensates investors for market risk, deal success risk, and deal failure risk. Since deal risk is binary, the contribution of deal risk to expected returns is hump-shaped in the probability of success. As a result, expected returns are not proportional to volatility. When the probability of deal success increases, volatility decreases and expected returns exhibit a hump-shape. As a consequence, the Sharpe ratio is concave in the probability of success and largest in deals with a high probability of success.

Empirically, I confirm the model's predictions for merger arbitrage returns in cross-sectional and Fama-MacBeth regressions. The results indicate that the volatility of merger arbitrage decreases with the probability of deal success. This finding aligns with the model's prediction and is robust to including control variables as well as calendar time, event time, and industry fixed effects. In addition, I show that a high-probability merger arbitrage strategy, which invests only in deals with a high share-implied probability of success, increases the monthly Sharpe ratio and CAPM alpha t-statistic by more than 50% relative to an equal-weighted portfolio. This agrees with the model's prediction that merger arbitrage earns a larger Sharpe ratio in deals with a high probability of success. Finally, I extend the baseline model to study the dynamic properties of merger arbitrage in event time.[6] When the intensity of deal success is calibrated to the hump-shaped pattern documented in the data, the model features expected returns that are hump-shaped and volatility that is increasing in event time. This is consistent with the empirical features of merger arbitrage returns. Moreover, the event time analysis highlights another dimension of merger arbitrage returns

stock price. In practice, a nonparametric approach is challenging to implement because it requires computing the difference in the derivative of the call pricing function at the offer. It is also inapplicable in stock deals with fixed exchange ratios where merger arbitrage depends on the joint distribution of the target and acquirer stock prices. As a result, I build a dynamic model to estimate the risk-neutral probability of success from the reaction of target stock and option prices when deals are announced. Informally, the discussion suggests that option prices will be more informative about deal outcomes in cash deals than in stock deals. I confirm this hypothesis empirically. While the estimated risk-neutral probability is statistically significant for both types of deals, the economic and statistical significance is larger in cash deals.

[6] Giglio and Shue (2014) demonstrate that deal success intensity is hump-shaped in event time whereas the failure intensity is relatively constant. Shleifer and Vishny (2003) and Harford (2005) observe that mergers arrive in waves. I solve the baseline model and derive the main results in Appendix A. I present extensions of the baseline model that incorporate a time-varying success intensity and merger waves in Appendix B.

in which the nonlinear payoff profile results in expected returns that are not proportional to volatility.

In summary, I introduce a dynamic asset pricing model that can explain various features of merger arbitrage returns, capture market reactions to deal announcements, and deliver accurate forecasts of deal outcomes. In the model, priced deal risk and the nonlinear payoff profile of merger arbitrage investments are the key ingredients that generate these results. For example, when deal risk is not priced, the risk-neutral probability of deal success is counterfactually equal to the objective probability. In linear-probability regressions, I find that the objective probability is larger than the risk-neutral probability, which is consistent with the interpretation that deals fail in bad economic states with high marginal utility of wealth. Moreover, when deal risk is not priced, the model incorrectly predicts that merger arbitrage earns the same Sharpe ratio as the market portfolio, which is constant in the probability of deal success. In the data, I show that merger arbitrage earns a higher Sharpe ratio than the market portfolio, which is largest in high-probability deals. Finally, when deal risk is not priced, the model incorrectly predicts that expected returns are increasing as opposed to hump-shaped in event time. Together, these results highlight how priced deal risk is necessary for the model to match various features of merger arbitrage returns.

This paper makes several contributions to the literature. To my knowledge, it is the first dynamic model that presents a reconciled view of target stock and option pricing during the periods before and after deal announcements.[7] Related papers that study merger option pricing include Barraclough et al. (2013), Bester et al. (2013), and Subramanian (2004).[8] While these studies focus on option pricing in the postannouncement period, my model can be applied to analyze the market reaction to deal announcements. In addition, my approach features random deal durations, which allows me to study the event time properties of merger arbitrage returns.[9] Furthermore, my model delivers closed-form option prices

[7]Following Merton (1974) and Leland (1994), I perform valuation by computing the discounted expected value of dividends paid by the target firm under the risk-neutral measure. Similar to Duffie et al. (2000), I allow for jumps in the target stock price. In contrast to the affine jump-diffusion literature, jumps in the log stock price cannot be modeled with a fixed probability distribution because target shareholders receive a fixed amount of cash or acquirer shares when deals succeed. This difference motivates my model and derivation of target stock and option prices.

[8]Barraclough et al. (2013) illustrate that options can enhance the measurement of merger wealth effects by providing additional equations that identify latent firm values in the event of deal failure and success. Subramanian (2004) and Bester et al. (2013) study target option pricing in stock and cash deals respectively. Cao et al. (2005) finds that target announcement returns are increasing in preannouncement call volume imbalances. More broadly, there is a large literature that investigates the relationship between stock and option markets when markets are incomplete as a result of discrete trading, transaction costs, stochastic volatility, jumps, asymmetric information, and heterogeneous agents. For example, see Back (1993), Figlewski and Webb (1993), Grossman and Zhou (1996), Easley et al. (1998), and Garleanu et al. (2009).

[9]Existing studies assume that effective dates are fixed and known in advance by market participants. In practice, the amount of time until consummation is typically unknown and subject to significant uncertainty.

for any maturity and makes new predictions for stock deals that are consistent with the data.[10] In terms of similarities with the literature, my model features a volatility smile for postannouncement target options in cash deals along with a kink in implied volatility when the strike price equals the offer.[11]

My paper also contributes to the existing literature that studies the risks and returns of merger arbitrage, including Mitchell and Pulvino (2001), Baker and Savaşoglu (2002), and Giglio and Shue (2014).[12] More broadly, it can also be viewed as part of the literature that investigates the risk-return trade-off in hedge fund trading strategies.[13] With respect to the merger arbitrage, my model features a larger CAPM beta when deals have a low probability of success. This occurs because merger arbitrage places more weight on volatile target dividends and acquirer stock prices that are correlated with the market portfolio when deals are unlikely to succeed. To the extent that deals are more likely to fail in bad economic states, this result is similar to Mitchell and Pulvino (2001) who find that merger arbitrage exhibits larger CAPM betas when the market suffers a large loss. My model is also similar to Baker and Savaşoglu (2002) in that binary deal risk makes a hump-shaped contribution to expected returns. Finally, an extension of my baseline model incorporates the observation in Giglio and Shue (2014) that the intensity of deal success is hump-shaped in event time. When deal risk is priced, my model predicts that expected returns are hump-shaped and

Random deal durations circumvent this problem. An exception of interest for the models with fixed effective dates is a tender offer. In a tender offer, after the term sheet has been filed with the SEC, target shareholders know the date when they can exchange their stock for securities from the acquirer.

[10] In Bester et al. (2013), closed-form option prices are available only for maturities after the effective date. Before the effective date, it is necessary to integrate over both of the latent variables. In Subramanian (2004), the assumption of a fixed effective date implies that target and acquirer stocks are perfectly correlated with identical volatility while deals are pending, regardless of the probability of deal success. This contrasts the empirical fact that target and acquirer stocks are not perfectly correlated in the postannouncement period. For example, I find the postannouncement correlation is higher and that target volatility is closer to acquirer volatility when deals are likely to succeed, which is consistent with my model.

[11] Bester et al. (2013) find a similar result. Unlike Bester et al. (2013), I demonstrate that the kink in implied volatility is model-free. It stems from the discrete probability that a deal will succeed, in which case target shareholders receive a fixed payout in cash deals.

[12] Mitchell and Pulvino (2001) emphasize that linear asset pricing models will not properly account for the nonlinear risks in merger arbitrage based on the observation that merger arbitrage has a larger CAPM beta for economic states in which the market portfolio suffers a large loss. They advocate for a contingent claims approach and suggest a replicating portfolio that purchases a risk-free bond and sells an out-of-the-money put option on the market index. Baker and Savaşoglu (2002) posit that merger stocks are priced by a group of thinly capitalized investors who absorb supply shocks when deals are announced. They find empirical support for their predictions that expected returns are increasing in idiosyncratic deal risk and deal size. Giglio and Shue (2014) present a different perspective by studying merger arbitrage returns in event time. They find the deal success intensity is hump-shaped whereas the failure intensity is relatively constant, and also find that expected returns are hump-shaped whereas volatility is increasing in event time.

[13] For example, see Shleifer and Vishny (1997), Fung and Hsieh (2001), Mitchell et al. (2002), Liu and Longstaff (2004), Duarte et al. (2007), Mitchell et al. (2007), Mitchell and Pulvino (2012), Asness et al. (2013), Frazzini and Pedersen (2014), and Jurek and Stafford (2015).

that volatility is increasing in event time, which matches the empirical features of event time merger arbitrage returns that are documented in Giglio and Shue (2014).

The remainder of the paper proceeds as follows. Section 1 presents the model of target stock and option pricing. Section 2 describes the data and model estimation. Section 3 applies the model to forecast the outcomes of cash deals. Section 4 presents the analysis of merger arbitrage returns. Section 5 concludes. Finally, I derive the main results, presents extensions of the baseline model, and discusses the application to stock deals in the Appendix.

1 Model of Merger Stock and Option Pricing

Consider a continuous time economy in which a firm may become the target of a merger or acquisition. In the absence of arbitrage, I assume there exists a risk-neutral measure under which dividends follow

$$\frac{dD_t}{D_t} = g(s_t)dt + \sigma(s_t)dW_t, \tag{1}$$

where r is the constant risk-free rate, $g(s_t)$ is the dividend growth rate, $\sigma(s_t)$ is the dividend volatility, and W_t is a standard Brownian motion.[14] The firm resides in either a pretarget, target, or acquired state $s_t \in \{\mathcal{P}, \mathcal{T}, \mathcal{A}\}$. The state affects the dividend process as follows. In the pretarget and target states $s_t \in \{\mathcal{P}, \mathcal{T}\}$, the firm has not been acquired, and dividends evolve according to a geometric Brownian motion with growth rate g and volatility σ. When the firm is acquired $s_t \in \mathcal{A}$, target shareholders receive a liquidating payment in the form of cash V and acquirer shares ϕ. Simultaneously, when the target firm is acquired, the dividend growth rate and volatility are set to zero, and the target firm stops paying dividends.[15] For deals with stock financing $\phi > 0$, I model the acquirer stock price as

$$\frac{dP_{A,t}}{P_{A,t}} = (r - q_A)\, dt + \sigma_A dW_{A,t}, \tag{2}$$

where q_A is the dividend yield, σ_A is the acquirer volatility, and $W_{A,t}$ is a standard Brownian motion whose instantaneous correlation with W_t is ρ.[16]

[14] Formally I fix a probability space $(\Omega, \mathcal{F}, \mathbb{Q})$ where $(\mathcal{F}_t) = \{\mathcal{F}_t : t \geq 0\}$ is a filtration assumed to satisfy the usual conditions. For technical details on conditions that imply the existence of a risk-neutral or equivalent martingale measure such as the assumption of no approximate arbitrage see Chapter 6 in Duffie (2010).

[15] This can be modeled formally as $dD_t/D_{t-} = g(s_t)dt + \sigma(s_t)dW_t + J(s_{t-}, s_t)dM_t$, where M_t is a counting process equal to one when the firm transitions $dM_t = \mathbf{1}[s_{t-} \neq s_t]$ and $J(\mathcal{T}, \mathcal{A}) = -1$.

[16] For simplicity I assume the acquirer stock price is unrelated to the deal outcome. This can be motivated by either the free-rider problem in Grossman and Hart (1980) or the fact that acquirers are much larger than target firms. For example, Andrade et al. (2001) find that acquirer announcement returns are close to zero whereas target announcement returns are large and positive. If desired, the impact of the deal on the acquirer can be modeled as $dP_{A,t}/P_{A,t-} = (r - q_A)\, dt + \sigma_A dW_{A,t} + J_A(s_{t-}, s_t)dM_t$ where $J_A(\mathcal{T}, \mathcal{A}) = z_S$.

Transitions between states follow a continuous-time homogeneous Markov chain whose generator under the risk-neutral measure is

$$\Lambda = \begin{bmatrix} -\lambda & \lambda & 0 \\ \lambda_F & -\lambda_F - \lambda_S & \lambda_S \\ 0 & 0 & 0 \end{bmatrix}. \tag{3}$$

? $\sum_j P_{i,j} = 1$

The transition probability from state i to state j is approximately $\lambda_{ij}\Delta$ over a short interval of time Δ. Naturally, one may interpret transitions from the pretarget state to the target state as deal announcements that occur with intensity λ. Once a firm is in the target state, the pending deal will fail with intensity λ_F and succeed with intensity λ_S. The small number of states keeps the model parsimonious with the empirical application in mind. In particular, the pretarget and target states allow for stock and option pricing in the periods before and after deal announcements. The acquired state allows deals to succeed.

Several extensions of the baseline model are also possible. For example, the current setup implies that all firms are eventually acquired. I can relax this feature of the model by adding an absorbing nontarget state in which no mergers occur. As an example, the firm might go bankrupt or pay out the fundamental value of dividends. Similarly, I can model rival bids by enlarging the number of states. In addition, I can allow the success intensity $\lambda_S(t)$ to be a deterministic function of event time to accommodate the hump-shaped pattern in success intensity documented in Giglio and Shue (2014). Finally, I can also incorporate a random and mean reverting deal announcement intensity to allow for merger waves as in Shleifer and Vishny (2003) and Harford (2005).

1.1 Stock Prices

I derive the main results and present extensions of the baseline model in Appendix A and Appendix B respectively. To compute stock prices, I solve the system of risk-neutral pricing partial differential equations that applies in the pretarget and target states. As the proposition below indicates, the stock price follows a modified Gordon (1959) growth formula with extra terms for the cash and acquirer stock that shareholders receive upon the consummation of a successful deal. The corollary provides further intuition by considering the limiting case when the deal-announcement intensity and the expected deal duration decrease to zero. Under those simplifying assumptions, the price in the pretarget state converges to the expected value of dividends. In a similar fashion, the price in the target state converges to the risk-neutral probability of success times the deal payout plus the risk-neutral probability of failure times the discounted expected value of dividends. The proposition generalizes these results to allow for a positive announcement intensity and expected deal duration.

Proposition 1 ***Stock Price:*** *If $r - g > 0$, the stock price in the pretarget and target states is given by the formula below. The coefficients are provided in Appendix A.*

$$P\left(D_t, P_{A,t}, s_t\right) = \begin{cases} A_0 D_t + A_1 V + A_2 P_{A,t} & s_t \in \mathcal{P} \\ B_0 D_t + B_1 V + B_2 P_{A,t} & s_t \in \mathcal{T} \end{cases} \tag{4}$$

Corollary 1 *: Let $p_Q = \frac{\lambda_S}{\lambda_S + \lambda_F}$ and $\tau_Q = \frac{1}{\lambda_S + \lambda_F}$ denote the risk-neutral probability of deal success and the risk-neutral expected deal duration. When the deal announcement intensity decreases to zero the price is*

$$\lim_{\lambda \to 0} P(D_t, P_{A,t}, s_t) = \begin{cases} \frac{D_t}{r-g} & s_t \in \mathcal{P} \\ \frac{1 - p_Q + (r-g)\tau_Q}{1 + (r-g)\tau_Q} \frac{D_t}{r-g} + \frac{p_Q}{1 + r\tau_Q} V + \frac{p_Q}{1 + q_A \tau_Q} \phi P_{A,t} & s_t \in \mathcal{T}. \end{cases} \tag{5}$$

When the expected deal duration also decreases to zero the price in the target state is

$$\lim_{\tau_Q \to 0} \lim_{\lambda \to 0} P(D_t, P_{A,t}, \mathcal{T}) = (1 - p_Q) \frac{D_t}{r - g} + p_Q \left(V + \phi P_{A,t}\right). \tag{6}$$

Figure 1 plots the stock price as a function of dividends in the pretarget, target, and acquired states holding the offer fixed. The plot highlights two features of the model. First, when the firm transitions between states, the price exhibits a discontinuous jump between the different lines on the plot. For example, when a deal is announced, the price jumps from the dashed line to the solid line, which corresponds to a jump from the price in the pretarget state to the target state. In this manner, the model captures the large and positive announcement returns of target stocks and the nonlinear payoff profile in merger arbitrage. In addition, the plot indicates that the slope with respect to dividends is lower in the target versus the pretarget state. This result is consistent with the proposition and corollary above. In particular, the stock price puts more weight on the deal payout and less weight on dividends in the target state. Moreover, the corollary shows that the slope in the target state is decreasing in the probability of deal success. This has important implications for option prices that will be discussed shortly. As a preview, the slope indicates how much dividend risk contributes to the volatility of the target stock price. A smaller slope results in less volatility and lower option prices, which creates a tight link between the change in option prices when deals are announced and the risk-neutral probability of deal success.

Figure 2 presents a different perspective by plotting the risk-neutral distribution of the stock price in the pretarget and target states for a cash deal at a four-month horizon. As the plot indicates, deal announcements shift the mass in the probability density function to the right. This corresponds to the discontinuous jump in the stock price that was observed in the previous figure. Beyond this level effect, the probability density function also highlights how deal announcements affect the higher moments of the target stock price. In the target state, the two peaks in the probability density function illustrate the mixture across deals that fail and deals that remain pending. Compared to the pretarget state, the target state has increased skewness and kurtosis. The plot also illustrates the discontinuity in the cumulative distribution function, which equals the risk-neutral probability that the deal will succeed before the four-month horizon is reached. The discontinuity stems from the fixed payment of cash that target shareholders receive when the deal succeeds. In contrast to cash deals, stock deals produce a smaller change in the distribution of the target stock price. For example, when target dividend and acquirer volatility are close, the mixture of lognormal distributions in a stock deal is similar in the pretarget and target states. Of course, it is important to note that stock deals are a generalization of cash deals. As the acquirer volatility decreases, the distribution of the target stock price in a stock deal converges to the distribution in a cash deal.

1.2 Option Prices

I price options for the target firm by directly computing the discounted expected payoff under the risk-neutral measure. To do this, I break the price into three terms that correspond to the value of the option conditioned on the state of the firm at maturity multiplied by the risk-neutral probability of the state. To that end, I derive the risk-neutral transition probabilities between states in the proposition below. Closed-form solutions are helpful in my empirical application as they allow for the fast computation of option prices. I can also obtain the transition probabilities by computing the matrix exponential of the generator numerically.

Proposition 2 ***Transition Probabilities:*** *The risk-neutral transition probabilities between states, assuming s_t follows a continuous-time Markov chain with generator Λ, are given by*

$$Q(\tau) = \begin{bmatrix} q_{11}(\tau) & q_{12}(\tau) & q_{13}(\tau) \\ q_{21}(\tau) & q_{22}(\tau) & q_{23}(\tau) \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{aligned} q_{11}(\tau) &= \tfrac{\lambda}{v_2 - v_1}\left[\left(\tfrac{v_2}{\lambda}+1\right)e^{v_1\tau} - \left(\tfrac{v_1}{\lambda}+1\right)e^{v_2\tau}\right] \\ q_{12}(\tau) &= \tfrac{\lambda}{v_2 - v_1}\left[e^{v_2\tau} - e^{v_1\tau}\right] \\ q_{21}(\tau) &= \tfrac{\lambda}{v_2 - v_1}\left[\left(\tfrac{v_2}{\lambda}+1\right)\left(\tfrac{v_1}{\lambda}+1\right)\left(e^{v_1\tau} - e^{v_2\tau}\right)\right] \\ q_{22}(\tau) &= \tfrac{\lambda}{v_2 - v_1}\left[\left(\tfrac{v_2}{\lambda}+1\right)e^{v_2\tau} - \left(\tfrac{v_1}{\lambda}+1\right)e^{v_1\tau}\right], \end{aligned} \tag{7}$$

τ ?

where $v_1 < v_2 < 0$ *are equal to* $\frac{-[\lambda+\lambda_F+\lambda_S]\pm\sqrt{(\lambda+\lambda_F+\lambda_S)^2-4\lambda\lambda_S}}{2}$ *and* $q_{13}(\tau) = 1 - q_{11}(\tau) - q_{12}(\tau)$, $q_{23}(\tau) = 1 - q_{21}(\tau) - q_{22}(\tau)$.

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The proposition below presents European put prices for the general case with cash and stock financing. The corollary provides simplified formulas for cash deals. In particular, I derive put prices in cash deals by using the Black and Scholes (1973) formula with a strike price that is adjusted for the value of the cash offer, given the state of the firm at maturity. The key difference in stock deals is that the target stock price is the sum of two lognormal random variables corresponding to the value of target dividends and the acquirer stock. For a sufficiently high realization of the acquirer stock price, a put option will be out-of-the money in a stock deal. This value corresponds to the state-dependent upper bound of integration in the proposition. Thus, I can interpret the put price in the general case as the integral of the put price in a cash deal over the realizations of the acquirer stock price below the upper bound of integration. Alternatively, I can also compute option prices numerically using the cumulative distribution function of the target stock price, which is derived in Appendix A. Finally, I can compute call option prices by put-call parity or directly as in the proposition.

Proposition 3 ***Option Prices:*** *The price of a European put option with strike price* K *and maturity* τ *equals*

$$F\left(D_t, P_{A,t}, s_t\right) = \begin{cases} q_{11}(\tau)F_{\mathcal{P}} + q_{12}(\tau)F_{\mathcal{T}} + q_{13}(\tau)F_{\mathcal{A}} & s_t \in \mathcal{P} \\ q_{21}(\tau)F_{\mathcal{P}} + q_{22}(\tau)F_{\mathcal{T}} + q_{23}(\tau)F_{\mathcal{A}} & s_t \in \mathcal{T}. \end{cases} \tag{8}$$

Let $P_{BS}(S, K, \tau, r, q, \sigma)$ *denote the put price in the Black-Scholes model. Then the value of the option conditioned on the state of the firm at maturity is*

$$\begin{aligned} F_{\mathcal{P}} &= \int_{-\infty}^{x_A^*} P_{BS}\left(A_0 D_t, K_A(x), \tau, r, q(x), \sigma\sqrt{1-\rho^2}\right) f(x)dx \\ F_{\mathcal{T}} &= \int_{-\infty}^{x_B^*} P_{BS}\left(B_0 D_t, K_B(x), \tau, r, q(x), \sigma\sqrt{1-\rho^2}\right) f(x)dx \\ F_{\mathcal{A}} &= P_{BS}\left(\phi P_{A,t}, K - V, \tau, r, q_A, \sigma_A\right), \end{aligned} \tag{9}$$

where f *is the probability density function of a standard normal random variable. The definitions for* $q(x)$, x_i^*, $K_i(x)$ *for* $i \in \{A, B\}$ *are provided in the proof of the proposition.*

Corollary 2 *: For cash deals, the formula for the put price conditioned on the state of the firm at maturity simplifies to*

$$\begin{aligned} F_{\mathcal{P}} &= P_{BS}\left(A_0 D_0, K - A_1 V, \tau, r, r - g, \sigma\right) \\ F_{\mathcal{T}} &= P_{BS}\left(B_0 D_0, K - B_1 V, \tau, r, r - g, \sigma\right) \\ F_{\mathcal{A}} &= e^{-r\tau}\left(K - V\right)^+. \end{aligned} \tag{10}$$

Figure 3 plots the volatility smile and term structure of implied volatility for a cash deal. As the plot indicates, the level of implied volatility decreases when deals are announced. This occurs because cash has zero volatility. In the target state, the stock price puts more weight on cash and less weight on dividends. Simultaneously, an implied volatility smile emerges. Although diffusive risk is low in the target state because of the small slope on dividends, the price may still exhibit a large move if the deal fails or succeeds. As such, deal risk increases the implied volatility of out-of-the money options relative to at-the-money options. In terms of comparative statics, deals with a high probability of success place more weight on cash in the target state. This magnifies the reaction described above, creating a link between option prices and the risk-neutral probability of deal success. Beyond the volatility smile, the plot also indicates that the term structure of implied volatility is downward sloping. This reflects the horizon over which deal uncertainty is expected to resolve. For stock deals, the reaction of target option prices depends on whether the acquirer stock is more or less volatile than target dividends. When the acquirer has high volatility, implied volatility can actually increase because target shareholders will be left with the volatile acquirer stock instead of the less volatile target dividends. By way of contrast, when the acquirer has low volatility, the reaction is similar to a cash deal.

1.3 Merger Arbitrage Investments

Stock and option pricing is performed under the risk-neutral measure. To study the expected returns, volatility, and Sharpe ratio of merger arbitrage investments, I introduce market prices of risk that link the risk-neutral and physical dynamics.

First, I price target dividends and the acquirer stock with the CAPM in the spirit of Sharpe (1964) and Lintner (1965). Under the physical measure, this implies that target dividends and the acquirer stock price follow

$$\frac{dD_t}{D_t} = (g + \beta_D(\mu_M - r))\, dt + \sigma\rho_M dW^{\mathbb{P}}_{M,t} + \sigma\sqrt{1-\rho_M^2}dW_{i,t} \tag{11}$$

and

$$\frac{dP_{A,t}}{P_{A,t}} = (r - q_A + \beta_A\,(\mu_M - r))\, dt + \sigma_A\rho_M dW^{\mathbb{P}}_{M,t} + \sigma_A\sqrt{1-\rho_M^2}dW_{Ai,t}. \tag{12}$$

The risk premium is reflected in the drift. It is proportional to the CAPM betas β_D and β_A. For simplicity, I assume that the market price of risk $\eta = (\mu_m - r)/\sigma_m$ is a constant. This seems to be a reasonable approximation given the short horizon of merger arbitrage investments. That said, similar results apply for a time-varying price of risk.[17]

[17]Embellishing the previous setup, I assume that innovations in target dividends and the acquirer stock

Next, I allow deal risk to be priced. This can be motivated by the intertemporal capital asset pricing model (ICAPM) following Merton (1973) or by a limits-to-arbitrage argument as in Shleifer and Vishny (1997). My analysis highlights the nonlinear aspect of deal risk. In particular, the model predicts how deal risk affects the risk-return trade-off in merger arbitrage but remains agnostic about the source of deal risk. Specifically, I let the market prices of deal risk (κ_S, κ_F) determine the success and failure intensities under the physical measure as

$$\begin{aligned} \lambda_S^{\mathbb{P}} &= e^{-\kappa_S}\lambda_S \\ \lambda_F^{\mathbb{P}} &= e^{-\kappa_F}\lambda_F. \end{aligned} \tag{13}$$

In this setup, the relationship between the objective probability of deal success p and the risk-neutral probability of deal success p_Q is

$$p = \frac{p_Q}{p_Q + (1 - p_Q)\, e^{\kappa_S - \kappa_F}} \approx p_Q + p_Q\,(1 - p_Q)\,(\kappa_F - \kappa_S)\,. \tag{14}$$

Thus, when deal risk is priced $\kappa_F - \kappa_S > 0$, the risk-neutral probability is lower than the objective probability. This occurs because deals fail in bad economic states or because deals succeed in good economic states.[18]

In the empirical analysis, I focus on cash deals and stock deals with fixed exchange ratios. To capture the arbitrage spread in these transactions, investors purchase the target stock and sell the acquirer short in an amount equal to the exchange ratio. This motivates the

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price follow the factor structures $dW_t = \rho_M dW_{M,t} + \sqrt{1-\rho_M^2}\,dW_{i,t}$ and $dW_{A,t} = \rho_M dW_{M,t} + \sqrt{1-\rho_M^2}\,dW_{Ai,t}$ where $\rho_M \equiv \sqrt{\rho}$ so that $E_t^{\mathbb{Q}}[dW_t dW_{A,t}] = \rho dt$. The price of risk process η links the risk-neutral and physical dynamics by $dW_{M,t} = dW_{M,t}^{\mathbb{P}} + \eta_t dt$. Under the physical measure $\mathbb{P}$ market risk $W_{M,t}^{\mathbb{P}}$ is a Brownian motion by Girsanov's theorem. For a formal statement, see Duffie (2010) or Karatzas (1991). I assume that η is a constant for simplicity. The results also generalize to the case when $\eta_t = (\mu_{M,t} - r)/\sigma_{M,t}$ is an Ito process. In particular, this allows for well-documented features of aggregate returns like time variation in the equity risk premium and stochastic volatility. See, for instance, Bollerslev et al. (1994), Cochrane (2011), and van Binsbergen et al. (2013).

[18]For a general version of Girsanov's theorem with jumps, see Jacod and Shiryaev (1987) and Protter (2004). Similar to the previous discussion, the results extend to allow for time-varying market prices of deal risk. To interpret why deal risk might be priced, note that merger arbitrage will earn a risk premium as in the ICAPM if deal outcomes covary with economic state variables. In support of this hypothesis, Mitchell and Pulvino (2001) find that merger arbitrage exhibits downside risk. I confirm their result and demonstrate that merger arbitrage loads significantly on an index put-writing strategy. This suggests that deal failures embed systematic risk. To model this, suppose $dN_F = dN_{F,M} + dN_{F,i}$ with the intensity $\lambda_{F,M} + \lambda_{F,i}$ under $\mathbb{Q}$ and $e^{-\kappa_{F,M}}\lambda_{F,M} + \lambda_{F,i}$ under $\mathbb{P}$. Then, the wedge $(e^{-\kappa_{F,M}} - 1)\lambda_{F,M}$ results in a deal risk premium leading to the same qualitative results as my baseline model. As an alternative view, Baker and Savaşoglu (2002) argue that idiosyncratic deal risk commands a risk premium because capital-constrained or risk-averse arbitrageurs absorb supply shocks when deals are announced. In their model, the market price of deal risk is determined by arbitrageur risk aversion, the size of the supply shock relative to arbitrageur wealth, and the size of the loss in the event of deal failure.

following definition for instantaneous merger arbitrage excess returns

$$dR^e_{MA,t} \equiv \frac{dP_t + D_t dt - \phi \left[dP_{A,t} + D_{A,t} dt - rP_{A,t} dt \right]}{P_t} - rdt. \tag{15}$$

Building on this, proposition 4 derives the expected returns, variance, and beta for merger arbitrage investments.[19] As the proposition indicates, expected returns have a three-factor structure that compensates investors for bearing market risk, deal success risk, and deal failure risk. The first factor equals the merger arbitrage beta multiplied by the market risk premium. The second and third factors equal the arbitrage spread and the loss in the event of deal failure multiplied by the wedge between the physical and the risk-neutral success and failure intensities. The variance has a similar decomposition into three factors. Finally, the proposition indicates that the merger arbitrage beta is lower than the target dividend beta.

Proposition 4 ***Merger Arbitrage Risk Premium:*** *The merger arbitrage risk premium* $\mu_{MA,t} dt \equiv E^{\mathbb{P}}_t \left[dR^e_{MA,t} \right]$ *may be decomposed into compensation for market risk and deal risk*

$$\mu_{MA,t} = \underbrace{\beta_{MA,t} \left(\mu_M - r \right)}_{\text{Market Risk Premium}} + \underbrace{\left(e^{-\kappa_S} - 1 \right) \lambda_S \left(\frac{P_t(\mathcal{A})}{P_t(\mathcal{T})} - 1 \right) + \left(e^{-\kappa_F} - 1 \right) \lambda_F \left(\frac{P_t(\mathcal{P})}{P_t(\mathcal{T})} - 1 \right)}_{\text{Deal Risk Premium}} \tag{16}$$

where $P_t(s) \equiv P(D_t, P_{A,t}, s)$. *The variance* $\sigma^2_{MA,t} dt \equiv var^{\mathbb{P}}_t \left(dR^e_{MA,t} \right)$ *and CAPM beta are*

$$\sigma^2_{MA,t} = \underbrace{\lambda^P_S \left(\frac{P_t(\mathcal{A})}{P_t(\mathcal{T})} - 1 \right)^2 + \lambda^P_F \left(\frac{P_t(\mathcal{P})}{P_t(\mathcal{T})} - 1 \right)^2}_{\text{Deal Risk}} + \tag{17}$$

$$\underbrace{\frac{\left(B_0 \sigma D_t \right)^2 + \left(\left(B_2 - \phi \right) P_{A,t} \sigma_A \right)^2 + 2 B_0 \sigma D_t \left(B_2 - \phi \right) \sigma_A P_{A,t} \rho}{P_t \left(\mathcal{T} \right)^2}}_{\text{Market Risk}}$$

and

$$\beta_{MA,t} = \frac{\beta_D B_0 D_t + \beta_A \left(B_2 - \phi \right) P_{A,t}}{B_0 D_t + B_1 V + B_2 P_{A,t}}. \tag{18}$$

To summarize the model's predictions, Figure 4 plots comparative statics to illustrate how the expected returns, volatility, beta, and Sharpe ratio in merger arbitrage vary with the risk-neutral probability of deal success. When deal risk is priced, the plot indicates that

[19] The assumption that investments are funded at the risk-free rate is unrealistic in practice. For example, the activity of merger arbitrageurs can make it difficult for prime brokers to locate shares to short. When merger stocks are "on special," short sale proceeds can earn less than the risk-free rate. There is also a risk the lender will recall the short prior to the resolution of deal uncertainty. In addition, funding costs may exceed the risk-free rate and be correlated with an investor's past performance. I abstract from these concerns to study how the nonlinear payoff profile affects the risk-return trade-off.

expected returns are hump-shaped in the probability of success. This occurs because deal risk is binary. The contribution of the deal success and failure factors is roughly proportional to the risk of a binary outcome whose variance is largest when there is an equal probability of success and failure. At the same time, merger arbitrage volatility and beta are decreasing in the probability of success. This occurs because deals with a high probability of success place more weight on the arbitrage spread and less weight on volatile target dividends. To see this graphically, recall from Figure 1 that the slope of the target stock price with respect to dividends is decreasing in the probability of success. The combination of hump-shaped expected returns and decreasing volatility results in a Sharpe ratio that is concave in the probability of success. The largest Sharpe ratio occurs in deals with a high probability of success. In particular, high-probability deals earn a risk premium for bearing deal risk but have low volatility because of the low weight on target dividends. Finally, note that the model predictions change in the absence of deal risk. When deal risk is not priced, the Sharpe ratio is a constant and expected returns are decreasing in the probability of success.

2 Data Description and Model Estimation

2.1 Data Description

My empirical analysis relies on three primary sources of data. I obtain detailed information pertaining to merger activity from Thomson One Banker, using the database formerly known as SDC. I then match deals to CRSP and OptionMetrics for stock and option data. The sample period is 1996 to 2012.

To select deals, I impose the following filters: targets must be U.S. nonbankrupt public companies, acquirers must seek a majority share in the target, deals must be classified as mergers or acquisitions, and payouts to target shareholders must be in the form of cash or fixed amounts of acquirer shares.[20] Finally, to exclude rival bids and revisions to previous offers, I require offer announcement dates to equal original announcement dates, which are defined as the first date a target company is publicly disclosed as being a possible takeover candidate. Table 1 reports summary statistics for the deals matched to CRSP and Option-

[20]I include mergers, acquisitions, acquisitions of majority interest, acquisitions of remaining interest, and acquisitions of partial interest. I exclude deals with complicated payout features that involve collars, spin-offs, asset swaps, restructurings, or recapitalizations. For example, stock deals with collars embed implicit options for target shareholders in which the payout can depend on the average acquirer stock price during a pricing period 10 to 20 days before the effective date of the merger. Mitchell and Pulvino (2001) provide evidence that deals with complicated payouts are similar to cash deals and stock deals with fixed exchange ratios along a number of dimensions including the success probability, offer premium, announcement returns, and target returns after the announcement. Collars have been studied in the literature by Officer (2004, 2006) who finds that collars are useful in minimizing renegotiation costs.

Metrics. The full sample includes 3,836 deals consisting of 2,856 cash deals and 980 stock deals. In cash deals, the probability of success is 78%, the average deal duration is 3.7 months, the average offer size is $743 million, and the average offer premium is 40% relative to the target stock price one week before the announcement. In comparison to cash deals, stock deals are larger in size, more likely to succeed, longer in duration, and more likely to have a target and acquirer from the same industry. In terms of similarities, cash and stock deals both feature substantial offer premiums and acquirers that are significantly larger than target firms. Meanwhile, the subset of deals with options data includes 1,094 deals consisting of 744 cash deals and 350 stock deals. Compared to the full sample, the option sample has larger deals, smaller offer premiums, and smaller arbitrage spreads. Beyond these differences, the probability of success and average duration are similar for cash and stock deals in both the full sample and the option sample. Finally, it remains the case that acquirers are much larger than target firms in the option sample.

I estimate the risk-neutral probability of deal success by fitting the model from the previous section to the reaction of target stock and option prices when deals are announced. I perform the estimation with closing prices from OptionMetrics for each deal with available options data.[21] For an option price to be included in the estimation, I require a positive bid, positive offer, bid less than or equal to the offer, positive Black-Scholes implied volatility, Black-Scholes delta less than 70%, maturity between 8 and 365 calendar days, and moneyness, defined as the strike-to-spot price ratio, between 30% and 200%. I fit the model to the first 200 prices observed in the preannouncement and postannouncement windows surrounding the deal announcement. Specifically, I define the preannouncement window as the period between 15 and 5 calendar days before the announcement and the postannouncement window as the period between 1 and 10 calendar days after the announcement.[22] I also require that deals have at least 10 option prices in both the preannouncement and the postannouncement windows to be included in the option sample.

Table 1 reports summary statistics for the option data used in the model estimation and

[21]Target option prices are the mid-price from the best bid and best offer at the close. I estimate the model with the European option pricing function derived in the previous section. This abstracts from the fact that listed single stock options are American and subject to contract adjustments. For example, when cash deals succeed payments are accelerated for in-the-money options in accordance with OCC Rule 807. Empirically, I find the value of early exercise is small and significantly less than typical bid-ask spreads for the short-dated out-of-the money options in my sample. To that end, I filter option prices by removing violations of no arbitrage bounds and large violations of European put-call parity. In total, these filters remove less than .25% of option prices from the sample.

[22]The results are robust to changing the observation windows around deal announcements and the filters on option prices. For example, a shorter postannouncement window has little impact on the substantive conclusions, but it does remove some deals from the sample, given the requirement to observe at least 10 option prices before and after the announcement.

the average model pricing errors. The results indicate that the model is estimated with short-dated out-of-the money options. In particular, the average maturity and Black-Scholes delta are four months and 35%. Moreover, the table reveals a large increase in option volumes, open interest, and the percentage of puts being traded when cash deals are announced. This finding is similar to the stock market reaction to deal announcements, which is characterized by a significant increase in the trading volume of target and acquirer stocks. If the increase in volume is driven by informed trading, the results suggest that stock and option prices will be informative about deal outcomes. In addition to the amount traded, the table also reports the risk-neutral moments of the target stock price at a four-month horizon.[23] The change in the risk-neutral moments is consistent with the model developed in the previous section. For example, when cash deals are announced, the risk-neutral variance decreases whereas the risk-neutral skewness and kurtosis increase. This aligns with the intuition from Figure 2. The table also indicates that the model fits option prices significantly better than the Black and Scholes (1973) model. This is particularly true for postannouncement options in cash deals, which suggests the model captures the implied volatility smile in the data. By way of contrast, the Black-Scholes model has a flat volatility surface, which results in large percentage pricing errors for out-of-the money options in cash deals. Finally, the table also indicates that the change in the risk-neutral distribution of the target stock price is less severe in stock deals. While this finding is consistent with the model, it suggests that the reaction of option prices will be less informative about the probability of deal success in stock deals than in cash deals.

2.2 Model Estimation

To estimate the model, I assume that target options are observed with measurement errors. For example, errors might stem from asynchronous trading or bid-ask spreads. Under this setup, the measurement equation is

$$Y_{t,j} = F\left(X_{t,j}, \theta\right) + \epsilon_{t,j}, \tag{19}$$

where $Y_{t,j}$ is the observed closing price of option j on date t and F is the option pricing function from Proposition 3. The independent variable $X_{t,j}$ collects the level of dividends,

[23] I compute the risk-neutral moments of log returns at a four-month horizon following Bakshi et al. (2003), who show that the risk-neutral moments can be replicated with a portfolio of out-of-the-money call and put options. To implement their result, I use the fitted values from a regression of target implied volatility onto log-moneyness, log-moneyness squared, and maturity before and after deal announcements. I then estimate the risk-neutral moments with fitted values from the regressions truncated at the 5th and 95th quantiles of observed implied volatility. The truncation ensures the risk-neutral moments remain finite and is stronger than Lee (2004) who shows, in the absence of arbitrage, that the tail of Black-Scholes implied volatility is bounded by twice the square root of the absolute value of log-moneyness divided by maturity.

acquirer stock price, state of the firm, and option characteristics such as the strike, maturity, and whether the option is a call or put. I estimate the risk-neutral probability of deal success $\theta = p_Q$ by minimizing the sum of squared option pricing errors, having inferred the model-implied level of dividends from closing target stock prices,

$$\hat{\theta} = \arg\min_{\theta \in \Theta} \sum_{s \in \{\mathcal{P}, \mathcal{T}\}} \frac{1}{N_s} \sum_{t,j \in \mathcal{O}_s} \left(\frac{Y_{t,j} - F\left(X_{t,j}, \theta\right)}{Y_{t,j}} \right)^2 .$$

The number of options in the preannouncement and postannouncement windows [illegible]d as $N_s = |\mathcal{O}_s|$ for $s \in \{\mathcal{P}, \mathcal{T}\}$, respectively. In the upcoming section, I use the estimated risk-neutral probability of success to forecast deal outcomes. Abusing notation, I occasionally denote the estimated probability as p_Q instead of $\hat{p}_Q$ and, in some instances, refer to the estimated probability as the model-implied probability. Before presenting the forecasting results, I discuss a few applications to specific deals.[24]

2.3 Examples of Estimated Deals

On August 15, 2011, Google announced a \$12.45 billion offer to acquire Motorola for \$40 per share. Stock and option markets reacted similarly to the proposed deal, with both markets implying a high probability that the offer would succeed. Figure 5 plots the implied volatility of Motorola options against moneyness and maturity. After the announcement, at-the-money implied volatility decreased and skewness increased. Figure 6 contrasts the market reaction with the model's fitted option prices at the estimated risk-neutral probability of success $\hat{p}_Q = .79\,(.007)$. The model captures the decrease in the at-the-money implied volatility and the increase in skewness, which are characteristics of deals with a high probability of success. Figure 6 also plots the stock market reaction. When the deal was announced, Motorola's stock jumped over 50%, resulting in a share-implied probability of success equal to $\hat{p}_Q^S = .89$. Ultimately, Google succeeded in acquiring Motorola on May 22, 2012.[25]

[24] Singleton (2006) discusses the estimation of equity option pricing models. I set the remaining parameters to $r = .03$, $g = .01$, $\lambda = .01$, $\tau_Q = .33$ for each deal and let σ equal the Black-Scholes implied volatility that minimizes option pricing errors in the pretarget state. This approach is fast to implement and facilitates the computation of asymptotic and bootstrapped standard errors for the risk-neutral probability of deal success. It is motivated by Corollary 1, which shows that Black-Scholes option pricing applies exactly in the pretarget state when the announcement intensity decreases to zero. Alternative estimation strategies like nonlinear least squares and estimating $\theta = (p_Q, \tau_Q, \lambda, \sigma)$ separately for each deal produce similar results. For nonlinear least squares, the model is identified by the conditional mean identification condition. Specifically, short-dated in-the-money options are approximately linear in the target stock price so $\theta \neq \theta_0$ implies $F(X_{t,j}, \theta_0) \neq F(X_{t,j}, \theta)$. This permits the estimation of the coefficients (A_0, A_1, A_2) and (B_0, B_1, B_2).

[25] The deal with Motorola represented Google's largest acquisition to date and entry into the smart phone market. Uncertainty about the outcome was present from the outset. For example, on the announcement date, the *Wall Street Journal* published an article titled "Google-Motorola Deal: Signs of Regulatory Worries,"

To provide an example of a failed deal, Figure 6 also illustrates ConAgra's offer to acquire Ralcorp for $86 per share announced on April 29, 2011. In this case, stock and option markets diverged in their forecasts for the deal outcome. The stock market reacted positively to the offer $\hat{p}_Q^S = .84$ despite an unsupportive reception from Ralcorp's board. In particular, Ralcorp adopted a poison pill shortly after the announcement, indicating that ConAgra's offer was not in the best interest of shareholders.[26] In contrast to the stock market reaction, option prices exhibited a muted response to the proposed deal. The model captures this effect with an estimated risk-neutral probability of $\hat{p}_Q = .27$ (.057), which produces a relatively flat implied volatility surface in the pretarget and target states. In the end, ConAgra terminated its offer on September 19, 2011 and Ralcorp subsequently executed a spin-off of its subsidiary Post Cereals in January 2012.

3 Forecasting Deal Outcomes

The estimated risk-neutral probability of success significantly forecasts deal outcomes. Moreover, the estimated risk-neutral probability remains significant in the presence of target stock prices, reduced-form variables from target option prices, control variables, and time and industry fixed effects.[27] The results are also robust across time. In particular, the estimated risk-neutral probability outperforms the share-implied probability and the reduced-form variables from option prices throughout the sample period. Finally, the results reject the hypothesis that deal risk is not priced in favor of the alternative hypothesis that the risk-neutral probability of success is lower than the true probability of success.

Figure 7 provides the intuition for these results by plotting the average reaction of target option prices to cash deal announcements. As the plot indicates, implied volatility decreases

highlighting antitrust approval as a key risk. In addition to the requirement that the deal be approved by regulators in the United States, Europe, and China, the U.S. Department of Justice had recently launched an investigation into Google's search and advertising business, resulting in a concern that the deal might be subject to heightened regulatory scrutiny. Nonetheless, stock and option markets reacted positively to the announcement, which was an accurate forecast of the successful outcome.

[26] "ConAgra Bids $4.9 Billion for Ralcorp," *New York Times*, May 4, 2011. Ralcorp had also instituted a staggered board requiring at least two annual meetings to replace a majority of directors and was incorporated in Missouri, which requires two-third's shareholder approval as opposed to majority shareholder approval in Delaware.

[27] To be specific, I control for hostile deals, tender offers, leveraged buyouts, bridge financing, targets and acquirers being located in the same state or being in the same industry, whether the offer is greater than the 52-week high of the target stock price, the deal spread, the size of the target, the deal premium, and the offer level. In particular, I control for the variables highlighted in the literature that are known to forecast deal outcomes, including the target stock price, the attitude of the acquirer, and the relation of the offer to the 52-week high of the target stock price as discussed in Walkling (1985), Brown and Raymond (1986), Samuelson and Rosenthal (1986), Schwert (2000), and Baker et al. (2012). In comparison, Edmans et al. (2012) illustrate that decreases in target stock prices increase the likelihood of takeover.

and skewness increases when deals are announced. Furthermore, the change in the volatility smile is more pronounced in deals that are ex-post successful. For example, at-the-money implied volatility decreases over 60% in successful deals but only 25% in failed deals. This immediately suggests that target option prices forecast deal outcomes and motivates the definition of reduced-form variables that can serve as additional predictors to compete with the dynamic model in the regressions below. Specifically, I compute the risk-neutral moments of the target stock price, including the level of the risk-neutral variance and skewness after the announcement and the change in the risk-neutral variance. I also find similar results for stock deals when the acquirer is less volatile than the target. The results for stock deals are provided in Appendix C.

Table 2 reports linear-probability regressions for cash deals to illustrate the forecasting content of the estimated risk-neutral probability of success. The dependent variable equals one for successful offers and zero for failed offers. For ease of interpretation, the risk-neutral moments are standardized to be mean zero and standard deviation one. In the first three specifications, the table contrasts the estimated risk-neutral probability of success, the share-implied probability of success, and the risk-neutral moments derived from target option prices. The results indicate that the estimated risk-neutral probability, which relies on the joint information in target stock and option prices, produces the most accurate forecasts with an R^2_{adj} of 34%. The fourth specification demonstrates that the model has greater explanatory power than the second and third specifications combined. In addition, to illustrate the robustness of the results, the fifth and sixth specifications add control variables and time and industry fixed effects. In both cases, the estimated risk-neutral probability of success remains highly statistically significant. Moreover, in the sixth specification, the estimated risk-neutral probability drives out the significance of the risk-neutral moments and substantially decreases the point estimate on the share-implied probability of success. Finally, the R^2_{adj} increases only from 34% to 38% between the first and sixth specifications. Taken together, the results suggest that the model delivers significant and accurate forecasts that capture most of the explanatory power for predicting deal outcomes.

In addition to forecasting, the regression analysis provides evidence that deal risk is priced. In particular, under the null hypothesis that deal risk is not priced, the risk-neutral probability of success equals the true probability of success. In a linear-probability regression, this is equivalent to an intercept of zero and a regression coefficient of one on the risk-neutral probability of success.[28] The results in Table 2 reject this hypothesis. The point

[28]Recall that $p_{Q,i} = p_i/(p_i + (1-p_i)e^{\kappa_F - \kappa_S})$ from $\lambda^{\mathbb{P}}_{S,i} = e^{-\kappa_S}\lambda_{S,i}$ and $\lambda^{\mathbb{P}}_{F,i} = e^{-\kappa_F}\lambda_{F,i}$. Under the null hypothesis that deal risk is not priced $H_0 : \kappa_F - \kappa_S = 0$ it follows that $p_{Q,i} = p_i$. This is equivalent to $\beta_0 = 0$ and $\beta_1 = 1$ in a regression of deal outcomes onto the risk-neutral probability of success $Y_i = \beta_0 + \beta_1 p_{Q,i} + \epsilon_i$. The alternative hypothesis that deal risk is priced $H_1 : \kappa_F - \kappa_S > 0$ implies that $p_{Q,i} < p_i$.

estimate on the risk-neutral probability of success is significantly less than one in each of the specifications. In particular, the results favor the alternative hypothesis that the risk-neutral probability of success is lower than the true probability of success.

A potential concern with this interpretation is measurement error. Empirically, I regress deal outcomes onto the estimated risk-neutral probability, which creates an errors-in-variables problem that might lead me to spuriously reject the null hypothesis. To account for this, I consider several robustness checks to ensure that measurement error is not driving my results. For example, the bottom panel in Table 2 illustrates that the point estimate is relatively stable and that explanatory power increases when the regression is run on subsets of deals with progressively smaller standard errors for the estimated risk-neutral probability. This indicates that measurement error is small compared to the deal risk premium supporting my interpretation of the results as an indication that deal risk is priced. In addition, I can also provide instrumental variable and Monte Carlo evidence that rejects the null hypothesis that deal risk is not priced and supports the conclusion that measurement error is small.[29]

To further illustrate the robustness of the results, Figure 8 plots the out-of-sample R^2_{adj} for cash deals using different initial estimation periods. For each split of the full sample, I estimate the first three specifications in Table 2 in rolling monthly regressions with deals that have already succeeded or failed. Forecasts for deals announced in the following month are then computed by combining the estimated coefficients from the linear model with the forecasting variables, including the estimated risk-neutral probability of success, the share-implied probability of success, and the risk-neutral moments derived from target option prices. The results indicate that the dynamic model outperforms the competing models throughout the entire sample period.

4 Merger Arbitrage

Nonlinear risk is a key feature of merger arbitrage. In my sample, when deals are announced, the median target stock price jumps 27% and trades at a 3.5% arbitrage spread to the offer. As a result, merger arbitrageurs have little upside. The payoffs when deals succeed are

[29] If I instrument with a constant following Friedman (1957), the variable $S \equiv E[Y]/E[\hat{p}_Q]$ satisfies $H_0 : S = 1$ and $H_1 : S > 1$ where Y is the deal outcome and $\hat{p}_Q$ is the estimated risk-neutral probability. In cash deals, $\hat{S} = 1.23$ with a 99% confidence interval of (1.18, 1.28), which rejects the null in favor of the alternative hypothesis that deal risk is priced. Also, due to the large number of option prices used in the first-stage estimation, the average standard error for cash deals is .025. In Monte Carlo simulations, this results in an empirical size of 5.61% in 50,000 draws for a 5% nominal size test that is analogous to my regression setup. In particular, I draw the true p_Q with replacement from the empirical distribution of the estimated $\hat{p}_Q$ for $N = 738$ deals, generate outcomes under the null hypothesis that the deal risk premium is zero, and test whether I can reject the null hypothesis in linear-probability regressions after contaminating the true p_Q with normally distributed noise whose standard deviation is .025.

small relative to the losses when deals fail. To present a new perspective on the risk-return trade-off in these investments, I study merger arbitrage in the dynamic model outlined in this paper and test the model's predictions empirically.

In the data, there is strong support for the prediction that volatility is decreasing in the probability of deal success. Related to this result, there is also evidence that Sharpe ratios are larger in deals with a high probability of success. For example, a trading strategy that invests in high-probability deals obtains a monthly Sharpe ratio that is over 50% larger than the Sharpe ratio in an equal-weighted portfolio that invests in all of the active deals in the economy. This is equivalent to nearly doubling the CAPM alpha t-statistic of a merger arbitrage portfolio and, in the context of the model, is consistent with the hypothesis that deal risk is priced. Finally, I show that an extension of the baseline model makes accurate predictions for the evolution of expected returns and volatility in event time.

4.1 Portfolio Returns

I construct merger arbitrage portfolio returns following the buy-and-hold strategy outlined in Mitchell and Pulvino (2001). Deals are added to portfolios two business days after the announcement date. They are held until the target firm delists from CRSP, two business days pass the termination date, or one year elapses, whichever comes first. The termination date refers to the effective date for successful deals and the date withdrawn for failed deals. The portfolios are rebalanced monthly. They make investments in deals with nonnegative arbitrage spreads whose offers are greater than one dollar. I compute portfolio returns each month in which at least 10 deals satisfy this criteria subject to a 10% maximum portfolio weight for an individual investment.

In my implementation of the buy-and-hold strategy, I consider arbitrage, cash, and high-probability portfolios.[30] The arbitrage portfolios invest in cash, stock, and hybrid deals. The cash portfolios invest exclusively in cash deals. The high-probability portfolios are new to the literature. They invest in deals with a share-implied probability of success that is 70% or more. Finally, to study the cross-section of returns, I construct five sorted arbitrage and cash portfolios using the share-implied probability of success. In particular, I use the share-implied probability for portfolio construction because it is available for all of the deals

[30] To provide a sense for what these portfolios comprise, the average number of deals, deal size in millions, percentage of cash deals, percentage of deals with target options data, and turnover are (75, 779, .72, .31, .33) for the equal-weighted arbitrage portfolio, (52, 599, 1, .26, .35) for the equal-weighted cash portfolio, and (49, 861, .72, .32, .47) for the high-probability portfolio that invests in cash and stock deals. As such, there are 15 and 10 deals in the sorted arbitrage and cash portfolios on average. Note also that the average turnovers are close to the average deal durations of .31 and .39 months in cash and stock deals. Last, I find that the results are robust to the definition of the high-probability portfolio. For example, an 80% cut-off produces a CAPM alpha of .0045 (7.93) versus .0046 (8.46) for a 70% cut-off.

in my sample at the time of investment. To provide complementary analysis, I also report cross-sectional regressions using the estimated risk-neutral probability for the subset of deals with target options data.

Table 3 reports summary statistics for the constructed monthly merger arbitrage returns alongside hedge fund index returns for merger arbitrage and event driven strategies.[31] In comparison to the index returns, the constructed returns appear representative along several dimensions. For example, the average returns, low volatility, large Sharpe ratios, low betas, and statistically significant monthly alphas of 40 to 50 basis points are similar across the various merger arbitrage return series. In addition, the correlation matrix indicates that the merger arbitrage returns are positively correlated with each other, the market, and the small-minus-big factor from Fama and French (1993). The positive correlation with small-minus-big is consistent with the fact that merger arbitrage strategies are long small target firms relative to large acquirers that are sold short in stock deals.

4.2 Merger Arbitrage Volatility

In the data, there is strong support for the model's prediction that volatility is decreasing in the probability of deal success.[32] To illustrate this result, Table 4 reports cross-sectional regressions for cash deals and Fama-MacBeth regressions for merger arbitrage portfolios sorted on the share-implied probability of success. The cross-sectional regressions indicate that volatility is decreasing in the estimated risk-neutral probability and increasing in the estimated target dividend volatility. This is consistent with the model and robust across various specifications that include control variables and fixed effects.[33] For ease of interpretation, the explanatory variables are standardized to be mean zero and standard deviation one. For example, in the third specification, a one-standard deviation increase in the estimated risk-

[31] The HFRI and Dow Jones Credit Suisse index returns are reported net of fees. To adjust for this, I report summary statistics for pre-fee excess returns, assuming a 2% flat fee and 10% incentive fee are payable monthly following Jurek and Stafford (2015). To compare the average monthly returns reported in other studies, Giglio and Shue (2014) indicate that buy-and-hold strategies earned 51 basis points per month from 1991-2010 and 71 basis points per month from 1970-2010.

[32] By way of contrast, I find no evidence to accept or reject the model's prediction that expected returns are hump-shaped in the probability of success. In part this is attributable to the robust finding for volatility. Volatile returns for low-probability deals result in wide confidence bands making the hump-shaped pattern difficult to detect or reject. Results illustrating this finding are available upon request.

[33] Specifically, I control for hostile deals, tender offers, leveraged buyouts, bridge financing, targets and acquirers being located in the same state or being in the same industry, whether the offer is greater than the 52-week high of the target stock price, the deal spread, the size of the target, the deal premium, the offer level, the share-implied probability of success, and the risk-neutral moments of the target stock price. The second and third specifications add market returns, small-minus-big, high-minus-low, momentum, and the absolute value of market returns as aggregate control variables. The fourth and fifth specifications replace the aggregate control variables with calendar time fixed effects.

neutral probability is associated with a 1.26% decrease in monthly absolute excess returns. The bottom panel provides further evidence by reporting Fama-MacBeth regressions for the sorted arbitrage and cash portfolios. The results indicate that the share-implied probability significantly explains the cross-section of realized volatility with a magnitude that increases with the forecasting horizon.

Figure 9 provides graphical evidence to complement the regressions. It plots the average monthly volatility and Sharpe ratio for each of the five sorted arbitrage portfolios along with 95% confidence bands against the average share-implied probability of success. In comparison to the low-probability portfolios, the sorted high-probability portfolios exhibit less volatility and earn higher Sharpe ratios. I also find that similar results hold for the high-probability portfolios that invest in deals with a share-implied probability of success that is 70% or more. For example, Table 3 reports that the monthly volatility, Sharpe ratio, alpha, and alpha t-statistic are (.0090, .5364, .0046, 8.46) for the high-probability arbitrage portfolio versus (.0170, .3276, .0049, 4.4368) for the equal-weighted arbitrage portfolio. This indicates that volatility is lower, the Sharpe ratio is higher, the alpha is similar, and the alpha t-statistic is higher in the high-probability portfolio. Moreover, Table 5 indicates that the results are robust for various risk models. As an example, merger arbitrage loads significantly on a put-writing strategy that is shown to replicate hedge fund returns in Jurek and Stafford (2015). This is consistent with the interpretation in Mitchell and Pulvino (2001) that merger arbitrage exhibits downside risk. Under this specification, the high-probability and equal-weighted strategies earn alphas of .0043 (7.09) and .0042 (3.58) which are similar to the CAPM alphas and alpha t-statistics. To relate the discussion to the dynamic model outlined in this paper, the model predicts only that the Sharpe ratio is larger in high-probability deals when deal risk is priced. As such, the large Sharpe ratios for the high-probability portfolios provide further evidence that deal risk is priced, which corroborates the forecasting evidence from the previous section.

4.3 The Path of Merger Arbitrage Returns

My baseline model assumes that deal success and failure intensities are constant. While this is consistent with empirical estimates for the deal failure intensity, it stands in contrast to Giglio and Shue (2014), who document a hump-shaped pattern in the intensity of deal success. To incorporate this observation into my setup, I extend the baseline model to allow the risk-neutral success intensity $\lambda_S(t)$ to be a deterministic function of event time. Calibrating the success intensity to the pattern in the data, the model predicts that expected returns are hump-shaped and that volatility is increasing in event time.

I present the extended model in Appendix B. To summarize the results, the target stock price continues to follow a modified Gordon growth formula

$$P\left(D_t, P_{A,t}, \mathcal{T}\right) = B_0\left(t\right) D_t + B_1\left(t\right) V + B_2\left(t\right) P_{A,t}, \tag{21}$$

in which the coefficients on target dividends and the deal payout are now functions of event time ($B_0(t), B_1(t), B_2(t)$) that solve linear first-order differential equations with closed-form solutions. As before, I assume the relationship between the objective and the risk neural intensities is

$$\begin{aligned} \lambda_S^{\mathbb{P}}\left(t\right) &= e^{-\kappa_S}\lambda_S\left(t\right) \\ \lambda_F^{\mathbb{P}} &= e^{-\kappa_F}\lambda_F, \end{aligned} \tag{22}$$

where (κ_S, κ_F) are the market prices of deal risk.[34]

To understand the path of expected returns, it is important to distinguish between the probability of deal success and the success intensity. In particular, the contribution of deal success risk to expected returns is

$$\left(e^{-\kappa_S} - 1\right)\lambda_S(t)\left[\frac{V + \phi P_{A,t}}{P_t(\mathcal{T})} - 1\right]. \tag{23}$$

When the success intensity $\lambda_S(t)$ is high, the leading term above is large, which increases expected returns. However, there could be a mitigating effect as the price $P_t(\mathcal{T})$ is also affected by the success intensity. A higher intensity might lead to a higher price, which could potentially decrease the arbitrage spread so that expected returns would not display a hump shape in event time.

Figure 10 indicates this is not the case. Expected returns are hump-shaped and volatility is increasing in event time because the target stock price is determined by the probability of success rather than the success intensity. In particular, once the success intensity peaks, the average intensity of success over future dates is decreasing along with the probability of success and the target stock price. As such, the arbitrage spread is actually increasing when the success intensity is at its highest point. The result is a hump-shaped pattern in expected returns and volatility that increases in event time because the probability of deal success peaks and then begins to decrease.

[34] For notational convenience, I assume that deal announcements occur at time zero. As such, the probability of deal success is $p(t) = 1 - \int_t^\infty \lambda_F^{\mathbb{P}} e^{-\int_t^u \lambda_S^{\mathbb{P}}(x)dx - \lambda_F^{\mathbb{P}}(u-t)} du$ in event time.

5 Conclusion

In summary, this paper proposes a dynamic asset pricing model that exploits the joint information in stock and option prices to accurately forecast deal outcomes. In addition, I also apply the model to study merger arbitrage. When deal risk is priced, the model predicts that merger arbitrage exhibits low volatility and a large Sharpe ratio when deals are likely to succeed. Cross-sectional and Fama-MacBeth regressions confirm these results, indicating that merger arbitrage volatility is lower in deals with a high probability of success. Moreover, a portfolio that overweights deals with a high probability of success has a monthly Sharpe ratio that is 50% larger than an equal-weighted portfolio. Finally, an extension of the baseline model is consistent with the dynamic properties of expected returns and volatility in event time. Overall, these results highlight how a parsimonious model with a nonlinear payoff profile and priced deal risk can match various features of merger arbitrage returns and deliver accurate forecasts for deal outcomes. Moving forward, this research can be extended in several directions. For example, it would be interesting to investigate whether option markets anticipate rival bids or revisions to existing offers. I could also test whether positive skewness in option prices predicts deal announcements. Finally, I have emphasized throughout the paper that option prices are informative about corporate events that result in stock prices equaling a fixed value with a discrete probability. In addition to mergers and acquisitions, bankruptcy and certain lawsuits are natural examples where similar analysis may prove useful.

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Tables

Table 1: Deal and Option Summary Statistics

Panel A compares the average deal characteristics across the option sample and full sample for cash and stock financed transactions. Outcome equals one for successful offers and zero for failed offers. Panel B reports summary statistics for target option prices averaged across deals before and after announcements, including the number of options N, fraction of call options $Call$, days from the announcement T, maturity in years τ, implied volatility σ, absolute delta $|\Delta|$, four month risk-neutral variance, skewness, and kurtosis, open interest in thousands, volume in hundreds, and root mean squared percentage pricing errors in the estimated model and Black and Scholes (1973) model. To mitigate the impact of outliers, the variables are winsorized at the 1st and 99th quantiles.

	Option Sample		Full Sample	
Panel A: Deal Summary Statistics	Cash	Stock	Cash	Stock
Number of Deals	744	350	2,856	980
Outcome	0.76	0.83	0.78	0.88
Duration (yrs)	0.32	0.38	0.31	0.39
Premium	0.35	0.29	0.40	0.34
Spread	0.04	0.05	0.06	0.06
Price/Book	3.31	5.02	2.39	3.44
Price/EPS	29.60	36.82	27.20	27.95
Industry	0.54	0.79	0.53	0.84
Hostile	0.05	0.01	0.02	0.00
Deal Value (bn)	2.27	5.70	0.74	2.51
Target Size (bn)	1.67	4.72	0.56	2.07
Acquirer Size (bn)	36.57	20.59	20.63	9.84

	Cash Deals		Stock Deals	
Panel B: Option Summary Statistics	Pre	Post	Pre	Post
N	148	78	172	170
$Call$	0.45	0.36	0.45	0.42
T	10.46	5.37	10.43	5.46
τ	0.34	0.35	0.31	0.32
$\|\Delta\|$	0.37	0.31	0.37	0.36
σ	0.51	0.26	0.62	0.52
Variance	0.11	0.04	0.16	0.12
Skewness	-0.43	-1.47	-0.34	-0.49
Kurtosis	3.59	10.58	3.33	3.97
Interest	0.40	0.63	0.47	0.48
Volume	0.23	0.94	0.28	0.38
RMSE % BS	0.47	3.54	0.32	0.44
RMSE % Model	0.45	0.49	0.23	0.31

Table 2: Cash Deal Outcome Regressions

This table reports linear-probability regressions for the outcomes of cash deals. I estimate the risk-neutral probability of deal success p_Q in the model by pricing the target stock and minimizing target option pricing errors in the preannouncement and postannouncement windows. The estimated probability remains significant in the presence of the share-implied probability p_Q^S, reduced-form variables from target option prices, additional control variables (C), and time and industry fixed effects (FE). For ease of interpretation, I have standardized the risk-neutral moments from target option prices to be mean zero and standard deviation one. The bottom panel indicates that the model's explanatory power increases in the deals with low standard errors $SE(p_Q)$ for the estimated risk-neutral probability, and that the point estimate on p_Q is relatively stable.

	(1)	(2)	(3)	(4)	(5)	(6)
p_Q Model	0.859***				0.728***	0.645***
	[14.24]				[9.94]	[7.43]
p_Q^S Share		0.407***		0.293***		0.127**
		[10.04]		[8.69]		[3.35]
Variance			-0.129***	-0.109***		-0.00730
			[-5.92]	[-5.50]		[-0.37]
Skewness			-0.0568***	-0.0268*		0.00982
			[-5.18]	[-2.17]		[0.99]
Δ Variance			0.0775***	0.0628***		0.00247
			[5.28]	[4.17]		[0.19]
R^2_{adj}	0.340	0.139	0.173	0.235	0.376	0.382
Observations	738	738	738	738	738	738
Variables					C, FE	C,FE

robust t-statistics clustered by year: * p<0.05 ** p<0.01 *** p<0.001

	$SE(p_Q) \leq .05$	$SE(p_Q) \leq .03$	$SE(p_Q) \leq .02$	$SE(p_Q) \leq .01$
p_Q Model	0.715***	0.740***	0.763***	0.757***
Adjusted R^2	0.398	0.459	0.482	0.665
Observations	671	578	435	182

robust t-statistics clustered by year: *** p<0.001

Table 3: Merger Arbitrage Monthly Return Summary Statistics

This table reports summary statistics and the return correlation matrix for monthly excess returns from the constructed merger arbitrage returns alongside hedge fund index returns from 1996 to 2012. The HFRI Event Driven and Merger Arbitrage indexes and Dow Jones Credit Suisse Event Driven and Risk Arbitrage indexes are reported net-of-fees. To adjust for this, I assume that a 2% flat fee and 10% incentive fee are payable monthly following Jurek and Stafford (2015). The table reports summary statistics for the pre-fee excess returns above. The constructed returns are similar to the hedge fund index returns along several dimensions including their positive correlation with the market $RMRF$ and small-minus-big factor SMB. The correlation with SMB follows from the observation that merger arbitrage strategies are long target firms that are small relative to large acquirers that are sold short in stock deals.

	Hedge Fund Indexes*				Merger Arbitrage Returns			
	HFRI ED	HFRI MA	DJCS ED	DJCS RA	Arb Equal	Cash Equal	Arb HP	Cash HP
Mean	0.0064	0.0044	0.0079	0.0053	0.0056	0.0055	0.0049	0.0049
Std. Deviation	0.0212	0.0110	0.0195	0.0130	0.0170	0.0222	0.0090	0.0113
Sharpe ratio	0.2991	0.3981	0.4030	0.4079	0.3276	0.2468	0.5364	0.4378
Min	-0.0932	-0.0611	-0.1203	-0.0641	-0.0730	-0.0739	-0.0305	-0.0555
Max	0.0532	0.0313	0.0487	0.0404	0.0667	0.0910	0.0399	0.0456
Skewness	-1.1326	-1.5987	-2.0740	-0.8436	-0.7940	-0.4057	-0.2724	-0.6464
Kurtosis	6.2994	9.2782	12.4574	6.9618	7.3803	6.8643	6.8012	8.1034
Autocorrelation	0.3685	0.2287	0.3585	0.2608	0.1016	0.1527	-0.1101	-0.0869
Max Drawdown	0.2450	0.0769	0.1653	0.0727	0.1849	0.2429	0.0278	0.0513
% Negative	0.3350	0.2589	0.2538	0.2944	0.2640	0.2995	0.1980	0.2284
β_{CAPM}	0.3472	0.1390	0.2748	0.1445	0.1716	0.2446	0.0708	0.1043
α_{CAPM}	0.0051	0.0039	0.0069	0.0048	0.0049	0.0046	0.0046	0.0045
t-statistic	3.8589	4.8931	4.5572	5.3989	4.4368	3.0935	8.4600	6.9162

*Source: Author's calculations based on Hedge Fund Research, Inc. and Dow Jones Credit Suisse data.

RMRF	SMB	HML	MOM	HFRI MA	DJCS RA	Arb Equal	Cash Equal	Arb HP	Cash HP
1.00	0.26	-0.23	-0.33	0.60	0.53	0.48	0.52	0.37	0.44
	1.00	-0.26	0.02	0.33	0.33	0.27	0.32	0.19	0.26
		1.00	-0.07	-0.05	-0.06	-0.02	-0.06	0.00	-0.02
			1.00	-0.19	-0.15	-0.23	-0.23	-0.11	-0.12
				1.00	0.75	0.48	0.50	0.47	0.52
					1.00	0.37	0.41	0.38	0.44
						1.00	0.95	0.61	0.55
							1.00	0.57	0.57
								1.00	0.91
									1.00

Table 4: Merger Arbitrage Volatility Regressions

This table indicates that merger arbitrage volatility is lower when deals have a high probability of success. Panel A reports cross-sectional regressions in cash deals that have target options data. The dependent variable is the deal month absolute excess return $|Re_{i,t+1}|$. The explanatory variables are standardized to be mean zero and standard deviation one. I include control variables (C) and fixed effects for event time, target industry, and calendar time (FE-EIC). Panel B provides further evidence by reporting Fama-MacBeth regressions for cross-sections of arbitrage and cash portfolios that are sorted on the share-implied probability.

Panel A: Cross-Sectional Regressions in Cash Deals

	(1)	(2)	(3)	(4)	(5)
p_Q Model	-0.0231***	-0.0135***	-0.0126***	-0.0201***	-0.0133***
	[-13.76]	[-8.13]	[-7.61]	[-11.70]	[-6.95]
σ Model	0.0133***	0.0110***	0.0108***	0.0138***	0.0112***
	[10.34]	[4.50]	[4.49]	[9.84]	[4.28]
p_Q^S Share	-0.00285**	-0.00479***	-0.00449***	-0.00194	-0.00369***
	[-2.41]	[-3.90]	[-3.81]	[-1.56]	[-2.92]
Δ Variance		-0.00469**	-0.00448**		-0.00315
		[-2.25]	[-2.17]		[-1.60]
Skewness		-0.00159**	-0.00153**		-0.000862
		[-2.25]	[-2.15]		[-1.20]
|RMRF|		0.00564***	0.00557***		
		[3.49]	[3.65]		
R^2_{adj}	0.164	0.250	0.261	0.398	0.283
Observations	3542	3542	3542	3542	3542
Variables		C	C,FE-EI	FE-EIC	C,FE-EIC

robust t-statistics clustered by month: *p<0.10 **p<0.05 ***p<0.01

Panel B: Fama-MacBeth Regressions

Strategy	Horizon	$h = 1$	$h = 3$	$h = 6$	$h = 12$
Arb	p_Q^S Share	-0.03***	-0.06***	-0.08***	-0.12***
		[-10.02]	[-10.36]	[-11.08]	[-12.51]
Cash	p_Q^S Share	-0.03***	-0.07***	-0.10***	-0.15***
		[-10.20]	[-10.54]	[-10.86]	[-11.94]

Newey-West t-statistics with 10 lags: ***p<0.01

Table 5: Merger Arbitrage Return Regressions

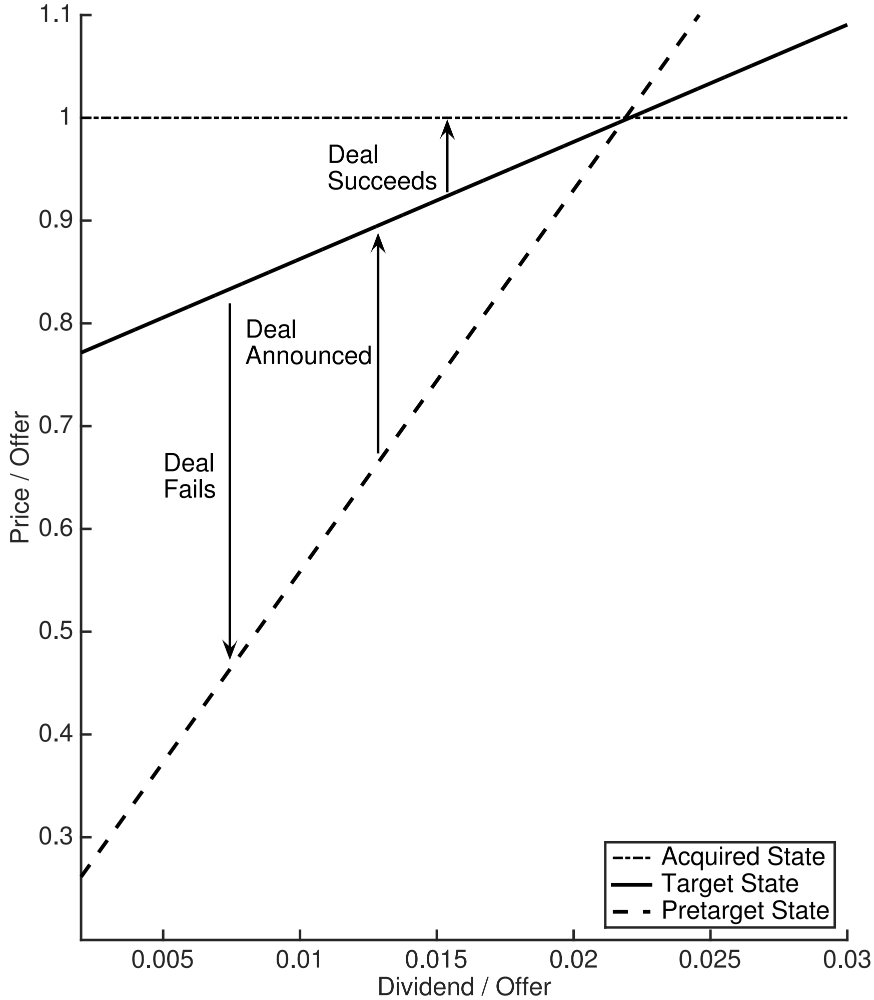
This table reports monthly excess return regressions during the 1996-2012 sample period. The dependent variables are the buy-and-hold merger arbitrage returns for the equal-weighted and high-probability merger arbitrage portfolios. The results indicate that merger arbitrage earns significant returns in excess of the CAPM, Fama and French (1993) model plus momentum, and the put-writing strategy in Jurek and Stafford (2015), which is found to closely match the risk profile of the HFRI broad hedge fund index. Relative to the equal-weighted portfolio, the high-probability strategy increases the significance of the intercept and lowers the loadings on the risk factors. Newey and West (1987) t-statistics are reported in brackets using five lags.

Arb Equal	(1)	(2)	(3)
Intercept	0.0049***	0.0048***	0.0042***
	[4.44]	[4.17]	[3.58]
RMRF	0.1716***	0.1543***	
	[5.03]	[4.17]	
SMB		0.0986**	
		[2.55]	
HML		0.064*	
		[1.83]	
MOM		-0.0248	
		[-1.18]	
PUT			0.2778***
			[8.48]
R^2_{adj}	0.22	0.25	0.21

Arb HP	(1)	(2)	(3)
Intercept	0.0046***	0.0044***	0.0043***
	[8.46]	[7.75]	[7.09]
RMRF	0.0708***	0.0708***	
	[4.46]	[3.86]	
SMB		0.0345	
		[1.47]	
HML		0.0338*	
		[1.73]	
MOM		0.0023	
		[0.18]	
PUT			0.1145***
			[3.7]
R^2_{adj}	0.13	0.14	0.13

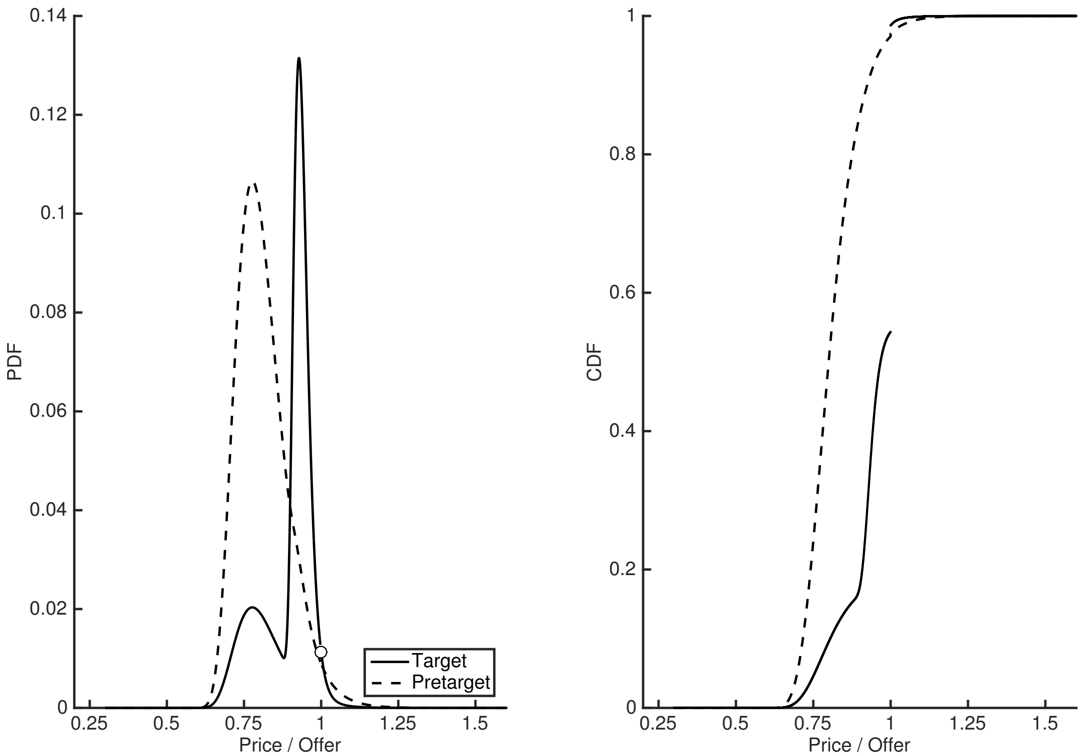
Figures

Figure 1: Stock Price of a Target Firm



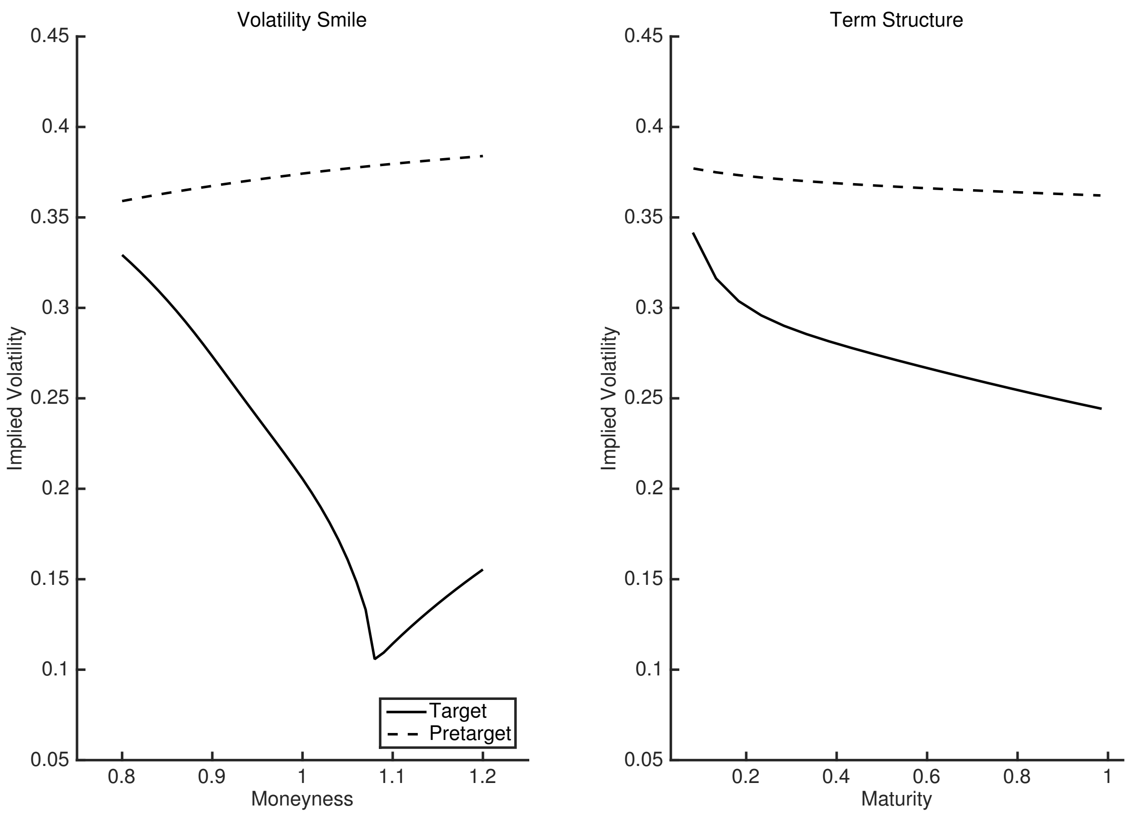
This figure plots the stock price $P(D_t, P_{A,t}, s_t)$ in the pretarget, target, and acquired states $s_t \in \{\mathcal{P},\, \mathcal{T},\, \mathcal{A}\}$ as a function of dividends D_t holding the offer $V + \phi P_{A,t}$ fixed. The plot highlights two features of the model. First, the stock price jumps when the firm transitions between states. For example, when a deal is announced the price jumps from the dashed line to the solid line. The plot also indicates that the slope with respect to dividends is lower in the target than in the pretarget state. The implication is that stock prices exhibit less diffusive risk when deals are pending, which results in a decrease in at-the-money implied volatility when deals are announced. The parameter values are $(p_Q, \tau_Q, \lambda, r, g) = (.70, .33, .01, .03, .01)$.

Figure 2: Stock Price Distribution in a Cash Deal



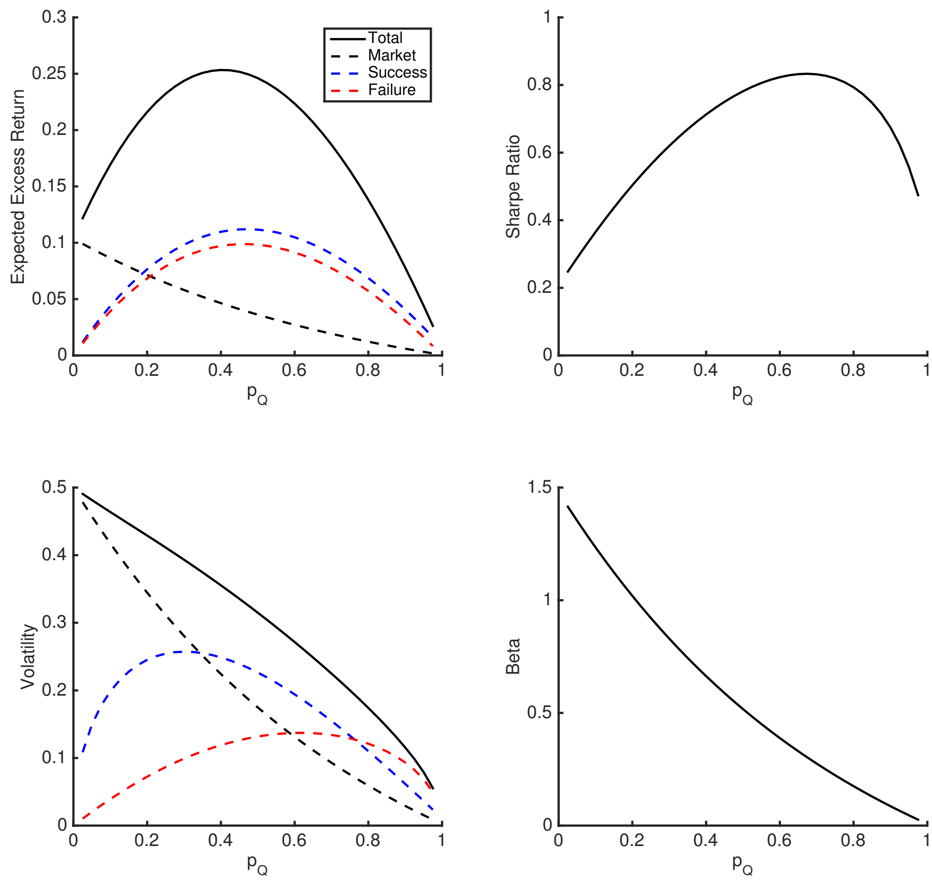
This figure plots the conditional probability density function and cumulative distribution function in a cash deal for the pretarget and target states at a four-month horizon. The x-axis is the stock price-to-offer ratio in four months time. The discontinuity in the cumulative distribution function corresponds to the risk-neutral probability that the deal will succeed over the next four months. The shift to the right in the probability density function indicates the jump in the stock price when deals are announced. Finally, the two peaks in the probability density function in the target state illustrate the mixture across deals that fail and deals that remain pending. Deals that fail result in a large negative jump in the target stock price. Deals that remain pending exhibit low volatility. The parameter values are $(p_Q, \tau_Q, \lambda, r, g, \sigma) = (.7, .33, .01, .03, .01, .5)$. The value of dividends and the offer are $D_t = .75$ and $V = 50$, which results in an offer premium of $V/(D_t/(r-g)) = 1.33$.

Figure 3: Option Prices in a Cash Deal



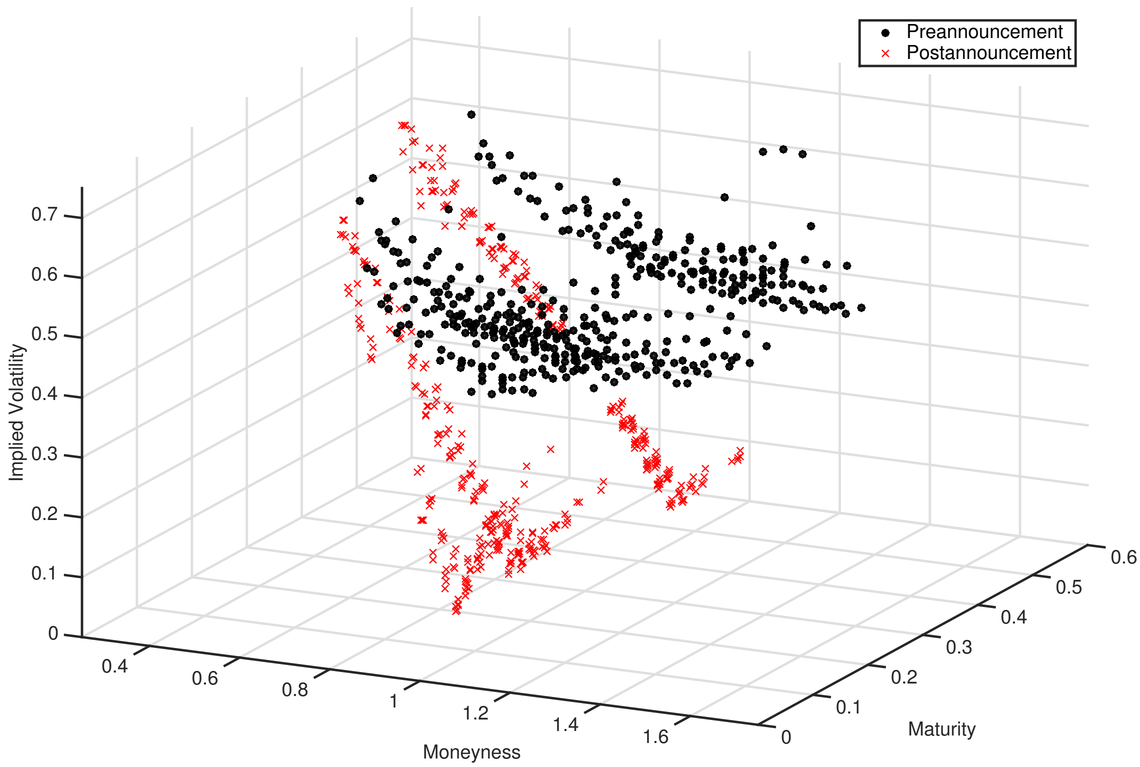
This figure plots the implied volatility of target option prices in the pretarget and target states for a cash deal. The left plot illustrates the volatility smile for six-month options. The x-axis is the level of moneyness relative to the forward price. As the plot indicates, the implied volatility of at-the-money options decreases when deals are announced. Simultaneously, the risk of a deal failure and the corresponding negative jump in the target stock price increases the implied volatility of out-of-the money put options relative to at-the money options, which results in a volatility smile. The binary nature of deal outcomes also produces a kink in implied volatility at the strike price equal to the offer. The right plot shows the term structure of implied volatility for out-of-the money options whose strike is a fixed value of moneyness equal to 90% of the forward price. The downward slope in the target state reflects the horizon over which deal uncertainty is expected to resolve. The parameter values are $(p_Q, \tau_Q, \lambda, r, g, \sigma) = (.7, .33, .01, .03, .01, .5)$. The value of dividends and the offer are $D_t = .75$ and $V = 50$, which results in an offer premium of $V/(D_t/(r-g)) = 1.33$.

Figure 4: Merger Arbitrage Risk Premium



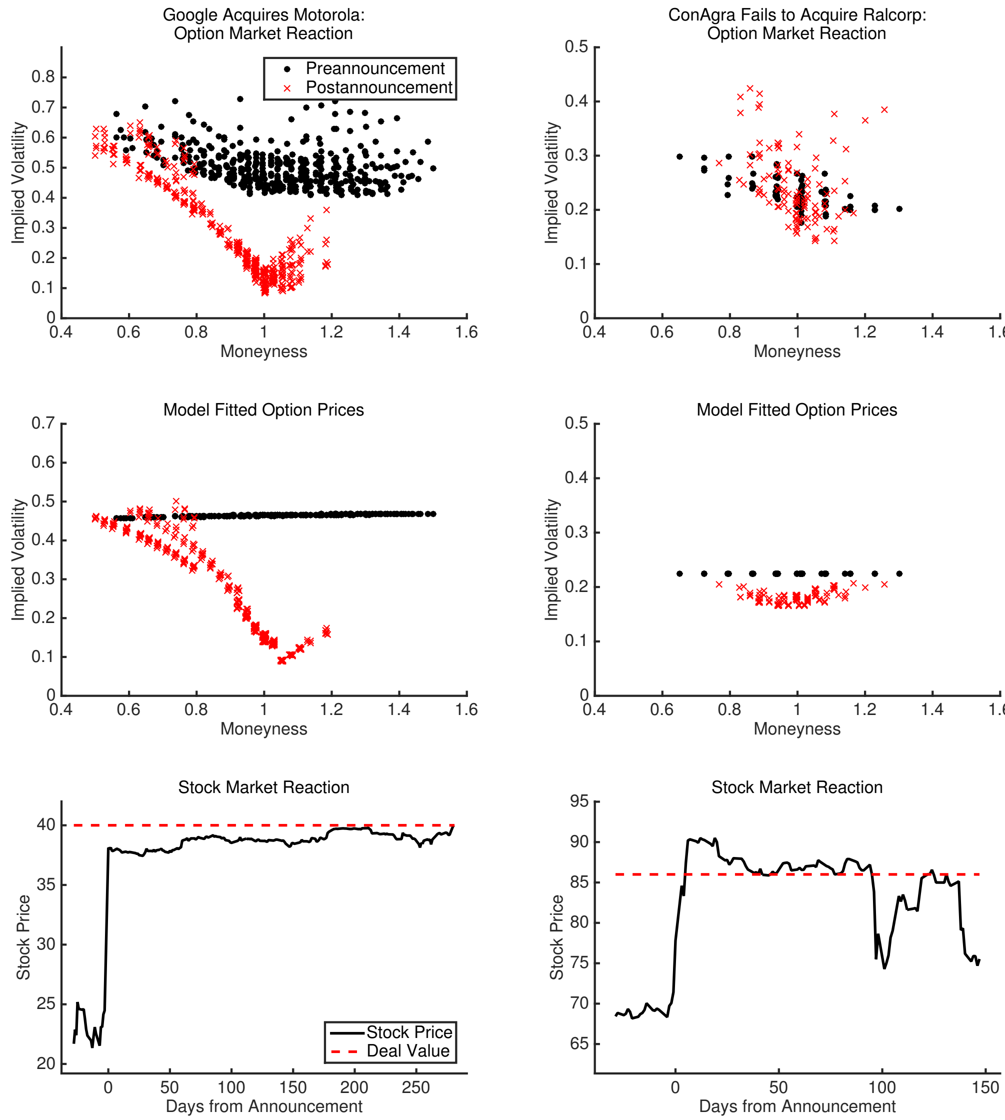
This figure plots the instantaneous risk premium, volatility, Sharpe ratio, and CAPM beta for a merger arbitrage investment in a cash deal as the risk-neutral probability of deal success p_Q varies. The risk premium is decomposed into compensation for fundamental risk and deal risk. As the probability of deal success increases, the volatility, CAPM beta, and expected return from fundamental risk all decrease. Meanwhile, binary deal risk results in a hump-shaped pattern in expected returns with the implication that the Sharpe ratio is not monotone, but is maximized for deals with a high probability of success. Similar results obtain for stock deals. The parameter values are $(p_Q, \tau_Q, \lambda, r, g, \sigma) = (.7, .33, .01, .03, .01, .5)$ and the market prices of risk are $(\kappa_S, \kappa_F, \eta) = (-.4, .6, .35)$. The value of dividends and the offer are $D_t = .75$ and $V = 50$, which results in an offer premium of $V/(D_t/(r-g)) = 1.33$.

Figure 5: Google Announces Cash Acquisition of Motorola



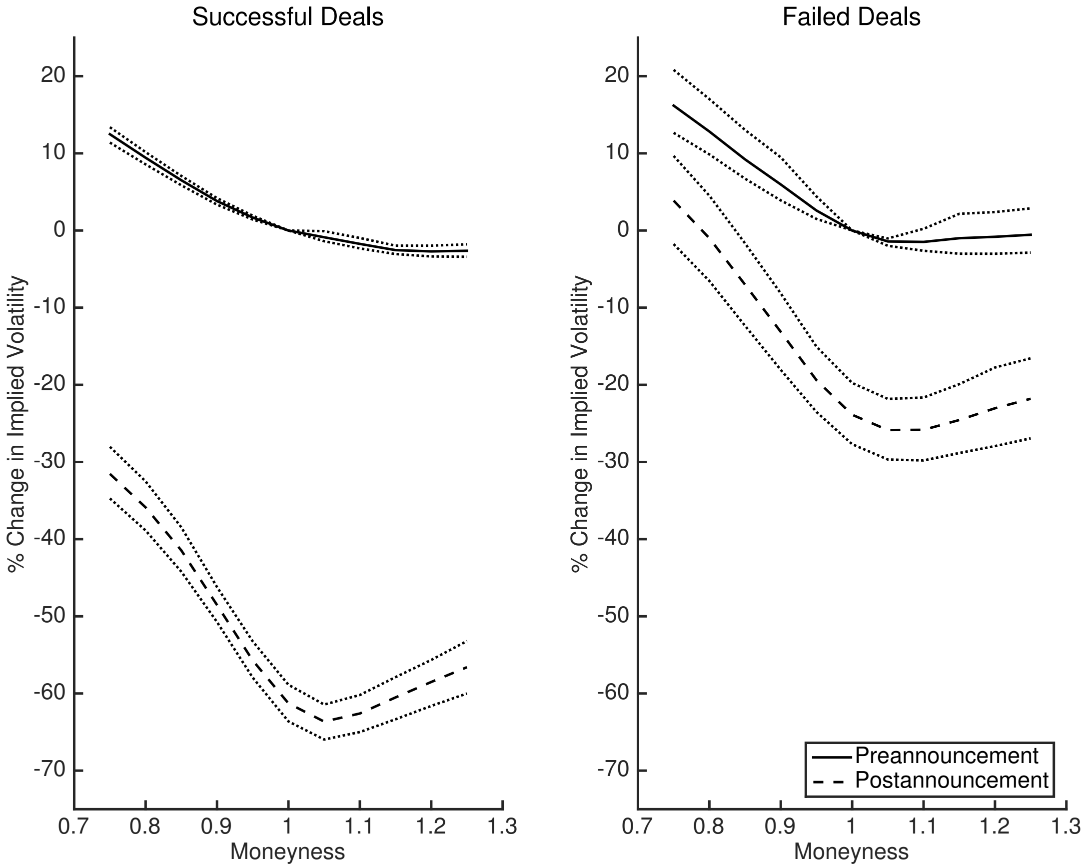
This plot illustrates the reaction of Motorola option prices to the announcement of a cash acquisition by Google on August 15, 2011, in a $12.45 billion deal valuing Motorola at $40 per share. Implied volatility from the closing prices of listed options with expirations in September, October, and January is plotted against moneyness, defined as the strike-to-spot ratio, and maturity in years.

Figure 6: Examples of Estimated Cash Deals



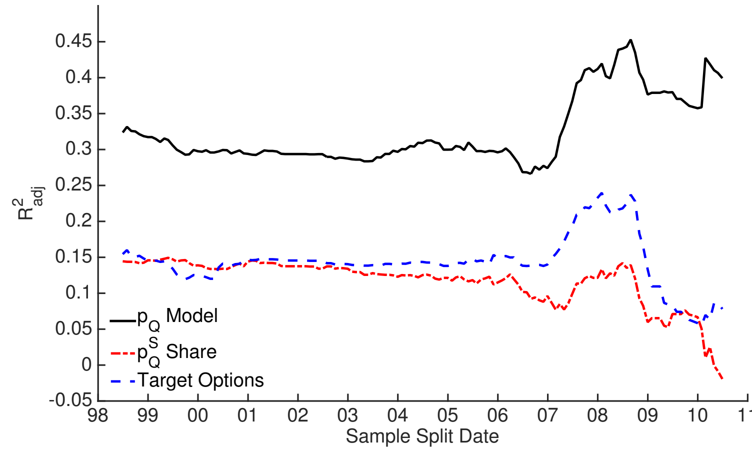
This figure plots the market reaction to the announcement of two cash deals. The top row plots the implied volatility of target option prices before and after the announcement against moneyness for various maturities. The middle row plots the implied volatility of target option prices in the model at the estimated risk-neutral probability of deal success, which is $\hat{p}_Q = .79\,(.007)$ in Google's successful acquisition of Motorola and $\hat{p}_Q = .27\,(.057)$ in ConAgra's failed bid for Ralcorp. The last row plots the target stock price versus the acquirer's offer. While the stock market reacts positively to both announcements, the lack of a reaction in Ralcorp options after ConAgra's bid leads to a low estimate for the risk-neutral probability of success whereas the decrease in the at-the-money implied volatility and increase in skewness of Motorola options after Google's announcement results in a high estimate for the risk-neutral probability of success.

Figure 7: Option Market Reaction to Cash Deal Announcements



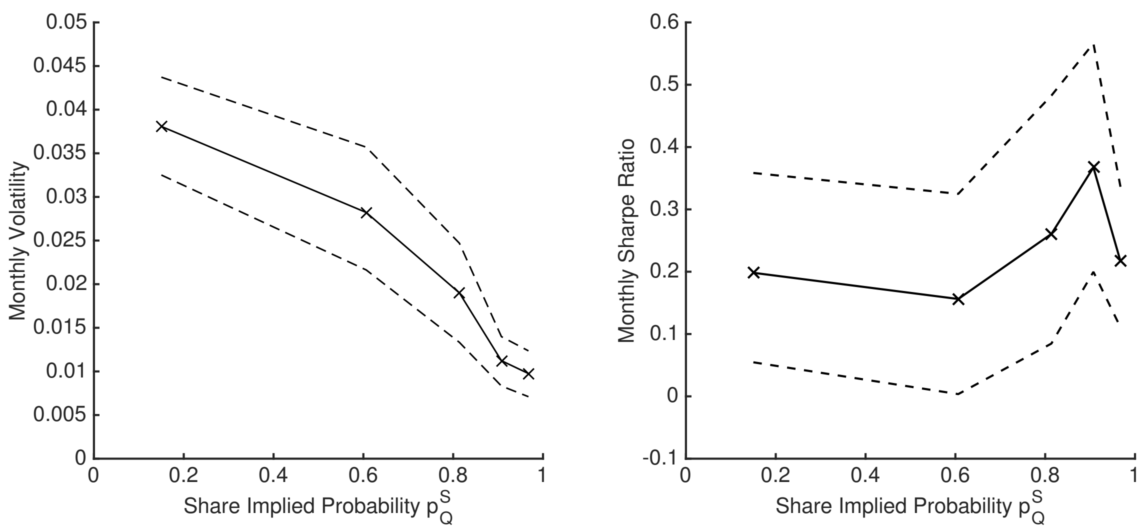
This figure plots the reaction of target option prices to cash deal announcements. The x-axis is moneyness defined as the strike-to-spot price ratio. The y-axis is the percentage change in the fitted four-month implied volatility of target option prices relative to the preannouncement at-the-money implied volatility. The left and right plots separate the average option market reactions for deals that ultimately succeed and fail alongside 95% pointwise confidence intervals. As the plot indicates, implied volatility decreases after the announcement, and a pronounced volatility smile emerges. Moreover, the decrease in implied volatility is larger for deals that are ex-post successful. I obtain the fitted implied volatility by running a regression of target implied volatility onto log-moneyness, log-moneyness squared, and maturity in the pre and post announcement windows for each deal and bound the fitted values at the 5th and 95th quantiles of the observed implied volatility to minimize the impact of outliers or misspecification of the implied volatility function. The sample includes 744 cash deals between 1996 and 2012 including 568 successful deals and 176 failed deals. The larger confidence intervals for the failed subset reflect the smaller sample size.

Figure 8: Out-of-Sample Forecasts for Cash Deal Outcomes



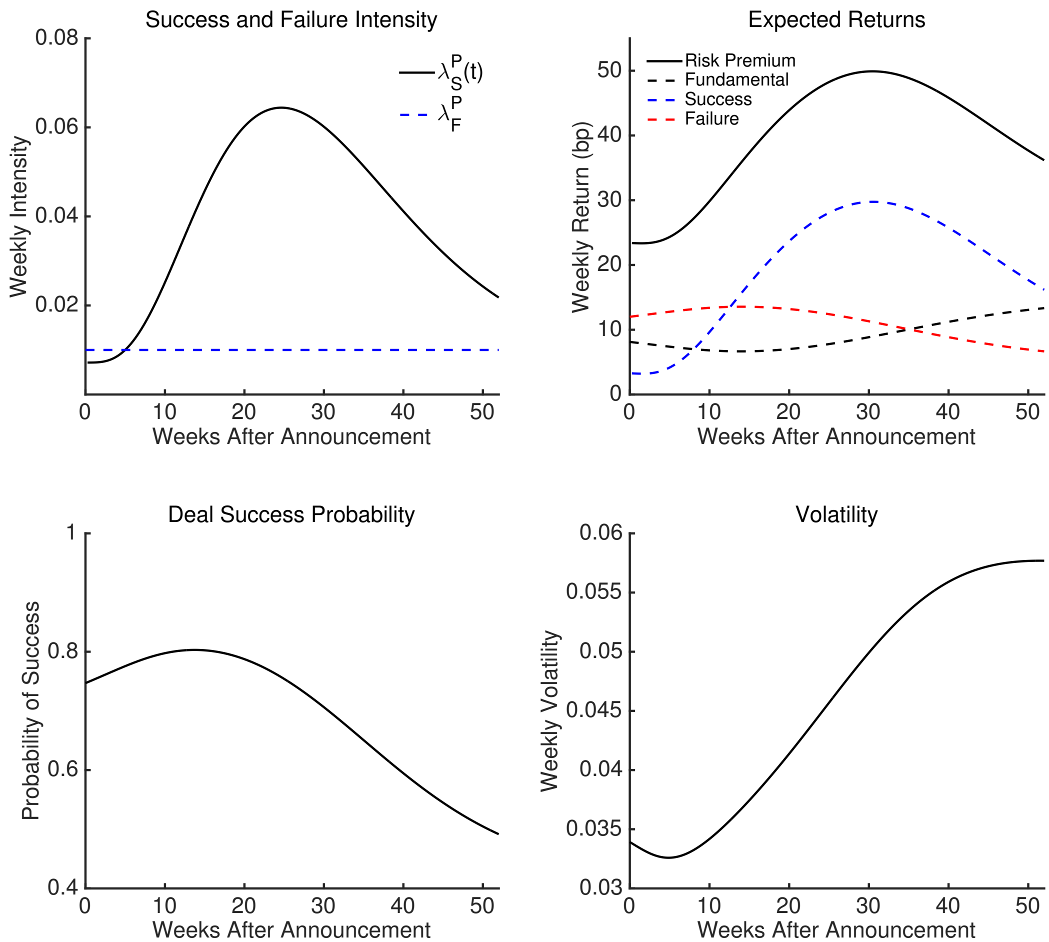
This figure plots the out-of-sample R^2_{adj} for forecasts of cash deal outcomes using different initial estimation periods for the estimated risk-neutral probability p_Q, the share-implied probability p_Q^S, and the reduced-form variables from target option prices.

Figure 9: Cross-Section of Merger Arbitrage Returns



This figure plots the volatility and Sharpe ratio for a cross-section of five merger arbitrage portfolios sorted on the share-implied probability of deal success p_Q^S against the average share-implied probability. Dashed lines represent 95% pointwise confidence intervals that are block bootstrapped to account for the autocorrelation in returns. The results indicate that deals with a high probability of success have low volatility and large Sharpe ratios, which is consistent with the model.

Figure 10: Path of Expected Merger Arbitrage Returns



This figure plots the instantaneous risk premium and volatility of merger arbitrage investments in event time in the extension of the baseline model. The extension allows deal success intensity to be a deterministic function of event time $\lambda_S(t)$. I calibrate $\lambda_S(t) = \lambda_{S0} + (\lambda_{S1} - \lambda_{S0}) f(t)$ to the empirical hump-shaped pattern in deal success intensity where f is the probability density function of a Gamma distribution with mean and standard deviation (μ_S, σ_S). The model predicts that expected returns are hump-shaped and that volatility is increasing in event time, which is consistent with the data. In the model, volatility initially declines but then begins to increase as the probability of deal success falls. Meanwhile, expected returns exhibit a hump-shaped pattern because the probability of deal success is already declining and putting downward pressure on the target stock price when the deal success intensity is reaching its peak. The parameter values are $(\lambda_F, r, g, \sigma, \kappa_S, \kappa_F, \eta) = (.95, .03, .01, .5, -.4, .6, .35)$ and $(\lambda_{S0}, \lambda_{S1}, \mu_S, \sigma_S) = (.25, 1.5, .6, .28)$ for the success intensity. The results are similar for cash and stock deals. The example above illustrates a cash deal with $V = 50$ and $D_t = .75$ at each point in event time.

Appendix

A Proofs and Derivations

Proposition 1: As dividends are specified under a risk-neutral measure $\mathbb{Q}$, I can compute stock prices by solving the risk-neutral pricing partial differential equations that apply in the pretarget and target states. A helpful guess is that prices follow a modified Gordon growth formula

$$P(D, P_A, s) = \begin{cases} A_0 D + A_1 V + A_2 P_A & s \in \mathcal{P} \\ B_0 D + B_1 V + B_2 P_A & s \in \mathcal{T}. \end{cases} \tag{24}$$

Then, the pricing pdes in the pretarget and target states are

$$\begin{gathered} D + gA_0 D + (r - q_A) A_2 P_A + \lambda \left[P(\mathcal{T}) - P(\mathcal{P})\right] = rP(\mathcal{P}) \\ D + gB_0 D + (r - q_A) B_2 P_A + \lambda_S \left[P(\mathcal{A}) - P(\mathcal{T})\right] + \lambda_F \left[P(\mathcal{P}) - P(\mathcal{T})\right] = rP(\mathcal{T}), \end{gathered} \tag{25}$$

where the price in the acquired state satisfies $P(\mathcal{A}) = V + \phi P_A$. Matching coefficients on (D, V, P_A) results in six equations in six unknowns whose solution is

$$\begin{array}{ll} A_0 = \frac{1+\lambda B_0}{r-g+\lambda} & B_0 = \frac{1+\lambda_F/(r-g+\lambda)}{\lambda_S+\lambda_F+r-g-\frac{\lambda\lambda_F}{r-g+\lambda}} \\ A_1 = \frac{\lambda B_1}{r+\lambda} & B_1 = \frac{\lambda_S}{\lambda_S+\lambda_F+r-\frac{\lambda\lambda_F}{r+\lambda}} \\ A_2 = \frac{\lambda B_2}{q_A+\lambda} & B_2 = \frac{\lambda_S\phi}{\lambda_S+\lambda_F+q_A-\frac{\lambda\lambda_F}{q_A+\lambda}}. \end{array} \tag{26}$$

The coefficients A_0 and B_0 are nonnegative if $r > g$. ■

Corollary 1: From the proof of Proposition 1, it is immediate that the stock price converges to the stated amounts as the deal announcement intensity decreases to zero. To see that this also equals the discounted expected payoff in the target state when $\lambda = 0$, let $\tau = \min\{N_S, N_F\} \sim \exp(\lambda_S + \lambda_F)$ be the time of failure or success and denote the probability density function of τ as f_τ. Conditioned on τ, the probability of success is $\lambda_S/(\lambda_S + \lambda_F)$. Let X_τ be the payoff when the deal fails or succeeds. By Fubini's theorem, it follows that

$$\begin{aligned} P(D_0, P_{A0}, \mathcal{T}) &= E_0^{\mathbb{Q}}\left[\int_0^\tau e^{-ru} D_u du + e^{-r\tau} X_\tau\right] \\ &= \int_0^\infty \Bigg[\int_0^t e^{-(r-g)u} D_0 du \quad + \\ &\qquad \frac{\lambda_S}{\lambda_S+\lambda_F}\left[Ve^{-rt} + \phi P_{A0} e^{-q_A t}\right] + \frac{\lambda_F}{\lambda_S+\lambda_F}\frac{D_0}{r-g}e^{-(r-g)t}\Bigg] f_\tau(t)dt \\ &= \underbrace{\frac{D_0}{\lambda_S+\lambda_F+r-g}}_{NPV\ of\ Dividends\ Before\ \tau} \quad + \end{aligned}$$

$$\underbrace{\frac{\lambda_S}{\lambda_S+\lambda_F+r}V+\frac{\lambda_S}{\lambda_S+\lambda_F+q_A}\phi P_{A0}}_{NPV\ of\ Success\ Payout}+\underbrace{\frac{\lambda_F}{\lambda_S+\lambda_F+r-g}\frac{D_0}{r-g}}_{NPV\ of\ Failure\ Payout}. \tag{27}$$

Rearranging, one can verify that the result matches the price given in the corollary. ■

Proposition 2: For a continuous time-homogeneous Markov chain, the transition probabilities equal $Q(t) = \exp(\Lambda t)$, which solves the Chapman-Kolmogorov forward and backward equations as discussed in Lando (2009). Alternatively, the transition probabilities can be derived from the limit of the discrete time approximation. For horizon t, discretize $[0, t]$ into n equal periods. The approximation $P_n = \left[I + \Lambda t\frac{1}{n}\right]^n$ converges in the limit to equal $\lim_{n\to\infty} P_n = \exp(\Lambda t) = \sum_{k=0}^{\infty} (\Lambda t)^k/k!$ as discussed in Jarrow et al. (1997). I diagonalize the generator matrix $\Lambda = PVP^{-1}$ to compute the transition probabilities in closed-form. It follows that

$$Q(t) = I + \sum_{k=1}^{\infty}\frac{\Lambda^k t^k}{k!} = P\exp(Vt)P^{-1}. \tag{28}$$

The eigenvalues of Λ are (v_1, v_2) reported in the proposition and $v_3 = 0$. The eigenvectors are

$$P = \begin{bmatrix} 1 & 1 & 1 \\ \frac{v_1}{\lambda}+1 & \frac{v_2}{\lambda}+1 & 1 \\ 0 & 0 & 1 \end{bmatrix}. \tag{29}$$

Computing the inverse of P and simplifying lead to the result in the proposition. ■

Proposition 3: At the time of maturity, the firm is in either the pretarget, the target, or the acquired state. Employing the assumption that firm transitions are independent of $(W_T, W_{A,T})$, the price of an option can be broken into the sum of three terms equal to the risk-neutral probability of being in each state at maturity multiplied by the discounted expected payoff conditioned on the state. For example, the price of a put option in the target state satisfies

$$\begin{aligned} F(D_0, P_{A,0}, \mathcal{T}) &= E^{\mathbb{Q}}\left[e^{-rT}\left(K - P(D_T, P_{A,T}, s_T)\right)^+ |D_0, P_{A,0}, s_0 \in \mathcal{T}\right] \\ &= q_{21}(T)F_{\mathcal{P}} + q_{22}(T)F_{\mathcal{T}} + q_{23}(T)F_{\mathcal{A}}, \end{aligned} \tag{30}$$

where

$$\begin{aligned} F_{\mathcal{P}} &= E_0^{\mathbb{Q}}\left[e^{-rT}\left(K - A_0D_T - A_1V - A_2P_{A,T}\right)^+\right] \\ F_{\mathcal{T}} &= E_0^{\mathbb{Q}}\left[e^{-rT}\left(K - B_0D_T - B_1V - B_2P_{A,T}\right)^+\right] \\ F_{\mathcal{A}} &= E_0^{\mathbb{Q}}\left[e^{-rT}\left(K - V - \phi P_{A,T}\right)^+\right]. \end{aligned} \tag{31}$$

The result follows from rewriting the expectations above using the Black-Scholes formula. I will derive $F_{\mathcal{P}}$ below to illustrate the idea. Define

$$\begin{array}{rcl} q(x) & \equiv & r-g-\frac{\sigma\rho x}{\sqrt{T}}+\frac{1}{2}\sigma^2\rho^2 \\ K_A(x) & \equiv & K-A_1V-A_2P_{A0}e^{(r-q_A-\frac{1}{2}\sigma_A^2)T+\sigma_A\sqrt{T}x} \\ x_A^* & \equiv & \frac{\ln\left(\frac{K-A_1V}{A_2P_A}\right)-\left(r-q_A-\frac{1}{2}\sigma_A^2\right)T}{\sigma_A\sqrt{T}}. \end{array} \tag{32}$$

The definitions for $K_B(x)$, x_B^* are analogous replacing the coefficients (A_0, A_1) with (B_0, B_1). Then, the price of a put option in the pretarget state is equal to

$$\begin{array}{rcl} F_{\mathcal{P}} & = & E_0^{\mathbb{Q}}\left[e^{-rT}\left(K-A_0D_T-A_1V-A_2P_{A,T}\right)^+\right] \\ & = & \int_{-\infty}^{x_A^*}\int e^{-rT}\left[K_A(x)-A_0De^{\left(g-\frac{1}{2}\sigma^2\right)T+\sigma\sqrt{T}y}\right]^+ f(y|x)f(x)dydx \\ & = & \int_{-\infty}^{x_A^*}\int e^{-rT}\left[K_A(x)-A_0De^{\left(g-\frac{1}{2}\sigma^2\right)T+\sigma\sqrt{T}\left(\rho x+\sqrt{1-\rho^2}z\right)}\right]^+ f(z)dzf(x)dx \\ & = & \int_{-\infty}^{x_A^*}P_{BS}\left(A_0D,K_A(x),T,r,q(x),\sigma\sqrt{1-\rho^2}\right)f(x)dx. \end{array} \tag{33}$$

In the second line $y|x \sim N(\rho x, 1-\rho^2)$ and $x \sim N(0,1)$. The change of variables in the third line is $z = (y-\rho x)/\sqrt{1-\rho^2}$. The method for computing $F_{\mathcal{T}}$ and $F_{\mathcal{A}}$ follows the same approach. Call option prices may be computed directly as above or by put-call parity. ■

Proposition 4: To compute the instantaneous merger arbitrage risk premium, apply Ito's lemma

$$\begin{array}{rcl} \mu_t & = & E_t^{\mathbb{P}}\left[\frac{dP_t+D_tdt-\phi\left[dP_{A,t}+D_{A,t}dt-rP_{A,t}dt\right]}{P_t}\frac{1}{dt}-r\right] \\ & = & \frac{\left[\beta_DB_0D+\beta_A(B_2-\phi)P_A\right](\mu_M-r)+\left(\lambda_S^{\mathbb{P}}-\lambda_S\right)(P_t(\mathcal{A})-P_t(\mathcal{T}))+\left(\lambda_F^{\mathbb{P}}-\lambda_F\right)(P_t(\mathcal{P})-P_t(\mathcal{T}))}{P_t(\mathcal{T})} \\ & & +\frac{D_t+B_0gD_t+B_2(r-q_A)P_{A,t}+\lambda_S(P_t(\mathcal{A})-P_t(\mathcal{T}))+\lambda_F(P_t(\mathcal{P})-P_t(\mathcal{T}))}{P_t(\mathcal{T})}-r \\ & = & \frac{\beta_DB_0D+\beta_A(B_2-\phi)P_A}{P_t(\mathcal{T})}\left(\mu_M-r\right) \\ & & +\left(e^{-\kappa_S}-1\right)\lambda_S\left(\frac{P_t(\mathcal{A})}{P_t(\mathcal{T})}-1\right) \\ & & +\left(e^{-\kappa_F}-1\right)\lambda_F\left(\frac{P_t(\mathcal{P})}{P_t(\mathcal{T})}-1\right). \end{array} \tag{34}$$

The simplification from the second to the third line follows from setting the pricing pde in the target state to zero. Then, for the market returns $\frac{dP_M}{P_M} = (\mu_M - r)\,dt + \sigma_M dW_{M,t}^{\mathbb{P}}$, it follows that

$$\begin{array}{rcl} \beta_{T,t} & = & \frac{cov_t\left(dR_{MA}^e,\frac{dP_M}{P_M}\right)}{cov_t\left(\frac{dP_M}{P_M},\frac{dP_M}{P_M}\right)} \\ & = & \frac{\frac{\sigma\rho_mB_0D_t+\sigma_A\rho_M(B_2-\phi)P_{A,t}}{P_t(\mathcal{T})}}{\sigma_M^2}\sigma_m \\ & = & \frac{\frac{\sigma\rho_M}{\sigma_M}B_0D_t+\frac{\sigma_A\rho_M}{\sigma_M}(B_2-\phi)P_{A,t}}{P_t(\mathcal{T})} \\ & = & \frac{\beta_DB_0D_t+\beta_A(B_2-\phi)P_{A,t}}{P_t(\mathcal{T})}. \end{array} \tag{35}$$

The derivation of $\sigma_{MA,t}^2$ follows by a similar application of Ito's lemma. ■

Stock Price Distribution: The cumulative distribution function of the stock price at time t for horizon T may be computed by conditioning on the state of the firm at time T. For example, letting $\tau = T - t$, the distribution of the stock price in the target state is

$$\begin{aligned} Pr^{\mathbb{Q}}(P_T \leq u | D_t, P_{A,t}, s_t \in \mathcal{T}) \quad = \quad & q_{21}(\tau) \cdot \int \Phi(\tfrac{u_A(x,P_{A,t},D_t)-\rho x}{\sqrt{1-\rho^2}})\phi(x)dx \\ & + q_{22}(\tau) \cdot \int \Phi(\tfrac{u_B(x,P_{A,t},D_t)-\rho x}{\sqrt{1-\rho^2}})\phi(x)dx \\ & + q_{23}(\tau) \cdot [\mathbf{1}[\phi = 0] \cdot \mathbf{1}[u \geq V] + \\ & \mathbf{1}[\phi > 0] \cdot \Phi(\tfrac{\ln\left(\frac{u-V}{\phi P_{A,t}}\right) - \left(r - q_A - \frac{1}{2}\sigma_A^2\right)\tau}{\sigma_A\sqrt{\tau}})], \end{aligned} \tag{36}$$

where I define

$$u_A(x, P_{A,t}, D_t) \equiv \frac{\ln\left(\frac{u - A_1 V - A_2 P_{A,t} e^{(r-q_A-\frac{1}{2}\sigma_A^2)\tau + \sigma_A\sqrt{\tau}x}}{A_0 D_t}\right) - \left(g - \frac{1}{2}\sigma^2\right)\tau}{\sigma\sqrt{\tau}} \tag{37}$$

and $u_B(x, P_{A,t}, D_t)$ analogously by replacing the coefficients (A_0, A_1, A_2) with (B_0, B_1, B_2). I can similarly replace the transition probabilities with $(q_{11}(\tau), q_{12}(\tau), q_{13}(\tau))$ to obtain the pretarget distribution. In cash deals, there is a discontinuity in the cumulative distribution function at the offer V, whose magnitude $q_{23}(\tau)$ equals the risk-neutral probability of success between t and T. This can be recovered directly from target option prices by applying Breeden and Litzenberger (1978). Let $G(K) \equiv Pr_t^{\mathbb{Q}}(P_T \leq K)$ and $C(K) \equiv \int_K^\infty e^{-r\tau}(P - K)dG(P)$. It follows that, $\frac{\partial C}{\partial K} = -e^{-r\tau}\left(1 - G(K)\right)$. Next, define the discontinuity function $D(x) \equiv \lim_{y \downarrow x} G(y) - \lim_{y \uparrow x} G(y)$. For cash deals, the kink in the call pricing function can be used to recover the risk-neutral probability of deal success, $e^{r\tau}\left[\lim_{K\downarrow V} \frac{\partial C}{\partial K} - \lim_{K\uparrow V} \frac{\partial C}{\partial K}\right] = D(V) = q_{23}(\tau)$. More broadly, the call pricing function can be used to recover the risk-neutral probability of any corporate event that results in a firm's stock price equaling a fixed value with a discrete probability. An additional result that follows from this analysis is that the implied volatility function is kinked at the discontinuity point. To see this, define $\sigma(K)$ as the solution to $C(K) = C_{BS}(S, K, \tau, r, q, \sigma(K))$. Differentiating both sides of the equation with respect to the strike price and rearranging yields $\frac{\partial \sigma}{\partial K} = \left(\frac{\partial C}{\partial K} - \frac{\partial C_{BS}}{\partial K}\right) / \frac{\partial C_{BS}}{\partial \sigma}$ hence,

$$\lim_{K\downarrow x} \frac{\partial \sigma}{\partial K} - \lim_{K\uparrow x} \frac{\partial \sigma}{\partial K} = \frac{e^{-r\tau} D(x)}{\frac{\partial C_{BS}}{\partial \sigma}}. \tag{38}$$

In merger arbitrage, the kink in the implied volatility function for cash deals at the offer is proportional to the risk-neutral probability of deal success.[35] Last, since $D \geq 0$ it follows that the slope of the implied volatility function is nondecreasing.

[35]Bester et al. (2013) derive the same result by assuming that Black-Scholes option pricing applies when deals fail. The contribution here is to emphasize the model-free nature of the kink in option prices and implied volatility. The kink stems from the discrete probability that the target stock price will equal a fixed value, which results in a discontinuity in the cumulative distribution function of the target stock price.

B Model Extensions

B.1 Time-Varying Intensity of Deal Success

Below, I present extensions of the model that allow for a time-varying intensity of deal success and merger waves. I allow for time-varying deterministic success intensity to incorporate the empirical observation from Giglio and Shue (2014) that the intensity of deal success is hump-shaped in event time. This extends the baseline model that assumes constant success and failure intensities. Prices continue to follow a modified Gordon growth formula. The key difference from the baseline model is that event time becomes a state variable. To be specific, let the generator equal

$$\Lambda(t)=\begin{bmatrix} 0 & 0 & 0 & 0 \\ \lambda_N & \lambda_2 & \lambda & 0 \\ \lambda_F & 0 & \lambda_3\left(t\right) & \lambda_S\left(t\right) \\ 0 & 0 & 0 & 0 \end{bmatrix}, \tag{39}$$

where $\lambda_S\left(\cdot\right)$ is a deterministic function of event time. This generator introduces two changes. First, if a transition to the target state occurs, the success intensity evolves deterministically according to $\lambda_S\left(\cdot\right)$. This complicates the analysis as the success intensity is no longer a constant. At the same time, I make the simplifying assumption that deal failures are permanent. This facilitates the computation of transition probabilities and allows me to obtain prices through backward induction. For example, the risk-neutral probability of remaining in the target state after a length of time τ is $q_{33}(\tau)=e^{-\lambda_F\tau-\int_0^\tau\lambda_S(u)du}$. Stock prices are derived in the proposition below. Option prices may also be derived following the approach from the baseline model.

Proposition 5 ***Target Stock Price with Time-Varying Success Intensity:*** *Consider a firm that transitions across deal states according to a continuous time inhomogeneous Markov chain with generator $\Lambda(t)$ where $\lambda_S(t)$ is continuous and satisfies $\lim_{t\to\infty}\lambda_S(t)=\lambda_{S,\infty}$. If $r-g>0$, the price is given below. The coefficients (A_0,A_1,A_2) and $\left(B_0\left(t\right),B_1\left(t\right),B_2\left(t\right)\right)$ are provided in the proof.*

$$P(D_t,P_{A,t},s_t,t)=\begin{cases} A_0D_t+A_1V+A_2P_{A,t} & s_t\in\mathcal{P} \\ B_0\left(t\right)D_t+B_1\left(t\right)V+B_2\left(t\right)P_{A,t} & s_t\in\mathcal{T} \end{cases} \tag{40}$$

Proof of Proposition 5: In the target state, the stock price is $V+\theta P_{A,t}$ in the event of deal success and $\frac{D_t}{r-g}$ in the event of deal failure. As a result, the pricing pde is

$$\begin{aligned} &D+\left[B_0'(t)D+B_1'(t)V+B_2'(t)P_A\right]+B_0(t)gD \\ &\quad+B_2(t)(r-q_A)P_A+\lambda_S(t)\left[V+\phi P_A-P(\mathcal{T})\right]+\lambda_F\left[\tfrac{D}{r-g}-P(\mathcal{T})\right]=rP(\mathcal{T}). \end{aligned} \tag{41}$$

Matching coefficients on (D,V,P_A) as in Proposition 1 leads to the following ordinary differential equations,

$$\begin{aligned} 1+\frac{\lambda_F}{r-g}+B_0'(t) &= B_0(t)\left[\lambda_S(t)+\lambda_F+r-g\right] \\ \lambda_S(t)+B_1'(t) &= B_1(t)\left[\lambda_S(t)+\lambda_F+r\right] \\ \lambda_S(t)\phi+B_2'(t) &= B_2(t)\left[\lambda_S(t)+\lambda_F+q_A\right]. \end{aligned} \tag{42}$$

These are first-order linear differential equations whose general solution $f'+pf=g$ is known to be $f=\frac{\int e^{\int p}g+c}{e^{\int p}}$ given the assumption that $\lambda_S(t)$ is continuous. For example, the solution for $B_0(t)$ is

$$B_0(t)=\frac{\left(1+\frac{\lambda_F}{r-g}\right)\left[\int_0^\infty e^{-\int_0^u \lambda_S(v)dv-(\lambda_F+r-g)u}du-\int_0^t e^{-\int_0^u \lambda_S(v)dv-(\lambda_F+r-g)u}du\right]}{e^{-\int_0^t \lambda_S(u)du-(\lambda_F+r-g)t}}, \tag{43}$$

which satisfies the boundary condition $\lim_{t\to\infty}B_0(t)=\frac{1+\lambda_F/(r-g)}{\lambda_{S,\infty}+\lambda_F+r-g}$. Numerical solutions can also be obtained by Runge Kutta. In the pretarget state, prices satisfy

$$D+A_0gD+A_2(r-q_A)P_A+\lambda\left[P(\mathcal{T},0)-P(\mathcal{P})\right]+\lambda_N\left[\frac{D}{r-g}-P(\mathcal{P})\right]=rP(\mathcal{P}), \tag{44}$$

where $P(\mathcal{T},0)=B_0(0)D+B_1(0)V+B_2(0)P_A$. Solving, I find that

$$(A_0,A_1,A_2)=\left(\frac{1+\lambda B_0(0)+\lambda_N/(r-g)}{\lambda+\lambda_N+r-g},\frac{\lambda B_1(0)}{\lambda+\lambda_N+r},\frac{\lambda B_2(0)}{\lambda+\lambda_N+r}\right). \tag{45}$$

■

B.2 Time-Varying Announcement Intensity

The observation that mergers arrive in waves has been documented in Shleifer and Vishny (2003) and Harford (2005). One approach to incorporate this observation into the model is to assume that the announcement intensity contains a common and time-varying component across firms. In particular, suppose λ_t follows a Cox-Ingersoll-Ross (CIR) square root process[36]

$$d\lambda_t=\kappa(\bar{\lambda}-\lambda_t)dt+\sigma_\lambda\sqrt{\lambda_t}dW_{\lambda,t}, \tag{46}$$

where $E_t^{\mathbb{Q}}\left[dW_{\lambda,t}dW_t\right]=E_t^{\mathbb{Q}}\left[dW_{\lambda,t}dW_{A,t}\right]=\rho_\lambda dt$ with firm transitions evolving according to a time-inhomogeneous Markov chain whose generator under the risk-neutral measure is

$$\Lambda_t=\begin{bmatrix} 0 & 0 & 0 & 0 \\ \lambda_N & \lambda_{2,t} & \lambda_T+\lambda_t & 0 \\ \lambda_F & 0 & \lambda_3 & \lambda_S \\ 0 & 0 & 0 & 0 \end{bmatrix}. \tag{47}$$

As in the previous extension, this generator embeds two distinctions from the baseline model. First,

[36] I assume that the Feller condition $2\kappa\bar{\lambda}\geq\sigma_\lambda^2$ is satisfied so the intensity remains positive.

deal announcements have a firm-specific component λ_T and a common time-varying component λ_t. This complicates the analysis as the announcement intensity is now a state variable. In addition, deal failures are assumed to be permanent. This allows prices to be computed by backward induction and facilitates the computation of transition probabilities, similar to the model with deterministic success intensity.[37] Stock prices are derived in the proposition below, whose proof is available on request. By combining the transition probabilities with the share price for the case when $\rho_\lambda = 0$, option prices can be computed by following the approach in the baseline model.

Proposition 6 ***Target Stock Price with Merger Waves:*** *Consider a firm that transitions across deal states according to a Markov chain with generator Λ_t where λ_t follows a Cox-Ingersoll-Ross process. If $r - g > 0$, the price in the target state is given in Corollary 1 and the price in the pretarget state for $\rho_\lambda = 0$ is,*

$$\begin{aligned} P(D_t, P_{A,t}, \lambda_t) \quad = \quad & \tfrac{D_t}{r-g} \tfrac{\lambda_F + r - g}{\lambda_S + \lambda_F + r - g} \left[1 + \lambda_S \tfrac{\lambda_N + r - g}{\lambda_F + r - g} \int_0^\infty e^{-A(u) - B(u)\lambda_t - (\lambda_T + \lambda_N + r - g)u} du \right] \\ & + V \tfrac{\lambda_S}{\lambda_S + \lambda_F + r} \left[1 - (\lambda_N + r) \int_0^\infty e^{-A(u) - B(u)\lambda_t - (\lambda_T + \lambda_N + r)u} du \right] \\ & + \phi P_{A,t} \tfrac{\lambda_S}{\lambda_S + \lambda_F + q_A} \left[1 - (\lambda_N + q_A) \int_0^\infty e^{-A(u) - B(u)\lambda_t - (\lambda_T + \lambda_N + q_A)u} du \right]. \end{aligned} \tag{48}$$

For $\rho_\lambda \neq 0$, the pretarget price may be computed numerically by solving the ordinary differential equations derived in the proof of the proposition.

C Stock Deals

Target option prices react significantly to cash deal announcements. By way of contrast, when stock deals are announced, there is less variation in option prices and a smaller change in the distribution of the target stock price. Table 1 demonstrates this observation empirically. In comparison to cash deals, stock deals coincide with smaller changes in the risk-neutral variance, skewness, and kurtosis of the target stock price. Similar results also hold in the model. In particular, cash deals result in large changes in the distribution of the target stock price because the deal payout, cash, has zero volatility. This in turn leads to large changes in option prices that provide useful information for forecasting deal outcomes. For stock deals, as long as target dividend and acquirer volatility are not substantially different, the higher moments of the target stock price are similar in the pretarget and target states. As such, option prices react less to stock deal announcements.

Figure C.1 illustrates this fact empirically. In the subset of stock deals with low acquirer volatility relative to target volatility, the implied volatility of target option prices decreases after deal announcements. Similar to cash deals, the decrease is larger and more significant for successful deals. In contrast to cash deals, skewness does not increase, and the magnitude of the decrease in

[37] The risk-neutral probability of staying in the pretarget state after a length of time τ is $q_{22}(\tau) = e^{-(\lambda_N + \lambda_T)\tau - A(\tau) - B(\tau)\lambda_0}$, where $A(\tau)$ and $B(\tau)$ are the coefficient functions for zero-coupon bond prices in the CIR model. The remaining transition probabilities may be computed in a similar fashion. Notably, this calculation would not apply if firms could transition back and forth between the pretarget and target states, but it would provide a useful empirical approximation over short periods of time.

implied volatility is relatively small. For example, in successful deals, at-the-money implied volatility decreases over 60% in cash deals but only 20% in stock deals. Cash deals produce larger reactions in target option prices because they are a special case of stock deals for which the acquirer has zero volatility. I also confirm in unreported results that acquirer options do not react significantly to stock deal announcements, which is expected given the previous observation that acquirers are much larger than target firms.

Table C.1 reports linear-probability regressions for stock deal outcomes. As before, the dependent variable is one for successful offers and zero for failed offers. I standardize the risk-neutral moments and the postannouncement correlation of the target and acquirer stock prices to be mean zero and standard deviation one. Similar to cash deals, the estimated risk-neutral probability and the share-implied probability are significant and robust to including control variables and time and industry fixed effects. In contrast to cash deals, the postannouncement correlation is significant, but the risk-neutral moments of the target stock price are not. In addition, there is less explanatory power and a lower point estimate on the estimated risk-neutral probability for stock deals. In part, this appears to be driven by measurement error. As the bottom panel shows, the point estimate is higher in deals with lower standard errors for the estimated risk-neutral probability. While this reconciles some of the difference between cash and stock deals, measurement error cannot explain all of the gap. Even in deals with low standard errors, the point estimate in stock deals remains well below the point estimate in cash deals.

Figure C.2 complements the regression results with two examples of estimated stock deals. In particular, the left panel illustrates the successful deal between Microsoft and Visio announced on September 15, 1999. In this instance, Microsoft offered .45 shares per Visio share valuing Visio at \$1.37 billion or \$42.78 per share. In response, the closing price of Visio jumped 19% from \$33.50 to \$39.88, which corresponds to a share-implied probability of $\hat{p}_Q^S = .85$. Simultaneously, the implied volatility of Visio options decreased from 58% to 36% on average moving closer to Microsoft's 37% realized volatility during the previous three months. This reaction is characteristic of a stock deal with a high probability of success. It results in an estimated risk-neutral probability of $\hat{p}_Q = .80$ (.0058). Ultimately, Microsoft successfully acquired Visio on January 7, 2000.

To provide an example of a failed stock deal, the right panel illustrates Staples offer of 1.14 shares to acquire Office Depot for \$22.23 announced on September 4, 1996. In this case, the stock market reacted positively to the offer, resulting in a share-implied probability of $\hat{p}_Q^S = .83$. Meanwhile, the average implied volatility of Office Depot options decreased from 45% to 37%. In contrast to the previous example, the implied volatility of Office Depot options moved in the opposite direction from Staple's 50% realized volatility in the three months prior to the announcement. The model captures this reaction with an estimated risk-neutral probability of deal success equal to $\hat{p}_Q = .22$ (.02). Ultimately, the deal failed to obtain antitrust approval, which was consistent with the low estimate for the risk-neutral probability of success.[38]

[38]As a July 1, 1997 *New York Times* article "Office Depot and Staples Merger Halted" described, the

Table C.1: Stock Deal Outcome Regressions

This table reports linear-probability regressions for the outcomes of stock deals. I estimate the risk-neutral probability of success in the model p_Q by pricing the target stock and minimizing target option pricing errors in the preannouncement and postannouncement windows. The estimated probability remains significant in the presence of the share-implied probability p_Q^S, reduced-form variables from target option prices, additional control variables (C), and time and industry fixed effects (FE). For ease of interpretation, the correlation and risk-neutral moments from target option prices are standardized to be mean zero and standard deviation one. The bottom panel indicates that the point estimate on p_Q and explanatory power of the model increase in the subset of deals with low standard errors $SE(p_Q)$ for the estimated risk-neutral probability.

	(1)	(2)	(3)	(4)	(5)	(6)
p_Q Model	0.302***				0.249***	0.209***
	[5.27]				[4.13]	[3.31]
p_Q^S Share		0.282***				0.190**
		[4.80]				[2.17]
Correlation			0.0912***			0.0658***
			[4.08]			[3.79]
Variance				-0.0167		0.00179
				[-0.76]		[0.04]
Skewness				-0.0332**		-0.0191
				[-2.19]		[-0.89]
Δ Variance				0.0264		0.00964
				[1.55]		[0.44]
Adjusted R^2_{adj}	0.061	0.076	0.059	0.006	0.117	0.160
Observations	348	348	348	348	348	348
Variables					C, FE	C,FE

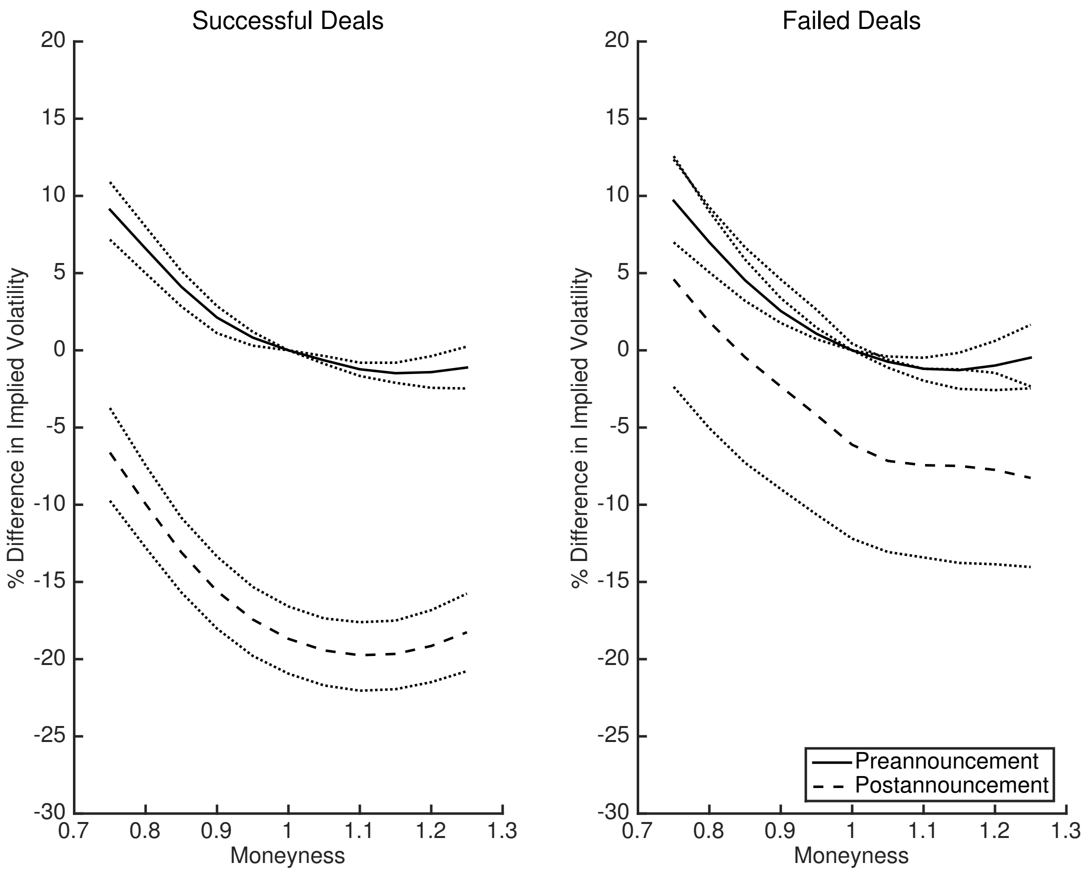
robust t-statistics clustered by year: * p<0.05 ** p<0.01 *** p<0.001

	$SE(p_Q) \leq .10$	$SE(p_Q) \leq .05$	$SE(p_Q) \leq .03$	$SE(p_Q) \leq .02$
p_Q Model	0.281***	0.327***	0.409***	0.408***
Adjusted R^2	0.127	0.134	0.134	0.139
Observations	309	271	226	165

robust t-statistics clustered by year: *** p<0.001

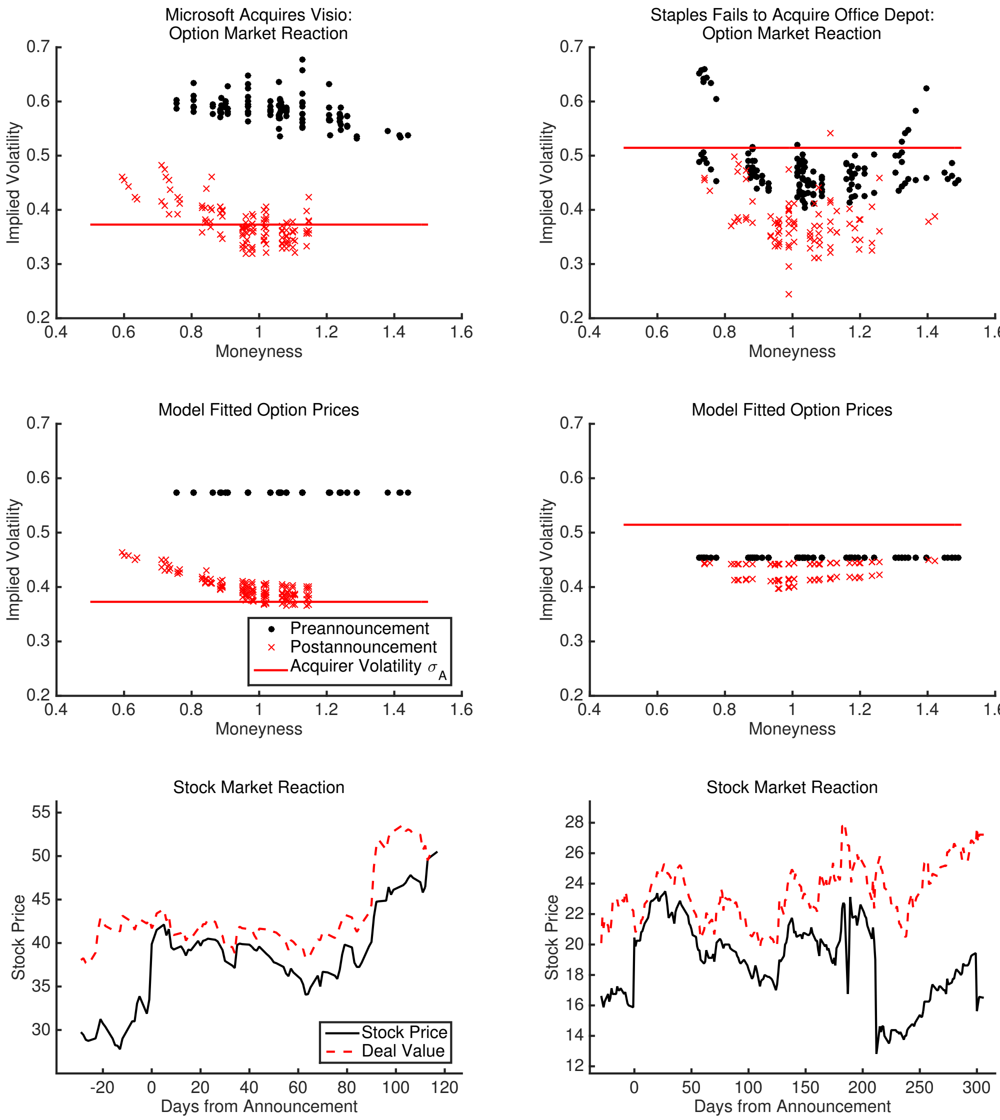
Federal Trade Commission concluded that large office supply stores occupied a specialized market in which the two companies would command significant pricing power despite the fact that Staples and Office Depot only controlled 6-8% percent of the office products market.

Figure C.1: Option Market Reaction to Stock Deal Announcements



This figure plots the reaction of target option prices to stock deal announcements. I focus on the subset of deals with low acquirer volatility relative to the target. The x-axis is moneyness defined as the strike-to-spot price ratio. The y-axis is the percentage change in the fitted four-month implied volatility of target option prices relative to the preannouncement at-the-money implied volatility. The left and right plots separate the average option market reactions for deals that ultimately succeed and fail alongside 95% pointwise confidence intervals. The results indicate that deal announcements coincide with a decrease in the implied volatility of target option prices. Similar to cash deals, the decrease is more pronounced for deals that are ex-post successful. In contrast to cash deals, the volatility smile is not as pronounced in the postannouncement window. As before, I obtain the fitted implied volatility by running a regression of target implied volatility onto log-moneyness, log-moneyness squared, and maturity in the pre and post announcement windows for each deal and bound the fitted values at the 5th and 95th quantiles of the observed implied volatility to minimize the impact of outliers or misspecification of the implied volatility function. The sample includes 269 stock deals between 1996 and 2012, of which 226 succeeded and 43 failed.

Figure C.2: Examples of Estimated Stock Deals



This figure plots the market reaction to the announcement of two stock deals. The top row plots the implied volatility of target option prices against moneyness for various maturities. The middle row plots the implied volatility of target option prices in the model at the estimated risk-neutral probability of deal success, which is $\hat{p}_Q = .80\ (.0058)$ in Microsoft's successful acquisition of Visio and $\hat{p}_Q = .22\ (.02)$ in Staple's failed bid for Office Depot. The last row plots the target stock price versus the acquirer's offer. While the stock market reacts positively to both announcements, the muted reaction of Office Depot options after Staples' bid leads to a low estimated risk-neutral probability of success whereas the decrease in the implied volatility of Visio options after Microsoft's offer results in a high estimate for the risk-neutral probability of success.