Detecting Informed Trading Activities in the Options Markets*

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Abstract

This paper presents a new method to detect informed trading activities in the options markets. An option trade is identified as informed when it is characterized by an unusual large increment in open interest and volume, induces large gains, and is not hedged in the stock market. For the period 1996–2006, each put option contract on 14 companies traded in the Chicago Board Options Exchange is analyzed. Our method detects several informed trades which can be associated to one of the following three events: merger and acquisition announcements, quarterly financial/earning related statements, and the terrorist attacks of September 11th.

Keywords: Put Options, Open Interest, Informed trading

JEL Classification: G12, G13, G14, G17, G34, C61, C65

Introduction

Informed trading activities in stock markets have been extensively studied in Finance. Various researchers have investigated the fundamental economic question of how new information gets incorporated into asset prices, how various frictions induced by trading mechanism impact this process, how informed traders should implement their trading strategies optimally to profit from their private signals, and other related aspects; e.g. O'Hara (1995), Easley and O'Hara (1987), Easley, Kiefer, and O'Hara (1997), Easley, O'Hara, and Srinivas (1998), Glosten and Milgrom (1985), Hasbrouck (1991), Huang and Stoll (1994), Boulatov, Hendershott, and Livdan (2009). Our paper contributes to this literature in two directions: it studies informed trading activities in option rather than stock markets, and it provides a statistical method to detect informed trades in option contracts.

Various incentives such as low initial capital, high financial leverage and discreetness offered by options market can induce traders with privileged information to trade in options rather than in the underlying asset. Unlike the stock market, options trading can involve the creation of new positions whenever the parties underwrite new contracts increasing the open interest (i.e. total number of existing option contracts on a given day). This paper shows that certain changes in open interest can reveal the information content of those specific trades. According to our method, an option trade is identified as informed when it is characterized by a statistically large increment in open interest and volume, induces large returns and gains, and is not hedged in the stock market. Specifically, for each option the increment in open interest is compared to its daily volume to check whether or not this transaction can be classified as unusual. If so, the corresponding return and gain are calculated over various horizons. When the return and gain are statistically important, the probability that the option trade is not delta hedged is calculated. When this probability is sufficiently low, the option trade is identified as informed. This method is applied to each put option

contract on 14 companies in various business sectors traded in the Chicago Board Options Exchange from January 1996 to April 2006 analyzing approximately 1.5 million of option contracts. In total 37 transactions are identified as informed trades: 6 occurring in the days leading up to merger and acquisition (M&A) announcements, 14 before quarterly financial/earnings related statements, 13 related to the terrorist attacks of September 11th, and 4 which could not be identified. For example four informed trades surrounding M&A announcements are detected in the airline sector. Two of them involved put options on American Airlines and United Airlines stock traded on May 10th and 11th, 2000, namely two weeks before UAL's acquisition of US Airways was announced. These trades generated a total gain of almost $3 million.[1] Another informed trade in a put option with underlying Delta Air Lines occurred a few weeks before the public announcement on January 21st, 2003 of the planned alliance among Delta, Northwest and Continental. In this case the total gain was more than $1 million. As noted in e.g. Keown and Pinkerton (1981) and Cao, Chen, and Griffin (2005), takeover announcements are ideal events for studying information discovery in the security price formation process. Whereas trades made before scheduled announcements might be based on speculative bets, takeover announcements are not planned and trades prior to such events are likely to be started by traders who possess private information as detected by our method. Other detected informed trades can be associated to announcements related to drops in sales, production scale backs, and earnings shortfalls. For example three informed trades on put options with underlying Philip Morris stock are detected a few days before three separate legal

[1] As reported in the New York Times edition of May 25th, 2000, AMR was considered the company most threatened by the merger, explaining therefore the 17% drop in its stock in the days after the public announcement. According to James Goodwin, chairman and chief executive of UAL, two major hurdles would challenge UAL: "the first is to get US Airways shareholders to approve this transaction. [The second] is the regulatory work, which revolves around the Department of Transportation, the Department of Justice and the European Union". The skepticism on Wall Street was immediately reflected on UAL shares which declined $7.19 to $53.19 on the announcement day.

cases against the company seeking a total amount of more than $50 million in damages for smokers' deaths and inoperable lung cancer. The corresponding gains in put options amounted to more than $10 million.

Our method is also applied to each put option on Swiss Re, Munich Re and EADS traded on EUREX from January 1999 to January 2008. Informed option trades on Swiss Re and Munich Re—the world's two largest reinsurers—are detected in the days leading up to the terrorist attacks on September 11th. Liabilities for the two companies were estimated to be in the amount of billions of dollars a few days after the attacks inducing large drops of stock prices and net gains in those transactions of more than €11.4 million. In the case of EADS, the parent of plane maker Airbus, six informed option trades are identified between April and June 2006. These trades precede the June 14th, 2006 announcement that deliveries of the superjumbo jet A380 would be delayed by a further six months period, causing a 26% fall in the underlying stock, and a total gain of €7.5 million in these option trades.

The paper is organized as follows. Section 1 reviews related literature on informed trading. Section 2 introduces our methodology to detect option informed trades. Section 3 describes the database. Section 4 presents the empirical results. Section 5 concludes.

1 Related literature

This paper is mainly related to two strands of literature dealing with informed trading activities and linkages of information between option and stock markets. Analysis of informed trades has typically focused on specific events such as stock and option trading prior to M&A announcements (e.g. Keown and Pinkerton (1981), Jayaraman, Frye, and Sabherwal (2001) and Cao, Chen, and Griffin (2005)), asset returns around quarterly earnings announcements (e.g. Lee, Mucklow, and Ready (1993), Amin and Lee (1997), Schachter (1998), Steven, Ferri, and Ange (2004) and Cheng

and Leung (2008)), or option trades in the days leading up to the terrorist attacks of September 11th (Poteshman (2006)). Our paper contributes to this literature in several ways. First, it does not focus on a single type of event but rather analyzes a long time period (more than ten years of daily and intraday data) uncovering various kinds of informed trading activities in different occasions. The case of EADS will be considered as an example. Second, previous papers use typically regression models in which the underlying stock return is the dependent variable and option variables are explanatory variables. We use a different, nonparametric approach. Option trades are identified as informed when they are statistically unusual according to the empirical probability of that event. Third, a novel feature in our approach is that it takes into account the hedging dimension. Option trades which are subsequently hedged should not be classified as informed trades. Fourth, we compute realized returns and gains from informed option trades quantifying the importance of such trades. Our methodology has some similarities to that of Poteshman (2006), such as using open interest to detect informed trading. However, there are also important differences concerning the data, method and aims. For example Poteshman focuses mainly on the airline sector and suspicious trading activities in the days leading up to the terrorist attacks of September 11th, but does not consider the potential hedging demand and uses a quantile regression approach. We perform a more general analysis, considering different sectors and events, and use a different approach. Easley and O'Hara (1987) and Easley and O'Hara (1992) develop the probability of information-based trading (PIN). This method has been mainly applied to detect informed trades in stock markets as for e.g. in Easley, Kiefer, and O'Hara (1997), Easley, O'Hara, and Paperman (1998) and Vega (2006).

The second strand of literature investigates the linkage and information flow between options and stock markets; e.g. Conrad (1989), Stoll and Robert (1990), Detemple and Jorion (1990), Mayhew, Sarin, and Shastri (1995), Easley, O'Hara, and Srinivas (1998), Chakravarty, Gulen, and

Mayhew (2004), Pan and Poteshman (2006), Lakonishok, Lee, Pearson, and Poteshman (2007), and Crameri (2009). In particular Easley, O'Hara, and Srinivas (1998) introduce an equilibrium model where informed investors decide endogenously whether to trade in the stock and the option market in a "pooling equilibrium" and Pan and Poteshman (2006) provide empirical evidence of this equilibrium analyzing put-call ratios. Overall this research indicates that signed option volumes have an impact on future underlying asset price dynamics. Cremers and Weibaum (2010) show that deviations from put-call parity contain information about future stock returns. Our goal is different. We aim at identifying the arrival of single informed trade in the option market for e.g. as soon as it takes place. Our findings suggest that informed trades detected by our procedure are not reflected into stock prices until the event occurs. Our paper is also related to the detection of insider trades, the latter being a subclass of informed trades; e.g. Meulbroek (1992), Biais and Hillion (1994), Ma and Sun (1998), Ma (2001) and Cheng and Leung (2008). Our empirical results show that option markets are profitable for informed traders suggesting that informed traders might consider options as superior trading vehicles; e.g. Bhattacharya (1987), Anthony (1988), Stephan and Whaley (1990), Chan, Chung, and Johnson (1993), Manaster and Rendleman (1982), Lee and Yi (2001) and Chan, Chung, and Fong (2002).

Chen, Hong, and Stein (2001) forecast asset crashes using shares trading volume. Blume, Easley, and O'Hara (1994) emphasize the role of transaction volume as a tool for technical analysis. We complement these works by showing that certain increments in open interest have predictive power for future drops in the underlying stock. Vijh (1990) studies information trading as well.

2 Detecting option informed trading activity

An informed trade in put options is defined as follows: C_1) an aggressive trade in an option contract, C_2) which is made a few days before the occurrence of a specific event and generates large gains

in the following days, and C_3) the position is not hedged in the stock market and not used for hedging purposes. These three characteristics, $C_i, i = 1, 2, 3$, lead to the following method to detect informed trading activities: first on each day the put option contract with largest increment in open interest relative to its volume is identified, then the rate of return and dollar gain generated by this transaction are calculated, and finally it is studied whether hedging demands were at the origin of the trades. Options trades which are delta hedged are not regarded as informed trades. Below we describe in detail and apply this method to a large dataset of American put option trades. The method could be easily applied to call option trades as well.

Informed traders can obviously undertake a large variety of trading activities for e.g. with various degrees of complexity to split their orders, jam the signals, etc. In this paper we restrict our attention to the economically sensible informed trade characterized by $C_i, i = 1, 2, 3$, above, that can be identified using available databases as we will see below.

2.1 The first criterion: Increment in open interest relative to volume

For every put option k available at day t we compute the difference $\Delta OI_t^k := OI_t^k - OI_{t-1}^k$, where OI_t^k is its open interest at day t and $:=$ means defined as. In the case that the option does not exist at time $t-1$, its open interest is set to zero. Since we are interested in unusual transactions, only the option with the largest increment in open interest is considered

$$X_t := \max_{k \in K_t} \Delta OI_t^k \tag{1}$$

where K_t is the set of all put options available at day t. The main motivation for considering increments in open interests is the following. Large volumes do not necessarily imply that large buy orders are executed because the same put option could be traded several times during the day. In contrast large increments in open interest are originated by large buy orders. These increments also imply that other long investors are unwilling to close their positions forcing the market maker

to issue new put options. Let V_t denote the trading volume corresponding to the put option selected in (1). We focus on transactions for which the corresponding volume almost coincides with the increment in open interest. The positive difference $Z_t := (V_t - X_t)$ provides a measure of how often the newly issued options are exchanged: the smaller the Z_t, the less the new options are traded during the day on which they are created. In that case the originator of such transactions is not interested in intraday speculations but has reasons for keeping her position for a longer period possibly waiting for the realization of future events.

This first criterion already allows us to identify single transactions as potential candidates for informed trading activities. Let q_t denote the *ex-ante* joint historical probability of observing larger increment X_t in open interest and lower values of Z_t

$$q_t := \mathbb{P}[X \geq X_t, Z \leq Z_t] = \frac{1}{N} \sum_{i=1}^{N} \mathbf{1}_{\{X_i \geq X_t, Z_i \leq Z_t\}}$$

where N represents the length of the estimation window, e.g. $N = 500$ days, and $\mathbf{1}_{\{A\}}$ is the indicator function of event A. By construction, low values of q_t suggest that these transactions were unusual. For example when $q_t = 1/N$, it means that what occurred on day t has no precedents in the previous two years.

2.2 The second criterion: Relative return and realized gain

The second criterion takes into consideration the ex-post relative returns and realized gains from transactions with a low ex-ante probability q_t. For each day t the trade with the largest increment in open interest is considered. Let R_t denote the maximum return generated in the following two trading weeks

$$R_t := \max_{j=1,\ldots,10} \frac{P_{t+j} - P_t}{P_t} \tag{2}$$

where P_t denotes the price of the selected option at day t. When R_t is unusually high, an unusual event occurs during the two trading weeks.

For the computation of realized gains, only the number of exercised options is considered. This can be done using decrements in open interest. Whenever the daily change in open interest of a specific option k, ΔOI_t^k, is negative, at least an amount of $|\Delta OI_t^k|$ options were exercised.[2] In the following we omit the superscript k and whenever we refer to a specific option we mean the one which was selected because of its largest increment in open interest and volume, i.e. lowest ex-ante probability q_t. It is generally more profitable to sell rather than exercise options but the OptionMetrics database used for our analysis does not provide information on that. Given our definition of informed trade, however, it is likely that on the event day the drop in the stock price is large enough to reach the exercise region. In the following we restrict our analysis to profits generated only through exercise. Hence our findings should be interpreted in a conservative manner.

Let G_t denote the corresponding cumulative gains achieved through the exercise of options

$$G_t := \sum_{\tilde{t}=t+1}^{\tau_t} [(K - S_{\tilde{t}})^+ - P_t] \cdot (-\Delta OI_{\tilde{t}}) \cdot \mathbf{1}_{\{\Delta OI_{\tilde{t}}<0\}}$$

where τ_t is such that $t < \tau_t \leq T$, with T being the maturity of the selected option. If the put options were optimally exercised (i.e. when the underlying asset $S_{\tilde{t}}$ is in the stopping region), the payoff $(K - S_{\tilde{t}})^+$ corresponds to the price of the option at time $\tilde{t}$. In principle the cumulative gains G_t could be calculated for every $\tau_t \leq T$. This has however the disadvantage that G_t can include gains which are realized through the exercise of options which were issued before time t.[3] Therefore

[2]The creation of new positions (which increases open interest), and the exercise of already existing options (which decreases open interest), can off-set each other so that a constant level of open interest does not necessarily mean that any options were exercised. In the database used for our analysis, OptionMetrics, the exercise of options can only be identified using the decrement in open interest which is a lower bound for the actual number of exercised options.

[3]Consider for example an option which exhibits an unusually high increment in open interest at time t, say $OI_{t-1} = 1000$ and $OI_t = 3000$, resulting in $X_t := OI_t - OI_{t-1} = 2000$. Suppose that in the days following this

time τ_t is defined as follows

$$\begin{aligned} \tau_t^* &:= \arg \max_{l \in \{t+1,\ldots,T\}} \Big\{ \sum_{\tilde{t}=t+1}^{l} (-\Delta OI_{\tilde{t}}) \cdot \mathbf{1}_{\{\Delta OI_{\tilde{t}}<0\}} \leq X_t \Big\} \\ \tau_t &:= \min(\tau_t^*, 30) \end{aligned}$$

giving the informed trader no more than 30 days to collect her gains. In general in the curly brackets the sum of negative decrements till time τ_t will be smaller than the observed increment X_t. In that case, we will add to G_t the gains realized through the fraction of the next decrement in open interest. Hence the sum of all negative decrements in open interest considered will be exactly equal to the increment X_t. Calculating G_t for each day t and each option in our database provides information on whether or not option trades with a low ex-ante probability q_t generate large gains through exercise. Using the maximal return R_t in (2) the ex-post joint historical probability p_t of the event $\{X_t, Z_t, R_t\}$ is

$$p_t := \mathbb{P}[X \geq X_t, Z \leq Z_t, R \geq R_t] = \frac{1}{N} \sum_{i=1}^{N} \mathbf{1}_{\{X_i \geq X_t, Z_i \leq Z_t, R_i \geq R_t\}}.$$

The empirical probability $(1 - p_t)$ can be interpreted as a proxy for the probability of informed trading in the option market.

2.3 The third criterion: Hedging option position

Option trades for which the first two criteria show abnormal behavior cannot be immediately classified as informed trading. It could be the case that such transactions were hedged by traders using the underlying asset. Without knowing the exact composition of each trader's portfolio, it is not possible to assess directly whether each option trade was hedged or not. For example

transaction the level of open interest decreases and after h days reaches the level $OI_{t+h} = 500$. One should only consider the gains realized through exercise till time $\tau_t \leq t + h$, where τ_t is such that the sum of negative decrements in open interest during $[t + 1, \tau_t]$ equals $X_t = 2000$.

suppose that a trader buys a large number of stock, hedges this exposure buying put options, and the stock price indeed drops a few days later. Using the first two criteria, such a transaction in put option would be classified as informed. Another misclassification would occur in the opposite situation when the investor buys a large amount of put options and hedges her position by buying the suitable amount of the underlying stock.

We attempt to assess indirectly whether unusual trades in put options are actually delta hedged using the underlying asset. The idea is to compare the theoretical total amount of shares bought for non-hedging purposes and the total volume of buyer-initiated transactions in the underlying stock. If the latter is significantly larger than the former, then it is likely that some of the buyer-initiated trades occur for hedging purposes. In the opposite case we conclude that the new option positions are naked. The difficulty is that the volume due to hedging is typically a small component of the total buyer-initiated volume. To approximate this volume we assume that newly issued options are hedged on the same day when hedging occurs and no informed trades take place. Moreover, a hedging analysis at the level of single option is not possible using the OptionMetrics database. We therefore check whether all the newly issued options are hedged on a specific day t. Given our definition of informed option trades, such trades certainly account for a large fraction of the newly issued options. For each day t, the total volume of the underlying stock is divided into seller- and buyer-initiated using intraday volumes and transaction prices according to the Lee and Ready (1991) algorithm.[4] Then the buyer-initiated volume, V_t^{buy}, is divided into volume due to hedging and to non-hedging purposes, $V_t^{\text{buy,hedge}}$ and $V_t^{\text{buy,non-hedge}}$, respectively. Let $\Delta_t^{P,k}$ be the delta of

[4]The algorithm states that a trade with a transaction price above (below) the prevailing quote midpoint is classified as a buyer- (seller-) initiated trade. A trade at the quote midpoint is classified as seller-initiated if the midpoint moved down from the previous trade (down-tick), and buyer-initiated if the midpoint moved up (up-tick). If there was no movement from the previous price, the previous rule is successively applied to several lags to determine whether a trade was buyer- or seller-initiated.

put option k and K_t^P the set of put option (newly issued or already existing) on day t. Similarly for $\Delta_t^{C,k}$ and K_t^C. Let

$$\alpha_t := \sum_{k \in K_t^P} |OI_t^{P,k} - OI_{t-1}^{P,k}| \cdot |\Delta_t^{P,k}| \quad , \quad \gamma_t := \sum_{k \in K_t^C} |OI_t^{C,k} - OI_{t-1}^{C,k}| \cdot \Delta_t^{C,k},$$

$$\beta_t := \sum_{k \in K_t^P} ||\Delta_t^{P,k}| - |\Delta_{t-1}^{P,k}|| \cdot OI_{t-1}^{P,k} \quad , \quad \delta_t := \sum_{k \in K_t^C} |\Delta_t^{C,k} - \Delta_{t-1}^{C,k}| \cdot OI_{t-1}^{C,k}.$$

The α_t and γ_t represent the theoretical number of shares to buy for hedging the new options issued at time t, whereas β_t and δ_t are the theoretical number of shares to buy to rebalance the portfolio of existing options at time t. Absolute changes in open interests and deltas account for the fact that each option contract has a long and short side that follow opposite trading strategies if hedging occurs. The theoretical buyer-initiated volume of stock at time t for hedging purposes, $V_t^{\text{buy,hedge-theory}}$, is

$$V_t^{\text{buy,hedge-theory}} := \alpha_t + \beta_t + \gamma_t + \delta_t.$$

When the first two criteria of our method do not signal any informed trade, we approximate $V_t^{\text{buy,hedge}}$ by $V_t^{\text{buy,hedge-theory}}$. Then the amount of stock bought for non-hedging purposes is calculated as

$$V_t^{\text{buy,non-hedge}} = V_t^{\text{buy}} - V_t^{\text{buy,hedge-theory}}.$$

When informed option trades take place on day i, $V_i^{\text{buy,non-hedge}}$ cannot be computed as in the last equation because $V_i^{\text{buy,hedge-theory}}$ would be distorted by the option informed trades. We circumvent this issue by forecasting the volume $V_i^{\text{buy,non-hedge}}$ on day i using historical data on $V_t^{\text{buy,non-hedge}}$. The conditional distribution of $V_i^{\text{buy,non-hedge}}$ is estimated using the adjusted Nadaraja–Watson estimator and the bootstrap method proposed by Hall, Wolff, and Yao (1999)

$$\tilde{F}(y|\mathbf{x}) \quad = \quad \frac{\sum_{t=1}^{T} \mathbf{1}_{\{Y_t \leq y\}} w_t(\mathbf{x}) K_{\mathbf{H}}(\mathbf{X}_t - \mathbf{x})}{\sum_{t=1}^{T} w_t(\mathbf{x}) K_{\mathbf{H}}(\mathbf{X}_t - \mathbf{x})} \tag{3}$$

with $Y_t := V_t^{\text{buy,non-hedge}}$, $\mathbf{X}_t := (|r_t|, V_{t-1}^{\text{buy,non-hedge}})$, $K_{\mathbf{H}}(.)$ being a multivariate kernel with bandwidth matrix $\mathbf{H}$, $w_t(\mathbf{x})$ the weighting function, and r_t the stock return at day t; we refer the reader to e.g. Fan and Yao (2003) for the implementation of (3).

We can now formally test the hypothesis, H_0, that hedging does not take place at day i. Whenever the observed V_i^{buy} is large enough, say above the 95% quantile of the predicted distribution of $V_i^{\text{buy,non-hedge}}$, it is likely that a fraction of V_i^{buy} is bought for hedging purposes. Hence we reject H_0 at day i when

$$V_i^{\text{buy}} > q_{0.95}^{V_i^{\text{buy,non-hedge}}}$$

where $q_\alpha^{V_i^{\text{buy,non-hedge}}} = \tilde{F}^{-1}(\alpha|\mathbf{X}_i)$ is the α-quantile of the predicted distribution of $V_i^{\text{buy,non-hedge}}$ estimated applying (3) to e.g. the last two years of data. Section 4.5 discusses the accuracy of the hedging detection method. We remark that the hypothesis H_0 of no hedging when informed trades occur refers to e.g. long positions in newly issued put options which are not hedged taking long positions in the underlying stock and motivating our hedging detection method. The corresponding short positions in the same put options might or might not be hedged, taking short positions in the underlying stock, without any impact on our hedging detection method. It is so because the total volume of the underlying stock is divided into buyer- and seller-initiated.

2.4 Detecting option informed trades combining the three criteria

Two methods are proposed to detect informed trades. The first method relies only on *ex-ante* information and is based on (C_1) changes in open interest and volume and (C_3) absence of hedging strategy using underlying asset. The second method uses information available before and after a given transaction, and is based also on (C_2) return and gain generated by the option trade. The first method aims at detecting informed trades as soon as they take place, while the second method allows for a more stringent assessment of informed trades. Let k_t denote the selected informed

trade at day t in option k. The two methods can be succinctly described using the following sets of events

- *Ex-ante criteria C_1 and C_3:*

  $\Omega_1 := \{k_t \text{ such that } q_t \leq 5\%\}$

  $\Omega_2 := \{k_t \text{ such that } H_0 : \text{non-hedging, not rejected at day } t\}$

- *Ex-post criterion C_2:*

  $\Omega_3 := \{k_t \text{ such that } r_t^{\max} \geq q_{0.90}^{r_t^{\max}}\}$

  $\Omega_4 := \{k_t \text{ such that } G_t \geq q_{0.98}^{G_t}\}$.

The first method detects an informed option trade when it belongs to the first two sets, i.e. $k_t \in \Omega_1 \cap \Omega_2$, while according to the second method the selected informed trade belongs to all four sets, i.e. $k_t \in \Omega_1 \cap \Omega_2 \cap \Omega_3 \cap \Omega_4$. The empirical quantiles at day t of $r_t^{\max}$ and G_t distributions, $q_{0.90}^{r_t^{\max}}$ and $q_{0.98}^{G_t}$, are computed using the last two years of data.

As any other statistical method our detection methods could generate false discoveries, i.e. the probability that an option trade could satisfy the three criteria by chance is nonzero. It is well-known that this misclassification is not eliminable and corresponds to the Type I error in hypothesis testing. However our detection method is designed to be as conservative as possible minimizing the Type I error. As shown in Section 4, setting the input parameters properly only a handful of option trades are identified as informed, for e.g. less than 0.1%.

3 Data

Various databases are used in the empirical study. For KLM and thirteen American companies, options data are from the Chicago Board Options Exchange (CBOE) as provided by OptionMetrics.

The dataset includes the daily cross section of available put options for each company from January 1996 to April 2006 and amounts to roughly 1.5 million of options. We eliminated obvious data errors such as open interest reported at zero for all existing options by excluding those days from our analysis. Stock prices are downloaded from OptionMetrics as well to avoid non-synchronicity issues and are adjusted for stock splits and spin-offs using information from the CRSP database. Intraday transaction prices and volumes for each underlying stock prices are provided by NYSE's Trade and Quote (TAQ) database. This database consists of several millions of records for each stock and is necessary to classify volumes in buyer- and seller-initiated. Discrepancies among datasets have been carefully taken into account when merging databases. For example data for J.P. Morgan from OptionMetrics and TAQ do not match. Whereas the stock volume reported in OptionMetrics for the years 1996–2000 is given by the sum of the volume of Chase Manhattan Corporation and J.P. Morgan & Co. (Chase Manhattan Corporation acquired J.P. Morgan & Co. in 2000), TAQ only reports the volume of J.P. Morgan & Co. Same issue was found for BankAmerica Corporation and NationsBank Corporation, whose merger took place in 1998 under the new name of Bank of America Corporation. Fourteen companies from airline, banking and various other sectors are analyzed. The list of companies includes: American Airlines (AMR), United Airlines (UAL), Delta Air Lines (DAL), Boeing (BA) and KLM for the airline sector; Bank of America (BAC), Citigroup (C), J.P. Morgan (JPM), Merrill Lynch (MER) and Morgan Stanley (MWD) for the banking sector; and AT&T (ATT), Coca-Cola (KO), Hewlett Packard (HP) and Philip Morris (MO) for the remaining sectors. Sample data range from January 1996 to April 2006. Options data for DAL and KLM were available only for somewhat shorter periods. For the analysis of European companies, Swiss Re, Munich RE and EADS, we use daily data from the EUREX provided by Deutsche Bank. Intraday data for such European companies were not available.

4 Empirical results

The proposed methods to detect option informed trades are applied to fourteen companies whose options are traded on the CBOE: AMR, UAL, DAL, BA and KLM (airline sector); BAC, C, JPM, MER and MWD (banking sector); and ATT, KO, HPQ and MO; see Section 3 for the ticker symbols. The first method which relies only on ex-ante information is already a powerful tool in order to detect potential informed trades as soon as they take place. On average, less than 0.1% of the total analyzed trades belongs to the set $\Omega_1 \cap \Omega_2$. For AMR, we found for example that the number of trades belonging to $\Omega_1 \cap \Omega_2$ is 141, the total number of analyzed options being more than 137,000. For the remaining companies, comparable numbers have been found. Due to space constrains we do not report the details of transactions belonging to $\Omega_1 \cap \Omega_2$ but these are available from the authors upon request. Based on the second method, the number of detected informed trades decreases substantially. Analyzing all daily cross sections of put options for all companies from January 1996 to April 2006, in total 37 transactions on the CBOE have been identified as belonging to the set $\Omega_1 \cap \Omega_2 \cap \Omega_3 \cap \Omega_4$; the total number of put option trades analyzed is roughly 1.5 million. Nearly all the events can be assigned to one of the following three event categories: merger and acquisition (M&A) announcements, 6 transactions; quarterly financial/earnings related statements, 14 transactions; and the terrorist attacks of September 11th, 13 transactions. 4 transactions could not be identified.

Table 1 summarizes the findings. 4 informed trades around M&A announcements are detected in the airline sector. These option trades have underlying stock American Airlines and United Airlines. Three informed trades took place on May 10th and 11th, 2000, two weeks before UAL's acquisition of US Airways was announced (for details see Footnote 1). Another informed trade took place on January 9th, 2003 with underlying Delta Air Lines, a few weeks before a public announcement on January 21st, 2003 related to the planned alliance among Delta, Northwest and Continental. In

both cases, the underlying assets were strongly affected by the public announcements, generating large gains ($3 and $1 million, respectively) through the exercise of these put options.

Eight out of 15 of the selected transactions for the airline sector can be traced back to the terrorist attacks of 9/11. Companies like American Airlines, United Airlines, Boeing and to a lesser extent Delta Air Lines and KLM seem to have been targets for informed trading activities in the period leading up to the attacks. The number of new put options issued during that period is statistically high and the total gains G_t realized by exercising these options amount to more than $16 million. These findings support the results in Poteshman (2006) who also reports unusual activities in the option market before the terrorist attacks.

In the banking sector 14 informed trading activities are detected, 6 related to quarterly financial/earnings announcements, 5 to the terrorist attacks of September 11th, and 3 not identified. For example the number of new put options with underlying stock in Bank of America, Citigroup, J.P. Morgan and Merrill Lynch issued in the days before the terrorist attacks was at an unusually high level. The realized gains from such trading strategies are around $11 million.

The last set of companies we analyze includes AT&T, Coca Cola, Hewlett Packard and Philip Morris. Two informed trades occurred in the pre-announcement period of the M&A deal between Coca Cola and Procter&Gamble announced on February 21st, 2001 (leading to gains of more than $2 million), and 5 transactions preceding the publication of quarterly financial/earnings statements. Information related to earnings shortfalls, unexpected drops in sales and production scale backs are the most common in this last category. For example three informed trades in put options with underlying Philip Morris stock are detected. These trades took place a few days before three separate legal cases against the company seeking a total amount of more than $50 million in damages for smokers' deaths and inoperable lung cancer. The realized gains amounted to more than $10 million. Perhaps as expected, no informed option trade is detected with underlying the previous

companies in the days leading up to the terrorist attacks of September 11th.

To provide a more detailed description of the detected informed trades, two tables are reported for every sector: Tables 2 and 3 for the airline sector; Tables 4 and 5 for the banking sector; and Tables 6 and 7 for the last group of companies. Tables 2, 4 and 6 report various information on the informed trades $k_t \in \Omega_1 \cap \Omega_3 \cap \Omega_4$, namely the day on which the transaction took place (Day); identification number of the put options (Id); the moneyness (S_t/K); its time-to-maturity (τ); the level of open interest the day before the informed transaction (OI_{t-1}); the increment in open interest from day $t-1$ to day t (ΔOI_t); its quantile with respect to its empirical distribution computed over the last two years ($q_t^{\Delta OI}$); the total increment in open interest (i.e. when considering all the available options at day t and not only the ones which had the highest increment, ΔOI_t^{tot}); the corresponding volume (Vol_t); the maximum return realized by the selected option in a two-week period following the transaction day ($r_t^{\max}$); the number of days between transaction day t and when this maximum return occurs (τ_2); the gains realized through the exercise of the new option issued at time t (G_t); the minimum between the number of days (starting from the transaction day) needed for the exercise of ΔOI_t and 30 days (τ_3); the percentage of ΔOI_t exercised within the first 30 days after the transaction ($\%ex.$); the ex-ante probability (q_t); the p-value of the hypothesis that hedging does not take place at time t; a proxy for the probability of informed trading ($1-p_t$). Tables 3, 5 and 7 have a more descriptive nature and report the following information for the selected events: the day on which the transaction took place (Day of transaction); the market condition at day t given by the average return of the underlying stock during the last two trading weeks (Market condition); the minimum return of the underlying stock in a two-week period following the transaction day (Return); when the stock crashed (Crash in the stock); a short description of the event and why the stock dropped (Event's description). In most of the cases this drop in the underlying stock is large enough that its cause is reported in the financial press such as the business section of the New

York Times. We could not identify the cause of a few events when the movements in the underlying stock were not significant. Interestingly, in most of these cases the hypothesis of non-hedging can be rejected at a 5% confidence level, suggesting that those option trades were not originated by informed traders. For transactions whose days are marked with asterisks the hypothesis of non-hedging can be rejected at a 5% level; see p-value reported on the last column of the corresponding tables.

Informed trades in the days leading up to quarterly financial statements might be somehow expected because the event day is known in advance. By definition, informed traders have either actively followed and analyzed the company's performance or are in possession of private information. Based on this knowledge they might therefore correctly guess the content of quarterly financial statements and develop profitable trading strategies. By contrast, the detected unusual activities in the options market before the terrorist attacks of September 11th and M&A public announcements deserve more attention. In what follows we concentrate therefore on these specific events. We analyze three cases in detail: the terrorist attacks of September 11th, the acquisition announcement in May, 2000 involving AMR and UAL, and the delay announcement of the EADS superjumbo jet A380. For the remaining selected trades one can do a similar analysis. To save space tables and figures are omitted but are available from the authors upon request.

4.1 The terrorist attacks of September 11th

The terrorist attacks have generated many articles, in which political, strategic and economic aspects have been considered. The financial dimension has also been discussed by the press. In particular, the question of whether the terrorist attacks of September 11th had been preceded by abnormal trading volumes, generated widespread news reports just after 9/11. As far as official regulators and control committees have been concerned, they dismiss charges against possible in-

formed traders. The American 9/11 Commission has stated that "exhaustive investigations by the Security and Exchange Commission, FBI and other agencies have uncovered no evidence that anyone with advance knowledge of the attacks profited through securities transactions".[5]

From an academic point of view, this topic did not generate much research interest. The article of Poteshman (2006) is a notable exception. Focused mainly on the airline sector, he computes the distributions of option market volume statistics both unconditionally and when conditioning on the overall level of option activity, the return and trading volume on the underlying stocks and the return on the overall market. He finds that "when the options market activity in the days leading up to the terrorist attacks is compared to the benchmark distributions, volume ratio statistics are seen to be at typical levels. As an indicator of long put volume, however, the volume ratio statistics appear to be unusually high which is consistent with informed investors having traded in the options market in advance of the attack". In the following the informed option trades detected by our method are discussed in detail.

4.1.1 Analysis of options traded in CBOE

In total 13 transactions satisfy our criteria of informed trade and involve five airlines companies (AMR, UAL, BA and to a lesser extent DAL and KLM) and four banks (BAC, C, JPM and MER). Concerning the airline sector, AMR and UAL are the two companies whose planes were hijacked and crashed by the terrorists. Informed option trade for KLM might be surprising, but supports the suspicion of "insider trading in KLM shares before September 11th attacks", as reported in a Dutch government investigation (Associated Press Worldstream). The terrorist attacks had indirect implications for BA and DAL, like a potential decrease in the number of passengers. Based on our methodology, AMR, UAL, and BA were more likely object of informed trade than DAL and KLM.

[5]The 9/11 Commission Report, Page 172, available on *http://www.9-11commission.gov/report/911Report.pdf.*

With respect to the banking sector, Merrill Lynch, Bank of America, and J.P. Morgan were located in World Trade Center or nearby, and the Travelers Insurance Unit of Citigroup was expected to pay $500 million in claims.

In the case of American Airlines we will now report the details of the transaction which took place on September 10th. Additional tables are available from the authors upon request. The upper graphs in Figure 1 show the plot of option volume, V_t, versus its increment in open interest, X_t. The informed trades are highlighted with the circles. The left graph covers the period from January 1997 to December 2001, to better visualize the option market condition up to December 2001. The right graph covers the period January 1997–January 2006. The selected transactions are isolated from the bulk of the data, suggesting that they are statistically unusual. For September 2001 Figures 2 and 3 show the dynamic of three variables: open interest, volume and the option return. As claimed in several newspaper articles, the volume and open interest of puts had been unusually high in the days leading up to September 11th. On September 10th 1,535 put contracts were traded and from September 7th to September 10th the open interest increased of 1,312 contracts (at 99.5% quantile of its two-year empirical distribution, Figure 2). The trading volume was more than 60 times the average of the total daily traded volume during the three weeks before September 10th. These puts had a strike price of $30 and a maturity in October. On September 10th, the stock price was $29.7 and the put price was $2.15. On September 17th, when markets reopened after the attacks, the stock price was $18 and the put price was $12. Such an investment in put options generated an unusually high return (458% in one week). Put options were obviously exercised on September 17th, the open interest decreased of 597 contracts, generating a gain of almost $600,000. A few days later, another considerable number of put options (475 contracts) were exercised; see Figure 2. Table 2 reports the gains (G_t) of such a trade. Twenty-six days later the sum of exercised options corresponded to the increment observed on September 10th and lead to a cumulative gain

of more than one million (G_t = \$1,179,171). The lower graph in Figure 1 shows the cumulative gain for all transactions selected using the three criteria. The trade in put options of AMR corresponds to the transaction that leads to the highest gains in the shortest time interval in the period we are considering. Figure 2 shows that the trading volume after September 17th was negligible meaning that the main gain was realized through exercise and not selling the options. Similar conclusions can be reached for the other trades selected using our procedure. For example two trading days before the terrorist attacks 4,179 new put options (at 98.5% quantile of its two-year empirical distribution) on Boeing were issued. The underlying stock was traded at \$45.18 and the option had a strike of \$50. On September 17th, the stock was traded at \$35.8. Six days afterwards these options were exercised leading to gains of more than five million. Concerning Bank of America, a large increment of 3,380 in open interest (at 96.3% quantile of its two-year empirical distribution) took place on September 7th for an option with a strike of \$60 when the underlying asset had a value of \$58.59 (on September 17th, the underlying stock had a value of \$54.35). The exercise of those options in the following seven days resulted in net gains of almost two million; for Merrill Lynch, on September 10th, 5,615 new put options (at 99.1% quantile of its two-year empirical distribution) with strike \$50 were issued, the underlying stock had a value of \$46.85. On September 17th the underlying stock was traded at \$41.48. Less than six days later these options had been exercised leading to gains of around \$4.5 million. For the remaining companies similar results can be reached from the reported tables. Based on Tables 2 and 4, the total gains in the airline sector amount to more than \$16 million, whereas in the banking sector \$11 million in gains have been computed. Interestingly, in nearly all cases the hypothesis of non-hedging cannot be rejected.[6]

[6]In the article "Not much stock in put conspiracy: the attacks on New York City and Washington have led to a new urban legend, namely that inside traders used put options on airline stocks to line terrorist pockets" published on June 3th, 2002 by Kelly Patricia O'Meara in *Insight on the News*, other repeated spikes of volumes of put options on American Airlines and United Airlines during the year before 9/11 are highlighted and used as argument that

4.1.2 Analysis of options traded in EUREX

Several reinsurance companies suffered severe losses from the terrorist attacks of September 11th. Liabilities for Munich Re and Swiss Re—the world's two biggest reinsurers—were estimated to be in the amount of billions of dollars a few days after the attacks. At the same time, several newspapers reported that trading in shares of these two companies were at unusual levels in the days leading up to September 11th, divulging some rumors of informed trading activities. A detailed analysis of transactions on the options market has however thus far been ignored. Options with underlying Swiss Re and Munich Re are mainly traded on the EUREX, one of the world's largest derivatives exchanges and the leading clearing house in Europe established in 1998 after the merger of Deutsche Terminbörse (DTB, the German derivatives exchange) and SOFFEX (Swiss Options and Financial Futures). In this section we use the EUREX database provided by Deutsche Bank to analyze transactions in put options with underlying Swiss Re and Munich Re. The database does not contain intraday data and hence the hedging dimension cannot be investigated.

In the case of Munich Re, 4 informed trades are detected between 1999 and 2008 which belong to the set $\Omega_1 \cap \Omega_3 \cap \Omega_4$, one of which took place on August 30th, 2001. As we are mainly interested in informed trades surrounding the terrorist attacks in this subsection, we only discuss the details of this transaction (the others took place on August 29th, 2002; September 2nd, 2002; and October 19th, 2007). The detected put option with underlying Munich Re matured at the end of September, 2001 and had a strike of €320 (the underlying asset was traded at €300.86 on August 30th). That option shows a large increment in open interest of 996 contracts (at 92.2% quantile of its two-year empirical distribution) on August 30th. Its price on that day was €10.22 and the ex-ante probability q_t is slightly lower than 5%. On the day of the terrorist attacks, the underlying stock

what occurred in the days leading up to 9/11 was not as unusual as other theories claim. Our method does not select any of those spikes mainly because of the relatively small gains that they generated.

lost more than 15% (the closing price on September 10th was €261.88 and on September 11th €220.53) and the option price jumped to €89.56, corresponding to a return of 776% in 8 trading days. On September 12th, 1,350 put options with those characteristics were exercised. The gains G_t related to the exercise of the 996 new put options issued on August 30th correspond to more than €3.4 million.

In the case of Swiss Re, 6 informed trades are detected between 1999 and 2008 which belong to the set $\Omega_1 \cap \Omega_3 \cap \Omega_4$, one of which took place a few weeks before the terrorist attacks, on August 20th. This option expired at the end of September, 2001, had a strike of €159.70 and had a large increment in open interest of 3,302 contracts (at 99.8% quantile of its two-year empirical distribution) on August 20th. That option was traded at €0.8 and exhibits an ex-ante probability q_t of 0.4%, meaning that such an event happens on average once every year. The Swiss Re closing share price was €177.56 on August 20th. On September 11th, when the stock price fell from €152.62 to €126.18, the option generated a return of 4,050% in three trading weeks, when its price jumped to €33.2. Through the exercise of these new put options in the 9 days following the attacks, the total gains were more than €8 million. Together with Munich Re, a total gain of €11.4 million had been realized in less than two trading weeks by using two options with underlying Munich Re and Swiss Re. To save space the corresponding tables and figures are omitted but are available from the authors upon request.

4.2 The acquisition announcement in the US airline sector in May 2000

Two informed trades detected by our method took place on May 10th and 11th, 2000. They involved AMR and UAL. On May 10th and 11th, the number of new options issued with strike $35 and maturity June 2000 with underlying AMR is very large: 3,374 on May 10th and 5,720 the day after (at 99.7% and 99.9% quantile of their two-year empirical distributions, respectively). These

transactions correspond to those which exhibit the strongest increments in open interest during a span of five years; see upper left graph in Figure 1 and Figure 3. On May 10th, the underlying stock had a value of \$35.50 and the selected put was traded at \$2.25. For UAL 2,505 new put options (at 98.7% quantile of its two-year empirical distribution) with strike \$65 and the same maturity as those of AMR were issued on May 11th at the price of \$5.25 when the underlying had a value of \$61.50. The market conditions under which such transactions took place do not show any particularity: the average return of the stock the week before is, in both cases, positive and less than 0.5%. The days of the drop in the underlying stock are May 24th and May 25th, 2000, with the first day corresponding to the public announcement of United Airline's regarding a \$4.3 billion acquisition of US Airways. As reported in the May 25th, 2000 edition of the New York Times, "shares of UAL and those of its main rivals crashed" (for details see Footnote 1). The stock price of AMR dropped to \$27.13 (-23.59% of value losses when compared to the stock price on May 11th) increasing the value of the put options to \$7.88 (resulting in a return of 250% in two trading weeks). The same impact can be found for UAL: the stock price after the public announcement dropped to \$52.50 (-14.63% when compared to the value on May 11th) raising the put's value to \$12.63 (corresponding to a return of 140% in two trading weeks). In the case of AMR, the decline in the underlying stock can be seen in Figure 3, where the option return largely increased. On the day of the public announcement 4,735 put options of AMR were exercised; see Figure 3. After this large decrement in open interest, 1,494 and 1,376 additional put options were exercised in the following two days respectively (reflected in additional drops in open interests in Figure 3). The unusual increments in open interest observed on May 10th and May 11th are therefore off set by the exercise of options when the underlying crashed. The corresponding gains G_t from this strategy are more than \$1.6 million within two trading weeks. These are graphically shown in the lower graph in Figure 1, from which we can see how fast these gains were realized. In the case of UAL similar

conclusions can be reached; see Tables 2 and 3. Based on these trades, a total gain of almost $3 million was realized within a few trading weeks using options with underlying AMR and UAL. The non-hedging hypothesis cannot be rejected suggesting that such trades are naked option positions.

4.3 The delayed delivery announcement of EADS superjumbo A380 in May 2006

At the time of the writing of this paper, European Aeronautic Defence and Space (EADS), a large European aerospace corporation and the parent of plane maker Airbus, is under investigation for illegal insider trading activities. On July 2nd, 2006, co-CEO Noël Forgeard and Airbus CEO Gustav Humbert resigned following the controversy caused by the June 14th, 2006 announcement that deliveries of the superjumbo jet A380 would be delayed by a further six months. Mr. Forgeard was one of a number of executives who sold his stake in EADS a few months before the public announcement. In June shares of EADS exhibited a 26% fall (the closing price of EADS shares on June 13th was €25.42 and on June 14th €18.73) wiping more than €5 billion from the company's market value. He and 21 other executives are currently under investigation as to whether they knew about the delays in the Airbus A380 project and sold their stock on the basis of this private information, constituting therefore illegal insider trading. In the financial press, the profits resulting from this strategy are estimated to total approximately €20 million.[7]

Based on reports in the financial press, French authorities' investigations have concentrated thus far on stock sales and stock options exercised before the announcement day. Apparently, trading strategies based on put options were ignored, despite their appealing features for investors in possession of private information. We apply our method to put options on EADS and detect various informed trades on the EUREX in the period leading up to the announcement day. Obviously our study does not constitute proof of illegal activities.

[7]The New York Times edition of June 18th, 2008: "Executive Questioned in EADS Insider Trading Case".

For the period 2003–2009 our procedure detects six informed trades in put options belonging to the set $\Omega_1 \cap \Omega_3 \cap \Omega_4$, all of which took place between April 6th and May 19th, 2006.[8] Table 8 summarizes the findings. Four of these six options had maturity at the end of June 2006, the remaining two end of May 2006 and end of July 2006. The four options maturing in June 2006 exhibited large increments in open interest and volume on April 7th (3,855 contracts), on April 20th (1,000 contracts), on May 8th (810 contracts) and on May 18th (2,518 contracts). These increments correspond to the 99.8%, 93.4%, 92.2%, and 99% quantiles of the corresponding two-year empirical distributions. The options had strikes of €32, €30, €30 and €31 and the underlying traded at €31.88, €31.30, €31.36 and €27.59 respectively on the transaction days. The maximum returns generated from these trades are large: for example, the option selected on May 8th traded at €0.71 on that day and on June 14th its price jumped to €11.27 when the stock crashed. This corresponds to a return of 1,487% within five trading weeks. On the announcement day 760 contracts of that option were exercised, generating a net profit of €802,560. The option selected on May 18th, traded at €3.46 on that day and at €12.27 on June 14th, resulting in a return of 255% within four trading weeks. On June 16th 2,667 contracts were exercised. Assuming that the 2,518 options issued on May 18th were exercised on that day, a net gain of €1.7 million is reached. The option with a large increment in open interest on May 19th and maturity end of July was bought for €0.71 on that day and had a strike of €26 when the underlying traded at €27.39. On the announcement day its value increased to €7.27, corresponding to a net return of 924% within four trading weeks. After the announcement day, these options were exercised and generated a net gain of almost €1.5 million.

[8] On May 12th, 2006, a meeting of the company board took place in Amsterdam in order to discuss possible solutions to the management crisis triggered by the future announcement day. This was planned to take place the following month. According to the New York Times edition of June 29th, 2006, 13 people were present, including Noël Forgeard and Gustav Humbert. The delay in A380 deliveries was likely to cost EADS €2 billion over the following four years.

Similar patterns are observed for the options traded on April 7th (strike €32 and underlying value €31.88): the large increment of 3,855 contracts generated total gains of almost €1.7 million. For the remaining options, a similar analysis can be made. Figure 5 shows the corresponding realized gains. Figures 6 and 7 show relevant variables for the transactions which took place on April 20th and May 19th, 2006; see also Table 8. Based on the six detected transactions, a total gain of €7.5 million had been realized within 60 trading days after the announcement.[9]

4.4 Robustness checks

The input parameters in our detection procedure are: the length N of the estimation window, chosen to be $N = 500$ trading days, used for the computation of the ex-ante probability q_t, the conditional distribution of $V_t^{\text{buy,non-hedge}}$, and the quantiles $q_\alpha^{r_t^{\max}}$ and $q_{\alpha'}^{G_t}$; the time period after the transaction day used for the computation of R_t, chosen to be 10 trading days; the time horizon τ_t used for the calculation of the gains G_t, chosen to be 30 trading days; the quantile levels α and α' in $q_\alpha^{r_t^{\max}}$ and $q_{\alpha'}^{G_t}$ used for the computation of the sets Ω_3 and Ω_4, chosen to be $\alpha = 90\%$ and $\alpha' = 98\%$; the probability level based on which we select trades belonging to the set Ω_1, chosen to be 5% in our selection procedure. In what follows we set the input parameters to different values and we repeat all previous analysis for all companies. To save space we report only some of the results but the remaining ones are available from the authors upon request.

When varying the length of the estimation window N between 200 and 1,000, (all other parameters being unchanged) the number of selected transactions does not change significantly. For example in the case of AMR, we selected 5 informed trades when considering the last two trading years ($N = 500$ days); for $N \in [200, 1000]$ the number of detected informed trades ranges between

[9] Options contracts with underlying EADS are traded at the EURONEXT in Paris as well. Using a database provided by EURONEXT NYSE, we were able to apply the first two criteria of our detection procedure. Six informed put options trades were identified in Spring 2006. The total gains collected amount at €25.6 million.

4 and 6; for UAL this number remains unchanged with respect to the original choice for $N > 450$ and decreases by one when $N \in [200, 450]$. In the case of BAC and AT&T, the deviation from the original number of selected trades is less than 2. With respect to the choice of the time period used for the computation of R_t and τ_t, our results are also robust. We let the length of the first period vary in the range $[1, 30]$ days and the second one in [1,40] days. In the case of AMR, the number of transactions ranges from 2 to 8, being therefore centered around the original number and with a small deviation from it. For UAL, the corresponding range is from 1 to 4, for BAC from 2 to 8 and for AT&T from 1 to 6. The number of detected trades is obviously a decreasing function of α and α' (all other parameters being unchanged). In the case of AMR, when $\{\alpha, \alpha'\} \in [0.85, 0.95] \times [0.96, 1]$, the number of transactions selected does not exceed 15. For UAL, the number of selected trades varies between 1 and 10, for BAC between 5 and 25, and for AT&T between 1 and 18. Finally, with respect to the probability level used to determine the set Ω_1, our findings are very robust as well. When increasing the level from 1% to 10%, the number of trades selected for AMR varies between 1 and 6; for UAL it ranges between 2 to 4, for BAC and AT&T from 1 to 7. We simultaneously changed several parameters and found that the number of detected transactions does not change significantly and in almost all cases in steps of one. We recall that approximately 1.5 million of options are analyzed. Based on these results, we conclude that our findings are robust.

4.5 Accuracy of the hedging detection method

In this section we provide an assessment of the accuracy of our hedging detection method introduced in Section 2.3. Recall that the hypothesis H_0 of no hedging when informed trades occur at day i is rejected whenever $V_i^{\text{buy}} > q_\alpha^{V_i^{\text{buy,non-hedge}}}$, suggesting that a sizable component of buyer-initiated trades in the stock is due to hedging. We measure the accuracy of the method computing the probability of rejecting H_0 when that the latter does not hold, i.e. the power of the test. Let

$V_i^{\text{buy}} = (1 + h_i)\ V_i^{\text{buy,non-hedge}}$, where $h_i \geq 0$. The h_i represents the ratio between buyer-initiated volume due to hedging and buyer-initiated volume due to non-hedging. By construction H_0 is equivalent to $h_i = 0$ meaning that volume trades due to hedging is zero. The hypothesis H_0 should be rejected when $h_i > 0$, and the higher the rejection rate the more accurate the hedging detection method. Let $q_\alpha := q_\alpha^{V_i^{\text{buy,non-hedge}}}$, the measure of accuracy $\mathbb{A}(h_i)$ reads therefore

$$\mathbb{A}(h_i) := \mathbb{P}\Big[V_i^{\text{buy}} > q_\alpha | h_i\Big] = \mathbb{P}\Big[V_i^{\text{buy,non-hedge}} > q_\alpha/(1+h_i) | h_i\Big]. \tag{4}$$

The hedging detection method is accurate whenever $\mathbb{A}(h_i)$ increases fast enough in h_i. The probability in (4) can be calculated as $(1-\tilde{F}(q_\alpha/(1+h_i)|\mathbf{X}_i))$, where $\tilde{F}$ is estimated using (3) and $\alpha = 0.95$ as in our empirical analysis. We computed $\mathbb{A}(h_i)$ for several stocks, sample periods, estimation windows, and different values of h_i and of the conditioning variables $\mathbf{X}_i = (|r_i|, V_{i-1}^{\text{buy,non-hedge}})$. Table 9 gives numerical values of $\mathbb{A}(h_i)$ for Citigroup on the random day December 17th, 2001. Corresponding results for other stocks are fairly similar and available upon request from the authors. When $h_i = 0$, $\mathbb{A}(h_i)$ is very close to $0.05 = (1 - \alpha)$, which is the non-eliminable size of the test. When h_i increases, $\mathbb{A}(h_i)$ increases as well although certain combinations of the conditioning variables are more favorable than others to reject the hypothesis of no hedging. Overall the power of the test is fairly satisfactory. For example when $h_i = 0.20$, $\mathbb{A}(h_i)$ can be as high as 20%. When $\mathbb{A}(h_i)$ does not increase fast enough, our method does not detect potential option informed trades. In this respect the results documented in the empirical section should be interpreted in a conservative manner.

5 Conclusion

Informed trading activities in stock markets have been extensively investigated in the finance literature. Our paper contributes to this literature in two directions: it studies informed trading activities in option rather than stock markets and provides a statistical method to detect informed

trades in option contracts. According to our method, an option trade is identified as informed when it is characterized by a large increment in open interest and volume, induces large gains, and is not hedged in the stock market. This method is applied to each put option contract on 14 companies in various business sectors traded in the Chicago Board Options Exchange from January 1996 to April 2006 analyzing approximately 1.5 million of options. In total 37 transactions are identified as informed trades the vast majority of which can be assigned to one of the following three event categories: merger and acquisition announcements, quarterly financial/earnings related statements, and the terrorist attacks of September 11th. For example two informed trades involve American Airlines and United Airlines on May 10th and 11th, 2000, namely two weeks before UAL's acquisition of US Airways was announced. Three informed trades on put options with underlying Philip Morris stock are detected a few days before three separate legal cases against the company seeking a total amount of more than $50 million in damages for smokers' deaths and inoperable lung cancer. Our method is also applied to each put option on Swiss Re, Munich Re and EADS traded on EUREX from January 1999 to January 2008. For example in the case of EADS, the parent of plane maker Airbus, six informed option trades are identified between April and June 2006. These trades precede the June 14th, 2006 announcement that deliveries of the superjumbo jet A380 would be delayed by a further six months, causing a 26% fall in the underlying stock, and a total gain of €7.5 million in these option trades.

Our results have also policy, option pricing, and market efficiency implications. If some of the detected informed trades are indeed illegal, for example originated by insiders, it might be optimal for regulators to expend relatively more monitoring efforts on the options markets. Option pricing models should account for all relevant information available at time t. However nearly all option prices involved in informed trades according to our method do not show any specific reaction to the large increments in open interest and volume. The strong increases in these put option prices

are simply due to subsequent large drops in stock prices originated for example by merger and acquisition announcements. From an efficient market perspective, our findings suggest that certain put option trades might predict large price drops. Trading strategies built on such predictions might generate potentially large gains.

Summary of Airline, Banking and Various sectors Jan 1996 - Apr 2006

	Airline		Banking		Various		Total
merger and acquisition announcement	4 (4)	22.22% (26.67%)	0 (0)	0.00% (0.00%)	2 (2)	8.00% (25.00%)	**6 (6)**
quarterly financial/earning related announc.	3 (3)	16.67% (20.00%)	15 (6)	55.56% (42.86%)	18 (5)	72.0% (62.50%)	**36 (14)**
terrorist attacks of September 11	10 (8)	55.56% (53.33%)	5 (5)	18.52% (35.71%)	0 (0)	0.00% (0.00%)	**15 (13)**
not identified	1 (0)	5.56% (0.00%)	7 (3)	25.93% (21.43%)	5 (1)	20.00% (12.50%)	**13 (4)**
Total	**18 (15)**		**27 (14)**		**25 (8)**		**70 (37)**

Table 1: Number of transactions identified as informed, percentage for the various sectors and corresponding event category. An informed put option trade is characterized by a statistically high increment in open interest and volume, generates an abnormal return and large gain a few days later and is not delta hedged. Entries refer to informed trades when disregarding the hedging dimension and when considering it (number in brackets when hedging demand is taken into consideration).

Summary of Airline Sector Jan 1996 - Apr 2006

Day	*Id*	$	τ	OI_{t-1}	ΔOI_t	$q_t^{\Delta OI}$	ΔOI_t^{tot}	Vol_t	$r_t^{\max}$	τ_2	G_t	τ_3	$\%ex.$	q_t	p-value	$1-p_t$
American Airlines (AMR) Jan 1996 - Apr 2006																
10 May 00	10821216	1.01	38	20	3374	99.7%	3378	3290	106%	9	906,763	11	100%	0.002	0.286	0.998
11 May 00	10821216	1.02	37	3394	5720	99.9%	5442	5320	98%	10	1,647,844	11	100%	0.002	0.349	0.998
31 Aug 01	20399554	0.91	22	96	473	95.7%	571	500	455%	7	662,200	11	100%	0.016	0.645	0.984
10 Sep 01	20428354	0.99	40	258	1312	98.5%	1701	1535	453%	2	1,179,171	26	100%	0.012	0.096	0.998
24 Aug 05	27240699	0.97	24	1338	4378	93.5%	8395	5319	163%	8	575,105	17	100%	0.048	0.123	0.952
United Airlines (UAL) Jan 1996 - Jan 2003																
11 May 00	11332850	0.95	37	35	2505	98.7%	2534	2505	132%	10	1,156,313	26	100%	0.002	0.373	0.998
6 Sep 01	20444473	1.06	44	21	1494	96.3%	1189	2000	1322%	7	1,980,387	28	100%	0.030	0.165	0.998
Delta Air Lines (DAL) Jan 1996 - May 2005																
*1 Oct 98	10904865	1.01	16	140	974	97.7%	483	924	261%	6	537,594	12	100%	0.016	0.000	0.996
29 Aug 01	20402792	0.98	24	1061	202	89.7%	224	215	1033%	9	328,200	13	100%	0.044	0.528	0.998
19 Sep 02	20718332	0.99	30	275	1728	98.7%	550	1867	132%	7	331,676	22	100%	0.004	0.190	0.998
9 Jan 03	21350972	1.10	44	274	3933	99.7%	4347	4512	112%	9	1,054,217	30	100%	0.002	0.065	0.998
Boeing (BA) Jan 1996 - Apr 2006																
24 Nov 98	10948064	0.99	53	3758	1047	93.5%	1285	1535	467%	7	883,413	24	100%	0.040	0.481	0.996
29 Aug 01	20400312	0.92	24	1019	2828	96.7%	3523	3805	382%	10	1,972,534	8	100%	0.028	0.252	0.998
5 Sep 01	20429078	1.01	45	472	1499	92.1%	2538	1861	890%	8	1,805,929	22	100%	0.048	0.085	0.998
6 Sep 01	11839316	0.75	135	13228	7105	99.3%	13817	7108	118%	7	2,704,701	3	100%	0.006	0.150	0.998
*7 Sep 01	20400311	0.90	15	7995	4179	98.5%	4887	5675	306%	6	5,775,710	7	100%	0.016	0.000	0.998
*17 Sep 01	20400309	0.90	5	116	5026	98.9%	2704	5412	124%	4	2,663,780	5	100%	0.010	0.000	0.998
KLM Jan 1996 - Nov 2001																
5 Sep 01	20296159	0.91	17	3	100	99.3%	34	100	467%	9	53976	9	100%	0.006	0.368	0.998

Table 2: Description of detected informed trades for the airline sector. For definition of entries see Page 37.

Summary of Airline Sector Jan 1996 - Apr 2006

Day of transaction	Market condition	Return	Crash in stock	Event's description
			American Airlines (AMR) Jan 1996 - Apr 2006	
10 May 00	0.4%	−17.6%	24/25 May 00	Announcement 24 May 00: Airline Deal UAL's acquisition of US Airways
11 May 00	0.0%	−17.6%	24/25 May 00	Announcement 24 May 00: Airline Deal UAL's acquisition of US Airways
31 Aug 01	−0.4%	−39.4%	17 Sep 01	9/11 Terrorist attacks in New York
10 Sep 01	−1.4%	−39.4%	17 Sep 01	9/11 Terrorist attacks in New York
24 Aug 05	0.4%	−5.3%	30 Aug 05	August 05: Hurricane Katrina, interrupted production on the gulf coast, jet fuel prices ↑
			United Airlines (UAL) Jan 1996 - Jan 2003	
11 May 00	0.3%	−12%	24 May 00	Announcement 24 May 00: Airline Deal UAL's acquisition of US Airways
6 Sep 01	−1.0%	−43.2%	17 Sep 01	9/11 Terrorist attacks in New York
			Delta Air Lines (DAL) Jan 1996 - May 2005	
*1 Oct 98	−1.7%	−11.4%	07/08 Oct 98	Not identified
29 Aug 01	0.0%	−44.6%	17 Sep 01	9/11 Terrorist attacks in New York
19 Sep 02	−5.2%	−24.4%	27 Sep 02	Announcement 27 Sep 02: Expected loss for 3rd quarter
9 Jan 03	2.1%	−15.7%	21/22 Jan 03	Announcement 21 Jan 03: Restrictions on planned alliance of Delta, Northwest and Continental
			Boeing (BA) Jan 1996 - Apr 2006	
24 Nov 98	−0.2%	−22.0%	02/03 Dec 98	Announcement 02. Dec 98: production scale back and cut in work forces
29 Aug 01	−0.4%	−25.0%	17/18 Sep 01	9/11 Terrorist attacks in New York
5 Sep 01	−0.8%	−25.0%	17/18 Sep 01	9/11 Terrorist attacks in New York
6 Sep 01	−0.9%	−25.0%	17/18 Sep 01	9/11 Terrorist attacks in New York
*7 Sep 01	−1.9%	−25.0%	17/18 Sep 01	9/11 Terrorist attacks in New York
*17 Sep 01	−5.6%	−25.0%	17/18 Sep 01	9/11 Terrorist attacks in New York
			KLM Jan 1996 - Nov 2001	
5 Sep 01	−1.9%	−31.6%	17/18 Sep 01	9/11 Terrorist attacks in New York

Table 3: Summary of detected informed trades for the airline sector. For definition of entries see Page 37.

Content of Tables 2, 4 and 6: day on which the transaction took place (Day); identification number (Id) of the put options; moneyness ($= S_t/K$); its time-to-maturity (τ); level of open interest the day before the informed trade (OI_{t-1}); increment in open interest from day $t-1$ to day t (ΔOI_t); its quantile with respect to its empirical distribution computed over the last two years ($q_t^{\Delta OI}$); total increment in open interest (i.e. when considering all the available options at day t and not only the ones which had the highest increment, ΔOI_t^{tot}); corresponding volume (Vol_t); maximum return realized by the selected option during the two-week period following the transaction day ($r_t^{\max}$); number of days between transaction day t and when this maximum return occurs (τ_2); gains realized through the exercise of the new option issued at time t (G_t); minimum between the number of days (starting from the transaction day) needed for the exercise of ΔOI_t and 30 days (τ_3); percentage of ΔOI_t exercised within the first 30 days after the transaction; ex-ante probability (q_t); p-value of the hypothesis that delta hedging does not take place at time t; proxy for the probability of informed trading ($1-p_t$).

Content of Tables 3, 5 and 7: day on which the transaction took place (Day); market condition at day t measured by the average return of the underlying stock during the last two trading weeks (Market condition); minimum return of the underlying stock during the two-week period following the transaction day (Return, comparable therefore with $r_t^{\max}$ of the previous tables); short description of the event and why the stock drops (Event's description). In most of the cases this drop in the underlying stock is large enough that its cause is reported in the financial press such as the business section of the New York Times. The cause of a few informed trades could not be identified. In those cases the movements in the underlying stock were not significant and in several of these cases the hypothesis of non-hedging can be rejected at a 5% confidence level. For transactions whose days are marked with asterisks the hypothesis of non-hedging can be rejected at a 5% level; see p-value reported in the last column of the corresponding tables.

Summary of Banking Sector Jan 1996 - Apr 2006

Day	*Id*	$	τ	OI_{t-1}	ΔOI_t	$q_t^{\Delta OI}$	ΔOI_t^{tot}	Vol_t	$r_t^{\max}$	τ_2	G_t	τ_3	%*ex.*	q_t	p-value	$1-p_t$
Bank of America (BAC) Jan 1996 - Apr 2006																
13 Jun 00	10196393	0.93	39	272	1996	94.10%	1883	2124	154%	7	1,505,256	28	100%	0.026	0.170	0.998
*13 Nov 00	11596097	1.00	5	1747	6273	99.10%	6240	7270	522%	5	3,081,216	5	100%	0.006	0.047	0.998
7 Sep 01	20400334	0.98	15	8720	3380	96.30%	3607	4303	241%	7	1,774,525	7	100%	0.026	0.091	0.994
Citigroup (C) Jan 1996 - Apr 2006																
30 Aug 01	20201221	1.07	23	9394	4373	94.50%	8880	5427	622%	10	2,045,940	12	100%	0.044	0.096	0.998
*18 Jun 02	20576902	0.96	95	3552	9984	97.90%	−8249	10090	114%	7	7,661,724	30	65%	0.002	0.000	0.998
*17 Jul 02	20732009	0.92	31	4467	4923	91.30%	9420	5148	227%	5	3,579,435	5	100%	0.028	0.000	0.996
28 Apr 04	21436285	0.97	24	38184	17803	99.90%	24618	21429	102%	9	3,172,024	18	100%	0.002	0.197	0.998
J.P. Morgan (JPM) Jan 1996 - Apr 2006																
*5 Oct 00	11674068	0.99	16	4632	2957	94.70%	3587	2843	391%	10	1,411,934	12	100%	0.030	0.004	0.998
*9 Nov 00	11848514	0.98	37	9303	9564	99.30%	10949	10681	164%	10	1,937,044	12	100%	0.004	0.000	0.998
29 May 01	11848586	0.99	18	22044	4290	95.70%	6603	5569	204%	9	1,508,490	10	100%	0.026	0.060	0.996
30 Aug 01	20435891	0.98	51	1370	3145	90.90%	2854	3407	153%	10	1,318,638	30	99%	0.026	0.058	0.998
6 Sep 01	20207536	0.92	16	22459	4778	96.30%	−9130	5359	178%	8	1,415,825	8	100%	0.014	0.075	0.998
18 Jan 02	20556357	1.03	29	6543	6168	97.10%	−85172	8421	225%	7	2,007,110	20	100%	0.024	0.145	0.996
17 Jan 03	21343021	0.95	36	5159	9597	99.10%	−133082	10527	117%	9	2,414,176	24	100%	0.006	0.061	0.998
Merrill Lynch (MER) Jan 1996 - Apr 2006																
*21 Aug 98	10840556	1.05	29	211	3679	99.50%	−6048	4165	428%	10	5,318,200	20	100%	0.002	0.000	0.998
*25 Aug 98	10963647	1.02	25	1410	1962	95.90%	2486	2207	629%	9	2,378,481	14	100%	0.020	0.000	0.998
*28 Aug 98	10840556	0.92	22	5138	2951	98.70%	2735	4703	186%	9	2,143,600	15	100%	0.012	0.000	0.996
*1 Sep 98	11499596	0.96	18	349	2224	96.70%	−1534	2548	136%	7	1,567,550	8	100%	0.014	0.000	0.998
10 Sep 01	20408663	0.94	12	6210	5615	99.10%	9898	7232	243%	5	4,407,171	6	100%	0.008	0.080	0.998
9 Apr 02	20642300	1.04	39	2549	3118	94.50%	5545	3513	129%	3	1,591,786	20	100%	0.010	0.135	0.998
Morgan Stanley (MWD) Jan 1996 - Apr 2006																
17 Aug 98	10174742	1.02	33	1003	1650	99.50%	1779	1660	341%	10	2,050,938	15	100%	0.004	0.197	0.998
*21 Aug 98	10148491	1.03	29	293	2064	99.70%	−3616	2362	554%	10	1,906,663	20	100%	0.004	0.005	0.998
25 Aug 98	10174742	0.98	25	2586	1291	98.70%	1638	2170	674%	9	1,467,850	6	100%	0.014	0.173	0.998
*28 Aug 98	11599638	0.93	22	2010	2010	99.50%	862	2010	265%	9	1,580,556	15	100%	0.002	0.000	0.998
3 Nov 00	10297869	1.04	15	4154	2297	97.90%	3285	3518	437%	8	1,947,447	11	100%	0.020	0.161	0.998
*22 May 01	20310213	1.06	25	1098	1816	90.30%	2284	1929	472%	6	1,871,086	18	100%	0.024	0.041	0.998
*6 Apr 05	31518375	1.03	10	14497	13807	99.90%	18342	18163	576%	8	2,780,148	8	100%	0.002	0.026	0.998

Table 4: Description of detected informed trades for the banking sector. For definition of entries see Page 37.

Summary of Banking Sector Jan 1996 - Apr 2006

Day of transaction	Market condition	Return	Crash in stock	Event's Description
			Bank of America (BAC) Jan 1996 - Apr 2006	
13 Jun 00	−1.0%	−14.8%	15/16 Jun 00	Announcement 15 Jun 00: Wachovia Corp. Correction of expected earnings for 2nd quarter
*13 Nov 00	−0.4%	−11.7%	14/15 Nov 00	Announcement 14 Nov 00: 3rd quarterly financial statements, potential write-offs for 4th quarter
7 Sep 01	−0.4%	−5.7%	17 Sep 01	9/11 Terrorist attacks in New York
			Citigroup (C) Jan 1996 - Apr 2006	
30 Aug 01	−0.5%	−6.7%	17 Sep 01	9/11 Terrorist attacks in New York
*18 Jun 02	0.6%	−5.4%	26 Jun 02	Not identified
*17 Jul 02	−0.3%	−26.7%	22/23 Jul 02	Announcement 22 Jul 02: Senate's investigations into Citigroup (Enron case)
28 Apr 04	−0.3%	−2.8%	10 May 04	Not identified
			J.P. Morgan (JPM) Jan 1996 - Apr 2006	
*5 Oct 00	−0.3%	−7.0%	12 Oct 00	Not identified
*9 Nov 00	−0.6%	−4.2%	15 Nov 00	Not identified
29 May 01	0.4%	−3.4%	6 Jun 01	Not identified
30 Aug 01	−0.8%	−7.5%	20 Sep 01	9/11 Terrorist attacks in New York
6 Sep 01	−1.5%	−7.5%	20 Sep 01	9/11 Terrorist attacks in New York
18 Jan 02	−1.4%	−6.6%	29 Jan 02	Announcement 16/22 Jan 02: financial statements for 4th quarter/losses on Enron's loans
17 Jan 03	−0.7%	−5.3%	24 Jan 03	Announcement 22 Jan 03: bigger 4th quarter loss than forecasted
			Merrill Lynch (MER) Jan 1996 - Apr 2006	
*21 Aug 98	0.0%	−16.3%	28/30/31 Aug 98	Announcement 17 August 98: Ruble crisis, Russian crisis, Asian crisis
*25 Aug 98	−0.4%	−16.6%	09/10 Sep 98	Announcement 17 August 98: Ruble crisis, Russian crisis, Asian crisis
*28 Aug 98	−2.6%	−16.6%	09/10 Sep 98	Announcement 17 August 98: Ruble crisis, Russian crisis, Asian crisis
*1 Sep 98	−3.7%	−16.6%	09/10 Sep 98	Announcement 17 August 98: Ruble crisis, Russian crisis, Asian crisis
10 Sep 01	−1.2%	−15.5%	17/18 Sep 01	9/11 Terrorist attacks in New York
9 Apr 02	−0.9%	−7.9%	11 Apr 02	Announcement 09 Apr 02: accusations of conflicts of interest, potential fine of > $100mio
			Morgan Stanley (MWD) Jan 1996 - Apr 2006	
17 Aug 98	0.7%	−17.2%	28/31 Aug 98	Announcement 17 August 98: Ruble crisis, Russian crisis, Asian crisis
*21 Aug 98	−0.3%	−17.2%	28/31 Aug 98	Announcement 17 August 98: Ruble crisis, Russian crisis, Asian crisis
25 Aug 98	−0.5%	−17.2%	28/31 Aug 98	Announcement 17 August 98: Ruble crisis, Russian crisis, Asian crisis
*28 Aug 98	−3.3%	−17.2%	28/31 Aug 98	Announcement 17 August 98: Ruble crisis, Russian crisis, Asian crisis
3 Nov 00	1.3%	−12.2%	07/08/09 Nov 00	Not identified
*22 May 01	2.3%	−5.7%	30 May 01	Not identified
*6 Apr 05	1.0%	−3.0%	20 Apr 05	Announcement 05 Apr 05: proposal of new CEO, discover credit card unit spin off

Table 5: Summary of detected informed trades for the banking sector. For definition of entries see Page 37.

Summary of various sectors Jan 1996 - Apr 2006

Day	*Id*	\$	τ	OI_{t-1}	ΔOI_t	$q_t^{\Delta OI}$	ΔOI_t^{tot}	Vol_t	$r_t^{\max}$	τ_2	G_t	τ_3	$\%ex.$	q_t	p-value	$1-p_t$
AT&T (ATT) Jan 1996 - Apr 2006																
*17 Apr 98	10307639	1.03	29	2178	2442	97.70%	−20484	2963	441%	9	1,605,881	21	100%	0.014	0.022	0.998
*25 Apr 00	10667683	1.04	25	14673	8512	99.50%	9847	12786	593%	10	9,407,938	19	100%	0.002	0.021	0.998
*26 Apr 00	10667683	1.02	24	23185	2637	93.90%	3422	1853	447%	9	2,348,288	15	100%	0.038	0.002	0.998
Coca Cola (KO) Jan 1996 - Apr 2006																
*24 Aug 98	10423228	1.00	26	4338	2134	94.50%	5285	3007	577%	9	2,246,363	6	100%	0.034	0.000	0.998
*26 Aug 98	10423228	0.99	24	7033	1439	88.90%	2910	1792	547%	7	1,381,344	4	100%	0.048	0.015	0.998
*18 Mar 99	11199798	0.98	30	1320	1902	93.10%	993	2082	175%	10	616,950	21	100%	0.006	0.000	0.998
*23 Aug 00	10973464	1.07	59	48	2257	96.10%	4890	2258	208%	7	698,259	17	100%	0.002	0.004	0.998
12 Feb 01	11851575	1.01	96	8130	756	72.80%	1060	759	166%	9	665,280	26	100%	0.012	0.117	0.996
20 Feb 01	20207914	0.97	25	945	1796	93.10%	3153	2349	254%	10	1,340,364	19	100%	0.042	0.248	0.998
28 Jun 02	20556780	1.12	50	12516	4664	98.70%	6891	5130	312%	10	1,935,470	17	100%	0.010	0.100	0.998
*9 Jul 02	20556781	1.03	39	4755	2659	97.30%	8167	3243	669%	9	789,515	29	100%	0.016	0.000	0.998
*10 Jul 02	20703870	0.99	10	5514	3013	97.70%	4528	5533	641%	8	779,200	4	100%	0.022	0.002	0.998
Hewlett Packard (HPQ) Jan 1996 - Apr 2006																
*14 May 98	10552311	1.00	37	2646	2745	96.90%	9720	4943	117%	10	1,470,119	13	100%	0.026	0.000	0.998
15 Sep 99	10087563	1.21	66	1785	1554	93.90%	4079	1917	200%	7	1,501,894	26	100%	0.022	0.344	0.998
*15 Oct 99	10848801	0.97	36	3403	6194	99.30%	−12522	7732	130%	9	1,277,513	4	100%	0.004	0.026	0.998
*28 Sep 00	11163103	0.97	23	2600	1220	85.90%	1449	1353	271%	10	1,166,625	3	100%	0.032	0.000	0.998
*30 Oct 00	11136235	0.96	19	5307	11513	99.90%	66131	5898	118%	10	4,178,669	15	100%	0.002	0.000	0.998
*31 Oct 00	10519981	1.16	18	0	13093	99.90%	43002	295	449%	10	3,917,616	14	100%	0.002	0.000	0.998
*9 Nov 00	10373575	0.95	9	17186	4453	98.50%	6502	7170	176%	3	1,847,794	4	100%	0.012	0.000	0.998
Philip Morris (MO) Jan 1996 - Apr 2006																
28 Jan 99	11211572	1.03	23	1237	3307	92.30%	3647	3314	444%	10	2,329,156	16	100%	0.008	0.187	0.998
30 Mar 99	11439476	0.94	18	5939	20993	99.10%	43843	21330	149%	6	6,038,594	13	100%	0.002	0.160	0.998
21 Aug 00	10577641	1.07	26	3590	5770	97.90%	8428	6262	145%	10	892,463	19	100%	0.010	0.489	0.996
*16 Mar 01	20241596	0.96	36	2902	3416	93.50%	−67790	3539	122%	5	938,726	16	100%	0.014	0.020	0.998
*3 Jun 02	20705047	1.04	47	16001	15344	97.90%	14567	16767	106%	10	3,291,798	16	100%	0.016	0.005	0.998
21 Jun 02	20705047	0.96	29	43143	7298	92.10%	−82813	8816	263%	5	2,079,930	2	100%	0.048	0.211	0.998

Table 6: Description of detected informed trades for various sectors. For definition of entries see Page 37.

Summary of various sectors Jan 1996 - Apr 2006

Day of transaction	Market condition	Return	Crash in stock	Event's Description
			AT&T (ATT) Jan 1996 - Apr 2006	
*17 Apr 98	0.4%	−2.9%	27 Apr 98	Announcement 20 Apr 98: financial statements for first quarter
*25 Apr 00	0.7%	−19.0%	02/03 May 00	Announcement 02 May 00: financial statements for first quarter
*26 Apr 00	1.5%	−19.0%	02/03 May 00	Announcement 02 May 00: financial statements for first quarter
			Coca Cola (KO) Jan 1996 - Apr 2006	
*24 Aug 98	0.6%	−10.5%	31 Aug 98	Announcement 17 Sept 98: international crisis (Russian, Asian) hurts KO's profit
*26 Aug 98	0.0%	−10.5%	31 Aug 98	Announcement 17 Sept 98: international crisis (Russian, Asian) hurts KO's profit
*18 Mar 99	1.4%	−3.0%	31 Mar 99	Announcement 29 Mar 99: unexpected drop in sales due to Pepsi IPO
*23 Aug 00	−0.9%	−3.8%	30 Aug 00	Not identified
12 Feb 01	0.9%	−9.6%	21/22 Feb 01	Announcement 21 Feb 01: Coca-Cola/Procter&Gamble deal
20 Feb 01	−0.5%	−9.6%	21/22 Feb 01	Announcement 21 Feb 01: Coca-Cola/Procter&Gamble deal
28 Jun 02	0.1%	−3.9%	12 Jul 02	Announcement 14 Jun 02: stock options granted to executives are recorded as expense
*9 Jul 02	0.1%	−10.0%	18/19 Jul 02	Announcement 17 Jul 02: financial statements for 2nd quarter
*10 Jul 02	−0.5%	−10.0%	18/19 Jul 02	Announcement 17 Jul 02: financial statements for 2nd quarter
			Hewlett Packard (HPQ) Jan 1996 - Apr 2006	
*14 May 98	−0.7%	−13.9%	14 May 98	Announcement 14 May 98: profit warning for 2nd quarter due to Asian crisis
15 Sep 99	−0.1%	−6.2%	29 Sep 99	Announcement 01 Oct 99: fall in 4th revenues growth
*15 Oct 99	−1.0%	−12.6%	27 Oct 99	Announcement 27 Oct 99: earnings shortfall in 4th quarter
*28 Sep 00	0.7%	−12.5%	29/02 Sep/Oct 00	Not identified
*30 Oct 00	−1.8%	−12.8%	10/13 Nov 00	Announcement 13 Nov 00: financial statements for 4th quarter (ended on Oct 31)
*31 Oct 00	−2.0%	−12.8%	10/13 Nov 00	Announcement 13 Nov 00: financial statements for 4th quarter (ended on Oct 31)
*9 Nov 00	−0.5%	−12.8%	10/13 Nov 00	Announcement 13 Nov 00: financial statements for 4th quarter (ended on Oct 31)
			Philip Morris (MO) Jan 1996 - Apr 2006	
28 Jan 99	0.1%	−8.7%	10 Feb 99	Announcement 10 Feb 99: punitive damages of 81 million for smoker's death
30 Mar 99	−1.6%	−15.1%	30/31 Mar 99	Announcement 30 Mar 99: punitive damages of 51.5 million for inoperable lung cancer
21 Aug 00	0.7%	−2.6%	30 Aug 00	Not identified
*16 Mar 01	−0.9%	−4.8%	20 Mar 01	Not identified
*3 Jun 02	0.5%	−2.0%	6 Jun 02	Not identified
21 Jun 02	−1.0%	−15.8%	21/24/25 Jun 02	Announcement 21 Jun 02: investors reject stock because of litigation risk

Table 7: Summary of detected informed trades for various sectors. For definition of entries see Page 37.

Summary of EADS Jan 2003 - Jan 2008

Day	K	τ	OI_t	ΔOI_t	$q_t^{\Delta OI}$	ΔOI_t^{tot}	Vol_t	$r_t^{\max}$	τ_2	G_t	q_t	$1-p_t$
6 Apr 06	31	May 06	2523	2518	0.998	4988	2518	280%	29	665,073	0.004	0.998
7 Apr 06	32	June 06	4015	3855	0.998	6663	7710	269%	29	1,676,925	0.004	0.998
20 Apr 06	30	June 06	1055	1000	0.934	1545	1000	389%	22	977,515	0.016	0.998
8 May 06	30	June 06	2865	810	0.922	1920	810	1,487%	28	816,670	0.020	0.998
18 May 06	31	June 06	3040	2518	0.990	2519	2518	255%	20	1,720,467	0.008	0.996
19 May 06	26	July 06	5236	4061	0.998	−220	4061	924%	19	1,472,680	0.004	0.998

Table 8: Summary of detected informed trades for the case of EADS: Day, day of the transaction; K, strike of the selected option; τ, maturity of the selected option; OI_t, level of open interest on the transaction day; ΔOI_t, increment in open interest from day $t-1$ to day t; $q_t^{\Delta OI}$, quantile of the increment ΔOI_t from its two-year empirical distribution; ΔOI_t^{tot}, total increment in open interest; Vol_t, corresponding option volume; $r_t^{\max}$, maximum return realized within 30 days of the transaction; τ_2, day of the maximum return after the transaction; G_t, realized cumulative gains after 60 trading days due to the exercise of these options; q_t, ex-ante probability; $1-p_t$, proxy for the probability of informed trading.

Accuracy of the hedging detection method for Citigroup on 17 Dec 2001

	h_i										
	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Percentiles											
20 20	0.051	0.052	0.077	0.089	0.094	0.124	0.151	0.193	0.227	0.277	0.306
20 40	0.046	0.058	0.079	0.106	0.116	0.174	0.196	0.235	0.287	0.290	0.299
20 60	0.051	0.063	0.070	0.100	0.131	0.156	0.157	0.210	0.210	0.265	0.282
20 80	0.069	0.072	0.072	0.075	0.076	0.076	0.076	0.077	0.095	0.125	0.180
40 20	0.055	0.057	0.064	0.087	0.117	0.124	0.168	0.185	0.198	0.207	0.223
40 40	0.053	0.055	0.090	0.096	0.147	0.158	0.167	0.182	0.219	0.239	0.272
40 60	0.056	0.064	0.081	0.120	0.125	0.159	0.183	0.218	0.253	0.284	0.298
40 80	0.041	0.104	0.188	0.190	0.201	0.231	0.254	0.265	0.282	0.291	0.306
60 20	0.051	0.052	0.059	0.078	0.098	0.102	0.161	0.180	0.198	0.200	0.217
60 40	0.049	0.066	0.070	0.098	0.119	0.125	0.136	0.161	0.161	0.249	0.253
60 60	0.051	0.051	0.062	0.065	0.065	0.065	0.097	0.114	0.125	0.126	0.138
60 80	0.050	0.055	0.074	0.075	0.099	0.114	0.151	0.153	0.157	0.192	0.208
80 20	0.049	0.088	0.131	0.147	0.153	0.156	0.166	0.178	0.189	0.195	0.210
80 40	0.049	0.056	0.063	0.075	0.116	0.136	0.158	0.179	0.183	0.192	0.195
80 60	0.049	0.071	0.085	0.085	0.092	0.100	0.110	0.136	0.150	0.183	0.183
80 80	0.033	0.070	0.070	0.080	0.084	0.099	0.099	0.099	0.151	0.154	0.231

Table 9: Entries are the probabilities of rejecting the hypothesis H_0 of no hedging when informed trades occur for the Citigroup stock on day i = December 17th, 2001, i.e. $\mathbb{A}(h_i)$ in (4), for various levels of h_i and $\mathbf{X}_i$. h_i is the ratio between volume due to hedging and volume due to non-hedging. $\mathbf{X}_i = (|r_i|, V_{i-1}^{\text{buy,non-hedge}})$ are the conditioning variables, i.e. stock return on day i and buyer-initiated volume due to non-hedging on day $i-1$, respectively. *Percentiles* are the levels of percentiles for the distributions of $|r_i|$ and $V_{i-1}^{\text{buy,non-hedge}}$, respectively, used as values of the conditioning variables in (4).

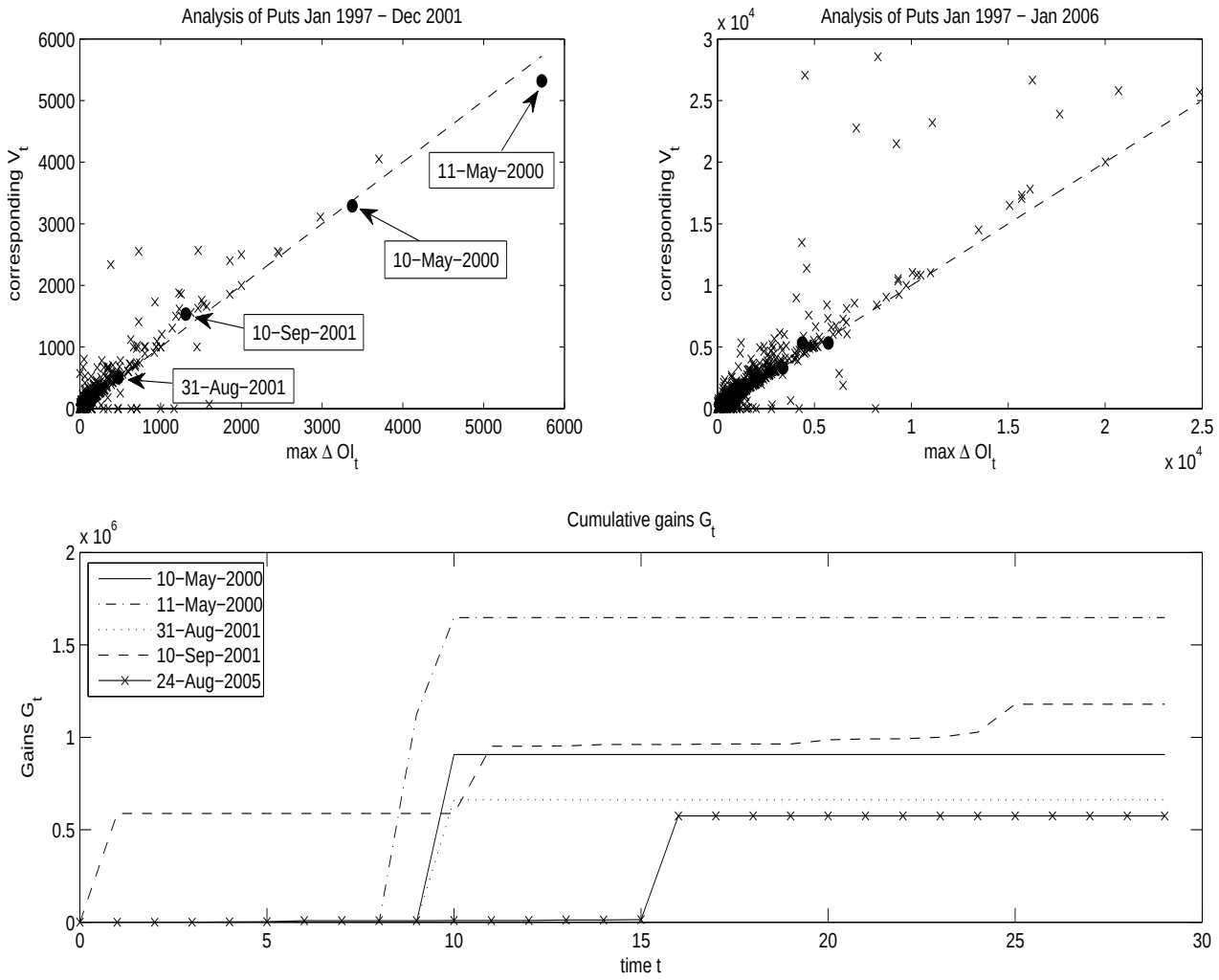

Figure 1: Upper graphs: Increment in open interest and volume of various put options with underlying American Airlines (AMR). Lower graph: Cumulative gains, G_t, in USD for detected informed trade options on AMR. Gains correspond to those realized by exercising the options (daily drop in open interest).

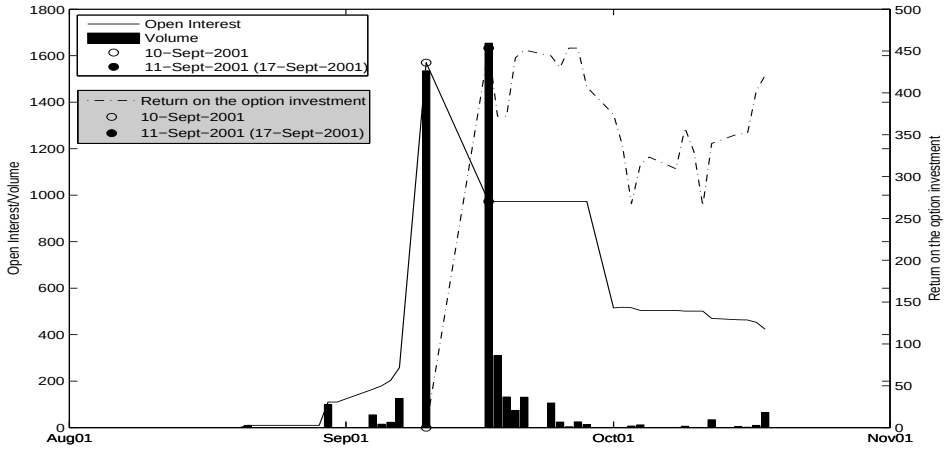

Figure 2: Selected put option for informed trading with underlying stock American Airlines (AMR) in the days leading up to the terrorist attacks of September 11th, 2001. The solid line shows the daily dynamic of open interest, the bars show the corresponding trading volume (left y-axis) and the dash-dot line the option return (right y-axis). The empty circle is the day of the transaction, the filled circle (partially covered by the highest bar) is the day when the market reopened after the terrorist attacks. This put option had a strike of \$30 and matured at the end of October 2001.

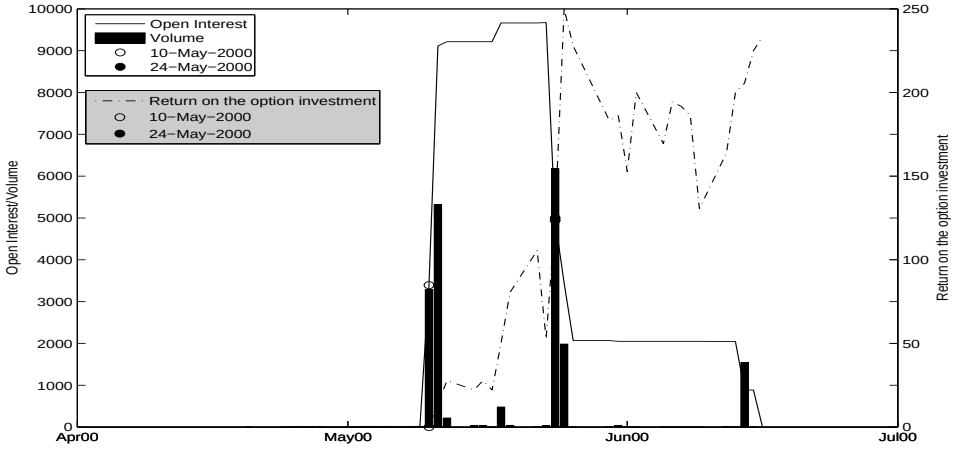

Figure 3: Selected put option for informed trading with underlying stock American Airlines (AMR) before the United Airlines (UAL) announcement of \$4.3 billion acquisition of US Airways in May 2000. Same variables as in Figure 2. The empty circle is the day of the transaction, the filled circle is the day of the announcement (partially covered by the highest bar). This put option had a strike of \$35 and matured at the end of June 2000.

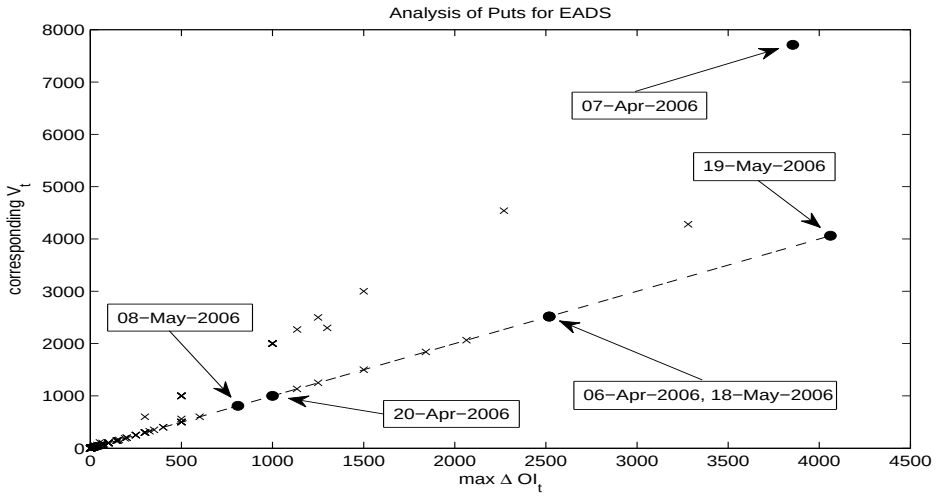

Figure 4: Increment in open interest and volume for various put options with underlying EADS.

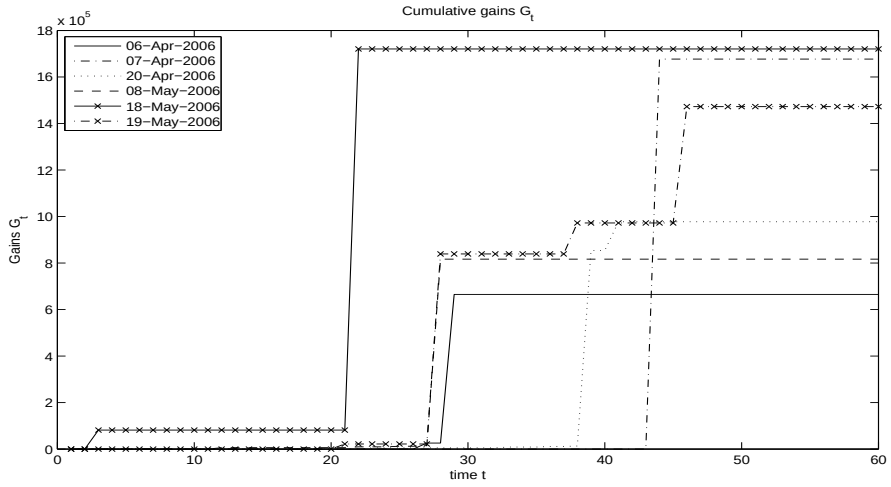

Figure 5: Cumulative gains, G_t, in € for detected informed trade options on EADS. Gains correspond to those realized by exercising the options (daily drop in open interest).

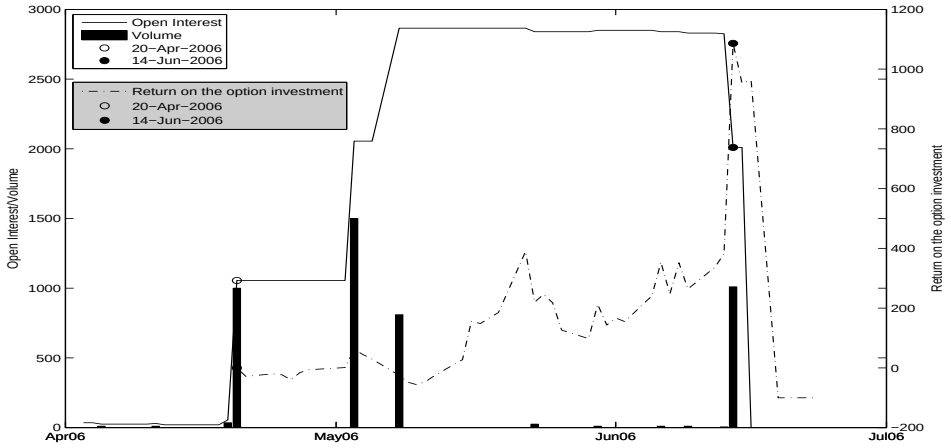

Figure 6: Selected put option for informed trading with underlying stock EADS before the delayed delivery announcement of the superjumbo A380 on June 14th, 2006. The option trade takes place on April 20th, 2006. The solid line shows the daily dynamic of open interest, the bars shows the corresponding trading volume (left y-axis) and the dash-dot line the option return (right y-axis). The empty circle is the day of the transaction, the filled circle is the announcement day, June 14th, 2006. This put option had a strike of €30 and matured at the end of June 2006.

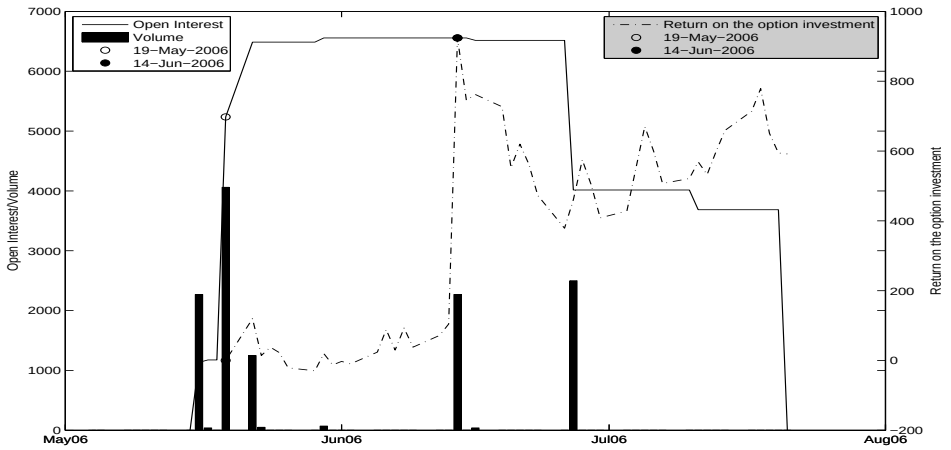

Figure 7: Selected put option for informed trading with underlying stock EADS before the delayed delivery announcement of the superjumbo A380 on June 14th, 2006. The option trade takes place on May 19th, 2006. Same variables as in Figure 6. This put option had a strike of €26 and matured at the end of July 2006.

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