Impact of Net Buying Pressure on Changes in Implied Volatility: *Before and After the Onset of the Subprime Crisis*

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This article examines whether net buying pressure affects the implied volatility function of TAIEX options in an order-driven market characterized by high individual participation. Using the intraday data of TAIEX options and futures for the period 2005 through 2008, we find that the shape of the implied volatility for TAIEX options changes from a smile before the subprime mortgage crisis to a smirk after the beginning of the crisis. This change was also observed for the S&P 500 Index implied volatility curve before and after the 1987 U.S. stock market crash. Unlike previous research that documents evidence that changes in implied volatility of S&P 500 options are mainly determined by buying pressure for index puts, we find that implied volatility changes of TAIEX options are dominated by buying pressure for index calls.

In 2001, the Taiwan Futures Exchange (TAIFEX) first introduced TAIEX options, the underlying asset of which is the Taiwan Stock Exchange (TWSE) Capitalization Weighted Stock Index. According to the Taiwan Futures Exchange [2009], TAIEX options have been the most popular derivative instruments in terms of trading volume on the TAIFEX since then. During the 2005–2008 period, the TAIEX options trading volume as a percentage of all derivative trading volume averaged 79.82%, highlighting the importance of TAIEX options in derivative transactions in Taiwan. Based on the statistics released by the World Federation of Exchanges [2009], the TAIEX options were ranked the fifth most frequently traded index options in terms of trading volume in the world in 2008. Exhibit 1 shows individual participation in stocks and derivatives in terms of trading volume in Taiwan for the same period (Taiwan Futures Exchange [2009]; Taiwan Stock Exchange [2009]). Individual participation, on average, accounted for 40.97% and 42.60% of the total derivative and stock trading volume. Although there had been an overall downward trend of individual participation in the derivative and stock markets over the years, individual investors still played an important role in both derivative and stock transactions. Unlike the markets in the developed countries, high individual participation characterizes the Taiwan derivative and stock markets. In addition, the TAIEX is an order-driven market. This article will examine whether net buying pressure affects the implied volatility function of TAIEX options in an order-driven market characterized by high individual participation.

Based on the Black–Scholes model's assumptions, the shape of the S&P 500 Index implied volatility is constant throughout the option's life. However, it appeared to be a symmetrical smile before the U.S. stock market crash in 1987, while it looked like a smirk after the crash (Bollen and Whaley [2004]). Several arguments have been put forward in the literature to explain why the implied volatility

EXHIBIT 1
Individual Participation in Stocks and Derivatives in Terms of Trading Volume

Year	2005	2006	2007	2008	Average
Individual participation in derivatives	48.82%	38.72%	37.44%	38.88%	40.97%
Individual participation in stocks	46.58%	43.38%	40.58%	39.84%	42.60%

Notes: Individual participation in derivatives: the volume of derivatives traded by individual investors as percentage of all derivative trading volume; individual participation in stocks: the volume of stocks traded by individual investors as percentage of all stock trading volume.
Sources: Taiwan Futures Exchange [2009] and Taiwan Stock Exchange [2009].

curve is not flat and why there is such a distinctive difference in the S&P index implied volatility before and after the stock market crash. Some possible causes include, among others, market inefficiency (Whaley [1986]; Stein [1989]), model misspecification (Fleming [1999]; Ederington and Guan [2002]), market imperfection (Christensen and Prabhala [1998]; Ederington and Guan [2005]), and imbalance between the supply and demand for options (Bollen and Whaley [2004]).

Empirical studies have documented sizable and persistent cross-sectional differences in implied volatility between options with different strike prices (e.g., Black [1975]; Rubinstein [1994]; Heynen [1994]; Das and Sundaram [1999]). The occurrence of such an implied volatility smile can be possibly explained as follows. First, the smile exists because a flawed model is used to infer implied volatilities (e.g., Hull and White [1987]; Heston [1993]; Fleming [1999]; Bates [2000]; Ederington and Guan [2002]). This implies that if a relatively suitable model (such as the one incorporating jumps and/or stochastic volatility) is used, there should be no variation in the implied volatility shape of options with different exercise prices. Another explanation for a smile is the measurement errors in implied volatilities due to market imperfections, such as bid–ask spreads and non-synchronous prices (e.g., Christensen and Prabhala [1998]). Finally, options smile because the demand for out-of-the-money puts for hedging against the risk of falling stock prices places upward pressure on the implied volatilities of options with low strike prices (Bollen and Whaley [2004]).

Dennis and Mayhew [2002] find no relation between trading pressure (proxied by the put-to-call option volume ratio) and the level of risk-neutral skewness implied by stock option prices. Bollen and Whaley [2004] argue that the reason Dennis and Mayhew fail to detect such a relation is that their proxy for net buying pressure is imprecise because volume and net buying pressure need not be highly correlated. In order to more accurately assess the impact of investor demand on the implied volatility shape, Bollen and Whaley tabulate trading volume and net buying pressure by option moneyness category and find that changes in implied volatility of S&P 500 index options are associated with net buying pressure for index puts.

Following Bollen and Whaley [2004], we define net buying pressure as the difference between the number of buyer-motivated contracts and the number of seller-motivated contracts times the absolute value of the option's delta. In their study, contracts traded during the day at prices higher (lower) than the prevailing bid–ask quote midpoint are classified as buyer (seller)-motivated trades. This definition is feasible for a quote-driven market (e.g., the Chicago Board Options Exchange), not for an order-driven market (e.g., the TAIEX). In our study, we change the proxies for buyer (seller)-motivated trades and define trades executed at a price above (below) the previous transaction price as buyer (seller)-motivated contracts.

Our results show that the shapes of implied volatility for TAIEX options are different before and after the onset of the subprime crisis. They give the appearance of changing from a smile to a smirk. Moreover, we document that the variation in the implied volatility for TAIEX options is mainly attributable to net buying pressure of at-the-money call options. Their net buying pressure continues playing an important role, though to a lesser degree, in changing the implied volatility over the 2005–2008 period.

This article extends prior research and contributes to the literature on the determinants of changes in the implied volatility function of index options. To our knowledge, most prior studies, excluding Bollen and Whaley [2004], attempt to explain the curve of the implied volatility using stochastic volatility option valuation models. Our study is the first to investigate the shape of the implied volatility function of index options before and after the onset of the subprime crisis and to examine the relation between net buying pressure and changes in implied volatility in an order-driven market characterized with high individual participation.

One prior paper that has a close connection to ours is Bollen and Whaley [2004]. However, a number of major differences exist. First, Bollen and Whaley use data on trades and quotes of S&P 500 index options traded on the Chicago Board Options Exchange (CBOE), while we use data on trades of TAIEX index options traded on the TAIEX. Since the TAIEX is an order-driven market, we decide to use alternative proxies for buyer-motivated and seller-motivated contracts. Moreover, unlike the CBOE, the TAIEX is characterized by high individual participation. Second, Bollen and Whaley [2004] find that changes in S&P 500 option implied volatility are strongly driven by buying pressure for index puts. In contrast, we find that changes in implied volatility of TAIEX options are dominated by buying pressure for index calls.

THE MODEL AND DATA

The theoretical relation between the spot and futures prices of index is as follows:

$$F_t = S_t e^{(r_f - q)(T-t)} \tag{1}$$

where F_t is the price of index futures; S_t is the spot price of index at time t; r_f is the risk-free rate; q is the dividend yield; $T - t$ is the time to expiration date. Assume that the expiration date of futures is the same as that of options. Plugging Equation (1) into the Black–Scholes model, we obtain

$$C_t = e^{-r_f(T-t)}[F_t N(d_1) - KN(d_2)] \tag{2}$$

$$P_t = e^{-r_f(T-t)}[KN(-d_2) - F_t N(-d_1)] \tag{3}$$

where C_t and P_t denote the prices of a European call and put, respectively, $d_1 = [\ln(F/K) + 0.5 * \sigma^2(T - t)]/\sigma\sqrt{T-t}$, and $d_2 = d_1 - 0.5 * \sigma\sqrt{T-t}$. Equations (2) and (3) are hereinafter collectively referred to as the modified Black–Scholes model. It is worth noting that the modified Black–Scholes model is different from Black's model (Black [1976]) in that the former model requires the option and futures contracts to mature at the same time, while the latter model does not. The modified Black–Scholes model will be used later to infer implied volatilities.

The sample period covers from January 3, 2005, to December 31, 2008. The trading hours at the Taiwan Futures Exchange are from 8:45 to 13:45 Monday through Friday (Taiwan time). The TAIEX option is a European-style option. The expiration months include three near-term months followed by two additional months from the March quarterly cycle (March, June, September, and December). The expiration date is the third Wednesday of the expiration month. Since options that are far from expiration are traded infrequently and thus cause problems in estimating implied volatilities, the nearest-month options are used in this study. However, the time value of options with very short remaining lifetimes is close to zero and their volatilities are sensitive to time value. Thus, microstructural factors such as tick size may lead to extreme instability of implied volatilities. Following previous studies (e.g., Ederington and Guan [2002]; Jiang and Tian [2005]; Ederington and Guan [2005]), we employ observations for the shortest term options with at least eight trading days to expiration. We then swich to the next option when the number of trading days falls below eight. Because the modified Black–Scholes model requires that futures and options have the same expirations dates, futures contracts with the same expiration dates as options are used for the calculation of implied volatilities. Because the sample in this study consists of the nearest-month options with at least eight trading days, there are futures contracts with the same maturity available on the market. The intraday data of TAIEX options and futures are obtained from the database of Taiwan Economic Journal (TEJ). The risk-free interest rate is measured by the simple average of one-month time deposit interest rates of five major banks in Taiwan. The data of interest rates are collected from the website of the Central Bank of the Republic of China (Taiwan). The risk-free rate is then expressed as a continuously compounded rate. The transaction data of options are matched with the price of futures with the closest trading time earlier than the options. Since TAIEX options are traded more frequently than TAIEX futures, it is possible that no transaction of futures contracts is completed before the first transaction of option contracts. If this is the case, the daily trading data of options will be matched with the price of futures with the closest trading time later than the transaction completion time of options. The last transaction price of options each day is used when calculating implied volatilities. Options with the last transaction price beyond the arbitrage boundary are removed to facilitate subsequent analyses. The lower limits of call and put options are $\max\{(F_t - K)e^{-r_f(T-t)}, 0\}$ and $\max\{(K - F_t)e^{-r_f(T-t)}, 0\}$, respectively. Within the sample data, there are no options touching the upper bound.

MONEYNESS CATEGORY

The ratio of the option's strike price to the futures price, K/F, is used to define moneyness. Since there is a daily price limit of 7% above and below the closing price of the previous day on the Taiwan stock market, the range for each category is set as 0.07. We then classify options' moneyness into five categories, using $K/F = 1$ as the central point. The upper and lower bounds are listed in Exhibit 2. Because the value of deeply in- and out-of-the-money options is extremely insensitive to volatility changes and the trading volume of these options is normally small, options with a strike price greater than 1.175 times or less than 0.825 times the futures price are eliminated in this study.

According to the Taiwan Futures Exchange [2009], the total trading volume of TAIEX options during the period from 2005 through 2008 was 362,369,337. As shown in Exhibit 3, the trading volume of TAIEX options (calls and puts) included in our sample was 221,440,711, accounting for about 61% of the total trading volume for the period. Moreover, since the subprime mortgage crisis broke out in July 2007 (CSI: Credit Crunch [2007]), we therefore use July 31, 2007, as the cutoff point. The whole sample period is then divided into two subperiods, Subperiods I and II, representing the subperiods before and after the beginning of the crisis, respectively. Panel A of Exhibit 3 shows that during the whole period 56% of all contracts traded were call options and 44% were puts. These proportions remained nearly unchanged in Subperiods I and II. According to Bollen and Whaley [2004, p. 732], 45% of all S&P 500 option contracts traded were calls and 55% were puts. It seems that investors of TAIEX options trade more calls than puts, compared with investors of S&P 500 options.

Comparing across moneyness categories, during the whole period trading volume is largest for ATM options, followed by OTM options. Before the subprime mortgage crisis, ATM options are traded more frequently than OTM options. After the onset of the crisis, however, OTM options have the heaviest trading volume, followed by ATM options. Moreover, the trading volume of OTM calls on TAIEX outweighs that of OTM puts, and the proportion for deep out-of-the money (DOTM) puts is always smaller than 5%. This evidence is consistent with the notion that investors use TAIEX calls as an instrument to speculate on future index movements. This finding contrasts with that of Bollen and Whaley ([2004], p. 731), who find that equity portfolio managers use S&P 500 puts to hedge against the possibility of the value of their portfolios decreasing over time.

EXHIBIT 2
Moneyness Category Definitions

Category	Label	Range
1	Deep in-the-money (DITM) call Deep out-of-the-money (DOTM) put	$0.825 \leqq K/F < 0.895$
2	In-the-money (ITM) call Out-of-the-money (OTM) put	$0.895 \leqq K/F < 0.965$
3	At-the-money (ATM) call At-the-money (ATM) put	$0.965 \leqq K/F \leqq 1.035$
4	Out-of-the-money (OTM) call In-the-money (ITM) put	$1.035 < K/F \leqq 1.105$
5	Deep out-of-the money (DOTM) call Deep in-the-money (DITM) put	$1.105 < K/F \leqq 1.175$

Notes: Options with K/F below 0.825 and above 1.175 are excluded.

IMPLIED VOLATILITY CURVE

We use the modified Black–Scholes model to infer implied volatilities for each contract. These implied volatilities are then averaged for each moneyness category. Exhibit 4 shows that the average ATM implied volatility level for calls and puts together is 17.13% in Subperiod I, and 33.24% in Subperiod II. In the first subperiod, the implied volatility curve appears to be a smile with the left slightly higher than the right by 5.37%. In the second subperiod, however, the curve forms a smirk with the left far higher than the right by 8.06%.

We use the five-minute index returns for the Taiwan Weighted Stock Index to calculate

Exhibit 3
Trading of TAIEX Options

	Calls		Puts	
Category	Number of Contracts	Proportion	Number of Contracts	Proportion
Panel A. Whole Period: January 2005–December 2008				
1	65,169	0.0003	5,474,461	0.0247
2	1,434,214	0.0065	37,604,539	0.1698
3	71,476,810	0.3228	51,699,849	0.2335
4	44,383,650	0.2004	1,494,793	0.0068
5	7,716,811	0.0348	90,415	0.0004
Total	125,076,654	0.5648	96,364,057	0.4352
Panel B. Subperiod I: January 2005–July 2007				
1	26,449	0.0002	2,061,898	0.0136
2	942,763	0.0062	23,692,568	0.1558
3	58,747,992	0.3864	40,754,191	0.2681
4	23,640,813	0.1555	661,553	0.0044
5	1,489,434	0.0098	12,379	0.0001
Total	84,847,451	0.5581	67,182,589	0.4419
Panel C. Subperiod II: August 2007–December 2008				
1	38,720	0.0006	3,412,563	0.0492
2	491,451	0.0071	13,911,971	0.2004
3	12,728,818	0.1834	10,945,658	0.1577
4	20,742,837	0.2988	833,240	0.0120
5	6,227,377	0.0897	78,036	0.0011
Total	40,229,203	0.5796	29,181,468	0.4204

Notes: With July 31, 2007, as the cutoff point, the whole sample period is divided into Subperiods I and II. The upper and lower bounds of the moneyness categories are listed in Exhibit 2.

the realized volatility ($RLZ_{t,T}$) over the period of $T-t$ as follows:

$$RLZ_{t,T} = \sqrt{\frac{252}{T-t} * \sum_{i=1}^{T-t} \sigma_{t+i}^2} \tag{4}$$

where $\sigma_{t+i}^2 = \Sigma_{k=1}^{54} \varepsilon_{k,t+i}^2$; $\varepsilon_{k,t+i}$ is the return innovations at the kth five-minute on day $t+i$. An ARMA(1,2) process is estimated for five-minute index returns each day, and serially uncorrelated return innovations are extracted. The daily trading time on TWSE is 9:00 to 13:30 for a total of 270 minutes. The intraday data of Taiwan Weighted Stock Index are obtained from the website of TWSE (www.twse.com.tw). The average difference between implied and realized volatilities is compiled in Panel B of Exhibit 4 and depicted in Exhibit 6. As shown in Panel B, the difference between ATM implied and realized volatilities increases from 3.15% in Subperiod I to 4.77% in Subperiod II. Exhibit 6 also shows that in Subperiod I the smallest discrepancy between implied and realized volatilities occurs at options of Categories 3 and 4. However, in Subperiod II the discrepancy decreases as strike price increases, implying that ATM implied volatility is no longer the least biased estimator for future volatility on the Taiwan stock market after the onset of the subprime mortgage crisis.

Note that Exhibit 6 is not the same as Exhibit 5 just lowered by the realized volatility. The reason is that the number of observations in each moneyness category differs in our sample. There are two possible scenarios for that. First, no observation is found in a particular moneyness category on a particular trading day. In most cases, it happens in Categories 1 and 5. Second, options with the last transaction price beyond the arbitrage boundary are removed

EXHIBIT 4
Average of Implied Volatilities for TAIEX Options

Period	Category	1	2	3	4	5
Panel A. Average of Implied Volatilities						
Whole Period	Call	0.3765	0.2681	0.2335	0.2268	0.2717
	Put	0.3098	0.2575	0.2325	0.2441	0.3413
	All	0.3432	0.2628	0.2330	0.2354	0.3065
Subperiod I	Call	0.3174	0.2084	0.1725	0.1680	0.2072
	Put	0.2634	0.2001	0.1701	0.1760	0.2662
	All	0.2904	0.2042	0.1713	0.1720	0.2367
Subperiod II	Call	0.4432	0.3658	0.3318	0.3050	0.3083
	Put	0.3845	0.3594	0.3331	0.3151	0.3582
	All	0.4138	0.3626	0.3324	0.3101	0.3332
Panel B. Average Difference between Implied and Realized Volatilities						
Whole Period	Call	0.1707	0.0751	0.0381	0.0232	0.0263
	Put	0.1260	0.0692	0.0372	0.0271	0.0358
	All	0.1483	0.0722	0.0377	0.0252	0.0311
Subperiod I	Call	0.1663	0.0670	0.0326	0.0274	0.0605
	Put	0.1190	0.0606	0.0303	0.0335	0.0985
	All	0.1426	0.0638	0.0315	0.0304	0.0795
Subperiod II	Call	0.1757	0.0884	0.0470	0.0177	0.0069
	Put	0.1373	0.0845	0.0484	0.0204	0.0217
	All	0.1565	0.0865	0.0477	0.0191	0.0143

Notes: The sample period is from January 3, 2005, to December 31, 2008. With July 31, 2007, as cutoff point, the sample period is divided into Subperiods I and II. The upper and lower bounds of the moneyness categories are listed in Exhibit 1.

from the sample since a positive implied volatility cannot be obtained. The lower limits of call and put options are $\max\{(F_t - K)e^{-r_f(T-t)}, 0\}$ and $\max\{(K - F_t)e^{-r_f(T-t)}, 0\}$, respectively. Within the sample data, there are no options touching the upper bound. If we only keep the trading days on which all moneyness categories have observations in our sample and recalculate the average of implied volatilities for TAIEX options, the shape of the difference between implied and realized volatilities will be the same as that of implied volatilities.

NET BUYING PRESSURE

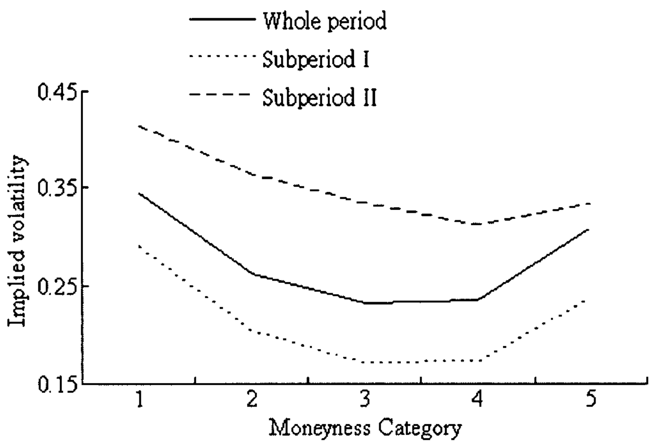
To investigate the role of supply and demand in the options market, Bollen and Whaley [2004] use the prevailing bid–ask midpoint to categorize trades and quotes of S&P 500 options traded on the CBOE, a quote-driven market. It is worth noting that the bids and asks of market makers are not always displayed in the Taiwan index options market. Thus, the measure for net buying pressure used in Bollen and Whaley [2004] is no longer applicable. Fortunately, the TAIFEX Options Trading System (OTS) discloses the five best bid and offer prices. We are able to use the first best bid (offer) price to proxy for the bid (ask) quote of market makers.

The first best bid/offer prices of TAIFEX index options and the bid–ask quotes of S&P index options actually play a similar role. Instead of using the bid–ask prices quoted by market makers, we use the first best bid and offer prices to determine whether a trade is initiated by buyers or sellers. Since the frequency of the best bid and offer prices is far higher than that of market prices, the transaction data of options are matched with the first best bid and offer prices with the nearest disclosure time earlier than that trade. Trades executed at a price strictly higher (lower) than the midpoint of the first best bid and offer prices are categorized as buyer (seller)-motivated trades, suggesting that the demand (supply) force is stronger. Trades executed at a price equal to the midpoint of the first best bid and offer prices indicate that the demand and supply forces are equal. This measure of net buying pressure is referred to as the Bollen and Whaley (BW) method. Net purchases of contracts are calculated as the number of buyer-motivated contracts minus the number of seller-motivated contracts. We use the BW method to calculate net purchases of contracts and the results are summarized in Panel A of Exhibit 7. From this panel, we find that investors are net sellers of TAIEX calls and puts on all moneyness categories in both subperiods. This result of heavy selling pressure apparently is inconsistent with the true market condition where the trading volume of TAIEX options has been increasing since 2004 (Taiwan Futures Exchange [2009]), implying the inapplicability of the BW method in interpreting the market imbalance of TAIEX options. This may be due to different trading mechanisms.

At CBOE, the bid and ask prices quoted by market makers indeed contain the latest and valuable information about the true price of options. Thus, it would be possible to measure market imbalance by comparing market prices and prevailing quotes. From the list of the market-maker

EXHIBIT 5

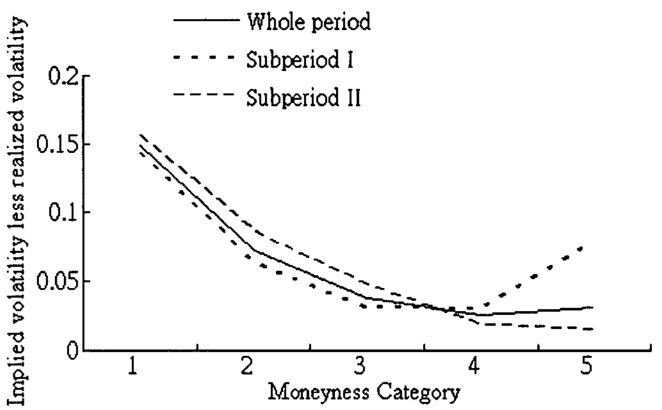
Estimated Implied Volatility Functions of TAIEX Options



Notes: The whole sample period is from January 3, 2005, through December 31, 2008. With July 31, 2007, as the cutoff point, the whole period is divided into two subperiods. The upper and lower bounds of the moneyness categories are listed in Exhibit 2.

EXHIBIT 6

Average Difference between Implied and Realized Volatilities for TAIEX Options



Notes: The whole sample period is from January 3, 2005, through December 31, 2008. With July 31, 2007, as the cutoff point, the whole period is divided into two subperiods. The upper and lower bounds of the moneyness categories are listed in Exhibit 2.

EXHIBIT 7

Net Purchases of Contracts

Periods	Whole Period		Subperiod I		Subperiod II	
Category	Calls	Puts	Calls	Puts	Calls	Puts
Panel A. Net Purchases of Contracts—BW Method						
1	2,280	-161,024	1,374	-139,767	906	-21,257
2	-94,161	-1,339,335	-67,532	-919,370	-26,629	-419,965
3	-1,515,123	-1,724,640	-1,337,875	-1,332,777	-177,248	-391,863
4	-2,048,769	-41,581	-1,088,036	-52,938	-960,733	11,357
5	-637,483	-469	-173,606	-49	-463,877	-420
Total	-4,293,256	-3,267,049	-2,665,675	-2,444,901	-1,627,581	-822,148
Panel B. Net Purchases of Contracts						
1	3,710	-17,594	1,042	-58,769	2,668	41,175
2	21,870	121,744	5,916	-186,663	15,954	308,407
3	880,910	534,077	577,861	229,194	303,049	304,883
4	-84,429	49,030	-240,897	19,758	156,468	29,272
5	-173,872	2,991	-75,742	652	-98,130	2,339
Total	648,189	690,248	268,180	4,172	380,009	686,076

Notes: The sample period is from January 3, 2005, to December 31, 2008. With July 31, 2007, as the cutoff point, the sample period is divided into two subperiods. Net purchases of contracts are calculated as the number of buyer-motivated contracts minus the number of seller-motivated contracts. In Panel A, we measure net purchases of contracts by the method proposed by Bollen and Whaley [2004]. In Panel B, we measure net purchases of contracts by the method proposed in this study.

commodities and market makers announced on the website of TAIFEX, however, we find that TAIEX options are not always from market makers, indicating that those options are heavily traded and market makers are not indispensable to the TAIEX option trading on the Taiwan Market. Therefore, it seems that in our analysis the BW method is not a suitable approach to measuring market imbalance of TAIEX options.

In an order-driven market, like the Taiwan index options market, the change of market prices depends upon the orders of both buyers and sellers, reflecting the relative power between market demand and supply forces. In this study, we thus use the changes in the prices of two adjacent transactions to measure net buying pressure. Trades executed at a price strictly higher (lower) than that of the previous transaction are classified as buyer (seller)-motivated trades, suggesting that the demand (supply) force is stronger. Trades executed at a price equal to that of the previous transaction indicate that the demand and supply forces are equal. Panel B of Exhibit 7 presents net purchases of contracts for each moneyness category using this definition. The net purchases calculated using the new definition provides a striking contrast to those using the BW method. In both subperiods investors are net buyers of calls and puts. This finding that investors have an inclination to own options is consistent with the fact of a thriving TAIEX options market.

During the whole period the net purchases of call options were 648,189 contracts and those of puts were 690,248 contracts. In Subperiod I, the net purchases of call options were 268,180 contracts, while those of puts were only 4,172. However, after the onset of the subprime crisis, the net purchases of call options were 380,009 contracts and those of puts dramatically increased to 686,076. This is remarkably different from the fact that investors of S&P 500 options are net sellers of calls but net buyers of puts.

Comparing across moneyness categories, TAIEX option investors are net sellers of DOTM and OTM options, but net buyers of other options during Subperiod I. This also contrasts with the finding of Bollen and Whaley [2004] that S&P 500 index option investors are net buyers of DOTM and OTM put options. However, after the beginning of the crisis, investors are net buyers of DOTM and OTM puts on TAIEX, indicating an increase in the demand for hedging in the stock market. The sudden surge in the demand for OTM puts is inconsistent with the transformation of the implied volatility curve from a smile to a smirk. Following the crisis, the falling stock index has increasingly obligated put option writers. The difficulty in hedging by selling TAIEX spots and futures made arbitrage activities infeasible. Therefore, writers would ask for a higher price to compensate for their high risk bearing. Consequently, the implied volatility of options with a lower strike price increases.

In this study, net buying pressure is defined as the changes in the prices of two adjacent transactions. Following Bollen and Whaley [2004], we multiply net purchases by the absolute value of delta to express demand in index equivalent units. Using the daily data of the last transaction for each option contract and the annualized volatility for the previous trading day, we calculate the delta through $N(d_1)/-N(-d_1)$ of the modified Black–Scholes model. The five-minute rate of return of the Taiwan Weighted Stock Index is used to compute the annualized volatility for the previous trading day, and the formula is as follows:

$$\sigma_{t-1} = \sqrt{252 * \sum_{k=1}^{54} \varepsilon_{k,t-1}^{2}} \tag{5}$$

where $\varepsilon_{k,t-1}$ is the return innovations of the ARMA(1,2) model at the kth five-minute on day $t-1$. The net buying pressure is reported in Exhibit 8.

EXHIBIT 8
Net Buying Pressure

Period	Whole Period		Subperiod I		Subperiod II	
Category	Calls	Puts	Calls	Puts	Calls	Puts
1	3,478	4,332	1,051	79	2,426	4,253
2	17,901	40,595	5,514	-2,677	12,387	43,272
3	504,327	312,664	366,662	179,896	137,666	132,768
4	31,445	40,140	-11,163	18,184	42,608	21,956
5	-1,026	2,295	-865	647	-161	1,648
Total	556,125	400,027	361,198	196,129	194,927	203,898

Notes: The sample period is from January 3, 2005, to December 31, 2008. With July 31, 2007, as the cutoff point, the sample period is divided into two subperiods. Net buying pressure = Net purchases of contracts × | Delta |. Net purchases of contracts are calculated as the number of buyer-motivated contracts minus the number of seller-motivated contracts. Trades executed at a price above (below) that of the previous transaction are categorized as buyer (seller)-motivated trades. Employing the modified Black–Scholes model, we use data of the last transaction every day for each options contract and the volatility of the previous trading day to calculate the delta.

Exhibit 8 shows that the buying pressure of call options was 1.84 times that of puts during Subperiod I, while the buying pressure of call options was only 0.96 times that of puts during Subperiod II. Again, these results suggest that the financial crisis changed investors' motivation of trading on TAIEX options. Comparing across moneyness categories, the net buying pressure for calls and puts is almost completely from the ATM options in both subperiods. It is worthwhile to note that during the financial crisis, net purchases of OTM puts were greater than those of ATM puts and calls. After considering the absolute value of delta, however, the situation changes dramatically. This finding supports that the net buying pressure of ATM options may be influential on the changes in the implied volatility.

REGRESSION ANALYSIS

Under the Black–Scholes assumption of frictionless markets, neither time variation in the demands for buying or selling options nor public order imbalances for particular option series will affect option price and implied volatility. Thus, in this study, the null hypothesis is that there is no relation between demand for options and corresponding implied volatilities. Following Bollen and Whaley [2004], the regression model is constructed as follows:

$$\Delta\sigma_t = \alpha_0 + \alpha_1 IR_t + \alpha_2 TV_t + \alpha_3 NBP_{1,t} + \alpha_4 NBP_{2,t} + \alpha_5 \Delta\sigma_{t-1} + \varepsilon_t \qquad (6)$$

In the above equation, $\Delta\sigma_t$ is the change in the average implied volatility in a moneyness category from the close on day $t-1$ to the close on day t; IR_t is the index return (proxied by the return of the Taiwan Weighted Stock Index from the close on day $t-1$ to the close on day t); TV_t is the trading volume (proxied by the natural logarithm of trading volume for TWSE on day t expressed in millions of New Taiwan (NT) dollars); $NBP_{1,t}$ and $NBP_{2,t}$ are the net buying pressure for two of the following variables, including ATM calls, ATM puts, OTM calls, and OTM puts; $\Delta\sigma_t$ is the lagged implied volatility changes variable.

To examine the relation between the shape of the implied volatility function and net buying pressure, the daily change in the average implied volatility of options in a particular moneyness category is regressed on index return, index trading volume, and net buying pressure. Return of the underlying index and its trading volume are included as control variables for leverage and information flow effects. Black [1976] shows that the stock return volatility is inversely related to stock returns due to a leverage effect, while Anderson [1996] argues that the stock return volatility is positively associated with trading volume due to an information flow effect. The net buying pressure is scaled by the total trading volume across all option series in the moneyness category on that day. We include the lagged change in implied volatility as an explanatory variable to correct the econometric problem caused by the serial correlation of regression residuals and to test whether the potential arbitrage activity would occur in imperfect markets. In an effort to correct for the heteroscedasticity problem, we estimated and reported the models using White's [1980] heteroscedasticity-corrected covariance matrix to derive heteroscedasticity-consistent estimates.

Exhibit 9 contains the ordinary least squares (OLS) regression results. F-tests for the overall statistical goodness-of-fit of the models are significant at the 0.01 level, suggesting that the fitted models are better than a null model with explanatory variables. The adjusted R-squared values for these models range from 7.38% to 33.90%. As expected, the coefficients on the index return variables consistently have the negative sign and are statistically significant at the 0.05 level across all models, confirming the leverage effect of Black [1976]. In Subperiod I, the trading volume variable has a positive effect on changes in implied volatility of options, confirming the information flow effect of Anderson [1996]. The coefficients on the lagged implied volatility changes variable are all negative, and in most cases, statistically significant.

Changes in Implied Volatilities of ATM Calls and Puts

We first test the relation between changes in ATM implied volatility with net pressure for ATM calls and puts for the whole sample period, and Subperiods I and II. The results are shown in the first two columns of Panels A, B, and C of Exhibit 9.

For call options, the estimate of NBP_t^{ATMC} is positive and statistically significant at the 0.05 level in the whole period, suggesting that net buying pressure for ATM calls is an important factor in driving changes in the implied volatility of ATM call options. The coefficient on NBP_t^{ATMP} is positive but insignificant. We also find that NBP_t^{ATMC} is

EXHIBIT 9

Regression Results of Change in Implied Volatility for TAIEX Options

$\Delta\sigma_t$	$ATMC_t$		$ATMP_t$		$OTMC_t$		$OTMC_t$		$OTMP_t$		$OTMP_t$	
Panel A. Whole Period: January 2005–December 2008												
Intercept	-0.0477*	(-2.25)	-0.0235	(-0.92)	-0.0423*	(-2.35)	-0.0458*	(-2.50)	-0.0344	(-1.58)	-0.0513*	(-2.30)
IR_t	-0.8635*	(-15.46)	-1.2544*	(-18.69)	-0.9240*	(-19.83)	-0.8365*	(-17.42)	-0.9005*	(-14.57)	-0.7562*	(-12.23)
TV_t	0.0041*	(2.23)	0.0020	(0.90)	0.0037*	(2.33)	0.0040*	(2.48)	0.0029	(1.55)	0.0045*	(2.30)
NBP_t^{ATMC}	0.1543*+	(5.67)	0.2483*+	(7.60)	0.1287*	(5.47)			0.2312*	(7.82)		
NBP_t^{ATMP}	0.0373	(1.31)	0.0557	(1.63)			0.0101	(0.41)			-0.0364	(-1.23)
NBP_t^{OTMC}					0.1411*	(2.14)	0.2159*+	(3.29)				
NBP_t^{OTMP}									0.1442	(1.39)	0.0667	(0.61)
$\Delta\sigma_{t-1}$	-0.1140*	(-4.07)	-0.2669*	(-10.16)	-0.0803*	(-2.99)	-0.0930*	(-3.42)	-0.1824*	(-6.52)	-0.1879*	(-6.52)
Adj. R^2	0.2337		0.3269		0.2953		0.2739		0.2415		0.1938	
F value	61.27		96.96		83.79		75.55		61.62		46.76	
Panel B. Subperiod I: January 2005–July 2007												
Intercept	-0.0483*	(-3.22)	-0.0659*	(-4.46)	-0.0579*	(-4.06)	-0.0689*	(-4.71)	-0.0552*	(-2.70)	-0.0764*	(-3.60)
IR_t	-0.9228*	(-14.01)	-0.8450*	(-12.99)	-0.9655*	(-16.73)	-0.7982*	(-13.35)	-0.7912*	(-9.33)	-0.4848*	(-5.78)
TV_t	0.0043*	(3.25)	0.0058*	(4.49)	0.0051*	(4.10)	0.0061*	(4.75)	0.0049*	(2.72)	0.0068*	(3.63)
NBP_t^{ATMC}	0.2183*+	(8.71)	0.1619*+	(6.54)	0.1618*	(6.46)			0.2713*	(8.07)		
NBP_t^{ATMP}	0.0289	(1.12)	0.0609*	(2.40)			-0.0246	(-0.98)			-0.0658	(-1.73)
NBP_t^{OTMC}					0.0377	(0.58)	0.1689*+	(2.66)				
NBP_t^{OTMP}									0.0963	(0.77)	0.0836	(0.61)
$\Delta\sigma_{t-1}$	-0.1204*	(-3.52)	-0.1185*	(-3.50)	-0.1130*	(-3.36)	-0.1290*	(-3.73)	-0.0850*	(-2.30)	-0.0921*	(-2.36)
Adj. R^2	0.3047		0.3046		0.3390		0.2961		0.1568		0.0738	
F value	56.49		56.45		65.94		54.26		24.55		11.09	
Panel C. Subperiod II: August 2007–December 2008												
Intercept	-0.0605	(-1.21)	0.0034	(0.05)	-0.0505	(-1.22)	-0.0399	(-0.95)	-0.0228	(-0.46)	-0.0166	(-0.33)
IR_t	-0.8754*	(-9.10)	-1.3702*	(-11.60)	-0.9471*	(-11.76)	-0.8738*	(-10.64)	-0.9577*	(-9.41)	-0.8841*	(-8.67)
TV_t	0.0051	(1.17)	-0.0006	(-0.11)	0.0042	(1.16)	0.0033	(0.90)	0.0017	(0.40)	0.0013	(0.30)
NBP_t^{ATMC}	0.1246*	(2.39)	0.2562*	(4.00)	0.1235*	(2.84)			0.1766*	(3.14)		
NBP_t^{ATMP}	0.0520	(0.96)	0.0946	(1.42)			0.0386	(0.85)			0.0357	(0.69)
NBP_t^{OTMC}					0.2337	(1.88)	0.2654*	(2.12)				
NBP_t^{OTMP}									0.2370	(1.29)	0.0998	(0.53)
$\Delta\sigma_{t-1}$	-0.1140*	(-2.42)	-0.2914*	(-6.69)	-0.0708	(-1.58)	-0.0856	(-1.90)	-0.2286*	(-4.94)	-0.2402*	(-5.09)
Adj. R^2	0.2174		0.3418		0.2849		0.2700		0.2950		0.2739	
F value	20.67		37.77		29.21		27.18		27.61		25.00	

Notes: The regression model is constructed as follows: $\Delta\sigma_t = \alpha_0 + \alpha_1 IR_t + \alpha_2 TV_t + \alpha_3 NBP_{1,t} + \alpha_4 NBP_{2,t} + \alpha_5 \Delta\sigma_{t-1} + \varepsilon_t$, where $\Delta\sigma_t$ is the change in the average implied volatility of options; IR_t is the return of the Taiwan Weighted Stock Index; TV_t is the natural logarithm of trading volume for TWSE. $NBP_{1,t}$ and $NBP_{2,t}$ are two of the following variables, including NBP_t^{ATMC}, NBP_t^{ATMP}, NBP_t^{OTMC}, and NBP_t^{OTMP}, which are the net buying pressure of ATM calls, ATM puts, OTM calls and OTM puts, respectively. Robust standard errors are used to correct for heteroscedasticity. The numbers in parentheses are t-statistics. The asterisk denotes that the coefficient is significantly different from zero at the 0.05 level, while the cross denotes that α_3 is significantly different from α_4. With July 31, 2007, as the cutoff point, the whole sample period is divided into Subperiods I and II. The regression results of the whole period and Subperiods I and II are compiled in Panels A, B, and C, respectively.

significantly different from NBP_t^{ATMP} at the 0.05 level. The evidence apparently supports the notion that the net buying pressure for ATM calls has a greater influence on changes in implied volatility of ATM calls than the net buying pressure of ATM puts. This finding is consistent with the result reported previously that ATM call options dominate ATM put options in terms of trading volume in TAIEX option trading.

As shown in Panel B, before the crisis NBP_t^{ATMC} is significantly positive and statistically different from NBP_t^{ATMP} which is positive but insignificant. After the beginning of the crisis, however, the coefficient on

NBP_t^{ATMC} is still significantly positive but not different from the coefficient on NBP_t^{ATMP}, as shown in Panel C. This result is not particularly surprising. As documented in the previous sections, the large difference between the net buying pressure for ATM calls and that for ATM puts almost disappears after the onset of the crisis.

As regards put options, during the whole period the coefficient on NBP_t^{ATMC} is significantly positive and different from the coefficient on NBP_t^{ATMP} which is insignificantly positive. In Subperiod I, the coefficient on NBP_t^{ATMC} is significantly positive and different from the coefficient on NBP_t^{ATMP} which is also significantly positive. However, after the beginning of the crisis NBP_t^{ATMC} remains significantly positive but its coefficient is not different from the positive, though insignificant, coefficient on NBP_t^{ATMP}. Again, it appears that the net buying pressure on ATM calls has a greater impact on the change in the level of the ATM put volatility than does the net buying pressure of ATM puts.

Changes in Implied Volatilities of OTM Calls and Puts

We then examine the determinants of changes in implied volatility of OTM calls and puts. We find that in the whole period both NBP_t^{ATMC} and NBP_t^{OTMC} have significantly positive influence on the changes in the implied volatility of OTM call options at the 0.05 level. After replacing NBP_t^{ATMC} with NBP_t^{ATMP}, we further find that NBP_t^{OTMC} remains significantly positive while NBP_t^{ATMP} is positive but insignificant. Overall, the evidence highlights the higher importance of call trading than put trading in determining changes in the implied volatility of OTM call options. Before the crisis, NBP_t^{OTMC} is insignificantly positive while NBP_t^{ATMC} is significantly positive. When NBP_t^{ATMC} is replaced with NBP_t^{ATMP}, NBP_t^{OTMC} is significantly positive but NBP_t^{ATMP} is insignificantly negative. Taken together, our results indicate that not only is call trading more influential than put trading but ATM call trading dominates OTM call trading. After the onset of the crisis, the significance of these net buying pressure variables remains qualitatively unchanged.

As for OTM put options, during the whole period both NBP_t^{ATMC} and NBP_t^{OTMP} are positive, but the former is significant while the latter is not. We also find that NBP_t^{ATMP} is negative, though insignificant. Our results offer several interesting insights. First, it appears that call trading is more influential than put trading for TAIEX options. Second, holding constant the net buying pressure of index calls, the net buying pressure of OTM puts has no discernible effect on the change in OTM put volatility. The results before the crisis are similar to those presented above. The results after the beginning of the crisis show that the coefficient of NBP_t^{OTMP} increases and is positive, though insignificant, even when NBP_t^{ATMP} is replaced by NBP_t^{ATMC}.

Inconsistent with the results of Bollen and Whaley [2004] for S&P 500 options, we find that the net buying pressure of ATM TAIEX index calls has a significant positive effect on changes in implied volatilities, while the net buying pressure of ATM puts does not. In fact, our results of the dominance of ATM TAIEX index calls are more like the results of Bollen and Whaley [2004] for stock options. We also document that the trading volume of TAIEX calls is larger than that of TAIEX puts. In the U.S., institutional investors dominate the stock market. Since the 1987 crash, fund managers commonly employ OTM puts to facilitate hedging activities for their funds. In Taiwan, however, the stock market is dominated by individual investors. Stock and index options may be regarded as a speculative device for individual investors. Since stock options are relatively illiquid, TAIEX index options become the best choice for investors who attempt to capitalize on their expectation of market movements. Moreover, institutional investors who wish to hedge their risk probably tend to use MSCI Taiwan Index futures rather than TAIEX options.

CONCLUSION

In our study, we conducted an empirical analysis to investigate whether net buying pressure influences the implied volatility function of index options traded in an order-driven market characterized by high individual participation. Using a sample of TAIEX options for the period 2005 to 2008, we find that the shape of the implied volatility for TAIEX options looked like a smile before the subprime mortgage crisis which occurred in 2007. After the onset of the crisis, the shape changed to a smirk due to the drastic increase in net purchases of put options. The shape of a smirk was similar to the implied volatility curve of S&P 500 Index options after the 1987 crash.

In Taiwan over 40% of derivatives and stocks in terms of volume are traded by individual investors. Since options have the feature of financial leverage, they provide individual investors on the Taiwan stock market with instruments for speculation. This partially justifies why call option trading was higher than put option trading before the crisis. The outbreak of the financial crisis, however, triggered the hedging function of TAIEX options. The ratio of the net purchases of TAIEX put options to the net purchases of TAIEX call options surged from 0.0156 to 1.8054. Although the net purchases shifted from call options to put options following the crisis, the net buying pressure of ATM call options continued to be the strongest of all. Our findings suggest that the implied volatility of TAIEX options is driven by the net buying pressure of call rather than put options.

Using a similar analysis, Bollen and Whaley [2004] document sharply different results for a quote-driven market. While we find that changes in implied volatility of TAIEX options are dominated by buying pressure for index calls, Bollen and Whaley [2004] show that buying pressure for index puts is the main factor in explaining the implied volatility changes of S&P 500 options. These opposite results enhance the fact that the relation between net buying pressure and implied volatility changes is indeed affected by market trading mechanisms and characteristics.

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