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Misreaction, hedging pressure, and its effect on the futures market[☆]

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ABSTRACT

This study investigates the effect of index option investors' misreaction to the Taiwan index futures market and examines the channel through which this effect occurs. We find that an increase in misreaction during periods of market pessimism leads to greater volatility and illiquidity in the futures market. This negative impact on futures volatility and liquidity can be attributed to market makers' hedging pressure, which is caused by the misreaction occurring within an option market characterized by high volatility and low liquidity during a pessimistic period. Our research presents evidence of a cross-market effect triggered by sentiment-induced misreaction.

1. Introduction

Since the introduction of option trading in 1973, the impact of option trading on the behavior of its underlying asset has been a concern among market participants, regulators, and researchers. Previous studies, such as those presented in works by Figlewski and Webb (1993), John et al. (1991), and Hu (2014), have presented evidence of an informational channel through which option trading can affect its underlying asset.[1] Most of these studies focus on individual stock options.[2] However, index options have become popular for speculative and hedge trading due to their higher leverage, lower trading costs, and absence of short sale restrictions. As index traders are unlikely to have access to private information, we investigate the cross-market effect induced by index option trading.

Recent research uncovers a noninformational channel through which option trading affects underlying assets. Ni et al. (2005) and Golez and Jackwerth (2012) find a phenomenon known as the pinning effect, which suggests that market makers' rebalancing and unwinding of their delta hedges around option expiration cause prices of stocks and stock index futures to cluster or pin at option strike prices on option expiration dates. Ni et al. (2021) demonstrate that option market maker rehedging away from expiration also affects

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[1] Hu (2014) finds that option market makers' initial hedging results in the information from option trading being incorporated into underlying prices. Figlewski and Webb (1993) and John et al. (1991) show that informed traders migrate to options markets because of the inherent leverage, lower trade costs, and lack of short-sale restrictions in option markets. This reduced participation of informed traders in underlying market decreases the adverse selection costs of market makers, leading to improved liquidity by lowering the spread.

[2] See, for example, Figlewski and Webb (1993), John et al. (1991), Kumar et al. (1998), Pan and Poteshman (2006), Ni et al. (2008), Cremers and Weinbaum (2010), Xing et al. (2010), Hu (2014), Lin and Lu (2015), Ge et al. (2016), Ni et al. (2021), and Weinbaum et al. (2023).

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stock price movements. In light of these findings, this study proposes that option investors' misreaction caused by sentiment-induced behavioral biases also affects the dynamics of underlying assets.[3] The mechanism behind this effect is explained as follows.

Our argument is that market sentiment can cause option mispricing, which can significantly impact the underlying futures market through market makers' hedging activities. When market sentiment is pessimistic, options can be mispriced (De Long et al., 1990; Chang et al., 2015; Chen, 2021), resulting in significant return fluctuations. This can increase volatility and illiquidity in the options market. In an illiquid market, market makers, who absorb the mispriced options to maintain liquidity, may find it challenging to quickly reduce their price risk, thereby creating pressing demand for hedging their positions. As futures contracts are often used as hedging instruments for option market makers,[4] their hedging activities may directly impact the dynamics of futures markets, as shown in De Roon et al. (2000) and Ni et al. (2021).

Several studies by De Long et al. (1990), Chang et al. (2015), and Chen (2021) show that pessimistic sentiment leads to overreaction and subsequently results in mispricing of options (Figlewski, 1989; Green and Figlewski, 1999; Bollen and Whaley, 2004; Han, 2008; Lemmon and Ni, 2010; Ofek et al., 2004).[5] Such mispricing can cause price fluctuations and thus drive up price volatility and broaden bid-ask spreads of options.[6] This puts market makers, who bear the responsibility of maintaining liquidity by absorbing mispriced options, in a challenging position, as they cannot rapidly offload their positions by trading options in the opposite direction. The difficulty faced by market makers in immediately neutralizing their net option positions may trigger hedging pressure due to their price risk exposure and capital and funding constraints.[7] As a result, the volatility, return, and liquidity of the futures market can be significantly impacted by market makers who transfer their price risk to the futures market through delta hedging (Stoll, 1979; Hirshleifer, 1989; Bessembinder, 1992; De Roon et al., 2000; Ni et al., 2021).

Despite the evidence of increasing misreactions in the index option market[8] and observed hedging pressure effects in broad futures markets (Stoll, 1979; Hirshleifer, 1989; Bessembinder, 1992; Frey and Stremme, 1997; Sircar and Papanicolaou, 1998; Schoenbucher and Wilmott, 2000; De Roon et al., 2000), the impact of investor behavioral bias in the option market on the dynamics of index futures markets is poorly understood. However, understanding these effects can provide insights for market participants seeking to engage in risk management, develop trading strategies, conduct market analysis, and make more informed decisions. Thus, we examine the effect of misreaction on the following return, volatility, and liquidity of index futures through hedging of option market makers.

In this study, we analyze the Taiwan index option (TXO) market. The TXO dataset is obtained from the Taiwan Futures Exchange (TAIFEX), which includes a trade indicator that identifies open trades, close trades, and market makers' trades in each time-stamped trade. This feature allows us to accurately track market makers' trades[9] and calculate their hedging demand pressure. Furthermore, in the TXO market, market makers constitute a significant proportion of trading volume, contributing on average to 28.47% of all daily option trading volume, as shown in Panel B of Table 1. We anticipate that this market will display a pronounced cross-market hedging pressure phenomenon. In addition, the TXO market is one of the most actively traded markets in the world.[10] Given its significant trading activity, our results on misreaction and hedging pressure effects can be fairly generalized to the other markets.

To identify misreaction (MReAct), we adopt the method developed by Poteshman (2001) and Jiang and Tian (2010), which observes implied volatility extracted from option market prices. MReAct represents the forecasting error of forward volatility, which is calculated as the difference between forward volatility and the corresponding spot volatility. In our empirical work, we use the monthly MReAct to measure investors' misreaction. Constructed on two near-month option contracts, we calculate MReAct as the cumulative daily forecasting error of forward volatility over a future one-month period. This is because MReAct is not measurable at present and requires additional information on one-month spot volatility.[11] To reduce the risk of model misspecification, we use the

[3] Behavioral theories indicate that investors may form mistaken beliefs and misreact to information shocks, thereby incorrectly evaluating asset prices (De Long et al., 1990; Lee et al., 1991; Kumar and Lee, 2006).

[4] See, for example, Black (1975), Kawaller et al. (1987), Stoll and Whaley (1990), Back (1993), Mayhew et al. (1995), Fleming et al. (1996), and Easley et al. (1998).

[5] For example, Stein (1989) demonstrates that long-term volatility overly reacts in the S&P 100 index option market. Poteshman (2001) and Chang et al. (2015) find option investors' misreaction in response to changes in market volatility. Mahani and Poteshman (2008) show that unsophisticated investors of options overreact to news released about the stock market.

[6] Prior studies, such as Roll (1984), Cohen et al. (1986), French and Roll (1986), Amihud and Mendelson (1987), and Glosten (1987), show a positive relation between price volatility and the bid–ask spread.

[7] Similar to the approach in the work of Dusak (1973), Black (1976), and Jagannathan (1985), hedging pressure is considered the net positions of hedgers.

[8] Existing studies support the existence of increasing misreaction in the index option markets, for example, as observed in the S&P 100 index options (Stein, 1989), the S&P 500 index options (Poteshman, 2001; Chao et al., 2005), and the Taiwan index options (Chang et al., 2015; Chen, 2021).

[9] For example, some studies such as Chordia et al. (2002) and Bollen and Whaley (2004) use the net buying pressure of nonmarket makers as a proxy for the net demand of market makers because market makers take the opposite side of the trade of option end users. The net buying pressure is calculated as the buyer-initiated trade volume less the seller-initiated trade volume, following Lee and Ready's (1991) algorithm. As documented in Savickas and Wilson (2003), the accuracy of this classification is only on the order of 80%.

[10] Globally, the TXO is ranked the fifth most frequently traded index option and eighth by the number of traded contracts of index futures and options in 2017. Detailed statistics are available at the World Federation of Exchanges website, http://www.world-exchanges.org/.

[11] In this study, we define the month trading period as the period between the two subsequent nearest option maturities. If the current date is not the option expiration date, a month trading period is given as the period between the prior option maturity and the current near-month option maturity; otherwise, it is the period between the two nearest option maturities.

Table 1
Descriptive statistics for the trading volume of market makers and other important variables.

	Mean	S.D.	Min	Q2	Q3	Max	Skewness	Kurtosis
Panel A: Daily option buy-and-sell volume of market makers by option moneyness (thousand contracts per unit)								
$OVol_{BS,All}$	672.62	437.89	61.44	562.97	873.46	4162.58	1.48	6.48
$mOVol_{BS,All}$	192.28	127.52	10.28	166.40	259.12	1319.53	1.46	7.42
$mOVol_{BS,ITM}$	2.63	4.39	0.01	1.14	2.83	55.94	4.47	32.83
$mOVol_{BS,ATM}$	98.24	98.48	1.73	62.44	132.69	865.93	1.97	8.15
$mOVol_{BS,OTM}$	91.42	62.77	7.53	73.35	122.26	563.52	1.56	6.70
Panel B: Daily ratios of option buy-and-sell volume of market makers to all option buy-and-sell volume								
$mPOVol_{All}$	0.28	0.06	0.10	0.28	0.32	0.64	0.48	3.53
$mPOVol_{ITM}$	0.21	0.10	0.01	0.20	0.27	0.65	0.73	3.53
$mPOVol_{ATM}$	0.25	0.08	0.05	0.24	0.30	0.48	0.21	2.45
$mPOVol_{OTM}$	0.33	0.07	0.11	0.33	0.37	0.68	0.37	3.43
Panel C: Descriptive statistics for other important variables in a monthly frequency								
MReAct	0.42	0.50	−2.98	0.46	0.63	1.56	−2.46	17.36
OHgPn	1.55	12.47	−60.75	2.37	9.60	33.18	−0.81	6.14
FR	0.01	0.05	−0.21	0.01	0.04	0.18	−0.86	5.66
FV	0.17	0.10	0.07	0.14	0.20	0.72	2.43	11.34
FLiq	3.E-03	2.E-03	2.E-03	3.E-03	4.E-03	0.01	2.24	9.54
PCR	1.87	1.41	0.20	1.67	2.34	14.07	4.53	37.86
OLiq	1.80	0.49	0.75	1.78	2.10	3.64	0.51	3.77
IV	0.14	0.06	0.07	0.12	0.16	0.49	1.77	6.39
OVol	15.76	0.26	15.15	15.75	15.94	16.42	0.05	2.72
FVol	14.56	0.29	13.45	14.59	14.74	15.20	−0.42	3.49

Note: This table reports the descriptive statistics for the important variables related to options trading. Our sample covers the period from January 2008 to December 2020. Panel A represents the results for the daily option buy-and-sell trading volume of market makers ($mOVol_{BS}$). $OVol_{BS,All}$ indicates the total buy-and-sell trading volume of options in a trading day. $mOVol_{BS,All}$, $mOVol_{BS,ITM}$, $mOVol_{BS,ATM}$, and $mOVol_{BS,OTM}$ are the buy-and-sell trading volume of options for market makers in all options and ITM, ATM, and OTM options, respectively. Panel B reports the daily percentages of the market makers' buy-and-sell trading volume in each moneyness category. For all options and each option moneyness category, we calculate the daily ratio of the buy-and-sell trading volume of market makers scaled by the total buy-and-sell trading volume. $mPOVol_{BS,All}$, $mPOVol_{BS,ITM}$, $mPOVol_{BS,ATM}$, and $mPOVol_{BS,OTM}$ denote the ratios of option buy-and-sell trading volume of market makers computed from all options and ITM, ATM, and OTM options, respectively. Panel C provides the other important variables at a monthly frequency. OHgPn is the monthly delta-hedged position for option market makers with one thousand spot positions per unit to purchase or sell in the futures market. It is calculated as the negative sum of the product of the option net positions of market traders with different strike prices and corresponding delta values across all options in a month. MReAct is investor misreaction, which is calculated as the cumulative daily forecasting error of forward volatility over a month. We use the put-call open interest ratio calculated from OTM options, denoted by PCR, to proxy for investor sentiment. FR, FV, and FLiq indicate futures return, volatility, and liquidity in a month, respectively. OLiq is the monthly percentage bid–ask spread of option as a proxy for the liquidity of the option market. IV denotes the implied volatility of the option market as a proxy for the total option market volatility, which is calculated as the daily average of option implied volatilities abstracted from near- and second-month options. We average 5-min option market volatility as daily option implied volatility. OVol and FVol are the logarithmic monthly trading volumes in the option and futures markets, respectively.

model-free method introduced by Jiang and Tian (2005, 2007) to calculate the implied volatilities derived from options with different maturity periods and exercise prices.

Using the TXO intraday dataset from January 1, 2008, to December 31, 2020, we find that misreactions exist in the TXO market, as evidenced by the increased forecasting error of forward volatility following a rise in short-horizon implied volatility. Our results coincide with those of Chang et al. (2015) and Chen (2021). Furthermore, we investigate the role of sentiment in driving investor misreaction by incorporating a sentiment dummy into the regression. Following Billingsley and Chance (1988), Dennis and Mayhew (2002), and Bandopadhyaya and Jones (2008), we adopt the put-call ratio (PCR) to distinguish between pessimistic and optimistic market sentiment. The PCR is calculated from the open interest of out-of-the-money (OTM) options over a month (Chen, 2021).[12] Our results show that misreaction becomes more pronounced during highly pessimistic periods, suggesting that misreaction varies over time with the level of sentiment and is more pronounced when market sentiment is pessimistic. Our findings support previous studies, such as those conducted by De Long et al. (1990) and Chang et al. (2015), that also demonstrate the role of sentiment in affecting market misreaction.

To examine the cross-market effect, we conduct OLS regression analyses to individually study the effect of misreaction on futures return, volatility, and liquidity and vice versa. Our results show that misreaction affects the futures market, leading to reduced volatility and improved liquidity. Conversely, when market sentiment is pessimistic, misreaction causes greater volatility and worsened liquidity. There is no evidence supporting the hedging pressure effect on futures return, as found by Bessembinder (1992). A

[12] The put–call ratio is a market-based sentiment indicator calculated as the total monthly put volume divided by the monthly call volume. Many studies, such as Billingsley and Chance (1988), Dennis and Mayhew (2002), and Bandopadhyaya and Jones (2008), employ this ratio to distinguish between pessimistic and optimistic sentiment. More puts (calls) traded than calls (puts) indicate pessimistic (optimistic) sentiment.

possible explanation is that the increase in futures volatility and bid-ask spread induced by the misreaction results in higher trading risk and costs in the futures markets (Jones and Seguin, 1997; Brown, 1999; Lee et al., 2002; Yuan, 2015).[13] As a result, more noise traders are attracted to the market, which, in turn, increases the risk of noise traders. Because a high level of noise trading risk diminishes the price discovery ability of the futures market (Shleifer and Vishny, 1997; De Long et al., 1990; Lin et al., 2018), the explanatory power of misreaction for futures return weakens. However, no evidence is found to support the influence of futures return, volatility, or liquidity on misreaction in the option market. In addition, Granger causality tests confirm a causal effect of misreaction to the futures market, suggesting that the misreaction of index option investors has a cross-market impact on volatility and liquidity in the index futures market.

We explore whether market makers' hedging activities act as a channel between misreaction and the futures market. Extant studies show that a large bid-ask spread and return volatility, which reflect the high inventory risk costs of liquidity suppliers (Stoll, 1978; Cohen et al., 1986; Constantinides, 1986; Amihud and Mendelson, 1987), can deteriorate liquidity, resulting in greater hedging pressure for market makers. To address this issue, our investigation begins by exploring the connection between misreaction and market makers' hedging pressure. We examine whether misreaction leads to increased hedging pressure for market makers in an option market with low liquidity or high volatility and during periods of market pessimism. Using the delta-hedging positions of market makers to proxy for hedging pressure,[14] our results reveal that misreaction does, in fact, increase the subsequent hedging pressure on market makers, particularly in low-liquidity or high-volatility markets when market sentiment is pessimistic. Furthermore, Granger causality tests show that misreaction has a causal impact on market makers' hedging pressure.

Next, we investigate the impact of hedging pressure on futures return, volatility, and liquidity. Our results reveal that market makers' hedging pressure contributes to a reduction in volatility and an improvement in liquidity in the futures market. However, during periods of market pessimism, this relationship is reversed, resulting in greater volatility and poorer liquidity. Our results are supported by Granger causality tests, which demonstrate a causal effect of hedging pressure. We also find similar effects on futures volatility and liquidity when we measure hedging pressure using market makers' gamma-hedging positions, delta- and gamma-hedging positions of market makers, and the relative ratio of market makers' hedging positions to futures open interest, in which open interest is used to represent demand for hedging in the futures market (Chen et al., 1995; Chang et al., 2000; Aguenaou et al., 2011).

Additionally, the effect of hedging pressure may vary depending on option moneyness. It is likely that market makers, who usually absorb mispriced options to maintain liquidity, can offload their positions quickly and thus avoid introducing hedging pressure. Additionally, prior literature shows that liquidity is greater for at-the-money (ATM) options and lower for in-the-money (ITM) and OTM options (Jameson and Wilhelm, 1992; George and Longstaff, 1993; Kamara and Miller, 1995). These results suggest a link between the hedging pressure effect and the liquidity of options. Thus, we analyze the impact of hedging pressure on the futures market based on option moneyness. Specifically, we group our analysis by ITM, ATM, and OTM options and calculate the hedging pressure of market makers for each group. Our findings reveal that market makers' hedging pressure has a greater impact on futures volatility and liquidity when considering ITM and OTM options than for ATM options due to lower liquidity in these options.

In our robustness checks, we carry out three different empirical exercises to confirm our findings on the misreaction-induced cross-market effect. First, we use an alternative measure of sentiment, known as the Baker and Wurgler (2006) composite sentiment index (BW6). This index is constructed by calculating the first principal component of six sentiment proxies that are orthogonalized. Second, we employ a vector autoregression (VAR) model that presents a more comprehensive and complex representation of the relationship between misreaction, futures return, volatility, and liquidity. This approach helped us gain a deeper understanding of the cross-market effect, allowing us to study the cross-market effect in greater detail. Finally, we re-examine the impact of misreaction on the futures market by excluding data from the periods of the 2008 financial crisis, the European debt crisis, and the COVID-19 pandemic, and consider these crises separately. These catastrophic events may impact investors' behavior and sentiment, potentially amplifying the misreaction effect. However, our results demonstrate that sentiment-induced misreaction consistently influences future volatility and liquidity in the futures market, regardless of catastrophic market events.

Our research contributes to the literature in two ways. First, we find that the misreaction driven by option investors can help explain the varying levels of liquidity and volatility in the futures market. An increase in misreaction leads to heightened hedging pressure on market makers of options, resulting in the transfer of price risk to the futures market through dynamic hedging. In turn, this process increases volatility and illiquidity. Indeed, this hedging pressure effect for market makers is most significant for ITM and OTM options. Our findings provide valuable insights for regulators and market participants. Regulators may consider increasing information disclosure, especially during periods of market pessimism, to mitigate the impact of sentiment on the liquidity and volatility of the option market. Market makers can monitor the option market for misreaction to manage their hedging pressure and thus reduce the negative impact on futures market volatility and liquidity. Doing so would contribute to reducing hedging pressure and enhancing market efficiency. Second, unlike previous studies that mainly focus on stock options (Stein, 1989; Poteshman, 2001; Mahani and Poteshman, 2008; Chang et al., 2013; Chang et al., 2015), we examine the cross-market impact of misreaction on the index futures market. Our results complement the literature and indicate that index option investors' misreaction can have a significant impact on the futures market.

[13] Several studies such as Jones and Seguin (1997), Brown (1999), Lee et al. (2002), and Yuan (2015) use price volatility as a proxy for trading risks.

[14] According to Chung et al. (2014), dynamic hedging pressure for market makers primarily arises from two elements, consisting of delta-hedging and gamma-hedging positions. In this study, we have much emphasis on delta-hedging pressure since market makers almost immediately delta-hedge after option trading. In our subsequent analyses, we also examine the hedging pressure effect with the delta- and gamma-hedging positions.

Our study aligns with several previous studies that investigate the impact of misreaction on the option market. Existing studies have provided evidence supporting the impact of sentiment-induced misreaction on option market returns, such as Figlewski (1989), Green and Figlewski (1999), Bollen and Whaley (2004), Ofek et al. (2004), Han (2008), Lemmon and Ni (2010), Chang et al. (2015), and Chen (2021). Mahani and Poteshman (2008) find that unsophisticated investors in the options market overreact to past news on the underlying stocks, resulting in deviations of stock prices from their fundamental values. Unlike these results, we demonstrate that misreaction leads to increases in subsequent hedging pressure of market makers, especially in low-liquidity or high-volatility markets when market sentiment is pessimistic.

Additionally, our research is related to the existing literature on the hedging pressure effect. Ni et al. (2005) and Golez and Jackwerth (2012) find that hedge rebalancing by market makers around option expiration dates lead to clustering of stock prices and stock index futures at option strike prices. Ni et al. (2021) demonstrate that option market makers' hedge rebalancing away from expiration also impacts stock return volatility. Furthermore, several empirical and theoretical studies, such as those conducted by Keynes (1930), Hicks (1939), Stoll (1979), Hirshleifer (1989), Bessembinder (1992), and De Roon et al. (2000), provide evidence of hedging pressure effects in futures markets. However, our study finds that hedging pressure driven by investor behavioral bias in the option market impacts subsequent futures volatility and liquidity.

The remainder of this paper is organized as follows. In Section 2, we formally develop our methodology. Section 3 describes the Taiwan futures market and presents our data source, and Section 4 explores the effect of misreaction on the futures market. Finally, Section 5 provides concluding remarks.

2. Empirical methodology

2.1. Construction of important variables

2.1.1. A proxy for investor misreaction

Previous research reveals that a shock to volatility can cause misreaction in the relative pricing of long-term options, as demonstrated by Stein (1989), Poteshman (2001), Chang et al. (2015), and Chen (2021). This indicates that if investors formulate their expectations for future volatility irrationally, changes in implied volatility will not entirely integrate all relevant information, including newly arrived data. Following Poeshman (2001) and Jiang and Tian (2010), we estimate the implied volatilities from option prices to gauge the ways in which investors react to new information. Misreaction (MReAct) is quantified as the forecasting error of forward volatility, calculated as the difference between forward volatility ($v(t, T_1, T_2)$) and corresponding spot volatility ($v(T_1, T_2)$), in which T_1 and T_2 indicate the maturities of near- and second-month options, respectively. A positive (negative) MReAct indicates overvaluation (undervaluation) of the market in response to information shocks. The specifications of $v(t, T_1, T_2)$ and $v(T_1, T_2)$ are provided below.

Using Eq. (1), we extract forward volatility based on option market prices for two maturities and across strike prices. To reduce the potential impact of model misspecification, we employ the model-free approach developed by Jiang and Tian (2005, 2007) to calculate forward volatility. As outlined in Jiang and Tian (2010), the annualized forward variance, denoted by $v(t, T_1, T_2)^2$ and implied by option prices, is formulated as

$$v(t, T_1, T_2)^2 = \frac{2}{T_2 - T_1}\int_0^{\infty} \frac{C_t\left[T_2, \frac{K}{B(t,T_2)}\right] - C_t\left[T_1, \frac{K}{B(t,T_1)}\right]}{K^2} dK, \tag{1}$$

in which $t \le T_1 \le T_2$ and $v(t, T_1, T_2)^2$ measure the integrated expected variance from T_1 to T_2 in the information at time t. The model-free forward variance is obtained by evaluating the right-hand side of Eq. (1), and its square root, $v(t, T_1, T_2)$, represents the model-free forward volatility. $B(t, T)$ is the zero-coupon bond price at time t that pays \$1 at time T, while $C_t(T, K)$ denotes the call option price at time t with strike price K and maturity at time T. When $T_1 = t$ and $T_2 = T$, Eq. (2) degenerates to the general form of a model-free forward variance, $v(t, T)^2 \equiv v(t, t, T)^2$, which is referred to as the spot variance. Its square root is the spot volatility $v(t, T)$. The spot variance, as reported in Eq. (2), at time t is formulated as

$$v(t, T)^2 = v(t, t, T)^2 = \frac{2}{T - t}\int_0^{\infty} \frac{C_t\left[T, \frac{K}{B(t,T)}\right] - max\{0, S_t - K\}}{K^2} dK, \tag{2}$$

in which S_t is the price of the underlying asset at time t.

In our empirical work, we estimate the model-free forward and spot variances directly from option prices using Eqs. (1) and (2), respectively. The forward volatility $v(t, T_1, T_2)$ is calculated by the square root of the model-free forward variance at current time t. Similarly, the spot volatility $v(T_1, T_2)$, measured at $t = T_1$, is computed as the square root of the model-free implied variance. To avoid truncation and discretization errors resulting from the limited availability of strike prices in the marketplace,[15] we employ the approach of Jiang and Tian (2005, 2007) to calculate forward and spot volatilities. Furthermore, we use the quote midpoint, rather than the transaction price, to compute the implied volatility to eliminate the bid-ask bounce issue (Bakshi et al., 1997, 2000).

To measure misreaction, we use the monthly MReAct based on two adjacent near-month option contracts. MReAct is calculated as the cumulative daily forecasting error of forward volatility over a one-month future period. Since MReAct requires additional information on the one-month spot volatility measured at $t = T_1$,[16] it is not quantifiable at the current time t. For the monthly MReAct measure, we calculate MReAct for each day and sum the measures over the month-long trading period. The daily MReAct averages the differences between forward volatility and corresponding one-month spot volatility across 5-min trading intervals on a trading day. As an estimation, MReAct can be utilized in OLS and VAR regressions to facilitate our predictions. Additionally, we utilize the same month-long trading period to determine the option market's volatility and liquidity and the futures market's return, volatility, and liquidity.

2.1.2. Hedging pressure for option market makers

Chung et al. (2014) suggest that market makers face hedging pressure mainly from delta-hedging positions, which involve offsetting new net positions of options in the current period, and gamma-hedging positions, which hedge cumulative option net positions in past periods. This study examines the misreaction effect, with much emphasis on delta-hedging pressure because market makers almost immediately delta-hedge after option trading due to eliminating their price risk and capital and funding constraints. In our subsequent analyses, we also account for the hedging pressure effect by incorporating delta- and gamma-hedging positions.

The hedge positions on futures for market makers at time t over a specified period T, denoted by $\mathrm{OHgPn}_{t,t+T}$, are computed as the negative cumulative delta-hedged net positions of options. Eq. (3) represents the calculation of $\mathrm{OHgPn}_{t,t+T}$ as the negative sum of the product of the option net positions of market makers for various strikes ($\mathrm{ONetPn}_{K,t}$) and their corresponding delta values ($\mathrm{Delta}_{K,t}$) at time t for all options. OHgPn serves as a proxy for the hedging pressure of market makers, with positive values of OHgPn indicating the need to buy futures contracts to hedge against price risk, while negative values suggest the need to sell futures contracts.

$$\mathrm{OHgPn}_{t,t+T} = -\sum_{i=t}^{t+T} \sum_{j=1}^{N_t} \mathrm{Delta}_{K_j,t}.\mathrm{ONetPn}_{K_j,t} \tag{3}$$

in which $\mathrm{ONetPn}_{K_j,t}$ denotes the net positions of market makers for options with strike price K_j at time t. $\mathrm{Delta}_{K_j,t}$ is the delta value for the option with strike price K_j at time t. N_t is the total number of strike prices for the option portfolio held by market makers at time t. In this study, we use Eq. (3) to compute the hedging pressure of market makers over a month. We use the quote midpoint to estimate the delta values of call and put options based on Black's (1976) option pricing formula because the underlying index of TXO is not traded directly.[17]

2.2. A linkage between sentiment and misreaction

We construct regression models without and with a sentiment dummy (DS) and an interaction term of short-horizon implied volatility ($v(t, T_1)$) and DS in Eq. (4) to investigate the misreaction of long-horizon implied volatility to changes in short-horizon implied volatility and to examine whether sentiment drives misreaction. The effect of implied volatility on misreaction during high pessimism periods includes the combination of β_1 and β_2, while during low pessimism periods, only β_1 is relevant. If sentiment does indeed play a role in the misreaction, then $(\beta_1+\beta_2)$ should have a more positive and significant value. We also calculate the asymptotic t statistics of the estimated parameters using Newey and West's (1987) autocorrelation correction.

$$\mathrm{MReAct}_t = \alpha_1 + \beta_1 v(t, T_1) + \alpha_2 DS_t + \beta_2 DS_t.v(t, T_1) + \varepsilon_t \tag{4}$$

where $v(t, T_1)$ represents the spot implied volatility over the period from t to T_1 of the information at time t. α_1 is the value of the intercept, and ε_t is the error term. DS_t is a sentiment dummy variable that equals 1 for pessimistic sentiment, measured by the monthly PCR, at time t exceeding 75% of its time series and 0 otherwise. We use PCR, a market-based indicator, to distinguish between

[15] In reality, the observed options in the market cover only a finite range of discrete exercise prices. To reduce the errors of both truncation and discretization, we follow Jiang and Tian (2005, 2007) to first employ cubic splines to fit a smooth function of the implied volatility surface between the maximum and minimum available exercise prices. Then, we extrapolate option prices beyond the maximum and minimum available exercise prices as the implied volatility with the closest available exercise price. Finally, based on the obtained implied volatility surface, we use the numerical integration method to calculate the forward variance and implied spot variance.

[16] In this study, we define the month trading period as the period between the two subsequent option maturities. If the current date is not the option expiration date, a month trading period is given as the period between the prior option maturity and the current near-month option maturity; otherwise, it is the period between the two nearest option maturities.

[17] We estimate the deltas of call and put options by using the midpoint of the option bid–ask quote based on the Black formula. The proxy for the volatility rate is the implied volatility of the spot market, which is calculated from index option prices following the approach of Jiang and Tian (2005, 2007).

pessimism and optimism (Billingsley and Chance, 1988; Dennis and Mayhew, 2002; Bandopadhyaya and Jones, 2008; Chen, 2021). PCR is calculated as the total OTM put open interest divided by the OTM call open interest in a month.

2.3. Effect of misreaction on the futures market

We employ the OLS regression model, as shown in Eq. (5), to assess the impact of misreaction (MReAct) and the interaction of a lagged pessimistic sentiment dummy variable (DS) and misreaction on one of futures dynamics (including futures return (FR), volatility (FV), and liquidity (FLiq)), and vice versa. The lagged trading volumes of option and futures markets (OVol and FVol), risk-free interest rate (r_f), and a time trend (T) are included as controls. The OLS regression is given as follows:

$$FMC_t = \alpha + \beta_1 MReAct_{t-1} + \beta_2 DS_{t-1} * MReAct_{t-1} + \beta_3 OVol_{t-1} + \beta_4 FVol_{t-1} + \beta_6 r_f + \beta_7 T \tag{5}$$

in which FMC is FR, FV, or FLiq. MReAct represents investor misreaction in the option market over a month. DS_t is a sentiment dummy variable at time t, which is equal to 1 when PCR exceeds 75% of the time series and 0 otherwise. FR denotes the monthly return of the index futures. FV_t indicates the monthly realized volatility of index futures in month t, which is used as a proxy for the volatility of the futures market. Following Andersen and Bollerslev (1998) and Andersen et al. (2002), we calculate FV as the square root of the sum of squared 5-min returns in the index futures over a month. FLiq is the cumulative daily percentage quote spread of index futures in a month and is used to proxy for the liquidity of the futures market. For the daily percentage quote spread, we average the 5-min percentage bid-ask spreads of index futures in a trading day. OVol and FVol are the logarithmic monthly trading volumes in the option and futures markets, respectively. r_f denotes the risk-free interest rate. T is a time trend. In addition, pairwise Granger causality tests are conducted to explore the causal relationships between MReAct and the futures market's return, volatility, and liquidity.

2.4. Market makers' hedging pressure and the misreaction-induced cross-market effect

In this section, we examine how misreaction influences the futures market through option market makers' hedging activities. We begin by connecting the misreaction to market makers' hedging pressure. Subsequently, we examine the impact of hedging pressure on the futures market and provide evidence to support our argument.

2.4.1. Misreaction and hedging pressure on market makers

Misreactions in the option market can cause significant hedging pressure for market makers. As demonstrated in De Long et al. (1990), Chang et al. (2015), and Chen (2021), pessimism-induced misreaction results in overreaction and mispricing of options. This mispricing creates price fluctuations and increases volatility and illiquidity in the option market. In an illiquid market, market makers cannot immediately unload their positions, leading to hedging pressure due to their price risk exposure and capital and funding constraints.

To explore whether pessimism-induced misreaction leads to increases in volatility and illiquidity in the option market, which in turn results in market makers' hedging pressure, we include an interaction term of lagged OHgPn and a dummy variable for the low-liquidity option market during periods of market pessimism (DSL) or a dummy variable for the high-volatility option market during periods of market pessimism (DSV) in Eq. (6). The regression controls for lagged OVol and FVol, r_f, and T. We expect a significantly positive coefficient β_2 of DSM_{t-1}*$MReAct_{t-1}$, indicating that misreaction increases volatility and illiquidity, leading to increased hedging pressure for market makers. The equation is formulated as follows:

$$OHgPn_t = \alpha + \beta_1 MReAct_{t-1} + \beta_2 DSM_{t-1} * MReAct_{t-1} + \beta_3 OVol_{t-1} + \beta_4 FVol_{t-1} + \beta_6 r_f + \beta_7 T \tag{6}$$

in which DSM_t indicates a dummy variable and is either DSL or DSV. DSL_t is a dummy variable that captures a low-liquidity option market during periods of market pessimism at time t. It is equal to 1 if PCR and OLiq are both >50% of their time series at time t and 0 otherwise. PCR is used to proxy for investor pessimistic sentiment. OLiq is used as a proxy for the liquidity of the option market. DSV_t captures a high-volatility option market during periods of market pessimism at time t. It is equal to 1 if PCR and IV are both >50% of their time series at time t and 0 otherwise. The IV measures the market's volatility in the option market. OHgPn denotes the hedging pressure of market makers, while MReAct represents investor misreaction in the option market. FR denotes the monthly return of the index futures. r_f is the risk-free interest rate, and T is the time trend.

2.4.2. Hedging pressure effect on the futures market

As market makers transfer their price risk to the futures market through delta hedging, it can impact the underlying futures. This is documented by several theoretical and empirical studies, such as Stoll (1979), Hirshleifer (1989), Carter et al. (1983), Bessembinder (1992), De Roon et al. (2000), and Ni et al. (2021), who find that hedging pressure influences the pricing dynamics of futures. To examine the effect of hedging pressure on futures return, volatility, and liquidity, we conduct a test using Eq. (7).

$$FMC_t = \alpha + \beta_1 OHgPn_{t-1} + \beta_2 DS_{t-1} * OHgPn_{t-1} + \beta_3 OVol_{t-1} + \beta_4 FVol_{t-1} + \beta_6 r_f + \beta_7 T \tag{7}$$

where FMC is FR, FV, or FLiq, which represent the return, volatility, and liquidity, respectively, in the futures market. OHgPn indicates the hedging pressure on market makers. DS is a sentiment dummy variable that is equal to 1 when PCR exceeds 75% of its time series and 0 otherwise. OVol and FVol are the logarithmic monthly trading volumes in the option and futures markets, respectively. r_f

represents the risk-free interest rate, and T is the time trend.

To more accurately capture hedging pressure, we use three alternative measures of OHgPn. Intuitively, as market makers enforce dynamic delta hedging using index futures, the cross-market hedging effect is associated with gamma-hedging positions and open interest in the futures market. The gamma-hedging positions are used for hedging the cumulative net positions of options in the prior period, which are caused by changes in the underlying price. We separately compute OHgPn using both gamma-hedging positions and the delta- and gamma-hedging positions of market makers. Additionally, we use a measure based on the relative ratio of hedged positions between financial markets, as suggested by De Roon et al. (2000). We redefine OHgPn as the ratio of option hedged positions for market makers to hedging positions in the futures market. Our calculation considers the monthly delta- and gamma-hedging positions of options for market makers and divides it by the average open interest of futures in a given month, which serves as a proxy for the demand for hedging in the futures market (Chen et al., 1995; Chang et al., 2000; Aguenaou et al., 2011).

In addition, the effect of hedging pressure on the futures market could vary depending on the moneyness of options. Certain strike prices may attract different preferences from investors due to factors such as leverage, trading costs, and price volatility. These dissimilarities in investor behavior can generate divergent degrees of hedging pressure. When options are liquid, market makers may avoid introducing hedging pressure through offloading their positions. Furthermore, the literature indicates that option liquidity varies according to moneyness, with ATM options being more liquid than ITM or OTM options (Jameson and Wilhelm, 1992; George and Longstaff, 1993; Kamara and Miller, 1995). These findings suggest that the moneyness of options may be correlated with hedging pressure.

For our analysis, we categorize options into three categories, including ITM options where $m < 0.975$, ATM options where $0.975 \leq m \leq 1.025$, and OTM options where $m > 1.025$. Moneyness is defined as $m = K/Se^{r_f\tau}$, where K is the strike price, τ is the time to maturity, r_f is the risk-free interest rate, and S is the underlying index price. We calculate the hedging pressure for each category and use Eq. (7) to assess its impact on the futures market.

3. Data description

3.1. Taiwan option market

The TXO option market is operated by an electronic call market with designated market makers responsible for ensuring liquidity provision.[18] These market makers respond to market participants' inquiries by offering bids that reflect the highest bid price and the lowest ask price listed in the limit-order book at that time. To comply with TAIFEX's regulations, bid-ask spreads must be within the mandated range, and the quantity ordered (minimum quantity) must meet the relevant requirements.

Both the Taiwan index futures (TX) and European-style TXO, traded on the TAIFEX, share the same underlying asset (the Taiwan Stock Exchange Capitalization Weighted Stock Index, TAIEX), expiration date (third Wednesday of the delivery month), and delivery months (spot month, next two calendar months, and next two quarterly months). In addition, both markets follow the same regular trading hours, from 8:45 A.M. to 1:45 P.M. (Taipei time), on weekdays except for public holidays.

3.2. Data sources

Our empirical analysis utilizes intraday data obtained from TAIFEX for TXO and TX. The data cover the period from January 1, 2008, to December 31, 2020. The data for both TXO and TX provide consolidated transactions and quotes, with each time-stamped TXO trade featuring the date, transaction time, trading price, volume, trade direction (buy or sell), and trade indicator for open, close or market maker trades. These detailed data enable us to precisely compute the option net positions for market makers, which serve as a proxy for their hedging pressure. In addition, we extract bid and ask prices, trading prices, and trading volume from the intraday TX data. We also include the three-month time deposit of the postal savings system, retrieved from the TEJ database, as a proxy for the risk-free interest rate.

To reduce the influence of illiquid trades on our outcomes, we restrict the use of data to option and futures contracts in the near month and second month. Our data-editing process involves scrutinizing the source files for typographical issues, thus preventing any significant pricing errors. Moreover, we exclude certain data from our analysis, such as outlier transaction prices and quotes, as well as observations containing missing values.

We further improve the accuracy of our sample by excluding options that are priced under 0.3 points. This helps eliminate the potential impact of microstructure-related bias. Additionally, to avoid the bid-ask bounce problem, we use the midpoint of the quote rather than the transaction price to calculate the implied volatilities (Bakshi et al., 1997, 2000). Adopting these measures increases the reliability, validity, and precision of our calculations, thereby enhancing the confidence in our results.

Table 1 presents summary statistics for the daily buy-and-sell trading volume of market makers ($mOVol_{BS,All}$), the ratio of the buy-and-sell trading volume of market makers to the total buy-and-sell trading volume ($mPOVol_{All}$), and other important variables on a monthly basis for the period from January 2008 to December 2020. Panels A, B, and C report the results calculated by the first and second nearest-to-maturity options. Panel A shows the daily buy-and-sell trading volume of option ($OVol_{BS,All}$), which are 672.62 and

[18] The TXO option market is a hybrid market and is similar to the New York Stock Exchange (NYSE) and American Stock Exchange (AMEX), in which both market makers and limit-order traders establish option prices.

192.28 thousand contracts for all traders and market makers, respectively. The market makers primarily engage in trading OTM and ATM options, with average daily trading volume values of 98.24 and 91.42 thousand contracts ($mOVol_{BS,ATM}$ and $mOVol_{BS,OTM}$), respectively, while the trading volume of ITM options is only 2.63 thousand contracts ($mOVol_{BS,ITM}$). The large values of $mOVol_{BS,ATM}$ and $mOVol_{BS,OTM}$ suggest that market makers provide greater liquidity in these options. In Panel B, the average $mPOVol_{All}$ ratio of 0.28 indicates that market makers account for >28% of the total buy-and-sell trading volume in near- and second-month options. Additionally, the $mPOVol_{ITM}$, $mPOVol_{ATM}$, and $mPOVol_{OTM}$ ratios suggest that market makers trade 21%, 25%, and 33%, respectively, of the total buy-and-sell trading volume in ITM, ATM, and OTM options. Our evidence that >28% of the total TXO volume is generated by market makers suggests that option hedging pressure from market makers can affect the futures market.

Panel C of Table 1 presents summary statistics for several market indicators, including monthly frequency misreaction (MReAct), market makers' hedging pressure (OHgPn), and various indicators of return, volatility, percentage bid-ask spread, and logarithmic trading volume in the futures market (FR, FV, FLiq, and FVol), as well as percentage bid-ask spread and logarithmic trading volume in the option market (OLiq and OVol), put-call open interest ratio computed from OTM options (PCR), and option market volatility (IV). A positive average of MReAct with a value of 0.42 indicates that long-horizon implied volatility tends to overreact to changes in short-horizon implied volatility. One possible explanation is that the option market reflects a bearish view, as evidenced by a high monthly PCR average of 1.87. More puts traded than calls represent pessimistic sentiment, leading to an overreaction, as documented in previous studies such as De Long et al. (1990), Brown and Cliff (2005), Baker and Wurgler (2006), Chang et al. (2015), and Chen (2021).

Additionally, the analysis of Panel C reveals that, on average, market makers' option hedging pressure creates a long hedging for 1.55 thousand delta-hedged spot positions in the futures market over a month. The hedging pressures differ by option moneyness (untabulated), with the ITM, ATM, and OTM options having average delta-hedged spot positions of 0.04, 2.62, and −1.10 thousand, respectively. The negative average delta-hedged futures positions for OTM options indicate that investors tend to buy OTM put (or sell OTM call) index options to hedge against price declines or to speculate on bearish trends (Bollen and Whaley, 2004; Gârleanu et al., 2009).[19] OHgPn varies widely from −60.75 to 33.18 thousand delta-hedged spot positions, suggesting a nonnegligible hedging pressure effect. Additionally, the average cumulative daily percentage bid-ask spreads over a month in the option and futures markets are 1.80 and 0.003, respectively, with skewed right distributions. Finally, the monthly return in the futures market is positive, with a value of 0.0053.

Table 2 presents the results of a regression analysis examining the relationship between the spot volatility implied from near-month option prices and investor misreaction. The analysis shows a significant positive coefficient of v, with a t value of 2.16, indicating that higher volatility leads to greater misreaction. These findings align with previous studies by Stein (1989), Poteshman (2001), Chao et al. (2005), Mahani and Poteshman (2008), and Chang et al. (2015) that identify misreaction in the option market. Additionally, we find that pessimism exacerbates overreaction in the TXO market, which coincides with the findings of Chang et al. (2015) and Chen (2021). Our result is evidenced by the coefficient of DS^*v at the 1% significance level and a positive sum of 3.60 for the coefficients on v and DS^*v, with corresponding values of −0.94 and 4.84, respectively. However, our results show that misreaction varies depending on the level of sentiment and is more pronounced during highly pessimistic periods.

4. Empirical results

4.1. *Impact of misreaction on the futures market*

We conduct OLS regression analyses to examine the influence of MReAct on subsequent return, volatility, and liquidity in the futures market and vice versa. The results are presented in Panels A and B of Table 3. Panel A shows that the coefficient of r_f for the dependent variable FLiq is significantly positive, with a t value of 2.88. This finding indicates that an increase in interest rates, which implies higher margin trading costs, leads to reduced liquidity in the market, as noted by Chordia et al. (2001). Additionally, we observe that an increase in interest rates is associated with decreased market returns and increased volatility in the futures market.

In Panel A, we find significantly negative coefficients of MReAct for FV and FLiq in Eq. (5), with t values of −5.00 and −4.36, respectively. These results indicate that misreaction causes a reduction in volatility and an improvement in liquidity. However, when market sentiment is pessimistic, i.e., DS = 1, MReAct causes greater volatility and worsened liquidity. This cross-market effect from the option market to the futures market is evidenced by the significantly positive DS*MReAct coefficients for the dependent variables FV and FLiq, with t values of 2.92 and 2.91, respectively. Additionally, our findings support sentiment spillover from the option market to the futures market. This is evident from the varying effect of misreaction on subsequent futures volatility and liquidity, depending on the level of sentiment. Therefore, MReAct implicitly transmits sentiment, potentially increasing volatility and illiquidity in the futures market.

Consistent with Bessembinder (1992), there is no evidence supporting the impact of misreaction on futures returns. A possible reason for this could be the high trading risks and costs resulting from elevated futures volatility and bid-ask spreads (Jones and Seguin, 1997; Brown, 1999; Lee et al., 2002; Yuan, 2015). Such increased trading risks and costs can attract more noise traders to the market, further adding to their risk. However, this higher level of noise trading risk may reduce the price discovery ability of the

[19] For example, Bollen and Whaley (2004) find large net buying pressure in OTM put options with the underlying on the S&P 500 index and suggest that the OTM index puts are used as portfolio insurance by equity portfolio managers. Gârleanu et al. (2009) find that end users have large net positions in OTM put options on the S&P 500 index.

Table 2
Regression results for investor misreaction.

	Coeff.	t-stat.	Coeff.	t-stat.
α	0.40**	2.48	0.43	1.35
$\nu(t, T_1)$	0.20**	2.16	−0.94	−0.56
DS_t	–	–	0.39	1.20
$DS_t{*}\nu(t, T_1)$	–	–	4.54**	2.46
$AdjR^2$ (%)	–	0.60	–	11.78

Note: This table presents the results for the effect of the spot volatility implied from near-month option prices ($\nu(t, T_1)$) on investor misreaction (MReAct). Additionally, we incorporate a sentiment dummy variable (DS) and the interaction term DS*$\nu(t, T_1)$ into the regression to investigate the sentiment effect on misreaction, in which sentiment is calculated as the ratio of OTM put-call open interest, denoted by PCR, in a month. We individually estimate the parameters without and with the interaction term DS*$\nu(t, T_1)$ and use Newey and West's (1987) autocorrelation correction to compute the asymptotic t statistics of the estimated parameters. The results are reported in Table 3. MisReAct denotes investor misreaction and is measured as the cumulative daily forecasting error over a month. The forecasting error is defined as the difference between forward volatility ($\nu(t, T_1, T_2)$) and the corresponding future spot volatility ($\nu(T_1, T_2)$), in which T_1 and T_2 indicate the maturities of near- and second-month options, respectively.

$$\text{MReAct}_t = \alpha_1 + \beta_1 \nu(t, T_1) + \alpha_2 DS_t + \beta_2 DS_t.\nu(t, T_1) + \varepsilon_t \tag{4}$$

in which MReAct_t indicates investor misreaction in month t. DS_t is a sentiment dummy variable at time t; it equals 1 for PCR at time t over 75% of its time series and 0 otherwise. $\text{v}(t, T_1)$ is the spot volatility implied from near-month option prices. $\nu(t, T_1, T_2)$ is the forward volatility over the period from T_1 to T_1 of the information at time t. ***, **, and * indicate that the t-values are significant at the 1%, 5%, and 10% levels, respectively.

futures market (Shleifer and Vishny, 1997; De Long et al., 1990; Lin et al., 2018), thus diminishing the explanatory power of the information implicit in MReAct for subsequent futures returns during the pessimism period.

In Panel B of Table 3, we examine the regression results of misreaction on lagged futures return, volatility, and liquidity. As depicted in Panel B, no evidence is found to support the impact of those factors on the misreaction in the option market.

To validate the causal influence of misreaction on the futures market, we conduct pairwise Granger causality tests between misreaction and futures return, volatility, and liquidity. The null hypothesis (H_0) is that the ith row variable does not Granger-cause the jth column variable. We test whether the lagged coefficients of i are jointly zero when j is the dependent variable in VAR. The results are reported in Table 4, where the p value of the corresponding cell is presented in parentheses. Our results demonstrate a significant causal effect of misreactions induced by index option investors on futures volatility and liquidity.

4.2. Misreaction-induced hedging pressure

We run the regression in Eq. (6) to examine the relationship between misreaction and hedging pressure. The results of our regression and pairwise Granger causality tests are presented in Panels A and B of Table 5. Panel A reveals the significant coefficient of MReAct, with a t-value of 3.08, indicating that high misreaction pressures market makers to hedge their positions. Moreover, the effect of misreaction on hedging pressure becomes more pronounced in a low-liquidity or high-volatility market during periods of market pessimism (i.e., DSL = 1 or DSV = 1). In these cases, the coefficients of DSL*MReAct and DSV*MReAct are significant, with t-values of 2.20 and 2.04, respectively. In summary, our results provide evidence that misreaction results in an increase in market makers' hedging pressure due to the greater volatility and illiquidity created in the option market related to inventory costs (Copeland and Galai, 1983; Roll, 1984; Glosten and Milgrom, 1985; O'Hara, 1995; Madhavan, 2000), which are driven by investor pessimism.

As displayed in Panel B, Granger causality tests indicate that misreaction has a one-way influence on the hedging pressure of market makers.

4.3. Effect of hedging pressure on the futures market

Using the delta-hedged futures positions of market makers as a proxy for hedging pressure, we analyze the impact of hedging pressure on the futures market using the regression in Eq. (7). Table 6 reports the results. We find that as market makers transfer their price risk to the futures market through delta hedging, this leads to a reduction in volatility and improved liquidity in the futures market. Our findings are supported by the evidence in Panel A of Table 6, which shows statistically significant negative coefficients of lagged OHgPn for FV and FLiq. The t-values of −2.94 and − 3.23 reinforce the credibility of our results.

Furthermore, when market sentiment is pessimistic, i.e., DS = 1, this relationship is reversed, resulting in greater volatility and poorer liquidity in the futures market, as evidenced by the significantly positive coefficient of DS*OHgPn and the positive sum of the coefficients on DS*OHgPn and OHgPn. Additionally, our results are further supported by Granger causality tests, which demonstrate an effect of hedging pressure on the futures market. Combined with these results in Eqs. (5), (6), and (7), we conclude that the misreaction effect on the futures market can be attributed to the hedging activities of option market makers.

To more precisely capture hedging pressure, we use three alternative measures of OHgPn, namely, the gamma-hedging positions of

Table 3
Effect of misreaction on the futures market.

Panel A: The impact of misreaction on futures return, volatility, and liquidity						
	FR_t		FV_t		$FLiq_t$	
	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
α	0.75***	2.73	−0.59	−1.30	0.01	1.25
$MReAct_{t-1}$	−3.E-03	−0.41	−0.07***	−5.00	−7.E-04***	−4.36
DS_{t-1}*$MReAct_{t-1}$	0.01	0.54	0.08***	2.92	1.E-03***	2.91
$OVol_{t-1}$	−0.04**	−2.00	−0.11**	−2.45	−2.E-03***	−3.15
$FVol_{t-1}$	3.E-04	0.02	0.18***	5.01	2.E-03***	3.62
r_f	−6.45***	−3.28	11.43***	3.03	0.16***	2.88
T	−0.07**	−1.99	−0.30***	−4.78	−0.01***	−7.50
$AdjR^2$ (%)	–	20.37	–	49.13	–	67.20
Panel B: The impact of futures return, volatility, and liquidity on misreaction						
	$MReAct_t$		$MReAct_t$		$MReAct_t$	
	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
α	0.95	0.49	2.03	1.11	1.35	0.76
FR_{t-1}	0.58	0.45	–	–	–	–
DS_{t-1}*FR_{t-1}	−0.87	−0.62	–	–	–	–
FV_{t-1}	–	–	0.58	0.88	–	–
DS_{t-1}*FV_{t-1}	–	–	−0.14	−0.21	–	–
$FLiq_{t-1}$	–	–	–	–	−18.26	−0.41
DS_{t-1}*$FLiq_{t-1}$	–	–	–	–	0.53	0.02
$OVol_{t-1}$	−0.09	−0.45	−0.02	−0.09	−0.16	−0.72
$FVol_{t-1}$	0.11	0.52	−0.04	−0.19	0.17	0.75
r_f	−44.96	−1.64	−55.61**	−2.19	−45.32*	−1.89
T	−0.95***	−2.81	−0.79*	−1.86	−1.13**	−2.17
$AdjR^2$ (%)	–	11.60	–	12.09	–	11.45

Note: This table presents the regression results for the effect of misreaction (MReAct) and the interaction term of a lagged dummy variable of higher pessimistic sentiment (DS) and misreaction on one lag of dynamics of futures (including futures return (FR), volatility (FV), and liquidity (FLiq)), and vice versa. We control the regression for the lagged trading volumes of option and futures markets (OVol and FVol, the risk-free interest rate (r_f), and a time trend (T). The results are reported in Panels A and B, respectively. DS_t is a pessimistic sentiment dummy variable at time t; it equals 1 for PCR at time t over 75% of its time series and 0 otherwise. MReAct indicates investor misreaction, which is calculated as the cumulative daily forecasting error of forward volatility. FR and FV indicate the monthly return and realized volatility of the index futures, respectively. Following Andersen and Bollerslev (1998) and Andersen et al. (2002), we calculate FV as the square root of the sum of squared 5-min returns in the index futures over a month. FLiq is the cumulative daily percentage quote spread of index futures over a month and is used to proxy for the liquidity of the futures market. We compute the daily percentage quote spread of futures as the average of 5-min percentage quote spreads of index futures in a trading day. OVol and FVol are the logarithmic monthly trading volumes in the option and futures markets, respectively. r_f denotes the risk-free interest rate. T is a time trend. ***, **, and * indicate that the t-values are significant at the 1%, 5%, and 10% levels, respectively.

Table 4
Pairwise Granger causality tests between misreaction and dynamics of the futures market.

Panel C: Pairwise Granger causality tests between misreaction and dynamics of futures market				
(i/j)	FR	FV	FLIq	MReAct
FR	–	RejectH_0 (0.06)*	Not rejectH_0 (0.29)	Not rejectH_0 (0.26)
FV	Not rejectH_0 (0.12)	–	RejectH_0 (0.00)***	RejectH_0 (0.05)*
FLIq	Not rejectH_0 (0.26)	Not rejectH_0 (0.18)	–	Not rejectH_0 (0.28)**
MReAct	Not rejectH_0 (0.22)	RejectH_0 (0.00)***	RejectH_0 (0.00)***	–

Note: This table presents the pairwise Granger causality tests between misreaction and dynamics of the futures market (including futures return (FR), volatility (FV), and liquidity (FLiq)). The null hypothesis (H_0) is that the *i*th row variable does not Granger-cause the *j*th column variable. We test whether the lagged coefficients of i are jointly zero when j is the dependent variable in VAR. The results are reported in Table 4, where the *p* value of the corresponding cell is presented in parentheses. FR, FV, and FLiq indicate the return, volatility, and liquidity in the futures market, respectively. MReAct is a misreaction. ***, **, and * indicate that the *p* values are significant at the 0.01, 0.05, and 0.10 levels, respectively.

market makers, the delta- and gamma-hedging positions of market makers, and the relative ratio of the delta- and gamma-hedging positions to futures open interest. We individually re-examine the hedging pressure effect for each measure and report the results in Panels A, B, and C of Table 7.

Table 5
Effect of misreaction on hedging pressure of market makers.

Panel A: Effect of misreaction on market makers' hedging pressure

	$OHgPn_t$		$OHgPn_t$		$OHgPn_t$	
	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
α	45.27	0.58	48.00	0.62	47.34	0.60
$MReAct_{t-1}$	5.54***	3.08	4.17**	2.19	5.81***	2.90
DSL_{t-1}*$MReAct_{t-1}$	–	–	7.81**	2.20	–	–
DSV_{t-1}*$MReAct_{t-1}$	–	–	–	–	1.79**	2.04
$OVol_{t-1}$	−11.53*	−1.85	−10.35*	−1.67	−12.14*	−1.91
$FVol_{t-1}$	9.09*	1.65	7.71	1.39	9.64*	1.66
r_f	623.44	1.55	574.09	1.40	605.25	1.50
T	−6.44	−0.93	−10.10	−1.42	−7.23	−1.00
$AdjR^2$ (%)	–	8.35	–	10.61	–	8.48

Panel B: Pairwise Granger causality tests (The null hypothesis (H_0) is that row variable does not Granger-cause column variable.)

(i/j)	MReAct	OHgPn
MReAct	–	Reject H_0 (0.00)***
OHgPn	Not reject H_0 (0.22)	–

Note: This table presents the regression results for the effect of misreaction (MReAct) on market makers' hedging pressure (OHgPn) and pairwise Granger causality tests. We incorporate an interaction term of lagged OHgPn and a dummy variable for the low-liquidity option market during market pessimism periods (DSL) or a dummy variable for the higher-volatility option market during market pessimism periods (DSV) into the regression and control for the lagged trading volumes of option and futures markets (OVol and FVol), risk-free interest rate (r_f), and a time trend (T). The results are reported in Panel A. OHgPn is the hedged position of market makers in the futures market and is calculated as the negative cumulative daily delta-hedged position of options over a month. DSL_t is a dummy variable captured for the low-liquidity option market during market pessimism periods at time t; it equals 1 for both PCR and OLiq at time t over 50% of its time series and 0 otherwise. DSV_t is a dummy variable captured for the higher-volatility option market during market pessimism periods at time t; it equals 1 for both PCR and IV at time t over 50% of its time series and 0 otherwise. IV indicates the market volatility in the option market. MReAct is a misreaction. ***, **, and * indicate that the t-values are significant at the 1%, 5%, and 10% levels, respectively. Panel B reports the pairwise Granger causality tests between misreaction and market makers' hedging demand pressure. The null hypothesis (H_0) is that the *i*th row variable does not Granger-cause the *j*th column variable. We test whether the lagged coefficients of i are jointly zero when j is the dependent variable in VAR. The cell with the *i*th row variable and the *j*th column variable shows the p-value in parentheses associated with this test. ***, **, and * indicate that the *p*-values are significant at the 0.01, 0.05, and 0.10 levels, respectively.

As shown in Table 7, regardless of whether OHgPn is measured by gamma-hedging positions, delta- and gamma-hedging positions, or the relative ratio of delta- and gamma-hedging positions to futures open interest, we still find that high hedging pressure leads to higher subsequent volatility and illiquidity in the futures market when market sentiment is pessimistic. For instance, this result is evident from the significantly positive coefficients of lagged DS*OHgPn for FV and FLiq, with t-values of 1.91 and 1.77 (2.01 and 1.91), respectively, when OHgPn is measured by the delta- and gamma-hedging positions (the gamma-hedging positions). In conclusion, our results provide compelling evidence that hedging pressure contributes significantly to understanding the dynamics of the futures market.

In addition, we study the hedging pressure effect by option moneyness and present the results for ITM, ATM, and OTM options in Panels A, B, and C of Table 8, respectively.

In Table 8, we find significant coefficients of DS*OHgPn for FV and FLiq when using ITM and OTM options to calculate OHgPn, but insignificant coefficients when using ATM options. These results suggest that the hedging pressure effect on FLiq and FV varies with option moneyness. Specifically, the hedging pressure stemming from ITM and OTM options has a greater impact on futures volatility and liquidity than that from ATM options. Positive coefficients of DS*OHgPn with t-values of 4.67 and 3.36 (2.42 and 1.84) in Panels A and C, respectively, demonstrate the significant ITM and OTM hedging pressure effects on FLiq (FV). This difference in effect can be attributed to the liquidity of the options; ATM options are more liquid than ITM and OTM options (Jameson and Wilhelm, 1992; George and Longstaff, 1993; Kamara and Miller, 1995); thus, they have a lower hedging pressure effect on the futures market because market makers, who take mispriced ATM options, can quickly and easily offload their positions. In conclusion, the liquidity of options plays a key role in shaping the hedging pressure effect on the futures market, with less liquid options resulting in a greater hedging pressure effect.

4.4. Robustness tests

To confirm our findings on the impact of misreaction on the futures market, we conduct three types of empirical exercises in our robustness tests. First, we use an alternative measure of sentiment, the Baker and Wurgler (2006) composite sentiment index (BW6), to

Table 6
Hedging pressure effect on the futures market.

Panel A: Hedging pressure effect on dynamics of futures market

	FR_t		FV_t		$FLiq_t$	
	Coeff.		t-stat.		Coeff.	
α	0.86***	3.14	−0.65	−1.37	0.01	1.25
$OHgPn_{t-1}$	−1.E-03	−1.05	−1.E-03***	−2.94	−2.E-05***	−3.23
DS_{t-1}*$OHgPn_{t-1}$	2.E-04	0.31	1.E-03*	1.91	4.E-05*	1.76
$OVol_{t-1}$	−0.05**	−2.43	−0.11**	−2.07	−2.E-03***	−3.01
$FVol_{t-1}$	3.E-04	0.02	0.17***	4.15	2.E-03***	3.36
r_f	−6.06***	−2.80	14.48***	2.82	0.20***	3.02
T	−0.07**	−2.11	−0.22***	−3.04	−0.01***	−6.79
$AdjR^2$ (%)	–	25.27	–	39.59	–	66.09

Panel B: Pairwise Granger causality tests between hedging pressure and dynamics of futures market

(i/j)	FR	FV	FLIq	OHgPn
FR	–	RejectH_0 (0.00) ***	Not rejectH_0 (0.56)	Not rejectH_0 (0.26)
FV	Not rejectH_0 (0.11)	–	RejectH_0 (0.00)***	RejectH_0 (0.07)*
FLIq	Not rejectH_0 (0.35)	Not rejectH_0 (0.25)	–	Not rejectH_0 (0.28)
OHgPn	Not rejectH_0 (0.15)	RejectH_0 (0.06)*	RejectH_0 (0.04)**	–

Note: This table presents the regression results for the effect of the hedging pressure of market makers (OHgPn) on subsequent futures return, volatility, and liquidity and the pairwise Granger causality tests. The regression controls for the lagged trading volumes of option and futures markets (OVol and FVol), the risk-free interest rate (r_f), and a time trend (T). Additionally, we include the product of lagged hedging pressure of market makers and a dummy variable for higher pessimistic sentiment (DS) in the regression and control for the lagged trading volumes of option and futures markets (OVol and FVol), the risk-free interest rate (r_f), and the time trend (T). The results are reported in Panel A. DS_t is a pessimistic sentiment dummy variable at time t; it equals 1 for PCR at time t over 75% of its time series and 0 otherwise. MReAct denotes investor misreaction. ***, **, and * indicate that the t-values are significant at the 1%, 5%, and 10% levels, respectively. Panel B reports the pairwise Granger causality tests between market makers' hedging pressure, futures return, volatility, and liquidity. The null hypothesis (H_0) is that the *i*th row variable does not Granger-cause the *j*th column variable. We test whether the lagged coefficients of i are jointly zero when j is the dependent variable in VAR. The cell with the *i*th row variable and the *j*th column variable shows the p value in parentheses associated with this test. ***, **, and * indicate that the *p* values are significant at the 0.01, 0.05, and 0.10 levels, respectively.

Table 7
Alternative measure of hedging pressure by delta- and gamma-hedging positions.

	FR_t		FV_t		$FLiq_t$	
	Coeff.		t-stat.		Coeff.	
Panel A: Hedging pressure induced by the gamma-hedging positions						
$OHgPn_{t-1}$	0.01	0.29	−0.11	−1.18	−4.E-04	−0.31
DS_{t-1}*$OHgPn_{t-1}$	0.13	1.34	0.19**	2.01	6.E-03*	1.91
$AdjR^2$(%)	–	21.00	–	37.62	–	64.15
Panel B: Hedging pressure induced by the delta- and gamma-hedging positions						
$OHgPn_{t-1}$	-1E-03	−3.05	−1.E-03***	−2.94	−2.E-05***	−3.24
DS_{t-1}*$OHgPn_{t-1}$	2E-04	0.32	1.E-03*	1.91	4.E-05*	1.77
$AdjR^2$(%)	–	25.27	–	39.61	–	66.11
Panel C: Hedging pressure calculated as the delta- and gamma-hedging positions divided by the futures open interest						
$OHgPn_{t-1}$	−0.06	−3.07	−0.07**	−2.54	−1.E-03***	−2.78
DS_{t-1}*$OHgPn_{t-1}$	0.03	0.55	0.08*	1.78	3.E-03*	1.73
$AdjR^2$(%)	–	25.63	–	38.95	–	65.76

Note: This table presents the results for the effect of hedging pressure of market makers (OHgPn) on subsequent futures volatility (FV), liquidity (FLiq), and returns (FR). To obtain the hedged positions of market makers in the futures market, OHgPn is separately calculated as the negative cumulative daily gamma-hedging positions and the negative cumulative daily delta- and gamma-hedging positions. Additionally, we calculate OHgPn as the delta- and gamma-hedging positions divided by the open interest of futures over a month. The results are reported in Panels A, B, and C, respectively. DS_t is a pessimistic sentiment dummy variable at time t; it equals 1 for PCR at time t over 75% of its time series and 0 otherwise. MReAct denotes investor misreaction. To save space, we report only the coefficients associated with the coefficients OHgPn and DS*OHgPn. ***, **, and * indicate that the t-values are significant at the 1%, 5%, and 10% levels, respectively.

Table 8
Hedging pressure effect by option moneyness.

	FR_t		FV_t		$FLiq_t$	
	Coeff.		t-stat.		Coeff.	
Panel A: Hedging pressure calculated from ITM options						
$OHgPn_{t-1}$	−1.E-03	−0.77	8.E-04	0.54	−9.E-06	−0.39
DS_{t-1}*$OHgPn_{t-1}$	4.E-03**	1.34	4.E-03**	2.42	1.E-04***	4.67
$AdjR^2$(%)	–	22.41	–	38.25	–	65.02
Panel B: Hedging pressure calculated from ATM options						
$OHgPn_{t-1}$	−1.E-03**	−2.40	−2.E-03***	−2.68	−3.E-05***	−2.97
DS_{t-1}*$OHgPn_{t-1}$	−7.E-04	−1.24	4.E-04	1.34	7.E-06	1.41
AdjR2 (%)	–	24.82	–	40.39	–	65.66
Panel C: Hedging pressure calculated from OTM options						
$OHgPn_{t-1}$	−3.E-03**	−2.26	−3.E-03**	−2.09	−6.E-05**	−2.18
DS_{t-1}*$OHgPn_{t-1}$	−4.E-03	−1.58	7.E-03*	1.84	2.E-04***	3.36
$AdjR^2$(%)	–	24.66	–	38.76	–	65.32

Note: This table presents the regression results for the effect of the hedging pressure of market makers (OHgPn) by option moneyness on subsequent futures volatility (FV), liquidity (FLiq), and return (FR). We include an interaction term of lagged OHgPn and a sentiment dummy variable (DS) in the regression and control for the lagged trading volumes of option and futures markets (OVol and FVol), the risk-free interest rate (r_f), and a time trend (T). The results for the hedging pressures of market makers abstracted from ITM, ITM, and OTM options are reported in Panels A, B, and C, respectively. DS_t is a pessimistic sentiment dummy variable at time t; it equals 1 for PCR at time t over 75% of its time series and 0 otherwise. MReAct denotes investor misreaction. To save space, we report only the coefficients associated with the coefficients of OHgPn and DS*OHgPn. ***, **, and * indicate that the t-values are significant at the 1%, 5%, and 10% levels, respectively.

explore the impact of sentiment-driven misreactions on the futures market. Second, we employ a VAR regression model to investigate the effect of misreaction on the futures market. Finally, we exclude three catastrophic events from the sample to examine the misreaction-driven cross-market effect. The tests are conducted as follows. However, the results for the sentiment-induced misreaction effect on the futures market remain unchanged.

A. **The effect of sentiment-induced misreaction by using an alternative measure of sentiment**

We adopt an alternative measure of sentiment known as the Baker and Wurgler (2006) composite sentiment index (BW6) to investigate the influence of misreaction on the futures market during the pessimistic period. Following Baker and Wurgler (2006), we form a composite sentiment index with six measures of investor sentiment, including the net purchases of mutual funds, the share turnover of the stock market, the number of initial public offerings, the average first-day returns of initial public offerings, the equity share in new issues, and the dividend premium. The BW6 is constructed by the first principal component of the six orthogonalized sentiment proxies. Then, we examine the effect of sentiment-induced misreaction on subsequent futures return (FR), volatility (FV), and liquidity (FLiq) by using Eq. (5), in which DS_t is a pessimistic sentiment dummy variable that is equal to 1 for BW6 at time t over 75% of its time series and 0 otherwise. The results are presented in Table 9.

The results, represented in Table 9, again confirm that sentiment-driven misreaction leads to subsequent increases in futures market volatility and illiquidity.

Table 9
Misreaction effect on the futures market by using an alternative measure of sentiment.

	FR_t		FV_t		$FLiq_t$	
	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
$MReAct_{t-1}$	−2.E-03	−0.11	−0.10***	−3.86	−1.E-03***	−4.47
DS_{t-1}*$MReAct_{t-1}$	−5.E-04	−0.03	0.11**	2.23	2.E-03***	3.05
$AdjR^2$ (%)	–	20.30	–	48.56	–	67.00

This table presents the regression results for the effect of misreaction (MReAct) on subsequent futures return (FR), volatility (FV), and liquidity (FLiq) by using an alternative measure of sentiment. We follow Baker and Wurgler (2006) to construct a composite sentiment index (BW6) with six measures of investor sentiment, including the net purchases of mutual funds, the share turnover of the stock market, the number of initial public offerings, the average first-day returns of initial public offerings, the equity share in new issues, and the dividend premium. The BW6 is constructed by the first principal component of the six orthogonalized sentiment proxies. Additionally, we include an interaction term of lagged MReAct and a sentiment dummy variable (DS) to capture the misreaction effect during periods of higher pessimism by controlling for the lagged trading volumes of option and futures markets (OVol and FVol), the risk-free interest rate (r_f), and a time trend (T). DS_t is a pessimistic sentiment dummy variable at time t; it equals 1 for PCR at time t over 75% of its time series and 0 otherwise. MReAct is a misreaction. To save space, we report only the coefficients associated with the coefficients of MReAct and DS*MReAct. ***, **, and * indicate that the t-values are significant at the 1%, 5%, and 10% levels, respectively.

Table 10
Robustness results.

Dependent variable	FR_t		FV_t		$FLiq_t$		$MReAct_t$	
	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
Panel A: Misreaction effect on dynamics of futures market by using the VAR model								
α	0.55**	2.08	0.11	0.35	0.02***	4.18	0.02	0.01
FR_{t-1}	0.10	1.13	−0.23**	−2.18	−9.E-04	−0.63	1.17	1.20
FV_{t-1}	0.13*	1.73	0.56***	6.63	0.01***	7.42	1.46*	1.89
$FLiq_{t-1}$	3.11	0.51	7.85	1.11	0.11	1.20	−97.83	−1.51
$MReAct_{t-1}$	2.E-03	0.28	−0.04***	−3.72	−2.E-04*	−1.91	−0.04	−0.48
DS_{t-1}*$MReAct_{t-1}$	−0.01	−0.60	0.04*	1.94	5.E-04*	1.88	2.E-03	0.01
$OVol_{t-1}$	−1.E-03	−0.06	−3.E-03	−0.09	−9.E-04**	−2.40	−0.11	−0.41
$FVol_{t-1}$	−0.03	−1.21	−1.E-03	−0.04	7.E-06	0.02	0.21	0.72
r_f	−8.60***	−5.39	2.76	1.50	0.06***	2.59	−48.13***	−2.86
T	0.01	0.14	−0.03	−0.55	−4.E-03***	−5.06	−1.34**	−2.54
$AdjR^2$ (%)	–	23.86	–	71.24	–	82.92	–	9.59
Panel B: Misreaction effect excluding the sample from the 2008 financial crisis period								
$MReAct_{t-1}$	2.E-03	0.19	−0.04***	−3.77	−3.E-04**	−1.97	−0.13	−1.49
DS_{t-1}*$MReAct_{t-1}$	−0.01	−0.68	0.04*	1.89	5.E-04*	1.69	1.E-03	0.01
$AdjR^2$ (%)	–	24.39	–	71.86	–	82.81	–	9.69
Panel C: Misreaction effect excluding the sample from the 2010 European debt crisis period								
$MReAct_{t-1}$	0.00	0.19	−0.03***	−3.38	−2.E-04*	−1.84	−0.06	−0.66
DS_{t-1}*$MReAct_{t-1}$	−0.02	−0.99	0.04**	1.96	6.E-04*	1.83	0.18	0.84
$AdjR^2$ (%)	–	28.10	–	73.04	–	81.06	–	6.75
Panel D: Misreaction effect excluding the sample from the 2020 COVID-19 pandemic period								
$MReAct_{t-1}$	0.01	0.62	−0.03***	−2.63	−2.E-04**	−2.25	0.05	0.58
DS_{t-1}*$MReAct_{t-1}$	−0.02	−0.94	0.04**	1.98	7.E-04**	2.19	0.02	0.13
$AdjR^2$ (%)	–	25.16	–	73.52	–	83.51	–	18.20
Panel E: Misreaction effect excluding the sample from the period of these three financial crises								
$MReAct_{t-1}$	6.E-04	0.05	−0.03**	−2.31	−2.E-04*	−1.89	−0.12	−1.33
DS_{t-1}*$MReAct_{t-1}$	−0.02	−1.09	0.05*	1.95	7.E-04**	2.04	0.05	0.28
$AdjR^2$ (%)	–	33.55	–	76.29	–	83.28	–	33.79

Note: This table represents the VAR regression results. Panel A reports the results for the effect of misreaction (MReAct) on subsequent futures return (FR), volatility (FV), and liquidity (FLiq). To explore the misreaction effect during periods of higher pessimism, we include an interaction term of DS_{t-1}*$MReAct_{t-1}$ in the regression and control for the lagged trading volumes of option and futures markets (OVol and FVol), the risk-free interest rate (r_f), and a time trend (T). DS indicates a dummy variable for pessimistic sentiment. Panels B, C, D, and E report the regression results for the effect of misreaction on dynamics of the futures market, excluding the sample from the periods of the 2008 financial crisis, the 2010 European debt crisis, and the 2020 COVID-19 pandemic, and consider these crises separately. To save space, Panels A, B, C, D, and E report only the coefficients associated with MReAct and DS*MReAct, respectively. ***, **, and * indicate that the t-values are significant at the 1%, 5%, and 10% levels, respectively.

B. The misreaction effect determined by using a VAR regression model

We employ a VAR model that offers a more comprehensive and complex representation of the relationship between misreaction, futures return, volatility, and liquidity. This allowed us to examine the cross-market effect in greater detail. Our analysis, detailed in Eq. (8), examines the impact of misreaction on the following futures return, volatility, and liquidity while controlling for lagged OVol and FVol, as well as r_f and T. The VAR(1) model is used to capture the misreaction effect because interactions among FR, FV, and FLiq are likely to occur simultaneously (Hausman, 1978; Wang and Yau, 2000) and because sentiment-induced misreaction in price is temporary (Brown and Cliff, 2005; Baker and Wurgler, 2006; Chang et al., 2015). The VAR regression model is represented as follows:

$$\begin{bmatrix} FR_t \\ FV_t \\ FLiq_t \\ MReAct_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & \beta_{14} \\ \beta_{21} & \beta_{22} & \beta_{23} & \beta_{24} \\ \beta_{31} & \beta_{32} & \beta_{33} & \beta_{34} \\ \beta_{41} & \beta_{42} & \beta_{43} & \beta_{44} \end{bmatrix} \begin{bmatrix} FR_{t-1} \\ FV_{t-1} \\ FLiq_{t-1} \\ MReAct_{t-1} \end{bmatrix} + \begin{bmatrix} \beta_{51} \\ \beta_{52} \\ \beta_{53} \\ \beta_{54} \end{bmatrix} OVol_{t-1} + \begin{bmatrix} \beta_{61} \\ \beta_{62} \\ \beta_{63} \\ \beta_{64} \end{bmatrix} FVol_{t-1} + \begin{bmatrix} \beta_{71} \\ \beta_{72} \\ \beta_{73} \\ \beta_{74} \end{bmatrix} r_f + \begin{bmatrix} \beta_{81} \\ \beta_{82} \\ \beta_{83} \\ \beta_{84} \end{bmatrix} T + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix} \quad (8)$$

in which MReAct represents option investor misreaction. FR, FV, and FLiq represent the monthly futures market return, realized volatility, and liquidity, respectively. OVol and FVol are the logarithmic monthly trading volumes in the option and futures markets, respectively. r_f denotes the risk-free interest rate. T is a time trend.

The findings presented in Panel A of Table 10 indicate that misreaction still causes significantly higher volatility and illiquidity in the futures market when the market is pessimistic, i.e., DS = 1. This is evident from the significantly positive coefficients of lagged DS* MReAct for the dependent variables FV and FLiq. Our study also supports sentiment spillover from the option market to the futures market. The transmitted sentiment implicit in MReAct could increase volatility and illiquidity in the futures market.

C. Exclusion of the 2008 financial crisis from the sample

Financial crises often cause significant declines in market prices, which can exacerbate investors' fears and lead to misreaction to information shocks. As a result, market illiquidity can arise, as demonstrated by studies such as Amihud et al. (1990), Chordia et al. (2001), Hameed et al. (2010), and Rösch and Kaserer (2013). However, financial crises also affect the option market, creating higher levels of illiquidity that make it challenging for market makers to unload their option positions and increase their hedging pressure. This higher hedging pressure can exacerbate the misreaction effect on the futures market.

The sample period covered in our empirical study includes significant price fluctuations related to events like the 2008 financial crisis, the European debt crisis, and the COVID-19 pandemic. These catastrophic events may impact investors' behavior and sentiment, potentially leading to a more pronounced misreaction effect. To substantiate that this misreaction effect on the futures market is a general result rather than a special case, we conduct further analysis using Eq. (8). Specifically, we exclude data from the sample periods of the 2008 financial crisis, the 2010 European debt crisis, and the 2020 COVID-19 pandemic, and consider these crises separately. The results, respectively presented in Panels B, C, D, and E of Table 10, show a significant positive coefficient for DS* MReAct in both FV and FLiq. This suggests that sentiment-induced misreaction consistently influences future volatility and liquidity in the futures market, regardless of catastrophic market events.

5. Conclusion

We investigate the impact of misreaction on subsequent return, volatility, and liquidity in the Taiwan index futures market through hedging pressure for option market makers. Using the forecast error of forward volatility, which is abstracted from index option prices, as a proxy for misreaction and based on intraday data for stock index futures and index options spanning more than ten years, we derive important results summarized as follows.

First, when market sentiment is pessimistic, there is an increased misreaction implicit in option prices, consistent with the findings of De Long et al. (1990) and Chang et al. (2015). Second, an increase in misreaction creates subsequent hedging pressure for market makers due to the resulting increased volatility and illiquidity in the option market, both of which are driven by pessimism. The increased hedging pressure of market makers then leads to greater volatility and poorer liquidity in the futures market when the market is pessimistic. The results are supported by Granger causality tests indicating a causal effect of hedging pressure on the futures market. Finally, our results demonstrate that a sentiment-induced misreaction can lead to higher volatility and illiquidity in the futures market. This effect can be attributed to the hedging activity of option market makers.

In addition, we conduct three robustness tests, including measuring sentiment using the Baker and Wurgler (2006) composite sentiment index and the VAR regression model and excluding data from periods of three catastrophic events. All the results confirm that the misreaction effect driven by investor pessimistic sentiment has an impact on the futures market, leading to subsequent higher volatility and illiquidity.

However, our study documents that sentiment-induced misreaction generates a cross-market effect. Further research could expand on our results by investigating the effect of misreaction on various types of futures markets and examining how it varies across markets. Such research enables a deeper understanding of the influence of misreaction on derivatives markets, which could help market regulators and participants in developing effective policies.

CRediT authorship contribution statement

Chin-Ho Chen: Writing – original draft, Validation, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Shu-Fang Yuan:** Writing – original draft, Resources, Project administration, Investigation, Formal analysis.

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