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# Japanese monetary policy and its impact on stock market implied volatility during pleasant and unpleasant weather

Marinela Adriana FINTA
*Singapore Management University*, mfinta@smu.edu.sg

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Marinela Adriana Finta*

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* Corresponding author: Marinela Adriana Finta, Department of Accountancy and Finance, Otago Business School, Po Box 56, 9054 Dunedin, New Zealand, Phone: +64 3479 5299; Sim Kee Boon Institute for Financial Economics, Lee Kong Chian School of Business, Singapore Management University, 50 Stamford Road, 178899 Singapore. Emails: mfinta@smu.edu.sg, marinela.finta@otago.ac.nz, marinela.finta@gmail.com.

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## Abstract

We investigate the effect of Japan's Monetary Policy Meeting releases on the intraday dynamics of the Nikkei Stock Average Volatility Index and its futures during pleasant and unpleasant weather. We show that at the time of a monetary policy release when the temperature is pleasant, there is a significant decline in Japanese equities' implied volatility and futures, which lasts for about 10 minutes and 5 minutes, respectively. This decline is longer and exhibits a greater variation when releases occur during cold days. Finally, we emphasize the achievable economic profits and losses, given the reaction of Nikkei VI futures to the Japanese monetary policy releases during pleasant and unpleasant weather days, respectively. In particular, taking a short position at the start of the trading day on pleasant days and closing this position at the end of the trading day generates an average annual return of 5.6%.



*Keywords*: Nikkei 225 VI, Nikkei 225 VI Futures, MPM Release, Intraday Data, Unpleasant Weather

JEL Codes: G13

# 1. Introduction

Monetary policy announcements are of considerable relevance for stock markets. These announcements provide information about the future state of the economy and affect the cash flows of firms and risk-adjusted discount rates, which influence stock markets (Hussain, 2011; Marshall et al., 2012). Their assessment also has a high bearing on market efficiency, market participants' macro-beliefs, and consensus expectations (Maghrebi, 2008). The empirical evidence documents that monetary policy decisions have led to an increase in the volatility of stock markets and a decrease in their implied volatility (Ederington and Lee, 1993, 1996; Bomfim, 2003; Farka, 2009; Hussain et al., 2011; Lucca and Moench, 2015). As such, these announcements contain relevant information on the values of financial assets, and therefore influence the valuation of these assets and cause an increase in their volatility (Nikkinen and Sahlstrom, 2004).

Beyond the above effects, the announcements' release mitigates the uncertainty associated with them, creating a decrease in implied volatility. This reaction is because implied volatility is an ex-ante rather than an ex-post measure of volatility, reflecting market participants' views of future uncertainty (Marshall et al., 2012; Nikkinen and Vahamaa, 2009). Nevertheless, market participants exhibit various moods and beliefs, and thus the degree of uncertainty mitigation may be influenced by them. According to psychological studies, individuals' affective states may subconsciously influence the risk-based decisions and lead to mood-congruent biases in them (Cunningham, 1979; Schwarz and Clore, 1983).[1] Therefore, factors not necessarily associated with the market information, such as the weather, can affect investors' behavior due to the influence on mood, which affects their trading decisions (Bodoh-Creed, 2013; Kamstra et al., 2014). For instance, as sunshine can induce positive affective states, investors may associate it with a positive market assessment. Indeed, the behavioral finance literature confirms these statements and shows that weather as a proxy for investors' mood affects stock markets. For instance, Hirshleifer and Shumway (2003) document a positive relationship between sunny days taken as a proxy for investors' positive mood and stock returns. Kamstra et al. (2003) find that investors are more risk-tolerant during the spring months, and, in an experimental setting, Bassi et al. (2013) confirm this result. Accordingly, the question is: Can monetary policy

[1] See the study of Keller et al. (2005) which provides a review of the psychological literature on the relationship between weather to mood.

announcements properly alleviate market participants' expectations of future uncertainty when occurring during both pleasant and unpleasant weather?

In this paper, we aim to assess the effects of Japanese monetary policy decisions' release occurring during both pleasant and unpleasant weather on the intraday dynamics of the Nikkei Stock Average Volatility Index (Nikkei 225 VI) and its futures contracts. The Japanese Policy Board, consisting of the governor, two deputy governors, and six members, takes the monetary policy decisions during each of their Monetary Policy Meetings (MPMs). The meetings are held fourteen times a year, with a double meeting in April and October, and are an essential source of public information.[2] Specifically, these meetings provide information on the Bank of Japan's views on economic and financial developments and affect stock prices and volatilities' daily dynamics. Therefore, the announcements might also quickly affect the market participant's expectations about future volatility within minutes after their release. Their effects may also be different during days when investors have different moods due to weather. Consequently, this study posits that the impacts of announcements' release on intraday stock market implied volatility might differ depending on investors' mood, namely if they are in a pleasant or unpleasant mood. Thus, Japanese investors may trade and incorporate news announcements based on their mood. For instance, if the MPMs occur on pleasant days and thus when investors experience a good mood, we expect that the resolution of uncertainty associated with these announcements is short-lived. Instead, we posit that investors may require more time to process and react to the unpleasant days' announcements given their mood, and hence, the resolution of uncertainty may last longer. Following Addoum et al. (2019) and Schlenker and Roberts (2009), we compute the exposure (in degree days) to temperatures above 25°C and below 5°C in Tokyo, where the MPMs are held.[3] We then use these measures to create two dummy variables equal to one during these exposure days and zero otherwise, as proxies for the unpleasant hot and cold weather. The pleasant weather variable captures the temperature exposure during the remaining days, namely, it is equal to one when the exposure to the temperatures above and below is zero, and otherwise is zero.

[2] The Bank of Japan changed the release of the Monetary Policy in 2016, and the meeting is now held eight times a year, each time for two days, https://marketnews.com/content/boj-releases-monetary-policy-meeting-schedule-2016.

[3] Note that Addoum et al. (2019) define the extreme hot and cold temperature days as those days with temperatures above 30°C and below 0°C in the U.S. Our study uses a different benchmark for the unpleasant temperatures, as during a year, in Tokyo there are not many days when the temperature exceeds 30°C or is under 0°C. Nevertheless, as proxies for the unpleasant hot and cold days, and thus also in defining the pleasant temperature days, we control for other benchmarks as well. In particular, our results are consistent for the unpleasant and pleasant weather measures when considering the exposure to temperatures above 22°C, 23°C, 25°C and 27°C and below 3°C. These findings are available on request.

Our examination yields several significant findings. First, we document a decrease in Japanese equity implied volatility and its futures contracts. Additionally, this drop is stronger for the first than for the second near-term Nikkei VI futures contract and lasts longer during cold than during pleasant weather days. Second, we show that this decline lasts for about 10 and 5 minutes on pleasant weather days in Nikkei VI and the first near-term Nikkei VI futures contract, respectively, and exhibits the least variation. Finally, we highlight the possible economic profits, given the reaction of Nikkei VI futures to the Japanese monetary policy releases during pleasant weather. By taking a short position at the start of the trading day and closing it at the end of the trading day, this would generate an average return of 40 basis points per day (or 5.6% per year based on 14 MPM release days per year). Note that during either hot or cold unpleasant temperature days, an investor would not be able to achieve economic profits but instead would experience large and significant losses. Overall, our findings show that investors can exploit the announcements and achieve profitable trading strategies when their release is during pleasant days. Thus, when they are in a better mood. This evidence implies that the release of monetary policy announcements when investors are in a pleasant mood is more effective and contains more relevant information that they can exploit than the release on unpleasant days.

In Appendices A.1–A.5, we show the reaction of Japanese equity implied volatility and its futures contracts around the MPM releases without distinguishing between the pleasant and unpleasant weather effects. Generally, these empirical findings are in line with the results focusing on pleasant temperature days. Given that the Nikkei Stock Average Volatility Index computation relies on the prices of Nikkei 225 futures and Nikkei 225 options on the Osaka Exchange, as robustness, we also use the temperature in Osaka. The results from Appendices A.6–A.7 once again confirm that MPM announcements occurring during the pleasant days are those that considerably matter.

Our paper relates to four streams of literature. First, by taking into account investors' mood, we add to the many studies exploring the effects of monetary policy decisions on the stock market returns and the realized and implied volatility, especially in the U.S. (Ederington and Lee, 1996; Nikkinen and Sahlstrom, 2004; Clements, 2007; Lunde and Zebedee, 2009; Vahamaa and Aijo, 2011; Fernandez- Perez et al., 2017; Lucca and Moench, 2015).[4] For instance, Lunde and Zebedee (2009) and Fernandez-Perez et al. (2017) document an increase in the U.S. stock market's intraday

[4] See also the study of Hussain et al. (2011) who examine the impacts of monetary policy announcements from the European Central Bank, Bank of England, Swiss National Bank and Federal Open Market Committee on the European (France, Germany, Switzerland and the U.K.) and U.S. stock market returns and volatilities. The authors show that monetary policy announcements affect the intraday returns and volatility, but their impacts fade away within 5 to 10 minutes after announcements.

volatility following the Federal Open Market Committee (FOMC) announcements which only dissipates within 15 minutes after them. Lucca and Moench (2015) find that while in the hours before the FOMC announcements, the realized volatility is low, at the time of announcements, there is an increase in volatility. Their results show a positive pre-FOMC announcement drift in the S&P 500 index when the equity implied volatility (VIX index) is high. Concerning the impacts of these announcements on the market's expectation about future volatility, Vahamaa and Aijo (2011) observe a decrease in VIX daily after the FOMC meetings (Nikkinen and Sahlstrom, 2004; Clements, 2007). Moreover, the authors emphasize that scheduled announcements have stronger impacts than those unscheduled, given that these are already well known in advance. Furthermore, using high-frequency data, Fernandez-Perez et al. (2017) provide evidence of a significant decline in VIX and its futures at the time of the FOMC announcement, which lasts for around 45 minutes. Focusing on the effects of Japanese MPMs (i.e., Monetary Policy Meetings), our study i) confirms the above studies' findings on the short-lived resolution of uncertainty and ii) contributes to them showing that the resolution of uncertainty depends on investors' mood. Specifically, the resolution is faster when the announcements occur on pleasant than unpleasant days, and thus when investors experience a good mood.

Second, our study complements a few studies addressing Japan's monetary policy decisions (Maghrebi, 2008; Shibamoto and Tachibana, 2014; Rogers et al., 2014; Hanisch, 2017). Shibamoto and Tachibana (2014), for example, using daily data between March 2001 and March 2006, explore the impacts of Japanese unconventional monetary policy, namely, "quantitative easing" on the Japanese economy. In line with Hanisch (2017), their findings show that the BoJ monetary policy response mitigates the downward pressure on the real economy generated by the stock market. Maghrebi (2008) finds that while before the MPMs, there is an increase in Japan's equity implied volatility, during and after the MPMs, implied volatility significantly decreases. Further, using daily and intraday data, Rogers et al. (2014) show that in a narrow window (i.e., 15 minutes), Japanese monetary policy has no impact on bond yields and stock prices. Instead, when considering a wider window, i.e., 15 minutes before to 1 hour and 45 minutes after, it has a negative impact.[5] While the above studies mainly use daily data to address Japan's monetary policy, the U.S.'s extant literature shows that as the resolution of uncertainty is short-lived, daily data cannot capture it. Therefore, only by examining the intraday reactions we can i) better

[5] The studies of Nikkinen and Vahamaa (2009) and Marshall et al. (2012) investigate the effects of MPM announcements on the implied volatility of foreign exchanges (e.g., USD/EUR, USD/GBP, USD/CHF, and USD/JPY). Marshall et al. (2012) show that on days when there are U.S. macroeconomic news announcements, foreign exchange implied volatility drops. Instead, on the BoJ announcement days, there is an increase in USD/JPY implied volatility, which then decreases in the days after announcements (Nikkinen and Vahamaa, 2009).

understand whether or not the uncertainty resolution is also present in Japan and ii) provide valuable information for investors. In other words, our study contributes to the existing studies on Japan by first providing a better picture of the effects of monetary policy in Japan at the intraday level, and second, showing that the occurrence of these announcements also matters.

Third, we relate to the behavioral finance literature finding that weather-induced mood affects investor behavior, and in particular, the weather conditions as a determinant of investor attention to news affect market outcomes (Hirshleifer and Shumway, 2003; Kamstra et al., 2003; Hirshleifer et al., 2009; Bassi et al., 2013; Goetzmann and Zhu, 2015; Dehaan et al., 2017; Jiang et al., 2019). For example, using survey and proprietary data, Goetzmann and Zhu (2015) show that institutional investors with lower exposure to sky cloud cover are more optimistic and exhibit an increase in their buy-sell trade imbalances. Dehaan et al. (2017) find that analysts experiencing unpleasant weather are slower at responding to earnings announcements than those experiencing pleasant weather. In addition, Jiang et al. (2019) provide evidence that unpleasant weather reduces institutional investors' trading activity around earnings news, leading to high earnings announcement premiums. In our study, we instead assess whether pleasant and unpleasant temperatures (both hot and cold temperatures) affect the behavior of implied volatility and its futures contracts around the MPM releases.

Finally, by connecting the information flow and behavioral attributes to asset prices, to some extent, our study also relates to the current literature on COVID-19 induced uncertain environment (Phan and Narayan, 2020; Narayan et al., 2020; Haroon and Rizvi, 2020). For instance, Phan and Narayan (2020) show that while during the early stage of the COVID-19 stock markets overreacted to this pandemic, later on, there is a correction of this reaction emphasizing the effectiveness of government's measures and the positive impacts that these had on stock market returns. In line with the investor sentiment hypothesis driving stock markets, Narayan et al. (2020) document that government responses to the COVID-19, such as lockdowns, travel bans, and economic stimulus packages, have positively affected the G7 stock returns. These findings indicate the investors' confidence and trust in government policies and these policies' success in mitigating the pandemic's effects on financial markets. Haroon and Rizvi (2020) observe that a flat curve of COVID-19 cases and deaths is associated with a decrease of uncertainty in equity markets and an improvement of investors' confidence. Other studies show that the pandemic contains valuable information for foreign exchange, oil, and gas markets (Devpura and Narayan, 2020; Iyke, 2020a, 2020b; Mishra et al., 2020; Narayan, 2020; Prabheesh et al., 2020; Vidya and Prabheesh, 2020). In particular, the COVID-19 outbreak explains the increases in oil volatility (Devpura and Narayan, 2020), the return and volatility of U.S. oil and gas firms (Iyke, 2020a). It also predicts oil prices (Narayan, 2020) and exchange rates return and volatility (Iyke, 2020b).[6] While the above studies show that investors' mood is influenced by certain factors associated with the pandemic (e.g., government restrictions, social distancing, and trust in the governments), our paper highlights that besides the unexpected events that affect investors trading behavior, the weather may contain relevant information about their mood and hence, allow us to understand their trading and reaction to MPMs better. Moreover, the advantage of our proxy for investors' mood is that this measure is easily and freely available anytime.

The remainder of the paper is structured as follows. In Section 2, we briefly review the literature. Section 3 presents the data. Section 4 discusses the empirical findings of our analysis, and Section 5 concludes the paper.

## 2. Data and methodology

In this section, we first discuss the intraday data on the Nikkei VI and Nikkei VI futures and, subsequently, the data on the MPM releases. Second, we present the methodology.

### *2.1 Nikkei VI and Nikkei VI Futures*

We use high-frequency data for the Nikkei VI and Nikkei VI futures from the Thomson Reuters Tick History.[7] Following Bailey et al. (2014) and Fernandez-Perez et al. (2017), our data are sampled at a one-minute frequency and cover the period from 04 April 2012 to 20 June 2016.[8] We consider the first and second nearby contracts of Nikkei VI futures[9] and, as in Shu and Zhang (2012), we roll over to the next nearest contract when the current first nearby contract expires. For each of these futures contracts, we then compute the midpoint of the bid and ask quotes which we use in our analysis, given their robustness to microstructure issues. We obtain Tokyo's daily

[6] See also the studies of Prabheesh et al. (2020) and Vidya and Prabheesh (2020) who document that during the COVID-19 pandemic there is a comovement between returns of oil and stock markets (largest Asian net oil-importing countries, China, India, Japan, and South Korea) and reduction in trade interconnectedness.
[7] The Nikkei Stock Average Volatility Index is calculated by using prices of Nikkei 225 futures and Nikkei 225 options on the Osaka Exchange (OSE). In the calculation, taking near-term future price as the basis of ATM, the volatility of the near-term option and the next-term option are calculated with OTM option prices of each delivery month. Then, the index value is calculated by linear interpolation or linear extrapolation between the volatilities of each delivery month to make the time to expiration as 30 days. See http://indexes.nikkei.co.jp/en/nkave/index/profile?idx=nk225vi.
[8] There are several reasons for the choice of our sample period. First, our sample's start coincides with approximately the introduction of the Nikkei Stock Average Volatility Index (Nikkei 225 VI) and Nikkei VI futures. Second, during our sample period, the BoJ holds the MPMs fourteen times a year, whereas, since 2016, these meetings are solely held eight times a year. Accordingly, our analysis provides trustworthy findings by including several announcements occurring in various months with diverse temperatures over a year, capturing investors' diverse moods.
[9] Although there are eight Nikkei VI futures contracts traded every day, the first and second nearby contracts are the most liquid ones; hence, we focus on those two contracts. See more about Nikkei VI futures at http://www.jpx.co.jp/english/derivatives/products/vi/225-vi-futures/01.html.

average, minimum and maximum temperatures from the National Oceanic Atmospheric Administration (NOAA).[10] To compute the degree days above 25°C and degree days below 5°C, we fit a double sine curve passing through the daily minimum and maximum temperatures on the consecutive days from 04 April 2012 to 20 June 2016 (Addoum et al., 2019; Schlenker and Roberts, 2009). Afterward, we define the unpleasant hot and cold measures as dummies equaling one during a particular day when degree days' measures exist and zero otherwise. The pleasant temperature variable equals one when both of the unpleasant measures are zero and zero otherwise.

Table 1 shows summary statistics on the intraday Nikkei VI and Nikkei VI futures for the levels (Panel A) and log differences (Panel B). In Panel A, we observe that Nikkei VI and the second nearby Nikkei VI futures contracts have the highest average. All series display excess kurtosis and have positive skewness. The Augmented Dickey-Fuller statistic rejects the presence of a unit root, indicating that Nikkei VI and Nikkei VI futures are stationary at the 1% level.

INSERT TABLE 1 HERE

Panel B shows the summary statistics for the log differences of the series. We notice that Nikkei VI and Nikkei VI futures have the mean close to zero and the maximum and minimum close to 0.15. The log changes in all our series reveal positive skewness and excess kurtosis, except the second futures contract, which has negative skewness. As in Panel A, they are stationary at the 1% level.

*2.2 MPM Releases*

During our sample period, there are a total of 57 MPM releases.[11] Most of these releases, around 39, occur between 11:30 am and 12:30 pm JST when the Nikkei stock market is closing for lunch. However, we focus on their impact on the Nikkei VI and Nikkei VI futures, which are trading

[10] We acknowledge that the Japanese stock market is open to global investors and domestic temperatures cannot directly influence foreign investors' investment behavior. However, their participation is limited in many sectors. Specifically, for investments of 10% or more in a Japanese company, foreign investors need to obtain approval from regulators (i.e., Bank of Japan). Recently, from 7th May 2020, to protect national security, Japan has tightened the regulation by lowering the threshold to 1% for both issued shares and all investments that are 1% or more of a company's total voting rights.

[11] The announcement dates are a priori known by the market participants, and thus, usually, the announcements are at least in part anticipated by the investors. For instance, the study of Rogers et al. (2014) shows that there are only a few Japanese monetary policy surprises in general, and these have the weakest effects on stock prices and corporate bond yields. Given the limited surprises and the inexistence of a consensus about a proper method to reliably estimate them at an intraday level in an era of unconventional monetary policy, we concentrate our analysis on the MPM's announcement days.

during this period. We obtain the exact minute of the monetary policy announcements from the website of the Bank of Japan.[12]

*2.3 Methodology*

In line with Fernandez-Perez et al. (2017), our study relies on an event-study approach to investigate if the effects of Japanese monetary policy on implied volatility matter and if they differ when conditioning the pleasant and unpleasant weather. We report the differences in performance of the Nikkei VI and its futures contracts on various windows around MPM announcement days versus non-announcement days occurring during pleasant and unpleasant weather. The statistical significance is obtained using the $t$-tests (mean differences) and Wilcoxon rank tests (median differences).

We also explore the relationship between the magnitudes of the implied and realized volatility of the Japanese equity market during all the release days. As most MPM releases occur during the lunch break, i.e., 11:30 am to 12:30 pm, we cannot match the Nikkei 225 index with its implied volatility index. Taking into account this limitation, we use one-minute frequency returns on the Nikkei 225[13] , covering a period of 15 minutes before to 60 minutes after the break. We compute the realized volatility (*R.V.)* as follows:

$$RV = \sqrt{\sum_{t=t_0^{11:30}-15}^{t_0^{12:30}+60} r_t^2}, \tag{1}$$

where $r_t$ are minute-by-minute returns on the Nikkei 225, $t_0^{11:30}$ is 11:30 am and $t_0^{12:30}$ is 12:30 pm. We then conduct the following regression:

$$\Delta\Delta\ Nikkei\ VI_N = \alpha + \beta\ \Delta RV_N + \varepsilon_N\ , \tag{2}$$

where $\Delta\Delta\ Nikkei\ VI_N$ is the difference in the change in the Nikkei VI or any of the Nikkei VI futures contracts during the (-15, +60) window for release days *N* and the average for the days without monetary policy release, and $\Delta RV_N$ is the difference in realized volatility for the release day and the average on days without monetary policy releases, respectively.

[12] The announcements' dates and time of releases are available on request and on the following website: http://www.boj.or.jp/en/mopo/mpmdeci/state_2015/index.htm/.
[13] We obtain intraday data on the Nikkei 225 index from Thomson Reuters Tick History.

## 3. Empirical Findings

In this section, we discuss the empirical findings of our study. We first investigate MPM releases' effect on the intraday dynamics in the Nikkei VI and Nikkei VI futures, distinguishing between the pleasant and unpleasant temperature days. We then examine whether these effects are different around the release days with both unpleasant hot and cold temperatures. Finally, we present the loss and profitability of a trading strategy that exploits the movements in the first and second near-term Nikkei VI futures contracts by focusing on the unpleasant and pleasant temperatures, respectively.

### *3.1 Reaction of the Nikkei VI on MPM Release Days*

Figures 1–3 plot the cumulative log changes on the Nikkei VI on MPM release days versus non-MPM release days with pleasant, unpleasant hot, and unpleasant cold temperatures. We cover the period from April 2012 to June 2016 and consider the interval from 9 am to 3 pm when the Nikkei stock market is open (including the session break between 11:30 am and 12:30 pm JST). We observe that on MPM release days, the Japanese equity implied volatility drops, indicating the uncertainty' resolution of the MPM content (see Fernandez-Perez et al., 2017). Instead, around the MPM releases occurring during the hot temperature days, we observe a small decline. Using daily data, Maghrebi (2008) also documents a decline in Japanese implied volatility. These findings are in line with Ederington and Lee (1996) and Fernandez-Perez et al. (2017), who find a decrease in the daily and intraday VIX following the FOMC announcements. In sum, Figures 1 and 3 clearly show the post-MPM releases' drift in the Japanese implied volatility.

Although previous figures are very intuitive, we are unable to fully appreciate the impact of the drop in Nikkei VI after the MPM release. This is because all the announcements are together, regardless of the precise announcement time. In the next section, we will address this issue.

INSERT FIGURE 1 HERE

INSERT FIGURE 2 HERE

INSERT FIGURE 3 HERE

### *3.2 Reaction of the Nikkei VI and Nikkei VI Futures around the MPM Release Times*

This section further examines the effects of MPM releases on the intraday dynamics in the Nikkei VI and Nikkei VI futures surrounding the MPM release times with pleasant and unpleasant hot and cold temperatures. Using the MPM releases occurring at various times during a trading day, we explore the minute-by-minute movements in Japanese implied volatility and its futures. Our analysis focuses on the 15 minutes before to 60 minutes after the monetary policy release.

Figures 4–6 plot the cumulative change in the Nikkei VI and the first two near-term Nikkei VI futures contracts during days with pleasant, unpleasant hot, and unpleasant cold temperatures. We note that around the MPM release time, there is a robust negative decrease in the Nikkei VI and the two nearby futures contracts. The reaction to the Japanese monetary policy release is stronger in the Nikkei VI, which drops twice as much as the first near-term contract, especially during days with pleasant temperatures. However, during the unpleasant hot and cold release days, the decline in the Nikkei VI first near-term contract is stronger than during pleasant release days. The decline in Japanese implied volatility emphasizes that the MPM announcements reduce the uncertainty associated with them. Moreover, the resolution of the uncertainty occurs faster and lasts longer for the cold than the pleasant temperature days. These figures also show that the nearest-term contract reacts more to the MPM releases than the second near-term Nikkei VI futures contract. The patterns of the Nikkei VI futures contracts suggest that the current resolution in uncertainty less and more affects the longer-term and nearby-term future contracts, respectively (Ederington and Lee, 1996; Fernandez-Perez et al., 2017). The decrease in futures contracts suggests a possible opportunity to set up a profitable trading strategy in them.

INSERT FIGURE 4 HERE

INSERT FIGURE 5 HERE

INSERT FIGURE 6 HERE

We further observe that the decline in the Nikkei VI and the first near-term contract on pleasant temperature days is not instantaneous but lasts for about 10 minutes and 5 minutes, respectively. During these days, the drop in Japanese equity implied volatility is less persistent than the effect of FOMC announcements on VIX. Fernandez-Perez et al. (2017) show that the post-FOMC announcement drift lasts for around 45 minutes. Our finding indicates that the effect of the MPM releases is incorporated faster into the Nikkei VI than the FOMC announcements on VIX. Nevertheless, during the cold release days, we observe slightly more variation in the implied volatility.

We investigate the statistical significance of these negative intraday reactions of Nikkei VI and its futures contracts by considering *t*-tests and Wilcoxon rank tests for the difference in means and medians, respectively. Tables 2–4 report the findings over various windows around the MPM release days with pleasant, unpleasant hot, and unpleasant cold temperatures. Panel A shows the differences in the reaction of Nikkei VI and Nikkei VI futures on MPM release days versus the non-MPM release days from opening (9:30 am) to closure (3 pm) of the market. We note that in all three tables, the Japanese implied volatility and its futures contracts are significantly negatively affected by the MPM release days compared with non-release days.

In Panel B, we consider a window ranging from 15 minutes before to 60 minutes after the MPM release. Once again, our findings highlight the adverse and significant intraday reaction of Nikkei VI and the Nikkei VI futures contracts to the monetary policy releases occurring during pleasant and unpleasant temperature days. We also observe how these statistics are generally more prominent than those of Panel A, indicating that the reaction of the Japanese implied volatility to MPM releases is stronger around the news.

Next, we split the interval from Panel B into the period before (Panel C) and after (Panel D) the MPM release time. The findings show that while the reaction before the monetary policy release is weak, this is significantly stronger post-release. Relying on the *t*-tests, Panel C emphasizes the significant movement in the Nikkei VI before the release and the insignificant reaction in its futures contracts. When examining the Wilcoxon tests, note that there is a significant reaction in the Nikkei VI and its futures contracts. In the hour after the monetary policy release, Panel D shows that Nikkei VI and its futures contracts significantly react to especially pleasant release days according to the *t*-test and Wilcoxon test. Moreover, these reactions are stronger than in Panel C.

Finally, we separate the hour following the MPM release into four quarters and present the findings in Panels E to H. On the whole, our results show that during pleasant weather days, there are significant adverse reactions in the Nikkei VI and the first near-term Nikkei VI contract, which stop after the first 15 minutes, with a small "after-shock" among 30 and 45 and 45 to 60 minutes after the news release, respectively. As shown before, in Figures 4–6, these findings highlight that the first near-term futures contract is more affected by the monetary policy releases than the second nearby futures contract.

INSERT TABLE 2 HERE

INSERT TABLE 3 HERE

INSERT TABLE 4 HERE

As shown in the studies of Lunde and Zebedee (2009), Fernandez-Perez et al. (2017), and Lucca and Moench (2015), among others, the FOMC announcements cause an increase in the realized volatility and a decrease in the implied volatility. In this study, we have also emphasized that the Japanese monetary policy release has led to a drop in the Nikkei VI and its futures contracts. In Appendix A.2, we present the relationship between the magnitudes of the implied and realized volatility of the Japanese equity market. Specifically, the first row of Appendix A.2 shows the estimations for the Nikkei VI and the next two rows for the first and second near-term Nikkei VI futures. As can be seen, the intercepts of Nikkei VI and its futures contracts are negative but only significant for Nikkei VI and the first near-term contract. These findings confirm the earlier ones that showed an adverse reaction in Nikkei VI and its first near-term futures contract on the MPM release days. The coefficient on $\Delta RV_N$ is negative and significant for the Nikkei VI and negative and almost significant for its first near-term futures contract. Therefore, although we cannot match the Nikkei 225 index with its implied volatility index around the MPM releases, we observe how the higher the uncertainty about the MPM announcement, measured by the $\Delta RV_N$, the more significant the drop in the implied volatility.

INSERT APPENDIX A.2 HERE

*3.3 Trading Strategy*

This section examines whether we can exploit the patterns observed in the Nikkei VI futures on MPM announcement dates through a trading strategy, that is, taking a short position 30 minutes after the start of the trading day at 9:30 am by selling futures contracts at the prevailing bid price and closing the position 30 minutes before the end of the trading day at 2:30 pm by offsetting the position at the current ask price. We thus avoid trading at the opening and closure of the market when there are high volatility and wider bid-ask spreads.

INSERT TABLE 5 HERE

INSERT TABLE 6 HERE

INSERT TABLE 7 HERE

In Tables 5–7, we show the findings for the trading strategy on pleasant and unpleasant hot and cold temperature days with MPM releases and days without them for the two near-term Nikkei VI futures contracts. Note that while on non-MPM release days, the trading strategies result in a significant loss, on the monetary policy release days with pleasant temperature, there is a reliable and profitable trading strategy in the first nearby futures contract (after accounting for transaction costs represented by the bid-ask spread).[14]

Specifically, the average daily return of the first nearby futures contract is 40 basis points for the MPM release days and is significant at the 1% level. Considering that there are 14 Japanese monetary policy releases per year, the strategy would result in an average annual return of 5.6% for the first near-term Nikkei VI futures contract. This strategy for the first near-term futures contracts has positive skewness and kurtosis above approximately 2, obtaining positive daily returns in 27% of the MPM dates. This near-term futures contract also produces a Sharpe ratio of around 0.33, which translates into an annual Sharpe ratio of 1.24.

Moreover, the omega ratio is above four, emphasizing that the probability of positive returns is higher than the likelihood of negative returns. Instead, this trading strategy does not work over the second nearby futures contract due to the transaction costs. Moreover, note that this strategy results in significant losses during both unpleasant hot and cold temperature days regardless of whether there are MPMs or not. On the whole, these findings reveal that the trading strategy involving the first near-term Nikkei VI futures contract is profitable solely when news releases occur during pleasant temperature days.

## 4. Conclusion

This study uses high-frequency data to investigate the effects of MPM releases on pleasant and unpleasant (cold and hot) temperature days on the Nikkei VI and Nikkei VI futures. Our analyses reveal that when the temperature is pleasant at the time of monetary policy release, there is a significant decline in the Nikkei VI and its futures contracts. Moreover, this decrease is not instantaneous but persists for around 10 and 5 minutes in Nikkei VI and Nikkei VI futures, respectively, after the release days with pleasant weather. We show the possible economic implications from the understanding of Nikkei VI futures' reaction to MPM releases. Notably, during pleasant temperature days, taking a short position in the first near-term Nikkei VI futures contract at the beginning of the trading day and closing out the position at the end of day results in an average return of 40 basis points per day (i.e., 5.6% per year using 14 MPM release days per year). Finally, we emphasize that taking similar strategies during the MPM release days with unpleasant temperatures can led to significant losses.

[14] Note these futures contracts are not highly liquid, which is confirmed by the wide bid-ask spreads. Notwithstanding, our strategy employs the bid and ask prices to take positions which lessen this concern.

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**Table 1. Summary statistics on the Nikkei VI and Nikkei VI futures**

| | Nikkei VI | Nikkei VI Futures | |
|---|---|---|---|
| | | 1st | 2nd |
| | Panel A: Levels | | |
| Mean | 24.02 | 23.72 | 24.15 |
| Max | 50.01 | 44.50 | 39.40 |
| Min | 14.14 | 15.12 | 17.45 |
| St. Dev. | 5.56 | 4.49 | 3.25 |
| Skewness | 0.97 | 0.79 | 0.36 |
| Kurtosis | 3.94 | 3.74 | 2.60 |
| ADF | -5.07*** | -7.69*** | -5.66*** |
| | Panel B: Log Differences | | |
| Mean | -0.0000 | 0.0000 | -0.0000 |
| Max | 0.15 | 0.18 | 0.14 |
| Min | -0.15 | -0.19 | -0.15 |
| St. Dev. | 0.0034 | 0.0089 | 0.0109 |
| Skewness | 1.20 | 0.5056 | -0.0052 |
| Kurtosis | 363.49 | 84.33 | 49.03 |
| ADF | -254.5*** | -86.50*** | -76.22*** |

Note: This table shows the descriptive statistics on the Nikkei VI and the Nikkei VI futures at a one-minute frequency. Panel A reports the summary statistics for the levels, and Panel B reports the log differences results. We report the mean, maximum, minimum, standard deviation, skewness, kurtosis, and ADF is the Augmented Dickey-Fuller statistic. We indicate the significance at the 10%, 5%, 1% level by *, **, and ***, respectively.

**Table 2. The reaction of Nikkei VI and Nikkei VI futures around MPM releases during pleasant weather**

| | Nikkei VI | | Nikkei VI Futures | | | |
|---|---|---|---|---|---|---|
| | | | 1st | | 2nd | |
| | | | *Panel A: Open to Close* | | | |
| | *Diff* | *Stat* | *Diff* | *Stat* | *Diff* | *Stat* |
| Mean | -0.0233* | -1.64 | -0.0122 | -1.44 | 0.0001 | 0.01 |
| Median | -0.0244*** | -3.17 | -0.0138** | -2.05 | 0.0028 | 0.26 |
| | | | Panel B: [ -15 : 60 ] minutes around release time | | | |
| Mean | -0.0219*** | -2.73 | -0.0069 | -1.52 | -0.0007 | -0.18 |
| Median | -0.0174*** | -5.52 | -0.0107*** | -3.83 | -0.0020 | -1.34 |
| | | | Panel C: [ -15 : 0 ] minutes around release time | | | |
| Mean | -0.0028 | -0.59 | 0.0019 | 0.36 | 0.0055 | 1.03 |
| Median | -0.0045*** | -2.32 | -0.0009 | -0.17 | 0.0011 | 0.22 |
| | | | Panel D: [ 0 : +60 ] minutes around release time | | | |
| Mean | -0.0206*** | -2.33 | -0.0079* | -1.85 | -0.0030 | -0.99 |
| Median | -0.0165*** | -4.96 | -0.0104*** | -4.56 | -0.0006 | -1.48 |
| | | | *Panel E: [ 0 : +15 ] minutes around release time* | | | |
| Mean | -0.0160*** | -3.48 | -0.0054*** | -3.24 | -0.0023 | -0.96 |
| Median | -0.0071*** | -4.61 | -0.0069*** | -4.12 | -0.0010 | -0.96 |
| | | | Panel F: [ +15 : +30 ] minutes around release time | | | |
| Mean | 0.0027 | 0.57 | 0.0019 | 0.46 | 0.0006 | 0.16 |
| Median | 0.0002 | 0.45 | 0.0000 | 0.37 | 0.0012 | 0.72 |
| | | | Panel G: [ +30 : +45 ] minutes around release time | | | |
| Mean | -0.0062** | -2.29 | -0.0018 | -1.25 | 0.0002 | 0.10 |
| Median | -0.0043*** | -2.38 | -0.0021 | -1.01 | 0.0000 | -0.50 |
| | | | Panel H: [ +45 : +60 ] minutes around release time | | | |
| Mean | -0.0007 | -0.27 | -0.0044 | -1.98 | -0.0031 | -1.81 |
| Median | -0.0017 | -1.07 | -0.0022 | -1.64 | -0.0020 | -1.35 |

Note: This table presents the differences in performance of the Nikkei VI and Nikkei VI futures on MPM release days versus non-release days occurring in pleasant weather. The different panels in this table consider various windows around the release. We compute the difference in mean and median and conduct a *t*-test and, respectively, a Wilcoxon rank test. We indicate the significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

**Table 3. The reaction of Nikkei VI and Nikkei VI futures around MPM releases during unpleasant hot weather**

| | Nikkei VI | | Nikkei VI Futures | | | |
|---|---|---|---|---|---|---|
| | | | 1st | | 2nd | |
| | | | *Panel A: Open to Close* | | | |
| | *Diff* | *Stat* | *Diff* | *Stat* | *Diff* | *Stat* |
| Mean | -0.0209** | -2.17 | -0.0076 | -0.89 | -0.0018 | -0.20 |
| Median | -0.0070* | -1.95 | -0.0064 | -0.96 | 0.0002 | 0.08 |
| | | | *Panel B: [ -15 : 60 ] minutes around release time* | | | |
| Mean | -0.0097 | -1.07 | -0.0140* | -1.90 | -0.0084 | -1.35 |
| Median | -0.0131*** | -2.46 | -0.0067*** | -2.36 | -0.0051*** | -2.63 |
| | | | *Panel C: [ -15 : 0 ] minutes around release time* | | | |
| Mean | -0.0132* | -1.76 | -0.0144 | -1.43 | -0.0076 | -1.55 |
| Median | -0.0042*** | -2.83 | -0.0026* | -1.85 | -0.0079* | -1.85 |
| | | | Panel D: [ 0 : +60 ] minutes around release time | | | |
| Mean | 0.0036 | 0.47 | -0.0060 | -1.49 | -0.0058 | -1.01 |
| Median | -0.0071 | -1.49 | -0.0051 | -1.61 | -0.0054** | -2.36 |
| | | | *Panel E: [ 0 : +15 ] minutes around release time* | | | |
| Mean | -0.0023 | -0.52 | -0.0032 | -1.10 | -0.0033** | -2.24 |
| Median | -0.0048** | -1.99 | -0.0021 | -1.20 | -0.0036** | -2.19 |
| | | | *Panel F: [ +15 : +30 ] minutes around release time* | | | |
| Mean | -0.0021 | -0.43 | 0.0015 | 0.38 | 0.0010 | 0.25 |
| Median | 0.0003 | 0.22 | 0.0025 | 0.99 | -0.0041 | -1.19 |
| | | | Panel G: [ +30 : +45 ] *minutes around release time* | | | |
| Mean | 0.0022 | 0.88 | -0.0034 | -1.57 | 0.0033 | 0.57 |
| Median | 0.0008 | 0.73 | -0.0023 | -1.39 | -0.0034 | -0.77 |
| | | | *Panel H: [ +45 : +60 ] minutes around release time* | | | |
| Mean | 0.0062 | 0.90 | -0.0028 | -1.02 | -0.0083* | -1.65 |
| Median | -0.0030 | -0.56 | -0.0034 | -1.81 | -0.0034*** | -2.33 |

Note: This table presents the differences in performance of the Nikkei VI and Nikkei VI futures on MPM release days versus non-release days occurring on unpleasant cold weather days. The different panels in this table consider various windows around the release. We compute the difference in mean and median and conduct a *t*-test and, respectively, a Wilcoxon rank test. We indicate the significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

**Table 4. The reaction of Nikkei VI and Nikkei VI futures around MPM releases during unpleasant cold weather**

| | Nikkei VI | | Nikkei VI Futures | | | |
|---|---|---|---|---|---|---|
| | | | 1st | | 2nd | |
| | | | *Panel A: Open to Close* | | | |
| | *Diff* | *Stat* | *Diff* | *Stat* | *Diff* | *Stat* |
| Mean | -0.0384*** | -2.67 | -0.0167* | -1.86 | -0.0154* | -1.79 |
| Median | -0.0261*** | -2.76 | -0.0134* | -1.74 | 0.0000 | -1.07 |
| | | | *Panel B: [ -15 : 60 ] minutes around release time* | | | |
| Mean | -0.0252** | -3.07 | -0.0107* | -1.78 | -0.0100** | -2.02 |
| Median | -0.0260*** | -3.55 | -0.0052* | -1.67 | -0.0051*** | -2.32 |
| | | | *Panel C: [ -15 : 0 ] minutes around release time* | | | |
| Mean | -0.0073* | -1.88 | -0.0108 | -1.06 | -0.0031 | -1.28 |
| Median | -0.0039** | -2.22 | -0.0064 | -1.08 | -0.0010 | -1.52 |
| | | | *Panel D: [ 0 : +60 ] minutes around release time* | | | |
| Mean | -0.0184** | -1.99 | -0.0086* | -1.88 | -0.0092** | -2.04 |
| Median | -0.0210*** | -3.02 | -0.0054 | -1.38 | -0.0054*** | -2.49 |
| | | | *Panel E: [ 0 : +15 ] minutes around release time* | | | |
| Mean | -0.0097 | -1.02 | -0.0057 | -1.09 | -0.0041 | -0.57 |
| Median | -0.0146*** | -2.73 | -0.0022 | -1.62 | -0.0039 | -1.37 |
| | | | *Panel F: [ +15 : +30 ] minutes around release time* | | | |
| Mean | 0.0005 | 0.09 | -0.0011 | -0.28 | -0.0023 | -1.13 |
| Median | -0.0013 | -0.31 | -0.0011 | -0.24 | -0.0001 | -0.57 |
| | | | Panel G: [ +30 : +45 ] *minutes around release time* | | | |
| Mean | 0.0001 | 0.02 | 0.0040 | 0.48 | 0.0011 | 0.87 |
| Median | -0.0019 | -0.54 | -0.0047 | -1.07 | 0.0000 | 0.39 |
| | | | *Panel H: [ +45 : +60 ] minutes around release time* | | | |
| Mean | -0.0099 | -1.49 | -0.0098 | -1.09 | -0.0101*** | -2.75 |
| Median | -0.0034* | -1.73 | -0.0030 | -1.05 | -0.0070*** | -2.80 |

Note: This table presents the differences in performance of the Nikkei VI and Nikkei VI futures on MPM release days versus non-release days occurring on unpleasant cold weather days. The different panels in this table consider various windows around the release. We compute the difference in mean and median and conduct a *t*-test and, respectively, a Wilcoxon rank test. We indicate the significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

**Table 5. Trading strategy in the Nikkei VI futures during pleasant weather**

| | Non-MPM release days | | MPM release days | |
|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd |
| Excess Returns | | | | |
| Average | -0.0055** | -0.0079*** | 0.0040*** | -0.0063*** |
| | (2.31) | (-3.89) | (2.33) | (-3.89) |
| Geometric mean | -0.0056 | -0.0080 | 0.0039 | -0.0064 |
| Risk Measures | | | | |
| Volatility | 0.0143 | 0.0153 | 0.0121 | 0.0115 |
| Downside Volatility (<0) | 0.0123 | 0.0132 | 0.0058 | 0.0102 |
| Skewness | -1.56 | -1.38 | 1.94 | -1.62 |
| Kurtosis | 7.81 | 5.35 | 6.86 | 4.32 |
| 99% VaR (Cornish-Fisher) | 0.0583 | 0.0566 | 0.0005 | 0.0391 |
| % of positive days | 7% | 4% | 27% | 4% |
| Risk-adjusted performance | | | | |
| Sharpe ratio | -0.3831 | -0.5148 | 0.3341 | -0.5504 |
| Sortino ratio (0%) | -0.4476 | -0.5994 | 0.6902 | -0.6186 |
| Omega ratio (0%) | 0.1457 | 0.0566 | 4.4308 | 0.0239 |

Note: This table presents the findings of a trading strategy in the first and second near-term Nikkei VI futures contract, where a short position has been taken at the bid quote at 9:30 am, and a long position has been taken at the ask quote at 2:30 pm. We compare this strategy's performance on days with and without MPM releases occurring during pleasant weather and report the statistics on daily returns, risk measures, and risk-adjusted-performance. The *t*-statistics are reported in parentheses and indicate the significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

**Table 6. Trading strategy in the Nikkei VI futures during unpleasant hot weather**

| | Non-MPM release days | | MPM release days | |
|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd |
| **Excess Returns** | | | | |
| Average | -0.0033 | -0.0047 | 0.0005 | -0.0020 |
| | (0.66) | (-1.47) | (0.66) | (-1.47) |
| Geometric mean | -0.0034 | -0.0047 | 0.0005 | -0.0020 |
| **Risk Measures** | | | | |
| Volatility | 0.0110 | 0.0113 | 0.0051 | 0.0100 |
| Downside Volatility (<0) | 0.0098 | 0.0102 | 0.0030 | 0.0081 |
| Skewness | -2.59 | -2.12 | 1.39 | -0.86 |
| Kurtosis | 14.45 | 7.66 | 10.47 | 10.43 |
| 99% VaR (Cornish-Fisher) | 0.0514 | 0.0419 | 0.0114 | 0.0460 |
| % of positive days | 5% | 2% | 12% | 7% |
| **Risk-adjusted performance** | | | | |
| Sharpe ratio | -0.3004 | -0.4119 | 0.0925 | -0.2007 |
| Sortino ratio (0%) | -0.3354 | -0.4557 | 0.1559 | -0.2437 |
| Omega ratio (0%) | 0.1423 | 0.0462 | 1.6165 | 0.3192 |

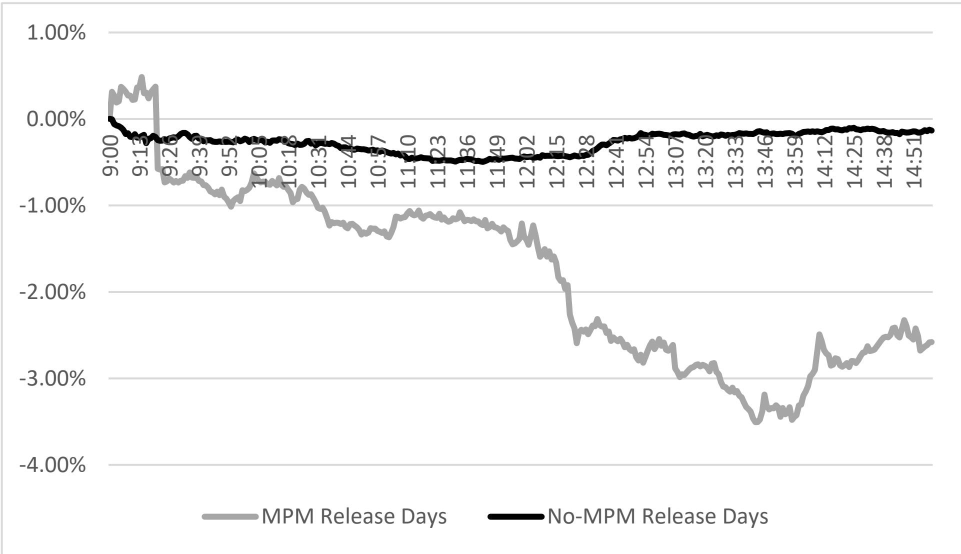
Note: This table presents the findings of a trading strategy in the first and second near-term Nikkei VI futures contract, where a short position has been taken at the bid quote at 9:30 am, and a long position has been taken at the ask quote at 2:30 pm. We compare this strategy's performance on days with and without MPM releases occurring during unpleasant hot weather and report the statistics on daily returns, risk measures, and risk-adjusted-performance. The *t*-statistics are reported in parentheses and indicate the significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

**Table 7. Trading strategy in the Nikkei VI futures during unpleasant cold weather**

| | Non-MPM release days | | MPM release days | |
|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd |
| Excess Returns | | | | |
| Average | -0.0026 | -0.0038*** | 0.0009 | -0.0049*** |
| | (0.57) | (-3.34) | (0.57) | (-3.34) |
| Geometric mean | -0.0026 | -0.0039 | 0.0008 | -0.0050 |
| Risk Measures | | | | |
| Volatility | 0.0103 | 0.0113 | 0.0112 | 0.0111 |
| Downside Volatility (<0) | 0.0093 | 0.0106 | 0.0036 | 0.0097 |
| Skewness | -2.97 | -3.04 | 6.00 | -1.40 |
| Kurtosis | 20.27 | 12.72 | 42.73 | 4.08 |
| 99% VaR (Cornish-Fisher) | 0.0563 | 0.0418 | -0.0723 | 0.0368 |
| % of positive days | 3% | 1% | 9% | 2% |
| Risk-adjusted performance | | | | |
| Sharpe ratio | -0.2492 | -0.3362 | 0.0782 | -0.4458 |
| Sortino ratio (0%) | -0.2746 | -0.3588 | 0.2405 | -0.5049 |
| Omega ratio (0%) | 0.1366 | 0.0312 | 1.9448 | 0.0626 |

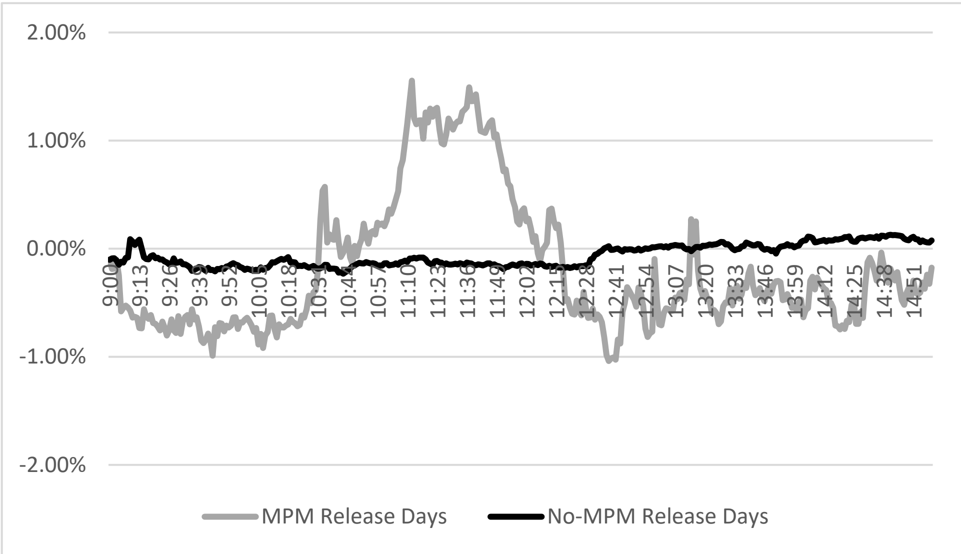
Note: This table presents the findings of a trading strategy in the first and second near-term Nikkei VI futures contract, where a short position has been taken at the bid quote at 9:30 am, and a long position has been taken at the ask quote at 2:30 pm. We compare this strategy's performance on days with and without MPM releases occurring during unpleasant cold weather and report the statistics on daily returns, risk measures, and risk-adjusted-performance. The *t*-statistics are reported in parentheses and indicate the significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

**Figure 1. Cumulative change in the Nikkei VI on MPM versus non-MPM release days during pleasant weather**



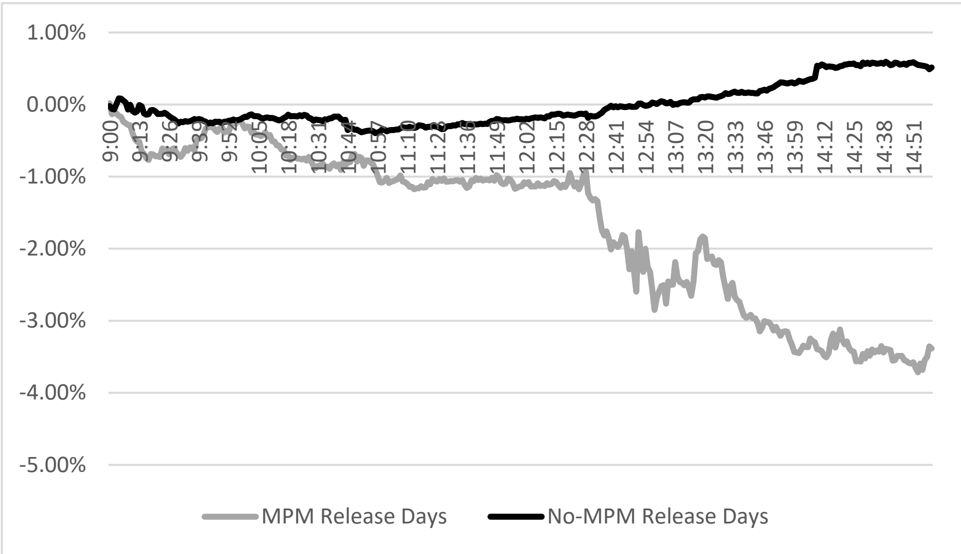

Note: This figure plots the evolution at a one-minute frequency of the Nikkei VI during non-release days (black line) and releases days (grey line) with pleasant weather. We consider the interval from 9 am to 3 pm JST.

**Figure 2. Cumulative change in the Nikkei VI on MPM versus non-MPM release days during unpleasant hot weather**



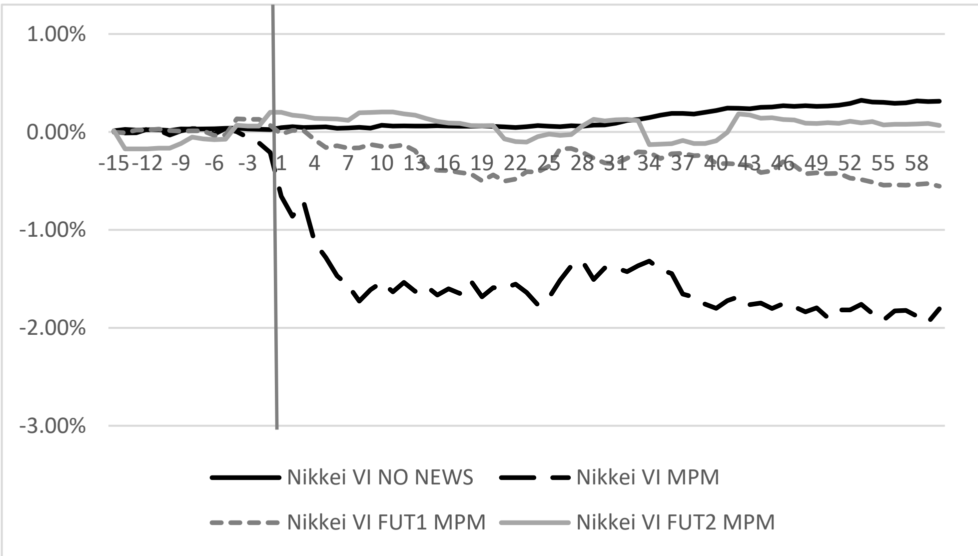

Note: This figure plots the evolution at a one-minute frequency of the Nikkei VI during non-release days (black line) and releases days (grey line) with unpleasant hot weather. We consider the interval from 9 am to 3 pm JST.

**Figure 3. Cumulative change in the Nikkei VI on MPM versus non-MPM release days during unpleasant cold weather**



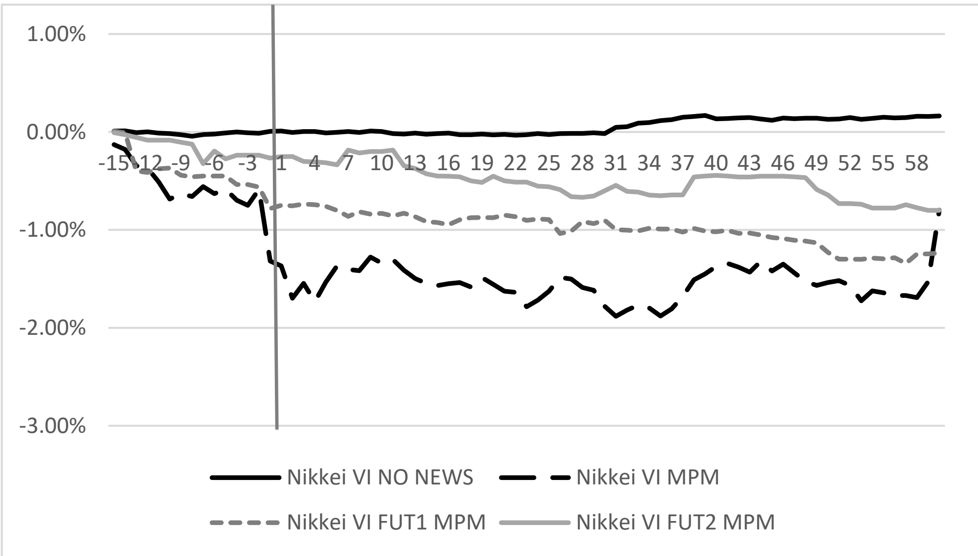

Note: This figure plots the evolution at a one-minute frequency of the Nikkei VI during non-release days (black line) and releases days (grey line) with unpleasant cold weather. We consider the interval from 9 am to 3 pm JST.

**Figure 4. Cumulative change in the Nikkei VI and Nikkei VI Futures around MPM release times during pleasant weather**



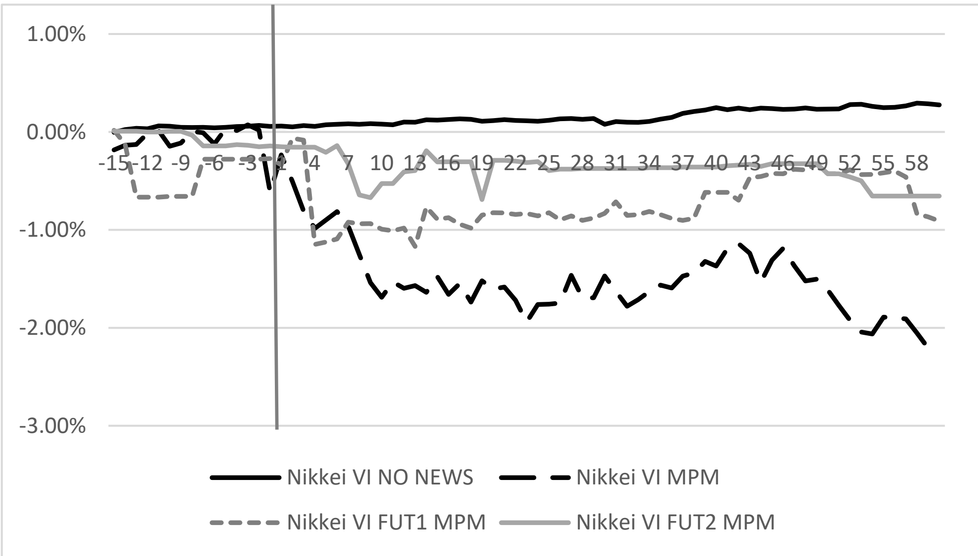

Note: This figure plots at a one-minute frequency the Nikkei VI on release and non-release days and the Nikkei VI futures on release days over the interval from 15 minutes before the MPM release to 60 minutes after the MPM release. We only consider those release and non-release days with pleasant weather. Given that each MPM release time is different and most of them occur around 12 pm, we consider *t*=0 as 12 pm for the non-MPM release days.

**Figure 5. Cumulative change in the Nikkei VI and Nikkei VI Futures around MPM release times during unpleasant hot weather**




Note: This figure plots at a one-minute frequency the Nikkei VI on release and non-release days and the Nikkei VI futures on release days over the interval from 15 minutes before the MPM release to 60 minutes after the MPM release. We only consider those release and non-release days with unpleasant hot weather. Given that each MPM release time is different and most of them occur around 12 pm, we consider *t*=0 as 12 pm for the non-MPM release days.

**Figure 6. Cumulative change in the Nikkei VI and Nikkei VI Futures around MPM release times during unpleasant cold weather**




Note: This figure plots at a one-minute frequency the Nikkei VI on release and non-release days and the Nikkei VI futures on release days over the interval from 15 minutes before the MPM release to 60 minutes after the MPM release. We only consider those release and non-release days with unpleasant cold weather. Given that each MPM release time is different and most of them occur around 12 pm, we consider *t*=0 as 12 pm for the non-MPM release days.

## Appendix A.1. The reaction of Nikkei VI and Nikkei VI futures around MPM releases

| | Nikkei VI | | Nikkei VI Futures | | | |
|---|---|---|---|---|---|---|
| | | | 1st | | 2nd | |
| | *Panel A: Open to Close* | | | | | |
| | *Diff* | *Stat* | *Diff* | *Stat* | *Diff* | *Stat* |
| Mean | -0.0260*** | -3.17 | -0.0133*** | -2.59 | -0.0084** | -1.98 |
| Median | -0.0251*** | -4.60 | -0.0137*** | -2.74 | -0.0055 | -0.31 |
| | *Panel B: [ -15 : 60 ] minutes around release time* | | | | | |
| Mean | -0.0139*** | -2.76 | -0.0086*** | -2.63 | -0.0044 | -1.55 |
| Median | -0.0124*** | -6.89 | -0.0071*** | -4.65 | -0.0032*** | -3.38 |
| | *Panel C: [ -15 : 0 ] minutes around release time* | | | | | |
| Mean | -0.0064** | -1.95 | -0.0074 | -1.50 | -0.0008 | -0.25 |
| Median | -0.0053*** | -4.18 | -0.0030 | -1.60 | -0.0027 | -1.59 |
| | *Panel D: [ 0 : +60 ] minutes around release time* | | | | | |
| Mean | -0.0083* | -1.56 | -0.0058*** | -2.29 | -0.0044* | -1.84 |
| Median | -0.0093*** | -5.70 | -0.0068*** | -4.58 | -0.0028*** | -3.44 |
| | *Panel E: [ 0 : +15 ] minutes around release time* | | | | | |
| Mean | -0.0101*** | -3.02 | -0.0050*** | -2.89 | -0.0026 | -1.44 |
| Median | -0.0071*** | -5.57 | -0.0049*** | -4.44 | -0.0037*** | -2.52 |
| | *Panel F: [ +15 : +30 ] minutes around release time* | | | | | |
| Mean | 0.0007 | 0.23 | 0.0011 | 0.43 | -0.0024 | -0.91 |
| Median | 0.0010 | 0.27 | 0.0001 | 0.58 | -0.0001 | -0.24 |
| | Panel G: [ +30 : +45 ] *minutes around release time* | | | | | |
| Mean | 0.0011 | 0.60 | 0.0010 | 0.43 | 0.0017 | 0.96 |
| Median | -0.0004 | -1.54 | -0.0002** | -2.06 | 0.0019 | -0.71 |
| | *Panel H: [ +45 : +60 ] minutes around release time* | | | | | |
| Mean | 0.00005 | 0.02 | -0.0044* | -1.92 | -0.0035** | -1.96 |
| Median | -0.0019* | -1.90 | -0.0010*** | -2.76 | -0.0013*** | -3.47 |

Note: This table presents the differences in performance of the Nikkei VI and Nikkei VI futures on MPM release days versus non-release days. The different panels in this table consider various windows around the release. We compute the difference in mean and median and conduct a *t*-test and, respectively, a Wilcoxon rank test. We indicate the significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

## Appendix A. 2. Impact of changes in realized volatilities on changes in VIX

| | α | β | $R^2$(adj) |
|---|---|---|---|
| ΔΔNikkei VI | -0.0163*** | -1.7178*** | 5.70% |
| | (-3.00) | (-2.66) | |
| ΔΔNikkei VI F1 | -0.0056*** | -0.6641 | 2.09% |
| | (-2.37) | (-1.56) | |
| ΔΔNikkei VI F2 | -0.0018 | 0.1443 | -1.65% |
| | (-0.94) | (0.26) | |

Note: This table reports the regression results for the regression of log changes in Nikkei VI and Nikkei VI futures on changes in realized volatility, namely,

$$\Delta\Delta\ Nikkei\ VI_N = \alpha + \beta\ \Delta RV_N + \varepsilon_N,$$

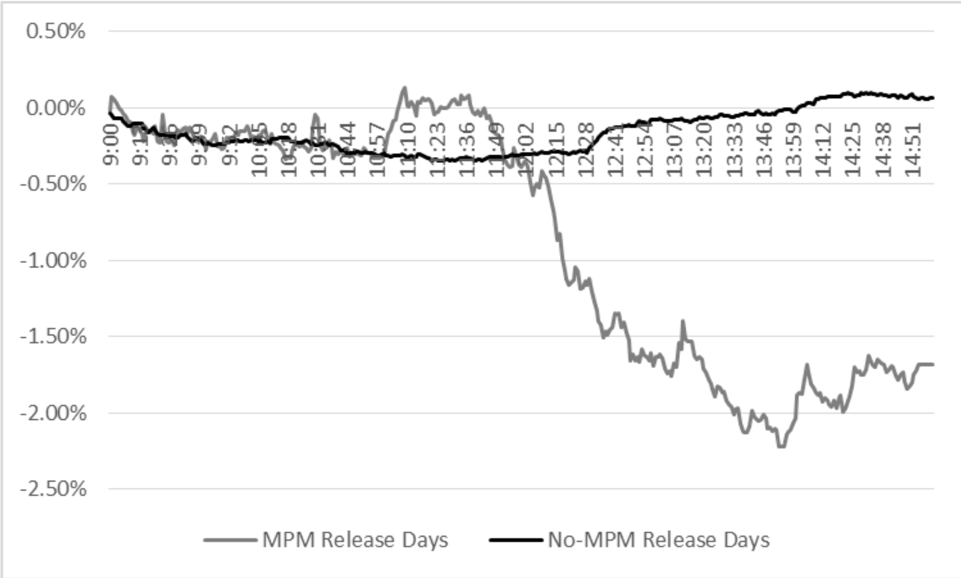
where $\Delta\Delta\ Nikkei\ VI_N$ is the difference in the change in the Nikkei VI from 15 minutes before the MPM release to 60 minutes after the MPM release on announcement days versus the average of non-release days, and $\Delta RV_N$ is the difference in realized volatility for release days versus the average non-monetary policy release days covering a period of 15 minutes before to 60 minutes after the break in Nikkei 225. In parentheses, we report the Newey-West corrected *t*-statistics and indicate significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

## Appendix A. 3. Trading strategy in the Nikkei VI futures

| | Non-MPM release days | | MPM release days | |
|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd |
| | Excess Returns | | | |
| Average | -0.0164*** | -0.0213*** | 0.0064** | -0.0146*** |
| | (-23.35) | (-37.41) | (2.22) | (-5.08) |
| Geometric mean | -0.0167 | -0.0215 | 0.0062 | -0.0122 |
| | Risk measures | | | |
| Volatility | 0.022 | 0.0172 | 0.0186 | 0.0146 |
| Downside Volatility (<0) | 0.0165 | 0.0121 | 0.0102 | 0.0087 |
| Skewness | -0.35 | 0.16 | 1.71 | 1.14 |
| Kurtosis | 3.89 | 3.28 | 6.85 | 4.49 |
| 99% VaR (Cornish-Fisher) | 0.0769 | 0.0603 | 0.0097 | 0.0318 |
| % of positive days | 18% | 9% | 57% | 18% |
| | Risk-adjusted performance | | | |
| Sharpe ratio | -0.7461 | -1.2376 | 0.3460 | -0.8351 |
| Sortino ratio (0%) | -0.9959 | -1.7595 | 0.6274 | -1.3793 |
| Omega ratio (0%) | 0.1236 | 0.0446 | 2.8220 | 0.1449 |

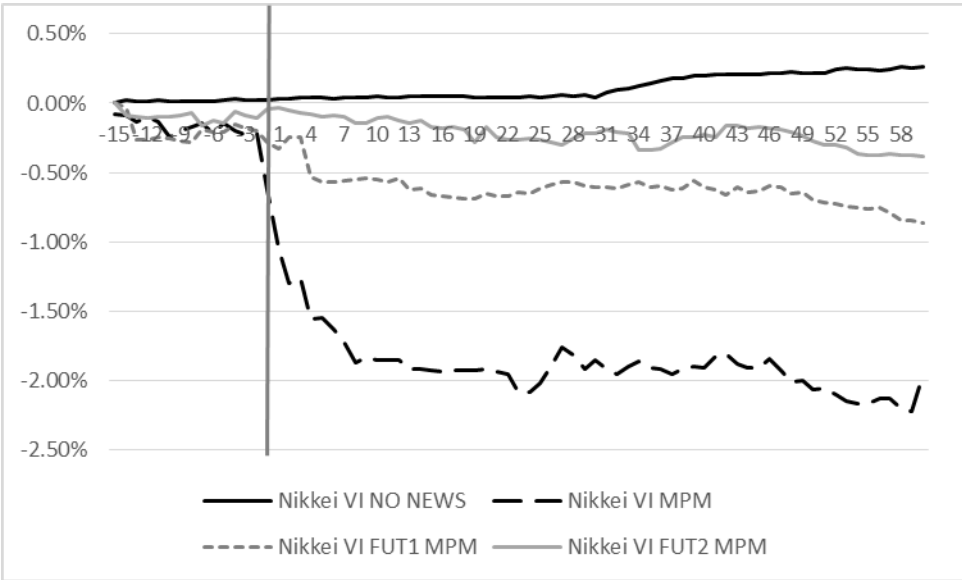
Note: This table presents the findings of a trading strategy in the first and second near-term Nikkei VI futures contract, where a short position has been taken at the bid quote at 9:30 am, and a long position has been taken at the ask quote at 2:30 pm. We compare this strategy's performance on days with and without MPM releases and report the statistics on daily returns, risk measures, and risk-adjusted performance. The *t*-statistics are reported in parentheses and indicate significance at 10%, 5%, and 1% level by *, **, and ***, respectively.

**Appendix A. 4. Cumulative change in the Nikkei VI on MPM versus Non-MPM release days**




Note: This figure plots the evolution at a one-minute frequency of the Nikkei VI during non-release days (black line) and release days (grey line). We consider the interval from 9 am to 3 pm JST.

**Appendix A. 5. Cumulative change in the Nikkei VI and Nikkei VI futures around MPM release times**




Note: This figure plots at a one-minute frequency the Nikkei VI on release and non-release days and the Nikkei VI futures on release days over the interval from 15 minutes before the MPM release to 60 minutes after the MPM release. Given that each MPM release time is different and most of them occur around 12 pm, we consider *t*=0 as 12 pm for the non-MPM release days.

## Appendix A. 6. Trading Strategy in the Nikkei VI Futures during pleasant and unpleasant weather

### Panel A: Pleasant weather

| | Non-MPM release days | | MPM release days | |
|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd |
| | Excess Returns | | | |
| Average | -0.0051 | -0.0071*** | 0.0047** | -0.0059*** |
| | (2.22) | (-3.56) | (2.22) | (-3.56) |
| Geometric mean | -0.0052 | -0.0072 | 0.0046 | -0.0060 |
| Volatility | 0.0135 | 0.0144 | 0.0147 | 0.0120 |
| Downside Volatility (<0) | 0.0118 | 0.0126 | 0.0058 | 0.0103 |
| Skewness | -1.92 | -1.61 | 3.20 | -1.32 |
| Kurtosis | 9.03 | 6.25 | 14.88 | 4.08 |
| 99% VaR (Cornish-Fisher) | 0.0557 | 0.0545 | -0.0207 | 0.0405 |
| % of positive days | 5% | 3% | 24% | 4% |
| Sharpe ratio | -0.3775 | -0.4907 | 0.3208 | -0.4980 |
| Sortino ratio (0%) | -0.4304 | -0.5607 | 0.8111 | -0.5735 |
| Omega ratio (0%) | 0.1185 | 0.0446 | 6.2407 | 0.0702 |

### Panel B: Unpleasant hot weather

| | Non-MPM release days | | MPM release days | |
|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd |
| | Excess Returns | | | |
| Average | -0.0041 | -0.0058* | 0.0012 | -0.0029* |
| | (0.97) | (-1.94) | (0.97) | (-1.94) |
| Geometric mean | -0.0041 | -0.0059 | 0.0011 | -0.0030 |
| Volatility | 0.0125 | 0.0130 | 0.0086 | 0.0110 |
| Downside Volatility (<0) | 0.0109 | 0.0115 | 0.0041 | 0.0090 |
| Skewness | -2.02 | -1.75 | 2.88 | -0.82 |
| Kurtosis | 11.17 | 6.20 | 15.84 | 7.98 |
| 99% VaR (Cornish-Fisher) | 0.0564 | 0.0476 | -0.0004 | 0.0452 |
| % of positive days | 6% | 3% | 15% | 9% |
| Sharpe ratio | -0.3247 | -0.4489 | 0.1365 | -0.2660 |
| Sortino ratio (0%) | -0.3723 | -0.5085 | 0.2820 | -0.3209 |
| Omega ratio (0%) | 0.1621 | 0.0599 | 1.9791 | 0.2583 |

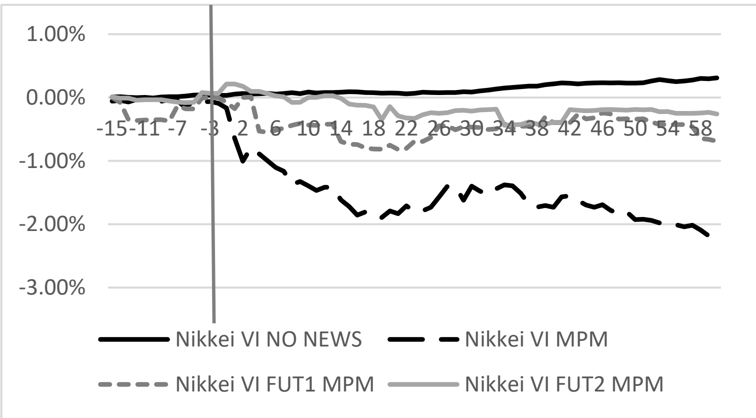
**Panel C: Unpleasant cold weather**

| | Non-MPM release days | | MPM release days | |
|---|---|---|---|---|
| | 1st | 2nd | 1st | 2nd |
| | Excess Returns | | | |
| Average | -0.0022 | -0.0035*** | -0.0004 | -0.0043*** |
| | (-0.82) | (-3.29) | (-0.82) | (-3.29) |
| Geometric mean | -0.0022 | -0.0035 | -0.0004 | -0.0044 |
| Volatility | 0.0097 | 0.0108 | 0.0035 | 0.0099 |
| Downside Volatility (<0) | 0.0087 | 0.0102 | 0.0030 | 0.0091 |
| Skewness | -2.95 | -3.20 | -2.37 | -2.02 |
| Kurtosis | 21.91 | 14.02 | 14.15 | 5.52 |
| 99% VaR (Cornish-Fisher) | 0.0569 | 0.0403 | 0.0164 | 0.0327 |
| % of positive days | 3% | 1% | 7% | 0% |
| Sharpe ratio | -0.2272 | -0.3197 | -0.1121 | -0.4399 |
| Sortino ratio (0%) | -0.2517 | -0.3400 | -0.1285 | -0.4756 |
| Omega ratio (0%) | 0.1598 | 0.0336 | 0.4854 | 0.0000 |

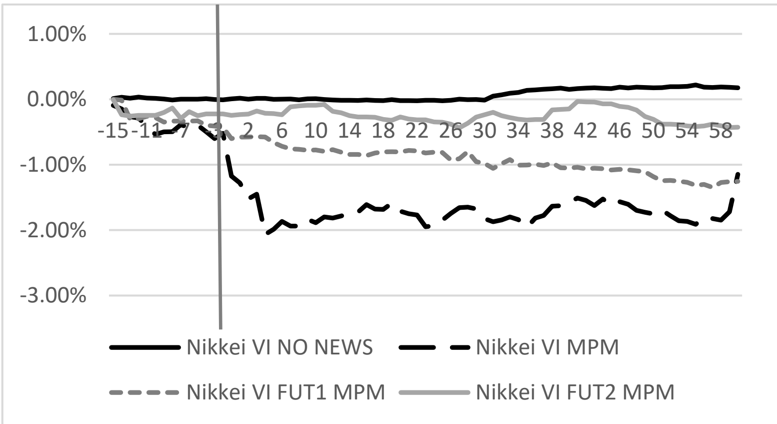
Note: This table presents the findings of a trading strategy in the first and second near-term Nikkei VI futures contract, where a short position has been taken at the bid quote at 9:30 am, and a long position has been taken at the ask quote at 2:30 pm. We compare the performance of this strategy on days with and without MPM releases occurring during pleasant (Panel A), unpleasant hot (Panel B), and cold (Panel C) weather in Osaka. We report the statistics on daily returns, risk measures, and risk-adjusted-performance. The *t*-statistics are reported in parentheses and indicate the significance at the 10%, 5%, and 1% level by *, **, and ***, respectively.

**Appendix A. 7. Cumulative change in the Nikkei VI and Nikkei VI futures around MPM release times during pleasant and unpleasant weather**

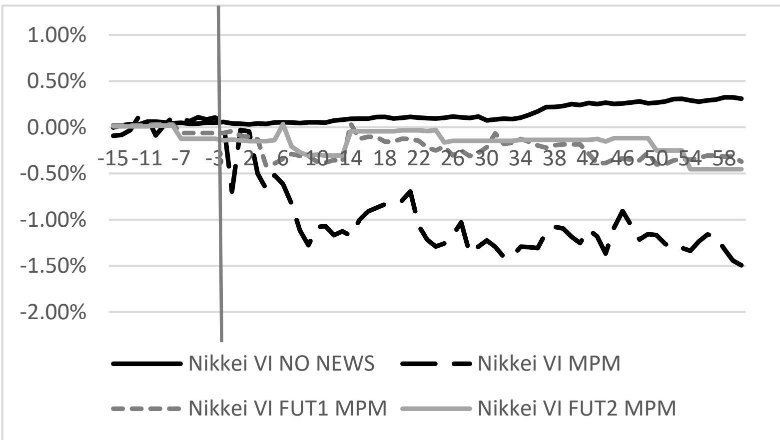
**Panel A: Pleasant weather**




**Panel B: Unpleasant hot weather**




**Panel C: Unpleasant cold weather**




Note: This figure plots at a one-minute frequency the Nikkei VI on release and non-release days and the Nikkei VI futures on release days over the interval from 15 minutes before the MPM release to 60 minutes after the MPM release. We only consider those release and non-release days with pleasant (Panel A), unpleasant hot (Panel B), and cold (Panel C) weather in Osaka. As each MPM release time is different, and most of them occur around 12 pm, we consider *t*=0 as 12 pm for the non-MPM release days.