The impact of ETF mechanics and the Bank of Japan intervention on the intraday volatility of the underlying stocks.

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ผลกระทบจากกลไกของ ETF และการแทรกแซงของธนาคารกลางของประเทศญี่ปุ่นต่อความผันผวนระหว่างวันของหุ้นใน ETFs

น.ส.ธาริตา จำรูญวัฒน์

สารนิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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ธาริตา จำรูญวัฒน์ : ผลกระทบจากกลไกของ ETF และการแทรกแซงของธนาคารกลางของประเทศญี่ปุ่นต่อความผันผวนระหว่างวันของหุ้นใน ETFs. (The impact of ETF mechanics and the Bank of Japan intervention on the intraday volatility of the underlying stocks.) อ.ที่ปรึกษาหลัก : ผศ. ดร.อนิรุต พิเสฏฐศลาศัย

เนื่องจากกองทุนรวมดัชนีอีทีเอฟที่จดทะเบียนซื้อขายในตลาดหลักทรัพย์ (อีทีเอฟ) มีต้นทุนการซื้อขายที่ต่ำและมีสภาพคล่องที่สูง อีทีเอฟจึงเป็นที่สนใจและดึงดูดนักลงทุนระยะสั้น ซึ่งผลกระทบจากสภาพคล่องนี้สามารถส่งผ่านไปยังหลักทรัพย์อ้างอิงได้โดยผ่านกลไกของอีทีเอฟ ดังนั้นอีทีเอฟจึงอาจเป็นสิ่งที่เพิ่มความผันผวนของราคาหุ้นอ้างอิงได้ ฉันทำการทดสอบที่ความถี่รายวันซึ่งช่วยให้ฉันสามารถวัดตัวแปรความถี่สูงอย่างการเก็งกำไรระหว่างอีทีเอฟ Nikkei 225 และหุ้นอ้างอิงได้ทัน ฉันพบผลลัพธ์ที่สอดคล้องกับ Ben-David et al. (2018) ว่าหุ้นที่มีสัดส่วนการถือครองโดยอีทีเอฟที่สูงกว่า มีความผันผวนของราคาในระหว่างวันที่สูงกว่าอย่างเห็นได้ชัด และความเข้มข้นของการเก็งกำไรอีทีเอฟ ซึ่งอ้างอิงจากความผิดพลาดของราคาตลาดของอีทีเอฟในระดับของหุ้นในอีทีเอฟ เพิ่มผลกระทบของอีทีเอฟต่อความผันผวนของราคาหุ้นในระหว่างวัน นอกจากนี้ ฉันพบว่าสัญญาณด้านบวกหรือลบของความผิดพลาดของราคาตลาดของอีทีเอฟในระดับของหุ้นในอีทีเอฟมีผลกระทบที่แตกต่างกันต่อความผันผวนของราคาหุ้นในระหว่างวัน ซึ่งสัญญาณด้านลบของความผิดพลาดของราคาตลาดของอีทีเอฟในระดับของหุ้นในอีทีเอฟ (เมื่ออีทีเอฟถูกซื้อขายในราคาที่ถูกกว่ามูลค่าสุทธิของหุ้นในอีทีเอฟ) มีผลกระทบน้อยกว่า เนื่องจากการเก็งกำไรของกรณีนี้มีต้นทุนที่สูงกว่า ฉันตรวจสอบเพิ่มเติมถึงผลกระทบทางตรงและทางอ้อมของการซื้ออีทีเอฟของธนาคารกลางประเทศญี่ปุ่นต่อความผันผวนของราคาหุ้นอ้างอิงในระหว่างวัน ผลยืนยันประสิทธิผลของการแทรกแซงของธนาคากลางประเทศญี่ปุ่น เนื่องจากการซื้ออีทีเอฟของธนาคารกลางประเทศญี่ปุ่นสามารถลดความผันผวนของราคาหุ้นอ้างอิงในระหว่างวันได้ และยังลดผลกระทบของการเก็งกำไรของอีทีเอฟต่อความผันผวนของราคาหุ้นอ้างอิงในระหว่างวันได้ด้วย นอกจากนี้ในช่วงของการแพร่ระบาดของโควิด 19 ผลกระทบของสิ่งที่ศึกษาอยู่นั้นลดลง เนื่องจากในช่วงวิกฤต ตลาดโดยทั่วไปมีสภาพคล่องต่ำ ดังนั้นความเข้มข้นของการเก็งกำไรของอีทีเอฟจึงลดลง ทำให้ความผันผวนของราคาหุ้นลดลง

สาขาวิชา	การเงิน	ลายมือชื่อนิสิต	....
ปีการศึกษา	2563	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....

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KEYWORD: ETF mechanism increases intraday price volatility of the underlying stock., BOJ ETFs purchase reduces intraday price volatility., BOJ ETFs purcahse reduces the impact of ETF mechanism., The impact of ETF mechanism reduces during the COVID-19 pandemic.

Tharita Jumroonwat : The impact of ETF mechanics and the Bank of Japan intervention on the intraday volatility of the underlying stocks.. Advisor: Asst. Prof. ANIRUT PISEDTASALASAI, Ph.D.

Due to their low trading costs and superior liquidity, exchange-traded funds (ETFs) attract short-term liquidity traders. The liquidity shocks can pass to the underlying securities through the ETF mechanism. ETF may therefore increase the non-fundamental volatility of the underlying stocks. I carry out the test daily which allows me to timely measure the high-frequency variable of arbitrage activity between Nikkei 225 ETFs and their components. I find the consistent result with Ben-David et al. (2018) that stocks with higher ETF holding display significantly higher volatility and the intensity of arbitrage activity, proxied by stock-level mispricing, magnifies the impact of ETFs on intraday volatility. In addition, I find that the sign of stock-level mispricing has a different impact on intraday volatility where the negative sign of net mispricing (ETFs are traded discounted) has less impact. This is because arbitrage treading involves higher costs. I further investigate the direct and indirect impact of BOJ ETFs purchase on intraday volatility. The evidence confirms the effectiveness of BOJ intervention as it could lower intraday volatility and reduce the impact of ETF arbitrage on stock price volatility. Moreover, during the COVID-19 pandemic, the effect of interest is lower because during the crisis, a market, in general, is illiquid. Hence, there is less intensity of ETF arbitrage and less volatility.

Field of Study:	Finance	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....

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Tharita Jumroonwat

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1. Introduction

1.1 Background

ETF General Structure and Mechanics

Apart from the ETF's characteristics that make it so popular, ETFs have an impact on financial markets bringing in a new source of systemic risks and causing more regulatory considerations (1). There are unintended effects on the price of securities in the ETFs' baskets resulting from the unique ETF mechanic. For example, ETFs appear to worsen end-of-day volatility because of the need to rebalance and minimize the tracking error. In other words, the creation and redemption mechanism in the primary market and the arbitrage activity in the secondary market contributes to higher price volatility of securities within the ETF basket. The creation (redemption) is performed by an Authorized Participants (APs) when ETF is traded at a premium (discount) relative to its Net Asset Value (NAV). This process is made to reduce the deviation of the ETF price and the NAV of the constituent securities. Besides, investors can reap an arbitrage profit from trading the ETF shares and its underlying securities in the opposite direction when the price of ETF deviates from the NAV. For instance, arbitrageurs short sell ETF shares when its market price is more expensive than its NAV per unit and use the process to buy the underlying stocks. They hold the positions until prices converge, then close the positions to recognize risk-free profits. Thus, there is a connection between the ETF and its underlying basket of shares. In fact, the majority of ETF trading occurs in the secondary market and is greater than in

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(1) See Eva Su, "Exchange-Traded Funds (ETFs): Issues for Congress," Congressional Research Service Report R45318 (24 September 2018) which discuss proposed SEC Rulemaking on ETFs trading.

the primary market. The effect on the financial market, therefore, mostly due to the transactions in the secondary market where investors sell and buy ETFs in exchange for their constituents.

ETFs and the impacts on the financial market

Empirical research has so far identified the impacts of ETFs which largely divide into two conjectures. The first conjecture is called price discovery. When there is some information that permanently changes the value of underlying securities, the ETFs' price firstly adjusts to a new fundamental layer due to their high liquidity and price discovery, but the price of the underlying securities remains unchanged ("stable pricing"), after the delay, the NAV moves up (Figure 1). In this case, the faster adjustment in prices from the fundamental information results in the increased volatility of the underlying stocks. This hypothesis is consistent with the various studies in U.S. domestic ETFs. Li and Zhu (2019) argue that ETFs contribute to a more informationally efficient market through the arbitrage mechanism. Glosten et al. (2021); Madhavan and Sobczyk (2016) also support that ETFs improve price discovery as they reflect new information faster than a stock-level. Then, demand shocks improve price efficiency.

Figure 1: Price Discovery

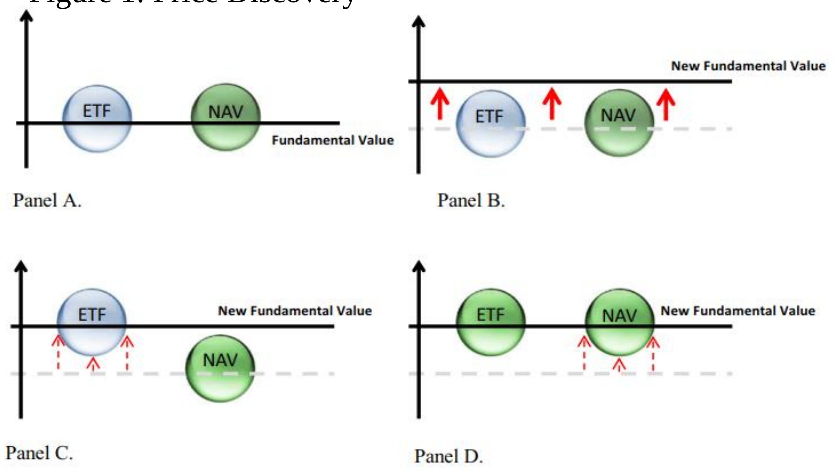

Illustration of the propagation of a fundamental shock with price discovery occurring in the ETF market. (Panel A) Initial equilibrium. (Panel B) Shock to fundamental value. (Panel C) Price discovery takes place in the ETF market. The ETF price moves to the new fundamental value. (Panel D) After a delay, the NAV catches up with the new fundamental. (Color figure can be viewed at wileyonlinelibrary.com)

Source: Ben-David et al. (2018)

The second conjecture is called liquidity trading. When a liquidity shock, which is irrelevant to fundament information such as expected cash flow, attacks the ETF industry driving the ETF price to rise. Arbitrageurs would short the ETF and hedge their position by taking a long position in the ETF components. As a result, the arbitrage activity eventually causes the prices to revert to the fundamentals (Figure 2). This hypothesis analogous to one of the dynamic models of the ETF market as suggested by Malamud (2016). Ben-David et al. (2018) also support the liquidity trading hypothesis and provide empirical evidence on the U.S. ETF market that arbitraging ETF creates price pressure on the underlying stocks from liquidity trading when a non-fundamental shock hits the ETF market, and the ETF price deviates from the NAV. It consequently increases the volatility of the basket securities.

Figure 2: Liquidity Trading

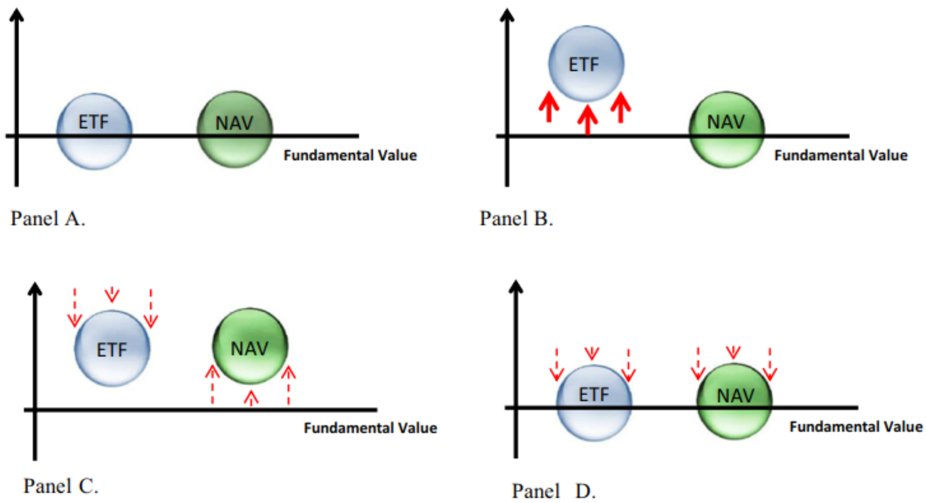

Illustration of the propagation of liquidity shocks via arbitrage. (Panel A) Initial equilibrium. (Panel B) Liquidity shock to ETF. (Panel C) Initial outcome of arbitrage: the shock is propagated to the NAV, and the ETF price starts reverting to the fundamental value. (Panel D) Equilibrium reestablished: after some time, both the ETF price and the NAV revert to the fundamental value.

Source: Ben-David et al. (2018)

However, there is also the other argument from Grossman (1989) that could be applied to ETFs that the introduction of a correlated asset class provides a liquidity buffer to the underlying securities. In other words, investors would satisfy their liquidity demand using the ETF so the liquidity shocks on the underlying stocks would disappear, and the volatility decreases.

In conclusion, the rapid growth of ETFs and their growing subset of complexity have meanwhile raised systemic risk concerns (2) to the global financial system and regulators to established comprehensive listing standards. As the arbitrage activity through the mechanism of ETF, there is a negative impact on the stock basket in terms of volatility. On the other hand, some researchers provide evidence that the implementation of ETFs improves information efficiency which is positive to a financial market. However, to date, most empirical evidence studied on the United State and European ETF industries, but the negative impact of ETF arbitraging on the underlying basket in the Japanese market is almost none in the literature.

The Growth of the Japanese ETFs market and the BOJ's ETFs purchase

The Japanese ETF market is not as same as other countries' ETF markets because the Bank of Japan (BOJ) dominates over ETFs, holding close to 80% of outstanding domestic ETF equity assets. The BOJ has continued purchasing the ETFs even after shifting to a more aggressive monetary policy regime of "quantitative and qualitative easing (QQE) in April 2013. The total purchase in aggregate is approximately 5% of the total market capitalization in 2019 and the total upper limit of purchases has extended year over year since the BOJ ETF purchasing program was

(2) See Bhattacharya and O'Hara, "ETFs and Systemic risks", CFA Institute Research Foundation (2020), which discuss the ETFs involvement in the market disruption. However, some systemic risks derived from ETFs also discuss in this paper in the background section: ETFs and the impacts on the financial market.

introduced, reaching ¥6tn in 2016. Due to the COVID-19 pandemic, the BOJ increases the annual ETF purchasing target to ¥12tn in 2020.

Purchasing the index-linked ETFs is a part of the Unconventional Monetary Policy of the BOJ to achieve the 2% target price stability but not to realize or maintain an individual stock price [(3)]. Moreover, this policy is also implemented to facilitate money market operations, increase aggregate demand, and lower long-term interest rate and risk premium. Alternatively, the BOJ indirectly holds stocks through its large holding in the tracked index ETFs to reduce costs of capital and induce corporate investments. When the market becomes more volatile, the systematic risk increases, and investors require more risk premium to compensate for the higher risk. Therefore, the higher investors' discount rates, the higher costs of capital of firms. As a result, the BOJ intervention by purchasing the ETFs aims to lower market volatility in a long-term, create a wealth effect, and stimulate the economy.

By looking at the frequency of BOJ's purchase, the BOJ takes a long position order on the ETFs in the afternoon when the market declines in the morning section (Fueda-Samikawa and Tetshushi (2017); Shirota (2018)). Research findings highlight that the BOJ's untraditional monetary policy has a large positive impact on an increase in the value of the component stocks in the ETFs basket. Harada and Okimoto (2019) point out that when the BOJ purchases ETFs, the Nikkei 225 component stocks' afternoon returns are significantly higher than the returns in the morning session, and also higher than those of non-Nikkei 225 stocks. Critics argue that the BOJ's program of ETFs buying raises concern on distorting influence the stock market in terms of artificially inflating valuations [(4)]. Hanaeda and Serita (2017) suppose that the BOJ's

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(3) Bank of Japan Governor Haruhiko Kuroda said at a press conference held on June 2016 after the monetary policy meeting.

(4) See Andrew Whiffin, "BoJ's Dominance over ETFs Raises Concern on Distorting Influence," Financial Times (21 March 2019).

intervention insignificantly increases the volatility of stocks in a short-term period, however, they lower the volatility of underlying stocks in Nikkei 225 index in a longer-term period like a monthly base. Moreover, they point out that the BOJ ETF purchasing program also temporarily affects the ETFs' price driving the market price to increase and deviate further from NAV due to a higher demand for the ETFs.

The COVID-19 pandemic and the ETF market

During the market uncertainty and illiquidity resulting from the COVID-19 outbreak, the ETF becomes an important asset class because of its high liquidity and well diversification. Investors increasingly turn to ETFs more than individual stocks in a period of market stress seeing that ETF trading volumes have risen both in the aggregate and as a percentage of equity market volumes. Equity ETFs listed in Japan had net inflows for the year to July 2020 amounting to ¥4.8tn much higher than the ¥2.8tn net inflows equity products had in the year to July 2019 as investors would like to lower their investment risks by investing in well-diversified portfolio and high liquidity securities.

Ben-David et al. (2018) provides empirical evidence that there is a larger impact of ETF holding on the stock return volatility during the global financial crisis in 2008. However, during the sluggish market due to the COVID-19, trading in the underlying market is impaired which affects the intensity of ETF arbitrage. For a part of how central banks respond to the spread of COVID-19, the Bank of Japan has enhanced monetary easing since March 2020 through the large-scale provision of liquidity including asset purchases to stabilize financial markets. One of them is an active purchase of ETFs to prevent the negative sentiment from deteriorating through volatility in financial markets, thereby supporting the market value and reducing the volatility.

1.2 Objectives and contributions

The ETF arbitrage has been proved by many researchers that it has an unintended impact on the ETFs' basket where it can improve the price discovery. In the meantime, it deteriorates the stocks' return volatility. The first purpose of this paper is to study the negative impact of ETFs on the Japanese stock market as suggested by Ben-David et al. (2018) who study this impact on the US stock market. I therefore study that the higher proportion of ETFs holding on the underlying stocks causes higher intraday volatility of that stocks. Moreover, I study that the intensity of ETF arbitrage magnifies the effect and causes higher intraday volatility. The ETF arbitrage is proxied by the difference between the ETF closing price and it's NAV, divided by the closing price of ETF, and multiplied by the holding amount of ETF on the stocks (it was later called "stock-level mispricing"). However, it involves higher cost for arbitrageurs when ETFs are traded at discount relative to when ETFs are traded premium. Therefore, I take the sign of stock-level mispricing into account and additionally study its impact.

The second objective is to test the direct effect of the Bank of Japan intervention (BOJ ETFs purchases) on intraday volatility of the component stocks and test its indirect effect on intraday volatility through the stock-level mispricing. In other word, I study how BOJ intervention changes the relationship between the stock-level mispricing and intraday volatility. According to Hanaeda and Serita (2017), there is a higher demand for ETFs on the intervention days driving the ETF price deviates further from NAV and higher arbitrage activity. Therefore, the intervention may indirectly cause volatility to increase through higher arbitrage activity. In addition, the prior study from Shirota (2018) finds the empirical evidence that there is an impact from the BOJ intervention only when the amount of ETFs purchases is large enough. Thus, I test the impact of the size of BOJ ETFs purchases on intraday volatility and its indirect impact through the stock-level mispricing by using the dummy variables to capture the days that BOJ purchases ETFs with the different upper limit of ETF purchase announced by BOJ. This is because BOJ keep increasing the upper limit of the ETF purchases and doubling the purchase during the COVID-19 outbreak. I therefore use the dummy variable to capture the different size of BOJ ETFs purchases and test its effect on intraday volatility.

The third objective of this paper is to test the direct impact of COVID-19 pandemic on intraday volatility and its indirect effect on intraday volatility through the stock-level mispricing. I hypothesize this relationship because the stock market is normally more volatile during the market stress. However, ETFs may become a source of stability due to an illiquidity of stock market during the crisis. Investors trade ETFs for transparency, liquidity, and price discovery rather than for an arbitrage profit. Therefore, the ETF arbitrage may have less impact on volatility during COVID-19 crisis.

Therefore, this paper contributes to the literature of ETFs in the following ways. First, this paper is the first paper studying the negative impact of ETF arbitrage activity in the Japanese stock market, and the effect of the BOJ ETFs purchases on the intraday volatility. The results of this paper would shed further light on empirical evidence of negative side effect of ETF mechanic in such a way that it deteriorates the market function by being a source of nonsystematic risk and driving the underlying stocks become more volatile in a short period. Second, based on my best knowledge, these impacts during the outbreak of the Coronavirus disease which globally suffers the stock market have not yet been examined in any papers. Thus, this paper is the first paper answering whether how ETF arbitrage activity affects volatility when ETFs are in high demand during the COVID-19 period. Finally, this paper can make the awareness of the policy makers and/or investors on the impact of ETFs and the unconventional monetary policy because ETFs could increase risk through the ETF arbitrage.

2. Literature review

To examine the liquidity trading hypothesis, Ben-David et al. (2018) study the effect of ETF ownership on the volatility of the underlying shares from 454 distinct equity ETFs traded on the major U.S. exchanges and only contain U.S. stocks for a 15-year period from January 2000 to December 2015. They estimate by using OLS regression and included month fixed effect and stock fixed effect. The result indicates that the relationship between ETF ownership and volatility is positive and strongly statistically significant. Intuitively, the more percentage that ETFs hold on the stock, the more volatility of that stock's return. However, the impact is weaker but still significant in the smaller stocks and out of the financial crisis period. They explain by the idea that smaller firms are traded less frequently so they have less impact from the ETF arbitrage activity and to minimize transaction costs, arbitrageurs normally focus on the large-cap stocks in the ETF baskets when constructing a replicating portfolio.

While during the crisis, a market, in general, is illiquid hence ETF arbitrage has more impact on stock prices. Moreover, Ben-David et al. (2018) also highlights that the coefficient of the intensity of arbitrage activity at day t proxied by the absolute mispricing at day t-1 is significantly positive meaning the intensity of arbitrage activity increases the volatility given level of ETF holding.

Due to arbitraging ETFs against the NAV, Xu and Yin (2017) argue that the trading volume of S&P 500 ETFs correlates with the index volatility. The slope of the index realized variance which is a proxy of volatility becomes steeper after the ETF was introduced to the financial market. In other words, ETFs' trading volume determines the volatility of the index. Moreover, the GARCH (1,1) estimation which calculates the trend of conditional variance of the S&P 500 index also shows a similar outcome. Wang and Xu (2019) show evidence from the emerging market in China that the daily ETF flows significantly increase total volatility and fundamental volatility of the underlying index in the next trading day. Total volatility is measured by the total change of return over a period, while fundamental volatility is the change driven by the relevant and available information. Furthermore, they point out that a greater today ETF mispricing (arbitrage opportunity) simulates APs to create or redeem ETF share to earn an arbitrage profit beyond their role as market makers and hence it intensifies the impact of ETF flows on the index volatility. Da and Shive (2018) study the effect of US equity ETFs on asset prices and provide the empirical evidence that the arbitrage activity between ETFs and their underlying portfolio transmits nonfundamental shocks from the ETFs to the underlying basket of shares. Consequently, the more ETF ownership, the higher co-movement of the stocks in its portfolio.

While other streams of literature pose that the ETF activity increases price efficiency since it incorporates public information more quickly and transmits that systematic information to its underlying securities. Therefore, ETF can improve price discovery of the underlying stocks (Li and Zhu (2019); Madhavan and Sobczyk (2016); Glosten et al. (2021)). However, Ben-David et al. (2018) express a different viewpoint and provide evidence of a price reversal in the 40 days after the demand shocks in the ETF market, supporting the conjecture that ETF increases volatility and ruling out the conjecture that ETF improves price discovery.

For the unconventional monetary policy conducted by the Bank of Japan, several research papers study the impact of the BOJ ETFs purchase on the Japanese stock exchange. Fueda-Samikawa and Tetshushi (2017) argue that the BOJ ETFs purchase not only prevents the stock price from declining but also increases the opportunities for arbitraging which may deteriorate the market function. Charoenwong et al. (2019) regress time-series portfolio return using Newey-West standard error with five lags from 15 December 2010 to 31 March 2018 and point out that the daily returns on a portfolio of stocks in the baskets of ETFs purchased by the BOJ is small but statistically and significantly higher than a portfolio that contain other stocks in the Japanese stock exchange. Moreover, they further study the impact of the BOJ ETFs purchase on the stock volatility in the cross-section, divided into upside and downside volatility. The result shows that the BOJ ETFs purchase in month t, measured by the total amount of the BOJ ETFs purchase of stock i in month t and scaled by total market capitalization in yen of stock i in the previous month, insignificantly increase the stock monthly upside volatility and decrease the stock monthly downside volatility. It indicates that the BOJ ETFs purchase positively affect the stock valuation but do not eliminate the systematic volatility. Barbon and Gianinazzi (2019) perform the event studies of two days before and after the BOJ announcement to purchase the ETFs tracked TOPIX index. The prices of the stocks held by the ETFs change upward following the BOJ announcement. They extend the scope to test the event studies for a longer period of time to see the persistent impact such as one-month period before and after the announcement. The result can be concluded that the impact of the monetary policy is persistent and increasing over time both in the cross-section and in the time-series, hence it can decrease the cost of capital of domestic firms.

Hanaeda and Serita (2017) study the characteristics of the deviations of the Nikkei ETFs using penal data and regress the deviations on two dummy variables of the date of BOJ ETFs purchase and the date of no BOJ ETFs purchase. They conclude that on the day that the BOJ purchases ETFs, the market price of the ETFs positively deviates further from the NAV per unit compared to the day without the BOJ ETFs purchase, meaning that the unconventional monetary policy conducted by the BOJ makes upward price pressure of the ETFs. However, the impact is not persistent. Moreover, they also argue for the daily data that the dummy variable, represented the days that the BOJ purchases ETFs, and the larger fraction of holding by Nikkei 225 ETFs increase the volatility of the underlying stocks. Contrastingly, the result shows a negative coefficient for the impact of the BOJ intervention on the volatility for the monthly data. As a result, the BOJ succeeds in reducing the market volatility in the long-term.

Harada and Okimoto (2019) use a difference-in-difference methodology to assess the influence of the BOJ's purchasing of Nikkei 225 ETFs on the underlying stocks by comparing the performance of the stocks in the Nikkei 225 ETFs and the stocks that are not in the Nikkei 225 index focusing on the 5-year period after the introduction of Quantitative and Qualitative Easing in 2013. They examine the return of the Nikkei 225 component stocks in the afternoon session because the BOJ normally intervenes in the afternoon after the market's performance seems severe in the morning session as argued by Fueda-Samikawa and Tetshushi (2017). The result suggests that the stocks on the Nikkei 225 index have higher afternoon return relative to the stocks outside the Nikkei 225 index when the BOJ purchases the Nikkei 225 ETFs. Shirota (2018) evaluate the effect of the unconventional monetary policy on the Japanese stock market by using the probit model and find that the causal interventions have statistically significant positive effects on stocks' price only when the amount of ETFs purchases is large enough and the effect is only significant on the intervention date and do not last unit the next day.

3. Data

3.1 Data and Data source

This paper focuses on the ETFs that track the Nikkei 225 index and their underlying stocks to study the impact of ETF arbitrage mechanism and the BOJ's unconventional monetary policy on volatility of the component stocks. Nikkei 225 ETFs are considered in this study because first, the stocks in the Nikkei 225 index have high liquidity relative to stocks in other indices in the Japanese stock exchange. Second, Nikkei 225 ETFs hold a smaller number of stocks compared to TOPIX index ETFs are JPX-Nikkei 400 index ETFs which are broader. Therefore, the effect of Nikkei 225 ETFs on individual stocks is large enough to see the relation of interest because each Nikkei 225 ETF hold a large enough fraction on the underlying stocks.

Moreover, according to the prior study, Shirota (2018) argues that the impact is only significant when the amount of ETFs purchases is large enough. Therefore, I focus on the sample period started from 5 April 2013 to 31 December 2020 which is after the implementation of the Quantitative and Qualitative Easing (QQE). The ETF purchase program has been operated more aggressively where the frequency of ETF purchases nearly tripling after the introduction of QQE. Therefore, the selected Nikkei 225 ETFs including those ETFs that have inception's date before 5 April 2013. The frequency of observations is daily which is high enough to measure high frequency of arbitrage activity.

All data used is retrieved from Bloomberg. The data of the Nikkei 225 ETFs which used to compute the stock-level mispricing and the proportion of ETF holding in the underlying stocks includes the ETF closing price, NAV, daily market capitalization of stocks, daily asset under management (AUM) of ETFs and daily weight on each constituent security. The data used to compute the intraday volatility, a dependent variable, includes daily highest price and daily lowest price. The other information including closing price and trading volume of stocks is used to compute the control variables.

The information of BOJ ETFs purchase is collected from the Bank of Japan Website and can be summarized as follow:

Dummy Variable	**Periods**	**ETFs Purchase Policy**	**The annual upper limit**	**Number of interventions**	**Average purchases**
			(trillion Yen)	*(day)*	*(100 million Yen)*
QQE1	5 Apr 2013 - 31 Oct 2014	proportionate to the total market value of the ETFs	1	113	155.90
QQE2	1 Nov 2014 - 29 Jul 2016		3	154	348.53
QQE3	30 Jul 2016 - 15 Mar 2020	25% for ETFs that track any of the three indices (TOPIX, Nikkei 225 or JPX-Nikkei 400) and 75% for the broader TOPIX ETFs	6	279	717.78
QQE4	16 Mar 2020 - 31 Dec 2020		12	51	1,031.41

3.2 Variable used

Measure the stock-level mispricing, a proxy of ETF arbitrage in a level of the underlying stock

The best proxy used to measure the arbitrage activity is the ETF mispricing which is deviation between the ETF price and its NAV. However, the larger ETF mispricing could instead be a proxy for the larger limit to arbitrage because the arbitrage activity theoretically converts the market price of both ETFs and the underlying stocks to fundamental value meaning that the market price of ETFs and the NAV should be closer to each other. Therefore, to mitigate this concern and endogeneity problem, Ben-David et al. (2018) use lagged ETFs mispricing as a proxy for arbitrage and calculate this mispricing on the level of the underlying stocks to study the impact on the intraday volatility of stocks. As a result, the arbitrage activity on the stock-level will be measured by summation of absolute yen ETF mispricing divided by the ETF price, and multiplied by the yen ETF holding in the stock across all ETFs holding in stock i, and expressed as a fraction of a stock's market capitalization.

$$|ETF\ mispricing|_{j,t} = \frac{\left|(the\ ETF\ daily\ closing\ price_{j,t} - the\ NAV_{j,t})\right|}{the\ ETF\ daily\ closing\ price_{j,t}} \quad (1)$$

$$|MispriceStock|_{i,t} = \frac{\sum_{j=1}^{J}(w_{i,j,t} * AUM_{j,t} * |ETF\ mispricing|_{j,t})}{the\ market\ capitalization\ of\ stock_{i,t}} \quad (2)$$

Where $w_{i,j,t}$ is the fund portfolio weight of ETF j in stock i and $AUM_{j,t}$ is the asset under management of ETF j.

Measure ETF holding, the fraction ETFs hold in the underlying stocks

To separate the liquidity trading from the price discovery hypothesis, Ben-David et al. (2018) examine that higher ETFs holding in stock has higher effect on the price volatility of the stock. The fraction held by ETFs is estimated by:

$$ETFholding_{i,t} = \frac{\sum_{j=1}^{J} w_{i,j,t} AUM_{j,t}}{Mkt\ Cap_{i,t}} \tag{3}$$

Measure the intraday volatility, the regressand

Intraday volatility is used due to the high frequency of arbitrage activity. At a daily frequency, the intraday volatility is computed by the highest price minus the lowest price divided by the average of the two:

$$IntraVol_{i,t} = \frac{MaxPrice_{i,t} - MinPrice_{i,t}}{Average\ (MaxPrice_{it}, MinPrice_{i,t})} \tag{4}$$

Regarding the control variables to avoid potentially omitted variables, I control for stock size and liquidity, which is measured by the logged market capitalization ($LogMktCap$), the inverse share price of stock ($InversePrice$) and the Amihud (2002) illiquidity measure ($ILLIQ$) (Amihud (2002)). The size and liquidity are mostly used by ample studies about volatility because the larger of size the lower risk, and the higher liquidity the lower risk (Cheung and Ng (1992)). Moreover, I include standard predictors of returns that could relate to volatility, such as the past return ($Return$) based on random walk theory that return today is the standard predictor of return tomorrow. The Amihud (2002) illiquidity ratio is calculated by:

$$ILLIQ_{i,t-1} = \frac{\left|Daily\ return\ of\ stock_{i,t-1}\right|}{Daily\ Yen\ trading\ Volume\ of\ Stock_{i,t-1}} \tag{5}$$

3.3 Data descriptive

Table 1 summarizes descriptive statistics on variables used in the regression. The mean of the regressand (IntraVol) is 0.02253 (or 2.253% per day) which means the selected stock daily prices are volatile around 2.253% on average. The mean of the absolute stock-level mispricing is 0.00003 (or 0.003% of the stock market capitalization) indicating that on average the intensity of ETF arbitrage measure on the underlying stock-level is around 0.003% of the stock market capitalization. While the maximum value of the daily intensity of ETF arbitrage is 0.00595 (or 0.59% of the stock market capitalization). It indicates how much short-term traders do intraday arbitrage between ETFs and the constituents. For ETF holding variable, its mean is 0.03468 (or 3.47% of the stock market capitalization). According to Ben-David et al. (2018), the mean of ETFs holding on US stock is around 2.8% of the stock market capitalization. Therefore, the ETFs holding on Japanese stock at 3.47% is large enough to see the impact of ETF mechanism.

Table 1 presents the summary statistics of all variables from 202 stocks in Nikkei 225 index during 5 April 2013 to 31 December 2020, excluding the holidays.

Variables	Obs.	Mean	SD	Min	Max
$\mathrm{IntraVol}_{i,t}$	382,184	0.02253	0.01332	0	0.25316
$\lvert\mathrm{MispriceStock}\rvert_{i,t-1}$	382,184	0.00003	0.00008	0	0.00595
$\mathrm{PositiveMispriceStock}_{i,t-1}$	185,442	0.00002	0.00007	0	0.00595
$\mathrm{NegativeMispriceStock}_{i,t-1}$	196,742	(0.00003)	0.00009	(0.00335)	0
$\mathrm{ETFholding}_{i,t-1}$	382,184	0.03468	0.03511	0.00032	0.23140
$\mathrm{LogMktCap}_{i,t-1}$	382,184	5.91010	0.49845	4.07963	7.47533
$\mathrm{InversePrice}_{i,t-1}$	382,184	0.00066	0.00063	0.00001	0.00704
$\mathrm{ILLIQ}_{i,t-1}$ ($x10^{-6}$)	382,184	0.01346	0.00256	0	1.47861
$\mathrm{Return}_{i,t-1}$	382,184	0.00041	0.02063	(0.25)	0.34247
$\mathrm{IntraVol}_{i,t-1}$	382,184	0.02255	0.01334	0	0.25316

Table 2 summarizes descriptive statistics on variables used in the regression during the COVID-19 pandemic period in which BOJ intensively intervened the ETF market. The mean of intraday volatility is 2.825% per day which is higher than the overall period. This indicates that the intraday price is more volatile during the crisis. The mean and SD of the stock-level mispricing are higher during the crisis comparing to Table 1. It means ETFs are traded at larger discount and premium. Hence, investors have higher opportunity for arbitrage activity between ETFs and the constituents during the COVID-19. Considering Table 1 and Table 2, I observe the change of statistics on each variable. Therefore, the relationship between intraday volatility and the stock-level mispricing when BOJ intensively intervened the ETF market due to the COVID-19 possibly differs from non-crisis periods.

Table 2 presents the summary statistics of some variables during COVID-19 period in which BOJ intensively intervened the ETF market from 1 March 2020 to 31 December 2020.

Variables	Obs.	Mean	SD	Min	Max
$\mathrm{IntraVol}_{i,t}$	41,612	0.02825	0.01707	0	0.25058
$\lvert\mathrm{MispriceStock}\rvert_{i,t-1}$	41,612	0.00005	0.00017	0	0.00595
$\mathrm{PositiveMispriceStock}_{i,t-1}$	18,172	0.00005	0.00022	0	0.00595
$\mathrm{NegativeMispriceStock}_{i,t-1}$	23,440	(0.00004)	0.00012	(0.00335)	0
$\mathrm{ETFholding}_{i,t-1}$	41,612	0.04503	0.04207	0.00084	0.22230

Based on Table 3, the stock-level mispricing and the ETF holding variables have positive correlation with intraday volatility. It can partly make a prediction without having to do regression that the stocks held by higher ETFs have higher intraday volatility due to arbitrage mechanism. Interestingly, the lagged positive stock-level mispricing has stronger positive relationship with intraday volatility relative to the lagged negative stock-level mispricing. This correlation result implies that the different sign of net mispricing has difference in impact on intraday volatility. This is because the negative sign of net mispricing (i.e. ETFs are traded at discount) involves short sale

Table 3 presents the correlation matrix between variables during 5 April 2013 - 31 December 2020.

	$IntraVol_{i,t}$	$\|MispriceStock\|_{i,t-1}$	$ETFholding_{i,t-1}$	$LogMktCap_{i,t-1}$	$InversePrice_{i,t-1}$	$ILLIQ_{i,t-1}$	$Return_{i,t-1}$	$IntraVol_{i,t-1}$
$IntraVol_{i,t}$	1.00000							
$\|MispriceStock\|_{i,t-1}$	0.13513	1.00000						
$ETFholding_{i,t-1}$	0.05276	0.33729	1.00000					
$LogMktCap_{i,t-1}$	-0.19779	-0.09577	-0.23782	1.00000				
$InversePrice_{i,t-1}$	0.09814	-0.05266	-0.19734	-0.29887	1.00000			
$ILLIQ_{i,t-1}$	0.12492	0.09936	0.21468	-0.32834	-0.13983	1.00000		
$Return_{i,t-1}$	-0.04388	-0.04659	0.00312	0.00884	-0.01285	0.01975	1.00000	
$IntraVol_{i,t-1}$	0.51846	0.14068	0.05218	-0.19812	0.09880	0.25118	-0.01435	1.00000

	$IntraVol_{i,t}$	Positive Misprice Stock $_{i,t-1}$	ETF $holding_{i,t-1}$
$IntraVol_{i,t}$	1.00000		
$PositiveMispriceStock_{i,t-1}$	0.20663	1.00000	
$ETFholding_{i,t-1}$	0.03631	0.27919	1.00000

	$IntraVol_{i,t}$	Negative Misprice Stock $_{i,t-1}$	ETF $holding_{i,t-1}$
$IntraVol_{i,t}$	1.00000		
$NegativeMispriceStock_{i,t-1}$	-0.05595	1.00000	
$ETFholding_{i,t-1}$	0.07047	-0.31550	1.00000

underlying stocks which is costly relative to the positive sign of net mispricing (i.e. ETFs are traded at premium). Therefore, the negative sign of net mispricing represents a failure of ETF arbitrage mechanism. Then, the correlation with intraday volatility shows the opposite direction.

Considering the correlations among independent variables from Table 3, it can be implied that there is no multicollinearity problem to concern because there is no pair of variables that has correlation higher than 0.8 which is the rule of thumb for severe multicollinearity.

4. Methodology

4.1 Measuring impact of ETF arbitrage mechanism on intraday volatility

The Regression model from Ben-David et al. (2018) has been adopted to examine the impact of the ETF arbitraging activity on the volatility. The daily frequency is tested to timely measure high-frequency fluctuation in arbitrage activity. Besides, the intraday volatility is regressed on the lagged explanatory variables because they are computed by the daily closing data so the explanatory variables on a given day is a good predictor of the next day. Moreover, the usual control variables that explain the price volatility including lagged Amihud's (2002) illiquidity ratio (ILLIQ) measuring the liquidity, lagged of logged market capitalization measuring firm's size, and lagged inverse of the stock price are incorporated to mitigate the endogeneity problem. In addition to the usual control variables, I include lagged intraday volatility to capture the persistency. Therefore, the identification of determinant of the volatility is based on the following multivariate model *(Equation 6)*:

$$\begin{aligned}\text{IntraVol}_{i,t} = {} & \beta_0 + \beta_1|\text{MispriceStock}|_{I,t-1} + \beta_2\text{ETFholding}_{I,t-1} + \beta_3\text{LogMktCap}_{I,t-1} + \\ & \beta_4\text{InversePrice}_{I,t-1} + \beta_5\text{ILLIQ}_{I,t-1} + \beta_6\text{Return}_{I,t-1} + \beta_7\text{IntraVol}_{I,t-1} + \\ & \text{Stock fixed effects} + \text{Day fixed effects} + \varepsilon_{i,t}\end{aligned} \tag{6}$$

Where i represents each stock held by the Nikkei 225 ETFs and t represents daily data from April 5, 2013 to December 31, 2020.

I use panel data analysis of the individual stocks in the Nikkei 225 ETFs across the sample period and use Hausman test to see whether the panel data fits random effects or fixed effects better. Hausman test result as shown below suggests that the data fits with fixed effects better because the null hypothesis is rejected. Then, I use fixed effect estimator to estimate coefficients by including stock and day fixed effects to mitigate endogeneity problem.

Hausman Test result:

Test of H0: Difference in coefficients not systematic
chi2(7) = 11775.22
Prob > chi2 = 0.0000

From Equation 6, β_1 captures the relationship between ETF arbitraging activity, proxied by the stock-level mispricing, and intraday volatility. If β_1 turns positive, it can be concluded that intraday arbitrage between ETFs and the underlying stocks causes higher intraday volatility of the underlying stocks which is consistent with the evidence from Ben-David et al. (2018). For the coefficient of ETF holding (β_2), it captures the relationship between ETF ownership of the underlying stocks and intraday volatility. If $\beta_2$is positive, it means that ETFs cause higher intraday volatility because superior liquidity of ETFs induce volatility into the underlying stocks through the arbitrage mechanism. This situation called liquidity trading hypothesis (Ben-David et al. (2018)). However, if $\beta_2$turns negative, it means that ETFs reduce intraday volatility of the underlying stocks. The negative coefficient of ETF holding is consistent with Box et al. (2021) who argue that ETFs are source of stability because investors trade ETFs for transparency and price discovery rather than arbitrage trading. Therefore, ETFs instead shield the underlying stocks from demand shock. The volatility of underlying stock then reduces.

Next, I separate the sign of mispricing. Although, the arbitrage trade involves a round-trip transaction in the underlying stocks, arbitragers may abstain from entering the market to earn a risk-free profit if arbitrage costs are too high and results in less profitability from arbitrage trading (Cohen et al. (2007)). For example, when

ETF shares are traded at discounted and an arbitrage activity involves shorting the underlying stocks, it discourages arbitragers if a stock lending fee is too high. It means that arbitrage transactions may not be able to carry out by some arbitrageurs. Therefore, I expect the negative stock-level of net mispricing to have less impact on intraday volatility comparing to the positive stock-level of net mispricing. The model is adjusted by separating the sign of net mispricing, and regress sub-sample by fixed effects estimator.

4.2 Measuring direct and indirect impact of BOJ intervention on intraday volatility

I add the dummy variable to capture the days that BOJ intervenes the ETF market to study that the intraday volatility of the underlying stock is higher due to the intervention because based on the empirical evidence of Shirota (2018), purchasing ETFs by the BOJ has significant impact on stocks' price only on the intervention date and do not last unit the next day. Moreover, I also add the variable interacting between the dummy variable that capture the intervention days and the stock-level mispricing because Hanaeda and Serita (2017) argue that the BOJ's unconventional monetary policy creates a larger deviation between the market price of ETF and the NAV on the date that the BOJ purchases ETFs. I therefore suspect that there is a structural break changing the relationship between the arbitrage activity and the intraday volatility due to the BOJ's intervention. Hence, the adjusted model *(Equation 7)* is as follow:

$$\begin{aligned} \mathrm{IntraVol}_{i,t} = {} & \beta_0 + \beta_1 |\mathrm{MispriceStock}|_{i,t-1} + \beta_2 \mathrm{ETFholding}_{i,t-1} + \beta_3 \mathrm{BOJ}_t + \\ & \beta_4 |\mathrm{MispriceStock}|_{i,t-1} \mathrm{BOJ}_{t-1} + \beta_{5-8} \mathrm{ControlVariables}_{i,t-1} + \beta_9 \mathrm{IntraVol}_{i,t-1} + \\ & \text{Stock fixed effects} + \text{Day fixed effects} + \varepsilon_{i,t} \end{aligned} \tag{7}$$

Where BOJ is the dummy variable, taking value 1 if the BOJ purchases ETF on the day t, and 0 otherwise.

From Equation 7, β_3 captures the impact of BOJ intervention on intraday volatility. If β_3 is positive, it means the intraday stock price is more volatile on the days that BOJ indirectly purchases stocks through ETFs. It will be consistent with the previous study from Hanaeda and Serita (2017). For the coefficient of the interaction term (β_4), it captures the incremental effect of ETF arbitraging activity on intraday volatility due to the impact of BOJ intervention. If β_4 turns positive, it means BOJ intervention creates larger arbitrage activity between ETF and the underlying stock which consequently causes higher volatility of the underlying stocks. However, the β_4 may turn negative meaning that BOJ intervention help to reduce the impact of ETF arbitraging activity on intraday volatility. The negative coefficient of the interaction term will be consistent with the objective of Bank of Japan intervention because BOJ tends to purchase ETFs during the downturn market to stabilize the stock market.

I additionally take into account the sign of mispricing and separately regress sub-sample of the positive and negative stock-level of net mispricing. This is because the different signs of ETF mispricing involve different arbitrage strategies between ETFs and the underlying stocks. Therefore, BOJ intervention may have the difference in impact on the different sign of ETF mispricing and indirectly causes different impact on intraday volatility. The coefficient of interaction term (β_4) then differ between the cases of positive and negative mispricing.

4.3 Measuring direct and indirect impact of the scale of BOJ ETFs purchase on intraday volatility and impact of BOJ intervention during COVID-19

I divide the BOJ's intervention into 4 periods following the annual purchasing target announcing by the BOJ to study whether the increase of the upper limit ETF purchases distorts the market mechanism and leads to a rise in volatility. In contrast, it may lower volatility as the expectation of the central bank to stabilize the stock market. I adjust the model to control for the days that the BOJ purchases ETFs in each period of the upper limit announcement by creating dummy variables and interact with the stock-level mispricing. The fixed effects model *(Equation 8)* of the intraday volatility determinants is as follow:

$$\begin{aligned} \mathrm{IntraVol}_{i,t} = {} & \beta_0 + \beta_1|\mathrm{MispriceStock}|_{i,t-1} + \beta_2\mathrm{ETFholding}_{i,t-1} + \beta_3\mathrm{QQE1}_t + \beta_4\mathrm{QQE2}_t + \\ & \beta_5\mathrm{QQE3}_t + \beta_6\mathrm{QQE4}_t + \beta_7|\mathrm{MispriceStock}|_{i,t-1}\mathrm{QQE1}_{t-1} + \\ & \beta_8|\mathrm{MispriceStock}|_{i,t-1}\mathrm{QQE2}_{t-1} + \beta_9|\mathrm{MispriceStock}|_{i,t-1}\mathrm{QQE3}_{t-1} + \\ & \beta_{10}|\mathrm{MispriceStock}|_{i,t-1}\mathrm{QQE4}_{t-1} + \beta_{11-14}\mathrm{ControlVariables}_{i,t-1} + \beta_{15}\mathrm{IntraVol}_{i,t-1} + \\ & \text{Stock fixed effects} + \text{Day fixed effects} + \varepsilon_{i,t} \end{aligned} \tag{8}$$

Where $QQE1$ represents dummy variables taking value 1 on the days that the BOJ purchases ETF during 5 Apr 2013 - 31 Oct 2014, $QQE2$ takes value 1 on the days that the BOJ purchases ETF during 1 Nov 2014 - 29 Jul 2016, $QQE3$ takes value 1 on the days that the BOJ purchases ETF during 30 Jul 2016 - 15 Mar 2020, and $QQE4$ takes value 1 on the days that the BOJ purchases ETF during 16 Mar 2020 - 31 Dec 2020 which is the COVID-19 period.

From Equation 8, β_3 to β_6 capture the impact of the scale of BOJ ETFs purchase on intraday volatility. If β_4 is significantly larger than β_3, it means that the scale of BOJ ETFs purchase has an impact on intraday volatility of the underlying stocks. However, I expect β_5 to be lowest or have a different sign relative to β_3, β_4, β_6 because β_5 captures the period that the central bank changed the method of ETFs purchase where Nikkei 225 ETFs were only less than 25% of its purchases while TOPIX ETFs made up the remaining 75%. For β_6, it also captures the impact of COVID-19 on intraday volatility. Therefore, if β_6 turns positive, it indicates that the underlying stocks price is more volatile due to the impact from both of BOJ intervention and COVID-19. For the coefficient of the interaction terms (β_7 to β_{10}), they capture the indirect impact of the scale of BOJ ETFs purchase on intraday volatility through ETF arbitraging activity. If β_8 is significantly larger than β_7, it means that the larger amount of BOJ ETFs purchase causes higher intraday volatility through the arbitraging activity between ETFs and the underlying stocks. However, β_{10} also captures the impact of COVID-19. Therefore, if β_{10} turns positive, it means both of BOJ intervention and COVID-19 crisis causes an incremental impact on intraday volatility through ETF arbitraging activity.

The sign of net mispricing is considered as 4.1 and 4.2 to study the indirect impact of the scale of BOJ ETFs purchase on intraday volatility through the ETF arbitrage activity.

5. Empirical results

5.1 Measuring impact of ETF arbitrage mechanism on intraday volatility

Column (1) and (2) of the table 4 reports regression results from Equation 6. The relationship between ETF holding and intraday volatility is positive and statistically significant at 1% level. It indicates that ETF mechanic increases intraday volatility of the underlying stock which is consistent with the evidence from Ben-David et al. (2018).

Table 4: The impact of ETF arbitrage on intraday volatility.

The table represents estimates from the regressions of intraday volatility on the lagged absolute stock-level mispricing and the ETF holding by using Equation 6 with firm and day fixed effects:

$\mathrm{IntraVol}_{i,t} = \beta_0 + \beta_1|\mathrm{MispriceStock}|_{i,t-1} + \beta_2\mathrm{ETFholding}_{i,t-1} + \beta_3\mathrm{LogMktCap}_{i,t-1} + \beta_4\mathrm{InversePrice}_{i,t-1} + \beta_5\mathrm{ILLIQ}_{i,t-1} + \beta_6\mathrm{Return}_{i,t-1} + \beta_7\mathrm{IntraVol}_{i,t-1}$ + Stock fixed effects + Day fixed effects + $\varepsilon_{i,t}$

The frequency is daily, and observations are at the stock level, including 202 stocks in Nikkei 225 index during 5 April 2013 to 31 December 2020, totaling 1,892 business days. In columns (2) and (3), I restrict the sample to observations for which the stock-level mispricing is positive and negative, respectively. The controls include logged market capitalization, the lagged inverse share price, the lagged Amihud (2002) illiquidity ratio, the lagged return and the lagged dependent variable. The t-statistics are presented in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

Dependent Variable:	Intraday Volatility		
	(1) |MispriceStock|	(2) PositiveMispriceStock	(3) NegativeMispriceStock
Mispricestock (t-1)	1.764***	4.712***	0.324
	(6.434)	(10.607)	(0.925)
Etfholding (t-1)	0.019***	0.018***	0.020***
	(11.149)	(7.438)	(8.678)
Logmktcap (t-1)	0.001***	0.002***	0.000
	(4.848)	(5.458)	(1.481)
Inverseprice (t-1)	0.777***	0.722***	0.826***
	(9.479)	(6.044)	(7.346)
Illiq (t-1)	-0.009***	-0.008***	-0.010***
	(-11.753)	(-7.273)	(-9.524)
Return (t-1)	0.010***	0.010***	0.011***
	(10.892)	(7.046)	(8.534)
Intravol (t-1)	0.266***	0.265***	0.267***
	(165.091)	(115.110)	(117.948)
Constant	0.033***	0.029***	0.139***
	(24.275)	(15.444)	(15.340)

(Continued)

Table 4: The impact of ETF arbitrage on intraday volatility. *(Continued)*

The table represents estimates from the regressions of intraday volatility on the lagged absolute stock-level mispricing and the ETF holding by using Equation 6 with firm and day fixed effects:

$\mathrm{IntraVol}_{i,t} = \beta_0 + \beta_1|\mathrm{MispriceStock}|_{i,t-1} + \beta_2\mathrm{ETFholding}_{i,t-1} + \beta_3\mathrm{LogMktCap}_{i,t-1} + \beta_4\mathrm{InversePrice}_{i,t-1} + \beta_5\mathrm{ILLIQ}_{i,t-1} + \beta_6\mathrm{Return}_{i,t-1} + \beta_7\mathrm{IntraVol}_{i,t-1}$ + Stock fixed effects + Day fixed effects + $\varepsilon_{i,t}$

The frequency is daily, and observations are at the stock level, including 202 stocks in Nikkei 225 index during 5 April 2013 to 31 December 2020, totaling 1,892 business days. In columns (2) and (3), I restrict the sample to observations for which the stock-level mispricing is positive and negative, respectively. The controls include logged market capitalization, the lagged inverse share price, the lagged Amihud (2002) illiquidity ratio, the lagged return and the lagged dependent variable. The t-statistics are presented in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

Dependent Variable:	Intraday Volatility		
	(1) |MispriceStock|	(2) PositiveMispriceStock	(3) NegativeMispriceStock
Stock fixed effects	YES	YES	YES
Day fixed effects	YES	YES	YES
Observations	382,184	185,442	196,742
Adjusted R-squared	0.498	0.526	0.465

The plausible explanation is that ETFs attract short-horizon liquidity traders due to their low trading cost and the liquidity shocks is propagated to the underlying stock through arbitrage channel. Therefore, stocks held by larger ETFs have higher volatility as they expose to ETF arbitraging activity.

For the direct impact of the intensity of ETF arbitrage, $\beta_1$in column (1) and (2) is statistically positive at 1% significant level. It can be inferred that the arbitraging activity between ETFs and the underlying stocks, as proxied by absolute and positive sign of net mispricing, has an incremental effect on intraday volatility of the underlying stocks for a given level of ETF holding. The positive and significant link of ETF arbitrage activity and intraday volatility provides evidence in support of the liquidity trading hypothesis and Ben-David et al. (2018). ETF arbitrage creates price pressure on the underlying stocks from liquidity trading when a non-fundamental shock hits the ETF market. Therefore, it consequently causes higher intraday volatility of the underlying stocks.

Interestingly, the coefficient of the lagged negative stock-level of net mispricing ($\beta_1$in column (3) of Table 4) is positive but insignificant meaning that ETF arbitrage does not cause higher intraday volatility when ETFs are traded at discount. This result confirms that the mispricing sign is a signal on which arbitrageurs condition their trading strategies because the size of ETF mispricing when ETF are traded at a premium and at a discount does not differ significantly. This result also supports to the view of Cohen et al. (2007) that arbitragers will not enter the market to earn a risk-free profit if arbitrage costs are too high. The negative stock-level of net mispricing (i.e., ETFs are traded at discount) involves short sale the ETF components which is more costly relative to the positive stock-level of net mispricing (i.e., ETFs are traded at premium). Therefore, the negative ETF mispricing represents a failure of ETF arbitrage or a limitation of ETF arbitrage. Then, the intensity of ETF arbitrage measured by the negative stock-level of net mispricing has no or less impact on intraday volatility.

Considering of the coefficient of controls variables, the results suggest that they strongly significant associate with intraday volatility meaning the control variables capture the variation in intraday volatility. The logged market capitalization (β_3) indicates the size of the firms. It has significantly positive relationship with the intraday volatility at 1% significant level, supporting that the larger firm has higher intraday volatility due to the higher liquidity and higher intraday trading volume (Osborne (1959)). The coefficient of the lagged inverse of share price (β_4) is positive statistically significant at 1% level. This result supports the view that the stock price and volatility are inversely related as high volatility indicates high uncertainty and high required return (Cheung and Ng (1992)). The lagged Amihud (2002) illiquidity ratio (β_5) has strongly negative relationship at 1% significant level with intraday volatility. It means Amihud (2002) illiquidity ratio causes lower intraday volatility. This result is supported by Osborne (1959) who found positive correlation between the absolute value of daily price changes and daily volume for both market indices and individual stocks. In addition, I also include the return on the stock on day t-1 (β_6) and lagged intraday volatility (β_7) to control for autocorrelation in intraday volatility. The results suggest that these controls enhance the explanatory power over intraday volatility which is consistent with the evidence from Ben-David et al. (2018).

5.2 Measuring direct and indirect impact of BOJ intervention on intraday volatility

Table 5 presents the results from fixed effects regression where I include stock and day fixed effects. The coefficient of BOJ (β_3) is strongly negative at 1% significant level, suggesting that intraday volatility decreases on the days that BOJ purchases ETFs. This result provides evidence in support of the studies from Hanaeda and Serita (2017); Barbon and Gianinazzi (2019); Harada and Okimoto (2019). It is also in line with the objective of the BOJ's unconventional monetary policy that the Bank of Japan looks to intervene to stabilize markets. The plausible explanation provided by Shirota (2018) is that BOJ tends to indirectly purchases stocks through ETFs when the market is likely to be in a downturn to create a demand pressure effect in stock price and causes stability to the stock market.

The indirect impact of BOJ intervention on intraday volatility through ETF arbitrage is captured by β_4. The β_4 in Table 6 is negative and statistically significant at 10% for the absolute stock-level mispricing and 1% for the positive and negative stock-level mispricing. These results indicate that the BOJ's unconventional monetary policy causes ETF arbitrage activity to have less impact on intraday volatility. In other word, BOJ intervention reduces intraday volatility of the underlying stocks through the failure of ETF mechanism. It is possibly due to the fact that BOJ purchases ETFs for long-term investment to lower market volatility, not for a short-term arbitrage trading. Although the intervention creates demand shocks in the ETF market (Hanaeda and Serita (2017)) it does not induce traders to do arbitrage during the downturn market. The negative relationship between the stock-level mispricing and intraday volatility would also be consistent with Box et al. (2021). They find the empirical evidence that greater liquidity

Table 5: The impact of Bank of Japan intervention on intraday volatility and ETF arbitrage.

The table represents estimates from the regressions of intraday volatility on the dummy variable BOJ, capturing the days that BOJ purchases ETFs and the interaction term between the absolute stock-level mispricing and the dummy variable BOJ by using Equation 7 with firm and day fixed effects:

$$IntraVol_{i,t} = \beta_0 + \beta_1|MispriceStock|_{i,t-1} + \beta_2 ETFholding_{i,t-1} + \beta_3 BOJ_t + \beta_4 |MispriceStock|_{i,t-1} BOJ_{t-1} + \beta_{5-8} ControlVariables_{i,t-1} + \beta_9 IntraVol_{i,t-1} + \text{Stock fixed effects} + \text{Day fixed effects} + \varepsilon_{i,t}$$

The frequency is daily, and observations are at the stock level, including 202 stocks in Nikkei 225 index during 5 April 2013 to 31 December 2020, totaling 1,892 business days. I restrict the sample to observations for which the stock-level mispricing is positive in columns (2), and negative in column in (3). The controls include logged market capitalization, the lagged inverse share price, the lagged Amihud (2002) illiquidity ratio, the lagged return, and the lagged dependent variable. The t-statistics are presented in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

Dependent Variable:	Intraday Volatility		
	(1) |MispriceStock|	(2) PositiveMispriceStock	(3) NegativeMispriceStock
Mispricestock (t-1)	2.235***	7.523***	0.901**
	(6.790)	(10.203)	(2.278)
Etfholding (t-1)	0.020***	0.017***	0.020***
	(12.269)	(7.096)	(8.624)
BOJ	-0.027***	-0.020***	-0.130***
	(-29.900)	(-21.695)	(-14.547)
Mispricestockboj (t-1)	-0.991*	-4.137***	-2.281***
	(-1.930)	(-4.767)	(-3.147)
Logmktcap (t-1)	0.001***	0.002***	0.000
	(4.788)	(5.456)	(1.503)
Inverseprice (t-1)	0.770***	0.725***	0.829***
	(9.396)	(6.064)	(7.372)
Illiq (t-1)	-0.009***	-0.008***	-0.010***
	(-11.722)	(-7.152)	(-9.504)
Return (t-1)	0.010***	0.010***	0.011***
	(10.918)	(7.037)	(8.561)
intravol (t-1)	0.266***	0.265***	0.267***
	(165.145)	(115.084)	(117.922)

(Continued)

Table 5: The impact of Bank of Japan intervention on intraday volatility and ETF arbitrage. *(Continued)*

The table represents estimates from the regressions of intraday volatility on the dummy variable BOJ, capturing the days that BOJ purchases ETFs and the interaction term between the absolute stock-level mispricing and the dummy variable BOJ by using Equation 7 with firm and day fixed effects:

$$\text{IntraVol}_{i,t} = \beta_0 + \beta_1|\text{MispriceStock}|_{i,t-1} + \beta_2\text{ETFholding}_{i,t-1} + \beta_3\text{BOJ}_t + \beta_4|\text{MispriceStock}|_{i,t-1}\text{BOJ}_{t-1} + \beta_{5-8}\text{ControlVariables}_{i,t-1} + \beta_9\text{IntraVol}_{i,t-1} + \text{Stock fixed effects} + \text{Day fixed effects} + \varepsilon_{i,t}$$

The frequency is daily, and observations are at the stock level, including 202 stocks in Nikkei 225 index during 5 April 2013 to 31 December 2020, totaling 1,892 business days. I restrict the sample to observations for which the stock-level mispricing is positive in columns (2), and negative in column in (3). The controls include logged market capitalization, the lagged inverse share price, the lagged Amihud (2002) illiquidity ratio, the lagged return, and the lagged dependent variable. The t-statistics are presented in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

Dependent Variable:	Intraday Volatility		
	(1) |MispriceStock|	(2) PositiveMispriceStock	(3) NegativeMispriceStock
Constant	0.033***	0.029***	0.139***
	(24.332)	(15.488)	(15.342)
Stock fixed effects	YES	YES	YES
Day fixed effects	YES	YES	YES
Observations	382,184	185,442	196,742
Adjusted R-squared	0.498	0.526	0.465

in the ETF leads to lower volatility in the portfolio and lagged ETF volume is negatively related to future underlying volatility. This is because ETF trading improves price discovery and shields the underlying stocks from demand shocks.

5.3 Measuring direct and indirect impact of the scale of BOJ ETFs purchase on intraday volatility and impact of BOJ intervention during COVID-19

Table 6 presents the regression results of Equation 8 with stock and day fixed effects. The coefficients of QQE1 - QQE4 capture the days that BOJ purchases ETFs with the different level of upper limit amount. Since BOJ keeps increasing the upper limit ETF purchase, QQE1 then represents the days that BOJ purchases ETFs with the lowest amount and QQE4 represents the days that BOJ purchases ETFs with the largest amount. The coefficient of QQE3 captures the period that the central bank changed the method of ETFs purchase where Nikkei 225 ETFs were less than 25% of its purchases while TOPIX ETFs made up the remaining more than 75%. Therefore, QQE3 becomes the dummy variable that captures the lowest amount of BOJ intervention on Nikkei 225 ETFs.

From Table 7, β_4 turns significantly larger negative than β_3 for all three samples meaning that the scale of the intervention has an impact on intraday volatility where the larger the amount that BOJ purchases ETFs the lower the intraday volatility. These results are consistent with the previous study from Shirota (2018) who argues that there is larger demand pressure effect in stock price on the days that BOJ increasingly and indirectly purchases stocks through ETFs. Therefore, the larger the amount of intervention the larger the impact on the stock prices. For β_5, it captures the impact of the lowest amount that BOJ purchases Nikkei 225 ETFs. The results

Table 6: The impact of the scale of BOJ intervention on intraday volatility and ETF arbitrage, and the impact of interest during COVID-19 pandemic.

The table represents estimates from the regressions of intraday volatility on the dummy variable QQE1 - QQE4, capturing the days that BOJ purchases ETFs with the different level of upper limit purchase, and the interaction term between the absolute stock-level mispricing and those dummy variables by using Equation 8:

$$\text{IntraVol}_{i,t} = \beta_0 + \beta_1|\text{MispriceStock}|_{i,t-1} + \beta_2\text{ETFholding}_{i,t-1} + \beta_3\text{QQE1}_t + \beta_4\text{QQE2}_t + \beta_5\text{QQE3}_t + \beta_6\text{QQE4}_t + \beta_7|\text{MispriceStock}|_{i,t-1}\text{QQE1}_{t-1} + \beta_8|\text{MispriceStock}|_{i,t-1}\text{QQE2}_{t-1} + \beta_9|\text{MispriceStock}|_{i,t-1}\text{QQE3}_{t-1} + \beta_{10}|\text{MispriceStock}|_{i,t-1}\text{QQE4}_{t-1} + \beta_{11-14}\text{ControlVariables}_{i,t-1} + \beta_{15}\text{IntraVol}_{i,t-1} + \text{Stock fixed effects} + \text{Day fixed effects} + \varepsilon_{i,t}$$

The frequency is daily, and observations are at the stock level, including 202 stocks in Nikkei 225 index during 5 April 2013 to 31 December 2020, totaling 1,892 business days. I restrict the sample to observations for which the stock-level mispricing is positive in columns (2), and negative in column in (3). The controls include logged market capitalization, the lagged inverse share price, the lagged Amihud (2002) illiquidity ratio, the lagged return, and the lagged dependent variable. The t-statistics are presented in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

Dependent Variable:	Intraday Volatility		
	(1) |MispriceStock|	(2) PositiveMispriceStock	(3) NegativeMispriceStock
Mispricestock (t-1)	2.232***	7.526***	0.782**
	(6.779)	(10.095)	(1.976)
Etfholding (t-1)	0.020***	0.013***	0.018***
	(11.769)	(5.000)	(7.640)
QQE1	-0.016***	-0.016***	-0.126***
	(-18.041)	(-17.126)	(-14.087)
QQE2	-0.023***	-0.022***	-0.127***
	(-24.952)	(-23.886)	(-14.256)
QQE3	0.031***	0.030***	-0.087***
	(33.459)	(29.661)	(-9.750)
QQE4	-0.027***	-0.020***	-0.130***
	(-29.980)	(-21.724)	(-14.543)
MispricestockQQE1 (t-1)	-5.073***	-8.727***	-5.411
	(-2.758)	(-3.770)	(-1.459)
MispricestockQQE2 (t-1)	-1.753*	-14.758***	1.027
	(-1.923)	(-5.622)	(1.061)
MispricestockQQE3 (t-1)	-3.778***	1.893	-4.791***
	(-4.019)	(0.899)	(-4.556)
MispricestockQQE4 (t-1)	0.711	-3.823***	-9.407***
	(1.128)	(-4.150)	(-4.010)

(Continued)

Table 6: The impact of the scale of BOJ intervention on intraday volatility and ETF arbitrage, and the impact of interest during COVID-19 pandemic. *(Continued)*

The table represents estimates from the regressions of intraday volatility on the dummy variable QQE1 - QQE4, capturing the days that BOJ purchases ETFs with the different level of upper limit purchase, and the interaction term between the absolute stock-level mispricing and those dummy variables by using Equation 8:

$$\text{IntraVol}_{i,t} = \beta_0 + \beta_1|\text{MispriceStock}|_{i,t-1} + \beta_2\text{ETFholding}_{i,t-1} + \beta_3\text{QQE1}_t + \beta_4\text{QQE2}_t + \beta_5\text{QQE3}_t + \beta_6\text{QQE4}_t + \beta_7|\text{MispriceStock}|_{i,t-1}\text{QQE1}_{t-1} + \beta_8|\text{MispriceStock}|_{i,t-1}\text{QQE2}_{t-1} + \beta_9|\text{MispriceStock}|_{i,t-1}\text{QQE3}_{t-1} + \beta_{10}|\text{MispriceStock}|_{i,t-1}\text{QQE4}_{t-1} + \beta_{11-14}\text{ControlVariables}_{i,t-1} + \beta_{15}\text{IntraVol}_{i,t-1} + \text{Stock fixed effects} + \text{Day fixed effects} + \varepsilon_{i,t}$$

The frequency is daily, and observations are at the stock level, including 202 stocks in Nikkei 225 index during 5 April 2013 to 31 December 2020, totaling 1,892 business days. I restrict the sample to observations for which the stock-level mispricing is positive in columns (2), and negative in column in (3). The controls include logged market capitalization, the lagged inverse share price, the lagged Amihud (2002) illiquidity ratio, the lagged return, and the lagged dependent variable. The t-statistics are presented in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

Dependent Variable:	Intraday Volatility		
	(1) |MispriceStock|	(2) PositiveMispriceStock	(3) NegativeMispriceStock
Logmktcap (t-1)	0.001***	0.002***	0.000
	(4.804)	(5.420)	(1.495)
Inverseprice (t-1)	0.771***	0.724***	0.834***
	(9.415)	(6.057)	(7.414)
Illiq (t-1)	-0.009***	-0.008***	-0.010***
	(-11.693)	(-7.036)	(-9.504)
Return (t-1)	0.010***	0.010***	0.011***
	(10.940)	(7.094)	(8.586)
intravol (t-1)	0.266***	0.265***	0.267***
	(165.170)	(115.013)	(117.858)
Constant	0.033***	0.029***	0.139***
	(24.419)	(15.654)	(15.348)
Stock fixed effects	YES	YES	YES
Day fixed effects	YES	YES	YES
Observations	382,184	185,445	196,739
Adjusted R-squared	0.498	0.526	0.465

unsurprisingly turn significantly positive at 1% level in column (1) and (2) of table 6 suggesting that the intervention amount is not large enough to help lower intraday volatility during the downturn market. For the coefficient of QQE4 (β_6), it is negative and statistically significant at 1% level implying that BOJ intervention achieve the objective of stabilizing the market and successfully reduce intraday volatility during COVID-19.

Table 7: The result from the test of linear combination of the difference in estimated coefficients between each group. P-value of one-tailed test for of each pair is in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

	(1) |MispriceStock|	(2) PositiveMispriceStock	(3) NegativeMispriceStock
β_4 - β_3	-0.007***	-0.006***	-0.001**
	(0.000)	(0.000)	(0.044)

Considering the coefficients of the interaction terms between the lagged stock-level mispricing and each lagged dummy variable QQE1 to QQE4 (β_7 to β_{10} of Table 6), ETFs arbitrage activity seems to have random impact on intraday volatility when BOJ purchases ETFs with the different amount. This result suggests that the size of BOJ intervention does not affect intraday volatility through ETF arbitraging activity. The different size of coefficients (β_7 to β_{10} of Table 6) possibly depends on arbitrage trading strategies of investors. I interpret this evidence as consistent with the argument from Ben-David et al. (2018) that the effect of ETFs on volatility depends on a limitation of arbitrage. However, the negative coefficient at least confirms the effectiveness of BOJ intervention as it could reduce the impact of ETF arbitrage on stock prices volatility regardless of the size of intervention.

The β_{10} also captures the impact of the size that BOJ intervene the market on the relationship between ETF arbitrage and intraday volatility during COVID-19.

From table 6, the β_{10} is negative and statistically significant at 1% level when the sign of net mispricing is considered. It indicates that BOJ intervention and COVID-19 reduce the impact of ETF arbitrage on intraday volatility. Thus, this result provides evidence that contradicts to Ben-David et al. (2018) but is in line with the view from the investment association, London (2020). ETFs can be a source of stability and price discovery during periods of significant market stress where trading in the underlying market is impaired causing the failure of the arbitrage mechanism. Investors increasingly turn to ETFs in a time of market stress for transparency and liquidity to diversify their portfolio rather than earn an arbitrage profit. Therefore, ETFs mechanism help to lower price volatility of the underlying securities (Glosten et al. (2021) and Box et al. (2021)).

6. Conclusion

In this study, I investigate the relationship between Nikkei 225 ETFs and their constituent securities in term of volatility by using fixed effects estimator to study whether the superior liquidity of ETFs induce volatility into the underlying stocks through the arbitrage mechanism. Moreover, I also examine the direct and indirect effect of BOJ intervention on intraday volatility through arbitrage activity, and the effect of interest during COVID-19 crisis. This study aims to provide empirical evidence that is valuable to investors as it could make awareness of the negative impact from the ETF arbitrage mechanism and BOJ intervention.

The empirical results confirm that Nikkei 225 ETFs attract shot-term traders and cause the price of the underlying stocks to be more volatile. Moreover, the sign of ETF mispricing as a fraction of stock's market capitalization affects arbitrage trading strategies. The lagged negative stock-level mispricing causes less impact on intraday volatility relative to the lagged positive stock-level mispricing. Moreover, the regression results confirms that the central bank's objective has been achieved because the intervention reduces intraday volatility both of direct and indirect through a limitation of ETF arbitrage activity. It means that the intervention causes ETFs to shield the underlying stocks from non-fundamental shock. Furthermore, the scale of intervention has an impact on intraday volatility where the larger the intervention amount the lower the intraday volatility. Finally, this paper provides empirical evidence of the interest during the COVID-19 crisis. The results suggest that the arbitrage trading is less intensive during market stress where the market is illiquid. ETFs then become a source of stability over the course of the crisis and lower price volatility of the underlying stocks.

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