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The Effects of the Bank of Japan's ETF Purchases on Risk Premia in the Stock Markets

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Abstract

This paper provides an empirical investigation of the effects of the Bank of Japan's exchange traded funds (ETF) purchases on risk premia in the stock markets. The analysis examines the following two indicators of risk premia: equity risk premium implied by Nikkei 225 option prices, and yield spreads of individual stocks. The former indicator is analyzed at daily frequency, and the latter is analyzed at weekly frequency. The analysis also examines how the effects of ETF purchases vary depending on market conditions and the size of ETF purchases. The results show that the Bank of Japan's ETF purchases have lowering effects on risk premia. The results also suggest that the lowering effects are larger (1) the lower the stock price index relative to its moving average trend, (2) the higher the volatility in the stock market when the stock price index is below its trend, (3) the larger the percentage decline in the stock price index immediately before the purchases, and (4) the larger the size of the purchases.

JEL Classification: E52, E58, G10, G12

Key Words: Monetary Policy, ETF Purchases, Risk Premia, Purchase Effect Function

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1. Introduction

Since December 2010, the Bank of Japan has been purchasing exchange traded funds (ETFs) to lower risk premia in the stock markets in order to exert positive effects on economic activity and prices. In this paper, we conduct an empirical analysis on the effects of the Bank's ETF purchases on risk premia in the stock markets.

There are an increasing number of studies on the Bank of Japan's ETF purchases, most of which focus on the impact of these purchases on stock prices. An early study by Ide and Minami (2013) focuses on the returns of ETFs linked to the Nikkei Stock Average (Nikkei 225) during the afternoon session, reporting that their returns during the afternoon session tend to be higher on days when the Bank of Japan purchased ETFs than they are on other days. Matsuki et al. (2015) and Shirota (2018) analyze stock price indices, showing that ETF purchases have positive effects on stock prices.[1] Recently, there are also an increasing number of studies that use panel datasets of individual stocks. For instance, Harada and Okimoto (2019) apply the difference-in-difference approach to individual stock prices that constitute the Nikkei 225 against other stock prices, finding that ETF purchases have increasing effects on stock prices. Charoenwong et al. (2020) estimate the amount of individual stocks which the Bank indirectly purchased through its ETF purchases and analyze the effects on individual stock returns. They report that ETF purchases have positive impacts on stock prices.

However, few empirical studies have investigated the effects of ETF purchases on risk premia in the stock markets using datasets that include recent data.[2] Another important, though

[1] Hattori and Yoshida (2020) examine the relation between ETF purchases and stock index returns during various intraday trading sessions.

[2] Among these few studies, Ide and Takehara (2020) estimate the "expected default frequency-adjusted implied cost of equity" for individual stocks. Based on the estimation result, they point out that ETF purchases contributed to curbing the increase in default risk premia during the market turmoil in early 2020 caused by the coronavirus pandemic. In addition, Yonezawa (2016) studies the historical risk premium calculated from the realized returns of a stock index, while Serita and Hanaeda (2017) and Kobayashi (2017) analyze the historical volatility of individual stocks and ETFs.

less investigated issue is whether the impact of ETF purchases varies depending on market conditions and the size of single ETF purchases.[3,4]

To fill these gaps in the literature, this paper focuses on empirically examining the effects of ETF purchases on risk premia in the stock markets, using data up to the end of 2020. We also investigate how the effects of ETF purchases vary depending on market conditions and the size of single ETF purchases.[5] Specifically, we analyze the effects of ETF purchases on risk premia by regressing changes in indicators of risk premia on the indicators of the Bank's ETF purchases. As indicators of risk premia, we use the following two variables: equity risk premium (ERP) implied by Nikkei 225 option prices, and the yield spreads of individual stocks.[6] Moreover, in our regression analysis, we employ the following two specifications. In the first specification, we assume that the effects of ETF purchases per unit purchase amount are constant. In the other estimation specification, the effects of ETF purchases per unit amount can vary depending on *state variables*, which represent market conditions and the size of single ETF purchases. In particular, we examine the following four state variables: (i) the percentage downward deviation of the current TOPIX (Tokyo Stock Price Index) from its moving average trend, (ii) the volatility index when TOPIX is below its moving average trend, (iii) the percentage decline in TOPIX immediately before the ETF purchases, and (iv) the size of ETF purchases (relative to the TOPIX market capitalization). These two estimation specifications allow us to examine not only the average effects of ETF purchases throughout our estimation period, but also how the effects vary depending on these state variables.

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3 A notable exception is Shirota (2018), who documents that the impact of ETF purchases becomes stronger during market downturns.

4 Among the literature, a number of analyses study issues related to ETF purchases, other than their effects on stock prices and risk premia. For example, Charoenwong et al. (2020) and Nguyen (2021) investigate the impact of ETF purchases on firms' capital expenditures, among other corporate variables. Hirayama (2021) considers the ETF purchase program from a historical perspective. These topics are beyond the scope of this paper, as we focus on investigating the effects of ETF purchases on risk premia in the stock markets.

5 Harada (2017) examines the impact of the redefinitions of the Nikkei 225 on individual stock prices by focusing on the redefinition events that have occurred since the Bank of Japan introduced the ETF purchase program. Barbon and Gianinazzi (2019) study how the announcements of an increase in the pace of ETF purchases in 2014 and 2016 affected stock prices. A recent study by Takahashi and Yamada (2021) investigates how ETF purchases affected individual stock prices during the market turmoil in early 2020 caused by the coronavirus pandemic.

6 Note, however, that developments in risk premia should be judged from a holistic perspective by taking into account developments in various indicators and anecdotal information of market conditions.

In conducting this kind of empirical analysis, however, one needs to bear in mind the so-called *endogeneity problem*. Specifically, the existing studies that also employ regression analysis point out that one cannot accurately estimate the effects of ETF purchases unless the endogeneity between the timing of ETF purchases and developments in stock prices or indicators of risk premia is taken into account. The previous literature tackles this endogeneity problem mainly based on the following two approaches. The first approach (e.g., Shirota, 2018) focuses on changes in the afternoon session (i.e., changes from the close of the morning session to the close of the afternoon session). The second approach uses panel datasets of individual stocks to mitigate the endogeneity problem in estimating the effects of ETF purchases; panel datasets provide cross-sectional variations in the data that are less susceptible to the endogeneity problem (see e.g., Charoenwong et al., 2020).

In this paper, we address the endogeneity problem by following these existing studies. Specifically, in the regressions of the single time-series of the estimated changes in ERP, we perform daily frequency time-series estimations using the changes in ERP during the afternoon session as a dependent variable. On the other hand, when we analyze the yield spreads of individual stocks, we perform weekly frequency panel estimations. Note that using the weekly frequency dataset in the latter panel estimations also enables us to investigate the influence of ETF purchases over somewhat longer horizons compared with the former daily frequency estimations.

The main results of our analysis are as follows. First, the estimation results obtained from the constant purchase effect specification show that ETF purchases have lowering effects on both of the two indicators of risk premia that we examined. This result implies that, on average throughout the period since the introduction of the ETF purchase program in December 2010, ETF purchases contributed to reducing risk premia. Second, the estimation results obtained from the other estimation specification, which allows the effects of ETF purchases per unit purchase amount to vary depending on state variables, suggest that the effects of ETF purchases are larger (1) the lower the stock price index relative to its moving average trend, (2) the higher the volatility in the stock market when the stock price index is below its trend, (3) the larger the percentage decline in the stock price index immediately before the purchases, and (4) the larger the size of the purchases.

The remaining part of this paper is structured as follows. In Section 2, we present the framework of our empirical analysis. Section 3 provides details of the data we use for our analysis. Section 4 reports our baseline estimation results, and Section 5 shows the results of robustness checks on our baseline estimations. Section 6 concludes the paper.

2. Framework of empirical analysis

We examine whether the Bank of Japan's ETF purchases have lowering effects on risk premia and how the effects vary depending on market conditions and the size of ETF purchases by regressing indicators of risk premia in the stock markets on the "purchase amount indicators," which denote the amount of the Bank of Japan's ETF purchases. To this end, we employ the following two alternative regression specifications: "Estimation I" and "Estimation II."

In Estimation I, we assume that the effects of ETF purchases per unit purchase amount (i.e., one unit of the purchase amount indicator) are constant and do not depend on market conditions or the size of ETF purchases; that is,

$$\begin{aligned}&\text{Change in risk premia indicator}\\&\qquad= \theta \times \text{purchase amount indicator} + \beta \times \text{controls.}\end{aligned} \tag{1}$$

The coefficient of the purchase amount indicator, θ, measures the effects of ETF purchases per unit purchase amount on the indicators of risk premia. Specifically, a negative estimate of θ suggests that ETF purchases have lowering effects on risk premia in the stock markets. Therefore, we can investigate the average effects of ETF purchases throughout our estimation period based on Estimation I.

On the other hand, in Estimation II, the effects of ETF purchases per unit purchase amount are allowed to vary depending on market conditions and the size of purchases. Specifically, our regression equations for Estimation II take the following form,

$$\begin{aligned}&\text{Change in risk premia indicator} =\\&\qquad\text{purchase effect function} \times \text{purchase amount indicator} + \beta \times \text{controls.}\end{aligned} \tag{2}$$

In this equation, the coefficient of the purchase amount indicator is not constant and is replaced with the "purchase effect function." As we will explain shortly, the purchase effect function is formalized as a function of "state variables" that represent market conditions or the size of ETF purchases. This specification allows us to examine how the effects of ETF purchases per unit purchase amount on the indicators of risk premia vary depending on market conditions and the size of ETF purchases.

In what follows, we provide a detailed explanation of the variables that appear in equations (1) and (2), namely, the indicators of risk premia, the purchase amount indicators, and the purchase effect functions.

2.1. Indicators of risk premia used as dependent variables

For the dependent variable in equations (1) and (2), we use the following two indicators of risk premia in the stock markets: changes in the option-implied ERP and changes in the yield spreads of individual stocks. Our estimations for the option-implied ERP are based on daily frequency data, whereas those for the yield spreads are based on weekly frequency data.

ERP is defined as the expected excess return over the risk-free rate (i.e., the expected stock return minus the risk-free rate), which is the compensation investors demand for bearing stock price risks. Although ERP is not observable, one can estimate ERP and use the estimated ERP as an indicator of risk premia. While various ERP estimation techniques have been proposed, there is a growing literature that estimates ERP using information on the distribution of future stock prices and the risk attitudes of market participants contained in option prices.[7] In this paper, we estimate ERP over the next 30-day period by applying one of the most popular methods proposed by Martin (2017) to intraday Nikkei 225 option price data. We then use the changes in the estimated ERP during the afternoon session as a dependent variable in equations (1) and (2). See Appendix A for an overview of Martin's (2017) method, estimation procedures using Nikkei 225 option price data, and the estimated ERP. Note that we conduct robustness exercises regarding the choice of ERP estimation method in Section 5; we investigate the impact of ETF purchases using an alternative estimate of the option-implied ERP obtained based on Duan and Zhang's (2014) method.

A yield spread is defined as the spread between the earnings yield and the risk-free rate (long-term government bond yield). It is one of the most commonly used measures of risk premia (see e.g., Duarte and Rosa, 2015; Omori, 2020). In this paper, we use changes in the yield spreads of individual stocks from the close of the previous week to the close of the current week as a dependent variable in equations (1) and (2).

[7] See Duarte and Rosa (2015) among others for ERP estimation techniques not employed in this paper.

2.2. Purchase amount indicators

We use either one of the following two different purchase amount indicators, depending on the left-hand side variables. When a single time-series of the estimated ERP is used as a dependent variable, we use the proportion of the daily ETF purchase amount to the TOPIX market capitalization (in percentage) as a purchase amount indicator,

$$BOJ_t^{day} = \frac{ETF_t^{day}}{MKC_{t-1}^{day}} \times 100, \tag{3}$$

where ETF_t^{day} is the amount of ETF purchase on day t and MKC_{t-1}^{day} is the TOPIX market capitalization at the close of day $t-1$.[8] This purchase amount indicator is a single time-series data.

For estimations on weekly changes in the yield spreads of individual stocks, we construct weekly stock-by-stock purchase amount indicators. Specifically, we define the purchase amount indicator of stock i in week t as follows,

$$BOJ_{i,t}^{week} = \frac{\sum_{j \in t} ETF_{i,j}^{day}}{MKC_{i,t-1}^{week}} \times 100, \tag{4}$$

where $ETF_{i,j}^{day}$ is the estimated purchase amount (indirectly, via ETF purchases) of stock i on day j, and $MKC_{i,t-1}^{week}$ is stock i's market capitalization at the end of week $t-1$. The summation in the numerator on the right-hand side runs through all business days j that belong to week t. Following the existing literature (e.g., Charoenwong et al., 2020), we estimate stock-by-stock (indirect) purchase amounts (in yen) $ETF_{i,j}^{day}$ as

$$ETF_{i,j}^{day} = \left(\omega_{i,j}^{TPX}\omega_{BOJ,j}^{TPX} + \omega_{i,j}^{NKY}\omega_{BOJ,j}^{NKY} + \omega_{i,j}^{JPX}\omega_{BOJ,j}^{JPX}\right) \times ETF_j^{day}, \tag{5}$$

where $\omega_{i,j}^{TPX}, \omega_{i,j}^{NKY}, \omega_{i,j}^{JPX}$ are the index weight of stock i on day j in TOPIX, the Nikkei Stock Average (Nikkei 225), and the JPX-Nikkei 400 Index (JPX-Nikkei 400), respectively, and $\omega_{BOJ,j}^{TPX}, \omega_{BOJ,j}^{NKY}, \omega_{BOJ,j}^{JPX}$ are the proportions of the purchase amount of ETFs linked to

[8] The "TOPIX market capitalization" we use in this paper is calculated on a free float basis, as that is how TOPIX is calculated. The market capitalizations of individual stocks mentioned below are also calculated on a free float basis.

TOPIX, Nikkei 225, and JPX-Nikkei 400 on day j, respectively. The stock-by-stock purchase amount indicators constructed in this way form a weekly panel data.

2.3. Specifications of estimation equations in Estimation I

In Estimation I, we formulate the estimation equations by assuming that the effects of ETF purchases per unit purchase amount are constant, as indicated by equation (1). In particular, our estimation equation for the changes in the option-implied ERP (Estimation I-1) and that for the changes in the yield spreads of individual stocks (Estimation I-2), respectively, are

$$\Delta ERP_t^{day} = \theta \times BOJ_t^{day} + \beta_0 + \beta \times X_t^{day} + \epsilon_t^{day}, \tag{6-1}$$

$$\Delta YS_{i,t}^{week} = \theta \times BOJ_{i,t}^{week} + \beta_0 + TE_t^{week} + IE_i^{week} + \epsilon_{i,t}^{week}, \tag{6-2}$$

where ΔERP_t^{day} is the change in the estimated ERP on day t, $\Delta YS_{i,t}^{week}$ is the change in stock i's yield spread from the close of week $t-1$ to the close of week t, and BOJ_t^{day} and $BOJ_{i,t}^{week}$ are the daily and the weekly purchase amount indicators defined in Section 2.2, respectively. X_t^{day} is a vector of control variables, TE_t^{week} denotes the time fixed effect, IE_i^{week} denotes the stock fixed effect, and ϵ_t^{day} and $\epsilon_{i,t}^{week}$ are the error terms. For control variables in equation (6-1), X_t^{day}, we include the percentage change in TOPIX and the dollar-yen foreign exchange rate during the "morning session" (i.e., the percentage change from the close of the stock market on day $t-1$ to the close of the morning session of the stock market on day t), ΔTPX_t^{AM} and ΔJPY_t^{AM}, respectively.

2.4. Specifications of estimation equations in Estimation II

In Estimation II, as equation (2) illustrates, we replace the constant coefficient on the purchase amount indicator θ in equations (6-1) and (6-2) with the "purchase effect function" that varies depending on its state variable. Specifically, we use the following four state variables: (i) the percentage downward deviation of the current TOPIX from its moving average trend, (ii) the volatility index when TOPIX is below its moving average trend, (iii) the percentage decline in TOPIX immediately before the ETF purchases, and (iv) the size of ETF purchases (relative to the TOPIX market capitalization).

The estimation equations in Estimation II take the following forms regardless of the choice of the purchase effect functions,

$$\Delta ERP_t^{day} = F_k\left(s_{k,t}^{day}\right) \cdot BOJ_t^{day} + \beta_0 + \beta \times X_t^{day} + \epsilon_t^{day}, \tag{7-1}$$

$$\Delta YS_{i,t}^{week} = F_k\left(s_{k,t}^{week}\right) \cdot BOJ_{i,t}^{week} + \beta_0 + TE_t^{week} + IE_i^{week} + \epsilon_{i,t}^{week}, \tag{7-2}$$

where $F_k(s_{k,t})$ is one of the four purchase effect functions used in "Estimation IIx" ($x = A, B, C, D$), which we will shortly explain in detail. While the arguments of the purchase effect functions (state variable), $s_{k,t}$, are the same variables for the two dependent variables we consider, their values are different depending on the data frequency of dependent variables. Therefore, we distinguish them by the superscript "day" or "week." In Estimation II, for control variables in estimations about changes in the estimated ERP, we include the respective variables which are used as the arguments of the purchase effect function, in addition to the percentage change in TOPIX and the dollar-yen foreign exchange rate during the morning session.[9]

In what follows, we explain the four purchase effect functions and their respective arguments in detail.

(1) Estimation IIA: downward deviation from 100-day TOPIX trend

The purchase effect function for Estimation IIA takes the percentage downward deviation of TOPIX from its 100-day moving average as a state variable, and is defined as follows,

$$F_A\left(\widehat{TPX}\right) = \alpha + \sigma \times \min\{0, \widehat{TPX}\}, \tag{8}$$

where $\min\{x, y\}$ equals the smaller value of x or y, and $\widehat{TPX}$ is the percentage deviation of TOPIX from its 100-day moving average. Therefore, the term $\min\left\{0, \widehat{TPX}\right\}$ denotes the *downward deviation* of TOPIX from its 100-day moving average trend. We use the deviation of TOPIX at the close of the previous trading day ($\widehat{TPX}_{t-1}^{day}$) when the dependent variable is the changes in the estimated ERP (Estimation IIA-1), while we use the deviation at the close of the

[9] To be precise, we include the following variables in the vector of control variables in addition to the percentage change in TOPIX and the dollar-yen foreign exchange rate during the morning session. Estimation IIA: the percentage deviation of TOPIX from its 100-day moving average ($\widehat{TPX}_{t-1}^{day}$). Estimation IIB: Nikkei VI at the close of the previous day (VI_{t-1}^{day}) and the percentage deviation of TOPIX from its 100-day moving average ($\widehat{TPX}_{t-1}^{day}$). Note that no additional control variables are included in Estimations IIC and IID because the respective arguments of the purchase effect function (Estimation IIC: ΔTPX_t^{AM}; Estimation IID: BOJ_t^{day}) are already included as explanatory variables.

previous week ($\widehat{TPX}_{t-1}^{week}$) when the dependent variable is the yield spreads of individual stocks (Estimation IIA-2).

This purchase effect function is motivated by the hypothesis that ETF purchases may become more effective when the current stock price is deviated downward from its trend.[10] We can examine this hypothesis by testing the statistical significance of the parameter σ. Indeed, a positive and statistically significant estimate of σ would suggest that the lowering effects on risk premia of ETF purchases per unit purchase amount become larger as the downward deviation of stock prices from their trend levels becomes larger.

(2) Estimation IIB: volatility index when TOPIX is below its trend

Estimation IIB uses the "volatility index when TOPIX is below its trend" as a state variable. Specifically, the purchase effect function for Estimation IIB is defined as follows,

$$F_B(VI; D) = \alpha + (\gamma + \sigma \times VI) \times D, \tag{9}$$

where the arguments of the purchase effect function are the Nikkei 225 Volatility Index (Nikkei VI) denoted by VI and the dummy variable D. This dummy variable equals one if the current TOPIX is below its 100-day moving average (i.e., if the deviation from its trend $\widehat{TPX}$ is negative) and equals zero otherwise. We use the values of these variables at the close of the previous day (VI_{t-1}^{day}, D_{t-1}^{day}) when the dependent variable is the changes in the estimated ERP, and use those at the close of the previous week (VI_{t-1}^{week}, D_{t-1}^{week}) when the dependent variable is the yield spreads of individual stocks.

With this purchase effect function, we examine the hypothesis that the impact of ETF purchases may become stronger when the stock markets become unstable. For example, if the stock market volatility increases while stock prices are running below their trend, the stability of the market can be weakened, and in such a situation ETF purchases may have a more positive

[10] Given the literature that documents counter-cyclical movements in the risk aversion of investors (e.g., Campbell and Cochrane, 1999; Cohn et al., 2015), it may be the case that the risk aversion of investors is heightened when stock prices deviate downward from their trend levels. On the other hand, studies on the effects of the portfolio rebalance channel suggest that the influence of asset purchases on risk premia is greater when the risk aversion of investors is higher (e.g., Vayanos and Vila, 2021). These results suggest that ETF purchases may become more effective when stock prices deviate downward from their trend prices.

influence on the risk taking attitudes of market participants.[11] In Estimation IIB, a negative and statistically significant estimate of σ would suggest that the lowering effects on risk premia of ETF purchases per unit purchase amount become stronger as Nikkei VI increases when TOPIX is below its trend line.

(3) Estimation IIC: decline in TOPIX immediately before ETF purchases

In Estimation IIC, we use the following purchase effect function, which takes the percentage decline in TOPIX immediately before ETF purchases as a state variable,

$$F_C(\Delta TPX) = \alpha + \sigma \times \min\{0, \Delta TPX\}, \tag{10}$$

where the argument ΔTPX is the percentage change in TOPIX immediately before ETF purchases. When the dependent variable is the changes in the estimated ERP, the percentage change of TOPIX during the morning session on day t, ΔTPX_t^{AM}, is used. On the other hand, when the dependent variable is the yield spreads of individual stocks, the weekly TOPIX return in the prior week (week $t-1$), ΔTPX_{t-1}^{week}, is used.

This purchase effect function corresponds to the conjecture that the effects of ETF purchases per unit purchase amount may become stronger, the larger the decline in stock prices immediately before ETF purchases.[12] In this specification, a positive and statistically significant estimate of σ would suggest that the lowering effects on risk premia of ETF purchases per unit amount become larger when stock prices decrease more sharply immediately before ETF purchases.

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[11] Nagel (2012) shows that the "price of liquidity provision" becomes higher when a market becomes less stable along with a higher VIX. Since ETF purchases partly act as liquidity provision to unstable stock markets, Nagel's (2012) result implies that the influence of ETF purchases may become stronger when the volatility index is elevated.

[12] Recent studies show that constraints faced by financial intermediaries (e.g., liquidity constraints) are important determinants of risk premia (see e.g., He and Krishnamurthy, 2013; Adrian et al., 2014; He et al., 2017; Chen et al., 2019 among others). Since asset purchase programs in part help to mitigate constraints faced by financial intermediaries, ETF purchases may become more effective in suppressing risk premia, particularly when large declines in stock prices occur and constraints on financial intermediaries become tighter.

(4) Estimation IID: size of ETF purchases

Lastly, we show the specification of Estimation IID, for which we use the size of ETF purchases (relative to the TOPIX market capitalization) as a state variable. The purchase effect function is defined as follows,

$$F_D(BOJ) = \alpha + \sigma \times BOJ, \tag{11}$$

where the argument of the purchase effect function is the daily ETF purchase amount (divided by the TOPIX market capitalization at the close of the previous day) BOJ_t^{day} (equation (3)) when the dependent variable is the estimated ERP, and the weekly total ETF purchase amount (divided by the TOPIX market capitalization at the close of the previous week) BOJ_t^{week} when the dependent variable is the yield spreads of individual stocks.

A negative and statistically significant estimate of σ would imply that the effects of ETF purchases per unit purchase amount become larger as the total amount of ETF purchases become larger.[13] In this case, the overall effects of a single ETF purchase on risk premia (which equal the effects per unit amount multiplied by the total purchase amount) become larger in a non-linear fashion.

3. Data

3.1. Estimation period and the stock universe for panel analysis

The estimation period in this paper starts from December 2010, the month in which the Bank of Japan commenced the ETF purchase program, and ends in December 2020.

For the panel analysis on the yield spreads of individual stocks, the stock universe is all stocks that were listed on the Tokyo Stock Exchange (TSE) First Section or Second Section during (at least) some part of the estimation period. For stocks which experienced "Section

[13] Existing studies argue that asset purchases influence financial markets via the signaling channel (e.g., Krishnamurthy and Vissing-Jorgensen, 2011; Nozawa and Qiu, 2021), and the sentiment improvement effect (e.g., Lutz, 2015), among other channels. The signaling and sentiment channels may become more active as the size of ETF purchases becomes larger.

Transfer," our dataset includes data about the period during which these stocks belonged to stock markets other than the TSE First and Second Sections.[14]

3.2. Data sources

Table 1 shows the list of variables we use in our analysis and their respective data sources.

Among the two indicators of risk premia, we estimate the changes in the option-implied ERP (ΔERP_t^{day}) based on Nikkei 225 Option (One-Minute) intraday traded price data obtained from JPX Data Cloud (see Appendix A for a detailed explanation of estimation procedures and results). Regarding the yield spreads of individual stocks ($\Delta YS_{i,t}^{week}$), we use the "consolidated yield spreads" obtained from QUICK DataLink.

The purchase amount indicators ($BOJ_t^{day}, BOJ_{i,t}^{week}$) defined by equations (3)—(5) are constructed using the following data. First, we obtain the daily ETF purchase amount (ETF_t^{day}) from the Bank of Japan's website.[15] We obtain the TOPIX market capitalization (MKC_{t-1}^{day}) and market capitalizations of individual stocks ($MKC_{i,t-1}^{week}$) from QUICK DataLink. Among the data sources related to the individual stock purchase amount indicators, the index weights of individual stocks in TOPIX, Nikkei 225, and JPX-Nikkei 400 ($\omega_{i,j}^{TPX}$, $\omega_{i,j}^{NKY}$, $\omega_{i,j}^{JPX}$) are obtained from QUICK DataLink. We estimate the proportions of the purchase amount of ETFs linked to TOPIX, Nikkei 225, and JPX-Nikkei 400 ($\omega_{BOJ,j}^{TPX}$, $\omega_{BOJ,j}^{NKY}$, $\omega_{BOJ,j}^{JPX}$) from ETF-by-ETF market value data obtained from QUICK DataLink and official announcement documents of the Bank of Japan.[16]

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[14] For example, our dataset includes the data before a stock was transferred to the TSE First or Second Section from JASDAQ or the TSE Mothers.

[15] https://www3.boj.or.jp/market/en/menu_etf.htm

[16] "Establishment of 'Principal Terms and Conditions for Purchases of ETFs and J-REITs Conducted through the Asset Purchase Program'" (published on November 5, 2010)
https://www.boj.or.jp/en/announcements/release_2010/mok1011b.pdf
"Establishment and Abolishment of Principal Terms and Conditions in accordance with the Introduction of the 'Quantitative and Qualitative Monetary Easing'" (published on April 4, 2013)
https://www.boj.or.jp/en/announcements/release_2013/rel130404a.pdf
"Change in the Maximum Amount of Each ETF to be Purchased" (published on September 21, 2016)
https://www.boj.or.jp/en/announcements/release_2016/rel160921c.pdf

Among variables used as control variables or state variables in the purchase effect functions in equations (6)—(11), we obtain the deviation of TOPIX from its 100-day moving average ($\widehat{TPX}_{t-1}^{day}$, $\widehat{TPX}_{t-1}^{week}$) and Nikkei VI ($VI_{t-1}^{day}$, VI_{t-1}^{week}) from QUICK DataLink. The morning return and the weekly return of TOPIX (ΔTPX_t^{AM} and ΔTPX_{t-1}^{week}, respectively) are calculated from TOPIX at the close of the morning and afternoon session obtained from QUICK DataLink. The morning return of the dollar-yen foreign exchange rate (ΔJPY_t^{AM}) is calculated from the foreign exchange rate at the close of the morning and afternoon session of the stock market obtained from Bloomberg.

3.3. Summary statistics

Tables 2 and 3 report the summary statistics of the data we use in our estimations. Table 2 presents the summary statistics of the full sample, whereas Table 3 shows those of the subsample restricted to the days the Bank of Japan purchased ETFs.

Regarding the summary statistics of the dependent variables, first, we can see that the median and mean of the changes in the estimated ERP during the afternoon session are smaller in the subsample compared with the full sample. This apparently suggests that the Bank of Japan's ETF purchases have lowering effects on risk premia in the stock markets. We will empirically investigate this point in the following sections.

The other dependent variable, the weekly changes in the yield spreads of individual stocks, is available for about 2,800 stocks. Specifically, Tables 2 and 3 report the summary statistics for the pooled data of approximately 1.18 million stock-week observations. From these two tables, we can see that the median and the mean of the weekly changes in the yield spreads are larger in the subsample (Table 3) than in the full sample (Table 2). However, this does not necessarily mean that the Bank of Japan's ETF purchases pushed up the yield spreads. On the contrary, the results of the panel regressions given below imply that ETF purchases have lowering effects on the yield spreads. This is because, in the panel analysis for the yield spreads,

"Outline of Purchases of ETFs" (published on July 31, 2018)
https://www.boj.or.jp/en/announcements/release_2018/rel180731h.pdf
Note that we estimate the proportions of the purchase amount of ETFs linked to each one of the three indices (TOPIX, Nikkei 225, JPX-Nikkei 400) by assuming that the Bank of Japan purchases all ETFs linked to these indices. Note also that, since May 1, 2020, the Bank of Japan takes into account the amount outstanding in circulation, not the total market value, for ETF purchases. However, our estimation here is based on the total market value of ETFs, including the period on and after May 1, 2020.

we exploit additional information that is not captured by the summary statistics of the pooled data; we identify the effects of ETF purchases by exploiting the cross-sectional relationship between the yield spreads of individual stocks and their respective purchase amount indicators.

4. Estimation results

4.1. Constant purchase effect specification (Estimation I)

Table 4, Column 3 shows the estimation result of Estimation I (estimation equation: equations (6-1) and (6-2)), in which the coefficient of the purchase amount indicator is assumed to be constant. We can see that the estimation results for both dependent variables, the estimated ERP (Estimation I-1) and the yield spreads of individual stocks (Estimation I-2), show that the respective coefficients of the purchase amount indicator θ are negative and statistically significant.[17] This result suggests that, on average throughout our estimation period, the ETF purchases by the Bank of Japan had lowering effects on risk premia in the stock markets.[18]

4.2. State-dependent purchase effect specifications (Estimation II)

Next, based on the results of Estimation II, we examine whether the effects of ETF purchases vary depending on market conditions and the size of ETF purchases.

Estimation IIA: downward deviation from 100-day TOPIX trend

To begin with, we present the results of Estimation IIA (estimation equation: equations (7-1) and (7-2); purchase effect function: equation (8)), in which the state variable of the purchase effect function is the "percentage downward deviation of TOPIX from its 100-day moving average trend." According to Table 4, Column 4, the estimated coefficient of the state variable in the purchase effect function, σ, is positive and statistically significant for both of the dependent variables, the estimated ERP (Estimation IIA-1) and the yield spreads of individual

[17] For panel estimations in this paper, we test statistical significance based on the clustered standard errors with respect to individual stocks.

[18] The estimated coefficient of the purchase amount indicator θ is -5.06 when the dependent variable is the estimated ERP, and -0.85 when the dependent variable is the yield spreads of individual stocks. These results suggest that a purchase of 1% worth of the TOPIX market capitalization has lowering effects of 5.06%pt on ERP and of 0.85%pt on yield spreads. Note, however, that one needs to interpret these quantitative results with caution, given the various uncertainties in the estimation.

stocks (Estimation IIA-2). This result suggests that the lower the stock prices relative to their trend, the larger the lowering effects of ETF purchases on risk premia. Figure 1 (1-1, 1-2) illustrates how the effects of ETF purchases per unit purchase amount differ depending on the state variable (percentage downward deviation of TOPIX from its moving average) based on the estimated parameters of the purchase effect function.[19]

Estimation IIB: volatility index when TOPIX is below its trend

Next, we report the results of Estimation IIB (estimation equation: equations (7-1) and (7-2); purchase effect function: equation (9)), where we use "Nikkei VI when the TOPIX is below its 100-day moving average" as a state variable. As shown in Table 4, Column 5, the coefficient of Nikkei VI (multiplied by the dummy variable indicating TOPIX is below its trend), σ, is negative and statistically significant for both of the two dependent variables. This result suggests that the higher the stock market volatility, the larger the lowering effects of ETF purchases on risk premia when the stock prices are below their trend. Figure 1 (2-1, 2-2) shows how the effects of ETF purchases per unit purchase amount differ depending on Nikkei VI.[20]

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[19] The parameter σ determines the slope of the graphs in Figure 1 (1-1, 1-2) over the negative horizontal axis region, that is, the part of the graph corresponding to the percentage downward deviation of TOPIX from its trend. For instance, the slope of the purchase effect function, σ, is estimated to be 0.69 when the dependent variable is the estimated ERP (Table 4(1), Column 4). This indicates that the effects of a purchase of 1% worth of the TOPIX market capitalization are 0.69%pt larger when the downward deviation of TOPIX is 1% than when TOPIX equals its trend level. Therefore, compared to situations where the deviation from moving average is non-negative, the effects of a purchase of 1% worth of the TOPIX market capitalization on the estimated ERP are about 6.9%pt larger when the percentage deviation equals -10% (approximately the 5 percentile point in the subsample excluding non-purchased days). Similarly, as for Estimation IIA-2, in which the dependent variable is the yield spreads of individual stocks, the lowering effects of a purchase of 1% worth of the TOPIX market capitalization on the yield spreads are about 1.8 %pt larger when the percentage deviation equals -10% compared to when the percentage deviation is non-negative.

[20] The estimated value of σ corresponds to the slope of the graphs in Figure 1 (2-1, 2-2). For example, the slope parameter, σ, equals -0.49 in Estimation IIB-1, in which the dependent variable is the estimated ERP (Table 4(1), Column 5). This means that, conditional on TOPIX being below its trend, a one-point increase in Nikkei VI is associated with a 0.49%pt increase in the effects of ETF purchases per 1% worth of the TOPIX market capitalization. To assess the economic magnitude of this result, let us compare the following two cases: (1) Nikkei VI equals 45 (approximately the 95 percentile point in the subsample excluding non-purchased days), and (2) Nikkei VI equals 25 (approximately the median in the subsample), both conditional on TOPIX being below its trend. Then, the lowering effects of an ETF purchase of 1% worth of the TOPIX market capitalization on the estimated ERP are larger by 9.6%pt in the former case. A similar calculation shows that the effects of an ETF purchase of 1% worth of TOPIX market capitalization on the yield spreads are larger by 1.4%pt in the former case.

Estimation IIC: decline in TOPIX immediately before ETF purchases

Now, we show the results of Estimation IIC (estimation equation: equations (7-1) and (7-2); purchase effect function: equation (10)), in which the state variable is the "percentage decline in TOPIX immediately before the ETF purchases" (Table 4, Column 6). Although the coefficient of the state variable in the purchase effect function, σ, is not statistically significant in Estimation IIC-1, σ is positive and statistically significant in Estimation IIC-2. Overall, these estimation results imply that the larger the decline in TOPIX immediately before ETF purchases, the greater the lowering effects of ETF purchases on risk premia.[21]

Estimation IID: size of ETF purchases

Finally, we check the results of Estimation IID (estimation equation: equations (7-1) and (7-2); purchase effect function: equation (11)), where "the size of ETF purchases" is used as a state variable (Table 4, Column 7). In Estimation IID-1, in which the dependent variable is the estimated ERP, the coefficient of the state variable in the purchase effect function, σ, takes a negative value, although it is not statistically significant. In Estimation IID-2, in which the state variable is the yield spreads, σ is also negative, but statistically significant. Overall, these results suggest that the larger the size of a single ETF purchase, the greater the effects of the purchase per unit purchase amount on reducing risk premia.[22]

In summary, our estimation results indicate that the effects of ETF purchases on risk premia vary depending on market conditions and the size of single ETF purchases. Specifically, the results above suggest that the effects of ETF purchases per unit purchase amount are larger (1) the lower the stock price index relative to its moving average trend, (2) the higher the

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[21] The estimated coefficient, σ, obtained from Estimation IIC-2 is statistically significant and equals 0.22 (Table 4(2), Column 6). This result suggests that the effects of a purchase of 1% worth of the TOPIX market capitalization on the yield spreads increase by 0.22%pt when the percentage decline in TOPIX in the previous week becomes 1%pt larger (Figure 1 (3-2)). Thus, the lowering effects of an ETF purchase of 1% worth of the TOPIX market capitalization on the yield spreads can be 1.1 %pt larger when the percentage decline in TOPIX in the previous week is -5% (approximately the 5 percentile point in the subsample) than when it is non-negative.

[22] The result of Estimation IID-2 shows that σ is estimated to be approximately -17 and statistically significant (Table 4(2), Column 7). This result means that the effects of a purchase of 1% worth of the TOPIX market capitalization increase by 17bps when the weekly purchase amount of ETFs by the Bank of Japan (relative to the TOPIX market capitalization) increases by 1bp (Figure 1 (4-2)). Therefore, we can infer that the lowering effects of a purchase of 1% worth of the TOPIX market capitalization on the yield spreads are approximately 0.85%pt larger when the weekly purchase amount of ETFs (relative to the TOPIX market capitalization) is 7bps (approximately the 95 percentile point in the subsample) than when it is 2bps (approximately the median in the subsample).

volatility in the stock market when the stock price index is below its trend, (3) the larger the percentage decline in the stock price index immediately before the purchases, and (4) the larger the size of the purchases.

5. Robustness results

In this section, we provide robustness results regarding the benchmark estimation results shown in Section 4. In Section 5.1, we examine alternative window lengths for the calculation of the trend of TOPIX, used in the purchase effect functions that take the deviation of TOPIX from its trend. In Section 5.2, we perform a subsample analysis using the data from August 2016, the month in which the pace of ETF purchases increased (in principle) to six trillion yen per annum. In Section 5.3, we examine whether our baseline results regarding the changes in the option-implied ERP are robust to methodologies for estimating ERP from option price data.

5.1. Robustness regarding the window length of the TOPIX trend

As we have described in Section 2, the purchase effect functions for Estimations IIA and IIB use the percentage deviation of TOPIX from its 100-day moving average trend in the baseline analysis. In this subsection, we examine whether these baseline results, shown in Section 4, are robust to the window length of the calculation of the TOPIX trend. In particular, we use two alternative window lengths, 25-day and 200-day moving averages, and re-estimate Estimations IIA and IIB.

Table 5 shows the estimation results. First, for Estimation IIA, the coefficient on the state variable of the purchase effect function (the percentage downward deviation from the trend), σ, is estimated to be positive and statistically significant regardless of the window length of the TOPIX trend. Similarly, we can see that the estimation results for Estimation IIB do not qualitatively change across the three window lengths of the TOPIX trend.

These results show that our baseline estimations are robust to the window length of the TOPIX trend.

5.2. Subsample analysis using the latter part of the sample period

As explained in Section 3, our baseline estimation period starts from December 2010, the month in which the Bank of Japan commenced the ETF purchase program. During the whole period of our baseline sample, however, the Bank of Japan changed the outline of the ETF purchase program several times, and there were various changes in the market environment. Therefore, it might be the case that the baseline estimation results do not reflect the effects of ETF purchases during recent periods. To consider this possibility, we conduct a subsample analysis, where the subsample period starts from August 4, 2016. We choose this day as the start of the subsample because the pace of ETF purchases increased (in principle) to six trillion yen per annum from this day.[23]

Table 6 shows the estimation results. First, the constant purchase effect parameter θ of Estimation I remained negative and statistically significant in the case where the dependent variable is the yield spreads of individual stocks (Estimation I-2). For the estimation of the changes in the option-implied ERP (Estimation I-1), the estimated purchase effect parameter θ does not become statistically significant, but the point estimate is negative. These results generally suggest that the ETF purchase program also had lowering effects on risk premia since the annual pace of ETF purchases increased to six trillion yen.

Next, we turn to the estimation results of Estimation II, where the effectiveness of ETF purchases may vary depending on state variables. Except in Estimation IIC-1, the parameter of the sensitivity of the effectiveness of purchases to state variables, σ, is estimated to be statistically significant and to have the same sign as the respective baseline estimation results. Regarding Estimation IIC-1, the estimated sensitivity parameter σ is not statistically significant, neither for the baseline nor for the subsample estimations. These results suggest that there is no qualitative difference in the estimated state-dependent patterns of the effectiveness of ETF purchases between the full sample and subsample estimations.

To summarize, our subsample exercise indicates that the estimation results in this paper are fairly robust to the estimation period.

5.3. Robustness regarding the estimation of option-implied ERP

One of the dependent variables in the baseline analysis of this paper, the changes in the option-implied ERP, is estimated based on Martin's (2017) method. Martin's (2017) ERP estimation

[23] As the beginning of our subsample period, we choose the first day (or the first week) on which the Bank of Japan conducted the ETF purchase after the announcement of the changes in the outline of the ETF purchase program on July 29, 2016. Note that, from March 16, 2020 toward the end of our sample period (December 2020), the Bank of Japan actively purchased ETFs with the upper limit of about 12 trillion yen per annum, but in principle the purchase amount was maintained at a pace of six trillion yen per annum.

method has several appealing features. For example, its theoretical framework requires no strong assumptions on future stock price distributions nor on investors' utility function (i.e., risk aversion). However, from a theoretical viewpoint, it should be noted that it provides an estimate of the lower bound of ERP and not ERP itself (see Appendix A for details).

In this subsection, we examine whether our baseline results on the effects of ETF purchases are affected by this caveat of Martin's (2017) ERP estimation method. Specifically, we re-estimate the effects of ETF purchases on the option-implied ERP, by replacing the dependent variable with an alternative estimate of the option-implied ERP obtained based on Duan and Zhang's (2014, henceforth DZ) method. Both the DZ method and Martin's method use option price data to estimate ERP. On the other hand, the DZ method differs from Martin's in that it enables us to estimate ERP itself in exchange for making an assumption on the functional form of investors' utility function. While the assumption on investors' utility function may lead to model mis-specification biases, the DZ method has the desirable property of directly estimating ERP itself (and not the lower bound of ERP).

In this paper, we modify the DZ method and estimate ERP based on this modified method. Since the original approach proposed by DZ requires the higher (up to the fourth order) moments of stock returns under the physical probability measure, one needs to estimate a GARCH-type model for the estimation of ERP. However, our modified method circumvents this difficulty by estimating ERP in terms of the risk-neutral moments of the stock returns, which can be calculated from option price data (see related discussions in Faccini et al., 2019). See Appendix B for more detailed explanations of the original DZ method and our modified version, and estimation results based on the modified DZ method.

Table 7 shows the estimation results of the effects of ETF purchases, where we use the changes in the estimated ERP based on the modified DZ method as a dependent variable. With regard to Estimation I (i.e., constant purchase effect specification), the estimated parameter of the effects of ETF purchases per unit purchase amount is a negative value of $\theta = -6.23$. Although this estimated value is not statistically significant, the absolute value of the point estimate is bigger than that of the baseline estimation based on the estimated ERP obtained by Martin's (2017) method ($\theta = -5.06$).[24]

Regarding Estimation II, where the effects of ETF purchases per unit purchase amount depend on state variables, the coefficient of the state variable, σ, is estimated to be statistically significant and to have the same sign as the baseline estimation, except in Estimation IIC. The results for Estimation IIC are not statistically significant, either for the baseline or for the robustness estimation. Furthermore, compared with the baseline results based on the ERP estimate based on Martin's (2017) method, the absolute values of the estimated σ from Estimations IIA, IIB, and IID are bigger, that is, the purchase effect function is more responsive to state variables. In addition, although the estimated σ from Estimation IID was not statistically significant in the baseline estimation, it becomes significant when the estimated ERP based on the modified DZ method is employed as a dependent variable.

Overall, these estimation results suggest that the main implications of our baseline estimations are robust to the choice of the ERP estimation method as well.

6. Conclusions

In this paper, we have empirically analyzed the effects of the Bank of Japan's ETF purchases on risk premia in the stock markets. We have also investigated how the effects vary depending on market conditions and the size of ETF purchases. In the analysis, we have used the following two indicators of risk premia: equity risk premium implied by Nikkei 225 option prices, and the yield spreads of individual stocks. Data frequency is daily for the former indicator and weekly for the latter. In the regression analysis, we employ the following two specifications. In the first specification, we assume that the effects of ETF purchases per unit purchase amount are constant. In the other estimation specification, the effects of ETF purchases per unit amount can vary depending on *state variables* that represent market conditions and the size of single ETF purchases. Specifically, we examine the following four state variables: (i) the percentage downward deviation of the current TOPIX from its moving average trend, (ii) the volatility

[24] By looking at the estimation results for the DZ-type ERP, we can see that the standard errors of the estimated coefficients are larger compared with those in the baseline estimations. This may reflect estimation errors in the higher moments. From a theoretical perspective, using information about higher moments helps to estimate ERP more accurately. On the other hand, estimation errors in higher moments tend to be larger as they are more susceptible to noise in data. Note that Martin's ERP estimation method does not use information on higher moments.

index when TOPIX is below its moving average trend, (iii) the percentage decline in TOPIX immediately before the ETF purchases, and (iv) the size of ETF purchases (relative to the TOPIX market capitalization).

The main results of the analysis are as follows. First, the estimation results obtained from the constant purchase effect specification show that ETF purchases had lowering effects on both of the two indicators of risk premia we have examined. Second, the estimation results obtained from the other estimation specification, which allows the effects of ETF purchases per unit purchase amount to vary depending on state variables, suggest that the effects of ETF purchases are larger (1) the lower the stock price index relative to its moving average trend, (2) the higher the volatility in the stock market when the stock price index is below its trend, (3) the larger the percentage decline in the stock price index immediately before the purchases, and (4) the larger the size of the purchases.

Appendix A. Estimation of ERP based on Martin's (2017) method

In this Appendix, we explain how we estimate the option-implied ERP based on Martin's (2017) method. Martin's (2017) ERP estimation method has appealing properties in that it enables us to estimate ERP from option price data under very mild assumptions. Thanks to these properties, there is a growing literature that uses the estimated ERP based on Martin's (2017) method (e.g., Cieslak et al., 2019; Cox et al., 2020; Kroencke et al., 2021).

A.1. Overview of Martin's (2017) method

Martin (2017) proves that the expected excess return of the stock market portfolio (which corresponds to the stock index) over the risk-free rate, namely, ERP, satisfies the following inequality under very mild conditions,[25]

$$\frac{1}{T-t}\left(E_t[R_T] - R_{f,t}\right) \geq R_{f,t} \cdot SVIX_{t\to T}^2, \tag{A-1}$$

where R_T is the gross return of the market portfolio from time t to T, $R_{f,t}$ is the risk-free rate, and $E_t[\cdot]$ is the conditional expectation operator given time-t information. Thus, the left-hand side of inequality (A-1) represents the annualized ERP over the period from time t to T.

Inequality (A-1) shows that the lower bound of ERP can be expressed by means of *SVIX,* which is an original variable proposed by Martin (2017). Martin (2017) shows that SVIX can be calculated based on the following equation,

$$SVIX_{t\to T}^2 = \frac{2}{(T-t)R_{f,t}S_t^2}\left[\int_0^{F_{t,T}} P_t(K,T)dK + \int_{F_{t,T}}^{\infty} C_t(K,T)dK\right], \tag{A-2}$$

where S_t is time-t underlying price (i.e., stock index), $F_{t,T}$ is time-t price of a forward contract maturing at time T, and $P_t(K,T)$ and $C_t(K,T)$ are the time-t put and call option prices with maturity T and strike price K, respectively. We can see from equation (A-2) that SVIX can be calculated from option prices.[26] Therefore, along with inequality (A-1), equation

[25] To be precise, inequality (A-1) holds as long as the pricing kernel and the market portfolio return satisfy the negative correlation condition (NCC). Martin (2017) shows that NCC holds under wide model classes, including standard asset pricing models.

[26] Martin (2017) names SVIX after "Simple VIX." As this suggests, SVIX shares similarities with VIX-style volatility indices. For example, both SVIX and VIX-style volatility indices can be calculated from option prices. On the other hand, there are important theoretical differences between SVIX and VIX-style volatility indices. Most importantly, VIX-style volatility indices cannot be interpreted as a measure of ERP.

(A-2) shows that one can estimate the lower bound of ERP directly from option price information.

From a theoretical perspective, as inequality (A-1) shows, the SVIX-based approach provides an estimate of the *lower bound* of ERP, not ERP itself. Nevertheless, based on an empirical analysis of the U.S. stock index (S&P 500), Martin (2017) reports that the estimated lower bound of ERP provides a good approximation of ERP itself on average. Based on this result, he claims that the SVIX-based estimator can be used as an estimate of ERP itself. In this paper, we also follow Martin (2017) and treat the right-hand side of inequality (A-1) as an estimate of ERP itself.

A.2. Estimation of ERP using Nikkei 225 option price data

In this subsection, we explain how we estimate the changes in ERP over the next 30-day period during the afternoon session (i.e., changes from the close of the morning session of the stock market to the close of the afternoon session). Specifically, we estimate the changes in the 30-day ERP by applying Martin's (2017) method to Nikkei 225 Option (One-Minute) intraday price data based on the following procedures.[27]

(1) Estimation of ERP corresponding to the first and the second contract months

First, we estimate ERP at the close of the morning session and the afternoon session, separately from Nikkei 225 option price data maturing in the first contract month and those maturing in the second contract month. Specifically, we calculate equation (A-2) from option price data, and then estimate ERP at each one of the two intraday times as the right-hand side of inequality (A-1).

In theory, the calculation of SVIX from equation (A-2) requires a continuum of option prices with respect to strike prices from zero to infinity. In reality, however, options are traded at discrete and limited strike prices. To circumvent this practical issue, we follow a standard

[27] We estimate ERP at the close of the afternoon session from option data recorded at 15:00, whereas we estimate ERP at the close of the morning session from data recorded at 11:00 (until November 20, 2011) or at 11:30 (from November 21, 2011). To be more precise, in order to increase available option price data across different strikes, we employ five-minute windows (15:00-15:05 for the close of the afternoon session, and 11:30-11:35 or 11:00-11:05 for the close of the morning session) to construct an option price dataset. Within these windows, for each maturity and strike, we keep the option price recorded at the nearest to the session close time.

approach taken in the literature; we interpolate and extrapolate option prices and numerically calculate the integral terms in equation (A-2) as follows.[28]

First, we convert observed out-of-the-money (OTM, put options whose strike prices satisfy $K < S_t$, and call options whose strike prices satisfy $K \geq S_t$) option prices to Black and Scholes (1973) implied volatilities (IV). For example, we convert a call option price $C_t(T, K)$ to $IV_t(T, K)$ based on the following relation,

$$C_t(T, K) = BS\left(S_t, K, T - t, r_f, q, IV_t(T, K)\right), \tag{A-3}$$

where BS is the Black and Scholes (1973) option pricing function. We use the close rate of euro-yen LIBOR obtained from Bloomberg for the risk-free rate parameter, r_f.[29] For the dividend yield parameter, q, we obtain the Nikkei 225 index (ex-dividend index) and Nikkei 225 Total Return Index (cum-dividend index), calculate daily dividend amounts from differences between these two indices, and convert dividend amounts to the continuously compounded dividend yield parameter.

Next, we interpolate IVs obtained from the above procedure by the piecewise cubic spline over the range from the lowest to the highest observed strike prices. We horizontally extrapolate the IV at the highest (lowest) observed strike price for strikes above the highest (below the lowest) observed strike price.

From these interpolation and extrapolation procedures, we obtain IVs at equally spaced 1,001 strike prices over the range $[S_t/3,\ 3S_t]$. Then, we convert these IVs to option prices using the Black-Scholes option pricing function. We then calculate the integral terms in equation (A-2) numerically with these 1,001 option prices and obtain the estimated ERP for each maturity at a specific intraday time. Note that we treat the estimated ERP as missing unless at least two call options and two put options are available.

Lastly, we calculate the changes in the estimated ERP during the afternoon session, separately for the first and the second contract months, by taking the difference between the estimated ERP at the close of the afternoon session and at the close of the morning session. For

[28] See Malz (2014) and Ammann and Feser (2019) among others for details about interpolation and extrapolation methodologies for option prices.

[29] To be precise, we linearly interpolate five euro-yen LIBOR rates (spot-next, one-week, one-month, two-month, and three-month rates) to obtain the risk-free rate corresponding to the day-to-maturity of options in consideration.

each contract month, we treat the changes in the estimated ERP as missing unless the estimated ERP is available both at the close of the morning session and the afternoon session.

(2) Calculation of changes in the estimated ERP over the next 30-day period

From the changes in the ERP estimated from the first contract month options (whose day-to-maturity is usually between one to 30 days) and those from the second contract month options (whose day-to-maturity is usually between 30 to 60 days) obtained from the above step, we calculate the changes in the 30-day ERP by interpolating these two estimated changes in ERP with respect to their day-to-maturity. If either one of the estimated changes in ERP is missing, we treat the remaining non-missing estimate as the estimate of the changes in the 30-day ERP. If the estimates are missing for both maturities, we treat the estimate of the changes in the 30-day ERP as missing and exclude it from our sample.

A.3. Estimation result

Figure A(1) illustrates the time-series of the estimated ERP at the close of the afternoon session. We can see that the estimated ERP exhibits spikes in March 2011 and in March 2020. This implies that the market turmoil following the Great East Japan Earthquake or the outbreak of COVID-19 had a considerable impact on risk premia. With regard to the changes in the estimated ERP, which is used as a dependent variable of our main analysis, Figure A(2a) shows that there are spikes in the changes in ERP when stock prices significantly declined and the stock market was destabilized, in addition to the aforementioned episodes of the earthquake and the pandemic.

Appendix B. Estimation of ERP based on Duan and Zhang's (2014) method

This Appendix explains how we obtain an alternative estimate of ERP based on Duan and Zhang's (2014) (DZ) method.

B.1. Overview of Duan and Zhang's (2014) method

DZ derive the following theoretical formula for ERP by assuming that investors have a power utility function,[30]

$$\begin{aligned} ERP &= \mu_P + \delta - r_f \\ &= \frac{2\gamma - 1}{2}\sigma_P^2 - \frac{3\gamma^2 - 3\gamma + 1}{6}\theta_P\sigma_P^3 + \frac{4\gamma^3 - 6\gamma^2 + 4\gamma - 1}{24}(\kappa_P - 3)\sigma_P^4, \end{aligned} \tag{B-1}$$

where γ is the constant relative risk aversion (CRRA) parameter, δ and r_f are the continuously compounded dividend yield and the risk-free rate, respectively, and μ_P, σ_P^2, θ_P, and κ_P are respectively the mean, volatility, skewness, and the kurtosis of the distribution of the log stock return, $\log(S_T/S_t)$, under the physical probability measure (P-measure). For notational simplicity, we suppress the time subscripts (t, T). For risk-neutral moments of the log stock return (i.e., the moments under the risk-neutral probability measure, Q) that appear below, we use the subscript Q instead.

To estimate ERP based on equation (B-1), DZ first estimate a GARCH-type time-series model to obtain the estimates of the moments under P-measure. They then calculate ERP once the CRRA parameter γ is obtained from a GMM estimation based on the following condition,

$$\frac{\sigma_Q^2 - \sigma_P^2}{\sigma_P^2} = -\gamma\theta_P\sigma_P + \frac{\gamma^2}{2}(\kappa_P - 3)\sigma_P^2,$$

where the risk-neutral variance σ_Q^2 is estimated from option prices.

B.2. Modified DZ method

In the DZ estimation method described above, one needs to employ historical data to estimate a GARCH-type model in order to obtain the estimates of the moments of the stock return under

[30] A power utility function has the property that its relative risk aversion parameter is constant.

P-measure. This approach may result in a bias in the estimation of ERP, because ERP is an *expected* excess return of the stock and is thus a forward-looking variable.

To amend this drawback, we express ERP using the risk-neutral moments instead of those under P-measure, and then estimate ERP by calculating the risk-neutral moments from option price data. Taking this approach enables us to estimate ERP without any time-series model estimations by directly incorporating forward-looking information of market participants contained in option prices. In what follows, we show the derivation of this *modified* DZ method.

Let r be the log stock return. Then, the fourth-order Taylor expansion of $e^{r-\mu_Q}$ is

$$e^{r-\mu_Q} = 1 + (r-\mu_Q) + \frac{(r-\mu_Q)^2}{2} + \frac{(r-\mu_Q)^3}{6} + \frac{(r-\mu_Q)^4}{24} + o\left((r-\mu_Q)^4\right), \tag{B-2}$$

where $o(\cdot)$ is the higher-order residual term. By taking the conditional expectation of equation (B-2) under Q-measure, we obtain

$$e^{r_f-\delta-\mu_Q} = 1 + \frac{\sigma_Q^2}{2} + \frac{\theta_Q\sigma_Q^3}{6} + \frac{\kappa_Q\sigma_Q^4}{24} + o(\sigma_Q^4). \tag{B-3}$$

Taking the logarithm of both sides of equation (B-3) and applying the approximation $\log(1+x) \approx x - x^2/2$ yields

$$r_f = \delta + \mu_Q + \frac{\sigma_Q^2}{2} + \frac{\theta_Q\sigma_Q^3}{6} + \frac{(\kappa_Q - 3)\sigma_Q^4}{24} + o(\sigma_Q^4). \tag{B-4}$$

Next, let us define $r^* = r - \mu_Q$ so that the P-expectation of r^* equals

$$\mathbb{E}_t^P[r^*] = \mu_P - \mu_Q \quad \Leftrightarrow \quad \mu_P = \mathbb{E}_t^P[r^*] + \mu_Q. \tag{B-5}$$

Equation (B-5) shows that one can express μ_P in terms of risk-neutral moments if $\mathbb{E}_t^P[r^*]$ can be expressed in terms of risk-neutral moments. To this end, let $\phi_P(\lambda) = \mathbb{E}_t^P\left[e^{\lambda r^*}\right]$ be the moment generating function of r^* under P-measure, and $\phi_Q(\lambda) = \mathbb{E}_t^Q\left[e^{\lambda r^*}\right]$ be the moment generating function under Q-measure. Then, the following equation shows that one can express $\phi_P(\lambda)$ in terms of $\phi_Q(\lambda)$,

$$\begin{aligned}\phi_P(\lambda) &= \mathbb{E}_t^P\left[m\frac{1}{m}e^{\lambda r^*}\right] = e^{-r_f}\mathbb{E}_t^Q\left[\frac{1}{m}e^{\lambda r^*}\right] = \beta^{-1}e^{-r_f}\mathbb{E}_t^Q\left[e^{\gamma r}e^{\lambda r^*}\right] \\ &= \beta^{-1}e^{-r_f}e^{\gamma\mu_Q}\mathbb{E}_t^Q\left[e^{(\lambda+\gamma)r^*}\right] = \frac{\mathbb{E}_t^Q\left[e^{(\lambda+\gamma)r^*}\right]}{\mathbb{E}_t^Q\left[e^{\gamma r^*}\right]} = \frac{\phi_Q(\lambda+\gamma)}{\phi_Q(\gamma)},\end{aligned} \tag{B-6}$$

where $m = \beta e^{-\gamma r}$ is the pricing kernel corresponding to the power utility function with β being the subjective discount factor. The second equality follows from the change of probability measure formula, $\mathbb{E}_t^P[mX] = e^{-r_f}\mathbb{E}_t^Q[X]$ for arbitrary time-T measurable random variable. Taking the fourth-order Taylor expansion of $\phi_Q(\lambda)$ yields

$$\phi_Q(\lambda) = 1 + \frac{\lambda^2}{2}\sigma_Q^2 + \frac{\lambda^3}{6}\theta_Q\sigma_Q^3 + \frac{\lambda^4}{24}\kappa_Q\sigma_Q^4 + o(\sigma_Q^4). \tag{B-7}$$

Therefore, equations (B-6) and (B-7), and $\mathbb{E}_t^P[r^*] = \left.\frac{\partial\phi_P(\lambda)}{\partial\lambda}\right|_{\lambda=0}$ yield

$$\mathbb{E}_t^P[r^*] = \frac{\left.\frac{\partial\phi_Q(\lambda+\gamma)}{\partial\lambda}\right|_{\lambda=0}}{\phi_Q(\gamma)} = \gamma\sigma_Q^2 + \frac{\gamma^2}{2}\theta_Q\sigma_Q^3 + \frac{\gamma^3}{6}(\kappa_Q - 3)\sigma_Q^4 + o(\sigma_Q^4). \tag{B-8}$$

By substituting equations (B-4) and (B-8) into equation (B-5), we obtain

$$\begin{aligned}\mu_P &= \mathbb{E}_t^P[r^*] + \mu_Q \\ &= r_f - \delta + \frac{2\gamma - 1}{2}\sigma_Q^2 + \frac{3\gamma^2 - 1}{6}\theta_Q\sigma_Q^3 + \frac{4\gamma^3 - 1}{24}(\kappa_Q - 3)\sigma_Q^4 + o(\sigma_Q^4).\end{aligned} \tag{B-9}$$

Furthermore, equation (B-9) and the relation $ERP = \mu_P + \delta - r_f$ in equation (B-1) yield the following expression of ERP in terms of the risk-neutral moments,

$$ERP = \frac{2\gamma - 1}{2}\sigma_Q^2 + \frac{3\gamma^2 - 1}{6}\theta_Q\sigma_Q^3 + \frac{4\gamma^3 - 1}{24}(\kappa_Q - 3)\sigma_Q^4 + o(\sigma_Q^4). \tag{B-10}$$

B.3. Application of the modified DZ method to Nikkei 225 options

To estimate ERP based on equation (B-10), we need the estimates of the risk-neutral moments $(\sigma_Q^2,\ \theta_Q,\ \kappa_Q)$ and the CRRA parameter γ. We estimate these variables as follows.

For the risk-neutral moments $(\sigma_Q^2,\ \theta_Q,\ \kappa_Q)$, we apply the following Bakshi et al. (2003) formulae to option price data of the two closest maturities recorded at the close of the morning session and the afternoon session,

$$\mu_Q = e^{r_f} - 1 - e^{r_f}\left(\frac{V}{2} + \frac{W}{6} + \frac{X}{24}\right),$$

$$\sigma_Q^2 = Ve^{r_f} - \mu_Q^2,$$

$$\theta_Q = \frac{e^{r_f}(W - 3\mu_Q V) + 2\mu_Q^3}{\sigma_Q^3},$$

$$\kappa_Q = \frac{e^{r_f}(X - 4\mu_Q W + 6\mu_Q^2 V) - 3\mu_Q^4}{\sigma_Q^4}.$$

The three terms in the above equations, V, W, and X can be calculated from OTM put and call option prices as follows,

$$V = \int_{S_t}^{\infty} \frac{2(1 - \log(K/S_t))}{K^2} C(K)dK + \int_{0}^{S_t} \frac{2(1 - \log(K/S_t))}{K^2} P(K)dK, \tag{B-11}$$

$$W = \int_{S_t}^{\infty} \frac{6\log(K/S_t) - 3[\log(K/S_t)]^2}{K^2} C(K)dK + \int_{0}^{S_t} \frac{6\log(K/S_t) - 3[\log(K/S_t)]^2}{K^2} P(K)dK, \tag{B-12}$$

$$X = \int_{S_t}^{\infty} \frac{12[\log(K/S_t)]^2 - 4[\log(K/S_t)]^3}{K^2} C(K)dK + \int_{0}^{S_t} \frac{12[\log(K/S_t)]^2 - 4[\log(K/S_t)]^3}{K^2} P(K)dK. \tag{B-13}$$

Similar to the calculation of SVIX discussed in Appendix A, the strike prices of actually traded options are discrete and limited. Hence, we employ the same interpolation and extrapolation procedures as in Appendix A to obtain option prices over a fine grid of strike prices and calculate the integral terms in equations (B-11)—(B-13). We treat the estimated risk-neutral moments associated with specific contract months as missing unless two OTM call option prices and two OTM put option prices are available.

From the estimated risk-neutral moments based on the above procedures, we calculate the risk-neutral moments over the next 30-day period at the two different intraday times (i.e., at the close of the morning and afternoon sessions) by interpolating the risk-neutral moments estimated from the first contract month options (whose day-to-maturity is usually between one to 30 days) and those from the second contract month options (whose day-to-maturity is usually between 30 to 60 days) with respect to day-to-maturity of these options. If the estimated risk-neutral moments are missing for either one of the two contract months, we treat the remaining non-missing estimate as the estimate of the 30-day risk-neutral moments. If the estimates are missing for both maturities, we treat the estimate of the 30-day risk-neutral moments as missing and exclude it from our sample. We treat the estimated risk-neutral moments as missing unless they are estimable both at the close of the morning session and at the close of the afternoon session.

Next, for the estimation of the CRRA parameter γ, we follow Faccini et al. (2019) and conduct a GMM estimation based on the following equation,

$$\frac{\sigma_P^2 - \sigma_Q^2}{\sigma_Q^2} = \gamma\theta_Q\sigma_Q + \frac{\gamma^2}{2}(\kappa_Q - 3)\sigma_Q^2,$$

where we use the estimated risk-neutral moments at the close of the afternoon session obtained from the procedures above for σ_Q^2, θ_Q, and κ_Q. The volatility under the P-measure, σ_P, is a one-month (21-business day) historical volatility calculated from the five-minute intraday Nikkei 225 data obtained from Bloomberg. For instrumental variables in the GMM estimation, we follow Faccini et al. (2019) and use constant and the one-period lag of σ_Q^2. Due to the availability of intraday stock price data, the GMM estimation period ranges from May 20, 2011 to December 30, 2020. The estimated CRRA parameter is $\gamma = 2.6$, which is in line with the estimation result for Japan reported in Faccini et al. (2019).

Once we obtain the estimates of the risk-neutral moments σ_Q^2, θ_Q, κ_Q, and the CRRA parameter γ, we substitute them into equation (B-10) to obtain the estimated ERP at the close of the morning session and at the close of the afternoon session. We take the difference of these ERP at two different intraday times to obtain the changes during the afternoon session.

B.4. Estimation result

Figure A(1) shows the time-series developments of the estimated ERP at the close of the stock market based on the modified DZ method. While the DZ-type ERP exhibits largely the same movement as the Martin-type ERP, the DZ-type ERP is always larger than the Martin-type ERP. This is consistent with the theoretical result that Martin's ERP estimation method provides an estimate of the lower bound of ERP.

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Table 1 Data descriptions and data sources

Variable			Description	Data source
Time-series estimation (daily)				
Dependent variable	ΔERP_t^{day}	Change in the estimated option-implied ERP (%pt)	ERP estimated based on Martin's (2017) method. Change from the close of the morning session of the stock market to the close of the afternoon session (see Appendix A for details).	JPX
State variables	$\widehat{TPX}_{t-1}^{day}$	Deviation of TOPIX from its 100-day moving average (%)	Percentage deviation of TOPIX at the close of the previous day from its 100-day moving average.	QUICK
	VI_{t-1}^{day}	Nikkei Stock Average Volatility Index	The value at the close of the previous day.	QUICK
	ΔTPX_t^{AM}	Change in TOPIX (%)	Percentage change from the close of the previous day to the close of the morning session.	QUICK
	BOJ_t^{day}	ETF purchase amount (relative to the TOPIX market cap) (%)	The proportion of the daily ETF purchase amount to the TOPIX market capitalization. The same variable as the daily purchase volume indicator.	QUICK BOJ
Purchase amount indicator	ETF_t^{day}	ETF purchase amount (amount of money)	The numerator of the purchase volume indicator (see equation (3)).	BOJ
	MKC_{t-1}^{day}	TOPIX market capitalization	The value at the close of the previous day. The denominator of the purchase volume indicator (see equation (3)).	QUICK
Control variables	ΔTPX_t^{AM}	Change in TOPIX (%)	Percentage change from the close of the previous day to the close of the morning session.	QUICK
	ΔJPY_t^{AM}	Change in dollar-yen exchange rate (%)	Change from the close of the stock market of the previous day to the close of the morning session.	Bloomberg
Panel estimation (weekly)				
Dependent variable	$\Delta YS_{i,t}^{week}$	Changes in the yield spreads of individual stocks (%pt)	Consolidated earnings basis. Changes from the close of the previous week to the close of the current week.	QUICK
State Variables	$\widehat{TPX}_{t-1}^{week}$	Deviation of TOPIX from its 100-day moving average (%)	Percentage deviation of TOPIX at the close of the previous week from its 100-day moving average.	QUICK
	VI_{t-1}^{week}	Nikkei Stock Average Volatility Index	The value at the close of the stock market of the previous week.	QUICK
	ΔTPX_{t-1}^{week}	Change in TOPIX (%)	Percentage change from the close of two weeks previous to the close of the previous week.	QUICK
	BOJ_t^{week}	ETF purchase amount (relative to the TOPIX market cap) (%)	Weekly aggregated ETF purchase amount. Relative to the TOPIX market capitalization at the close of the previous week.	QUICK BOJ
Purchase amount indicator	ETF_j^{day}	ETF purchase amount (amount of money)	Used in the estimation of indirect stock-by-stock purchase amounts (see equation (5)).	BOJ
	$\omega_{BOJ,j}^{TPX}$ $\omega_{BOJ,j}^{NKY}$ $\omega_{BOJ,j}^{JPX}$	The proportions of the purchase amount of ETFs linked to TOPIX, Nikkei 225, and JPX-Nikkei 400 (estimates)	Estimates based on ETF-by-ETF market value data (QUICK) and official announcement documents of the Bank of Japan. Used in the estimation of indirect stock-by-stock purchase amounts (see equation (5)).	QUICK BOJ
	$\omega_{i,j}^{TPX}$ $\omega_{i,j}^{NKY}$ $\omega_{i,j}^{JPX}$	Index weights of individual stocks	The index weights of individual stocks in TOPIX, Nikkei 225, and JPX-Nikkei 400. Used in the estimation of indirect stock-by-stock purchase amounts (see equation (5)).	QUICK
	$MKC_{i,t-1}^{week}$	Market capitalizations of individual stocks	The value at the close of the previous week. The denominator of the purchase volume indicator (see equation (4)).	QUICK

Table 2 Summary statistics of the dependent and state variables: Full sample

(1) Time-series estimation (daily)

		Mean	SD	Percentile 1%	5%	Median	95%	99%	Obs.
Dependent variable									
Changes in estimated ERP (%pt)	ΔERP_t^{day}	0.02	0.71	-1.31	-0.52	-0.01	0.64	1.83	2,454
State variables									
Deviations of TOPIX from its X-day moving average (%)									
X = 100	$\widehat{TPX}_{t-1}^{day}$	1.54	6.83	-13.54	-8.80	1.66	11.64	21.42	2,468
X = 25		0.38	3.42	-10.04	-5.62	0.67	5.49	7.42	2,468
X = 200		2.87	9.74	-15.49	-11.21	2.13	17.88	34.16	2,468
Nikkei VI									
All observations	VI_{t-1}^{day}	22.43	6.72	13.46	14.64	21.02	35.62	44.78	2,468
TOPIX is below its trend		25.44	7.76	14.60	16.15	23.94	39.41	52.61	1,014
Changes in TOPIX (%)	ΔTPX_t^{AM}	0.03	1.05	-2.86	-1.67	0.03	1.57	2.68	2,468
ETF purchase amount (%) (relative to TOPIX market cap)	BOJ_t^{day}	0.00	0.01	0.00	0.00	0.00	0.02	0.03	2,468

(2) Panel estimation (weekly)

		Mean	SD	Percentile 1%	5%	Median	95%	99%	Obs.
Dependent variable									
Changes in yield spreads (%pt)	$\Delta YS_{i,t}^{week}$	0.00	1.84	-1.92	-0.66	0.00	0.69	1.98	1,178,559
State variables									
Deviations of TOPIX from its X-day moving average (%)									
X = 100	$\widehat{TPX}_{t-1}^{week}$	1.55	6.89	-12.33	-8.99	1.65	11.80	20.64	526
X = 25		0.39	3.46	-10.09	-5.48	0.68	5.39	7.47	526
X = 200		2.86	9.79	-15.02	-11.45	2.16	18.33	33.94	526
Nikkei VI									
All observations	VI_{t-1}^{week}	22.41	6.67	13.30	14.74	20.94	35.88	45.18	526
TOPIX is below its trend		25.49	7.68	14.67	16.19	23.92	40.23	50.90	218
Changes in TOPIX (%)	ΔTPX_{t-1}^{week}	0.17	2.74	-7.05	-4.35	0.40	3.97	6.97	526
ETF purchase amount (%) (relative to TOPIX market cap)	BOJ_t^{week}	0.02	0.02	0.00	0.00	0.01	0.06	0.09	526

Notes: 1. We report the changes during the afternoon session for "Changes in estimated ERP" in (1), whereas we report the weekly changes for "Changes in yield spreads" in (2).

2. For "Changes in TOPIX", we report the changes in the morning sessions in (1) and the weekly changes of the previous week in (2), respectively.

3. For the deviations of TOPIX and Nikkei VI, we report the summary statitics at the close of the previous day in (1) and those at the close of the previous week in (2), respectively. In the row labeled "TOPIX is below its trend", we document the summary statistics of Nikkei VI within the subsample, where the contemporaneous TOPIX closing price is below its 100-day moving average.

Table 3 Summary statistics of the dependent and state variables: Subsample restricted to the days ETF purchases were conducted

(1) Time-series estimation (daily)

		Mean	SD	Percentile					Obs.
				1%	5%	Median	95%	99%	
Dependent variable									
Changes in estimated ERP (%pt)	ΔERP_t^{day}	0.02	1.02	-1.86	-0.82	-0.03	0.91	2.90	665
State variables									
Deviations of TOPIX from its X -day moving average (%)									
X = 100	$\widehat{TPX}_{t-1}^{day}$	1.07	6.54	-16.01	-9.33	1.28	10.45	18.48	668
X = 25		-0.17	3.48	-11.11	-6.16	0.23	4.75	7.50	668
X = 200		2.86	9.60	-15.46	-11.48	2.36	17.12	31.34	668
Nikkei VI									
All observations	VI_{t-1}^{day}	22.95	7.38	13.04	14.60	21.20	37.44	50.05	668
TOPIX is below its trend		26.39	8.55	14.30	16.11	24.79	42.45	56.63	279
Changes in TOPIX (%)	ΔTPX_t^{AM}	-1.06	0.93	-4.99	-2.64	-0.81	-0.14	-0.03	668
ETF purchase amount (%) (relative to TOPIX market cap)	BOJ_t^{day}	0.02	0.01	0.00	0.00	0.02	0.03	0.04	668

(2) Panel estimation (weekly)

		Mean	SD	Percentile					Obs.
				1%	5%	Median	95%	99%	
Dependent variable									
Changes in yield spreads (%pt)	$\Delta YS_{i,t}^{week}$	0.05	2.03	-1.80	-0.57	0.02	0.81	2.17	802,303
State variables									
Deviations of TOPIX from its X -day moving average (%)									
X = 100	$\widehat{TPX}_{t-1}^{week}$	1.34	6.82	-15.22	-9.50	1.70	10.84	21.00	355
X = 25		0.01	3.58	-10.34	-5.89	0.43	5.16	7.21	355
X = 200		3.18	9.94	-15.96	-11.57	2.55	16.96	33.92	355
Nikkei VI									
All observations	VI_{t-1}^{week}	22.76	7.09	13.21	14.61	21.12	36.68	47.75	355
TOPIX is below its trend		26.38	8.05	14.81	16.04	25.42	41.17	52.04	145
Changes in TOPIX (%)	ΔTPX_{t-1}^{week}	-0.11	2.85	-8.07	-4.74	0.06	3.95	7.52	355
ETF purchase amount (%) (relative to TOPIX market cap)	BOJ_t^{week}	0.03	0.02	0.00	0.01	0.02	0.07	0.11	355

Notes: 1. We report the changes during the afternoon session for "Changes in estimated ERP" in (1), whereas we report the weekly changes for "Changes in yield spreads" in (2).
2. For "Changes in TOPIX", we report the changes in the morning sessions in (1) and the weekly changes of the previous week in (2), respectively.
3. For the deviations of TOPIX and Nikkei VI, we report the summary statitics at the close of the previous day in (1) and those at the close of the previous week in (2), respectively. In the row labeled "TOPIX is below its trend", we document the summary statistics of Nikkei VI within the subsample, where the contemporaneous TOPIX closing price is below its 100-day moving average.

Table 4 Baseline estimation results

(1) Dependent variable: Changes in the estimated ERP

Parameter	Explanatory variables	Estimation I-1	Estimation IIA-1	Estimation IIB-1	Estimation IIC-1	Estimation IID-1
$\theta,\ \alpha$	BOJ_t^{day}	-5.06 **	-1.76	-2.33	-6.21 **	-1.04
		(0.02)	(0.49)	(0.41)	(0.01)	(0.80)
σ	$\min\{0, \widehat{TPX}_{t-1}^{day}\} \times BOJ_t^{day}$		0.69 ***			
			(0.01)			
	$D_{t-1}^{day} \times VI_{t-1}^{day} \times BOJ_t^{day}$			-0.49 ***		
				(0.01)		
	$\min\{0, \Delta TPX_t^{AM}\} \times BOJ_t^{day}$				-1.51	
					(0.39)	
	$BOJ_t^{day} \times BOJ_t^{day}$					-137.71
						(0.25)
γ	$D_{t-1}^{day} \times BOJ_t^{day}$			10.72 *		
				(0.10)		
β	ΔTPX_t^{AM}	-0.05 ***	-0.06 ***	-0.06 ***	-0.05 **	-0.05 ***
		(0.00)	(0.00)	(0.00)	(0.02)	(0.01)
	ΔJPY_t^{AM}	0.05	0.06 *	0.06 *	0.05	0.05
		(0.13)	(0.06)	(0.06)	(0.14)	(0.10)
	$\widehat{TPX}_{t-1}^{day}$		0.00	0.00		
			(0.20)	(0.83)		
	VI_{t-1}^{day}			0.01 **		
				(0.03)		
β_0	$Constant$	0.04 **	0.04 **	-0.09	0.04 **	0.04 **
		(0.01)	(0.02)	(0.14)	(0.02)	(0.04)
	$Observation$	2,436	2,436	2,436	2,436	2,436
	$Adjusted\ R^2$	0.00	0.01	0.01	0.00	0.00

(2) Dependent variable: Changes in the yield spreads of individual stocks

Parameter	Explanatory variables	Estimation I-2	Estimation IIA-2	Estimation IIB-2	Estimation IIC-2	Estimation IID-2
$\theta,\ \alpha$	$BOJ_{i,t}^{week}$	-0.85 ***	-0.09	-0.13	-0.56 ***	0.26
		(0.00)	(0.53)	(0.33)	(0.00)	(0.22)
σ	$\min\{0, \widehat{TPX}_{t-1}^{week}\} \times BOJ_{i,t}^{week}$		0.18 ***			
			(0.00)			
	$D_{t-1}^{week} \times VI_{t-1}^{week} \times BOJ_{i,t}^{week}$			-0.07 ***		
				(0.00)		
	$\min\{0, \Delta TPX_{t-1}^{week}\} \times BOJ_{i,t}^{week}$				0.22 ***	
					(0.00)	
	$BOJ_t^{week} \times BOJ_{i,t}^{week}$					-16.66 ***
						(0.00)
γ	$D_{t-1}^{week} \times BOJ_{i,t}^{week}$			0.73 *		
				(0.05)		
β_0	$Constant$	-0.15 ***	-0.15 ***	-0.15 ***	-0.15 ***	-0.15 ***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	$Time\ FE$	yes	yes	yes	yes	yes
	$Individual\ FE$	yes	yes	yes	yes	yes
	$Observation$	1,137,052	1,137,052	1,137,052	1,137,052	1,137,052
	$Within\ R^2$	0.02	0.02	0.02	0.02	0.02

Notes: 1. Numbers in parentheses are *p*-values. In (2), *p*-values are calculated based on the standard errors clustered by stocks.
2. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.
3. The sample period is from December 1, 2010 to December 30, 2020.

Table 5 Robustness regarding the window length of the TOPIX trend

(1) Dependent variable: Changes in the estimated ERP

Parameter	Explanatory variables	Estimation IIA-1			Estimation IIB-1		
		X = 25	X = 100	X = 200	X = 25	X = 100	X = 200
α	BOJ_t^{day}	-1.00	-1.76	-1.31	-2.60	-2.33	-2.93
		(0.67)	(0.49)	(0.62)	(0.33)	(0.41)	(0.34)
σ	$\min\{0, \widehat{TPX}_{t-1}^{day}\} \times BOJ_t^{day}$	2.19 ***	0.69 ***	0.74 **			
		(0.00)	(0.01)	(0.01)			
	$D_{t-1}^{day} \times VI_{t-1}^{day} \times BOJ_t^{day}$				-0.47 ***	-0.49 ***	-0.49 ***
					(0.01)	(0.01)	(0.00)
γ	$D_{t-1}^{day} \times BOJ_t^{day}$				7.20	10.72 *	12.12 *
					(0.25)	(0.10)	(0.05)
β	ΔTPX_t^{AM}	-0.06 ***	-0.06 ***	-0.06 ***	-0.06 ***	-0.06 ***	-0.06 ***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	ΔJPY_t^{AM}	0.07 **	0.06 *	0.06 *	0.07 *	0.06 *	0.06 *
		(0.02)	(0.06)	(0.06)	(0.05)	(0.06)	(0.06)
	$\widehat{TPX}_{t-1}^{day}$	-0.02 ***	0.00	0.00	-0.01 ***	0.00	0.00
		(0.00)	(0.20)	(0.56)	(0.00)	(0.83)	(0.74)
	VI_{t-1}^{day}				0.00	0.01 **	0.01 **
					(0.32)	(0.03)	(0.02)
β_0	$Constant$	0.05 ***	0.04 **	0.04 **	-0.01	-0.09	-0.10 *
		(0.01)	(0.02)	(0.03)	(0.89)	(0.14)	(0.09)
	$Observation$	2,436	2,436	2,436	2,436	2,436	2,436
	$Adjusted\ R^2$	0.02	0.01	0.01	0.01	0.01	0.01

(2) Dependent variable: Changes in the yield spreads of individual stocks

Parameter	Explanatory variables	Estimation IIA-1			Estimation IIB-1		
		X = 25	X = 100	X = 200	X = 25	X = 100	X = 200
α	$BOJ_{i,t}^{week}$	-0.14	-0.09	-0.01	-0.07	-0.13	-0.42 **
		(0.26)	(0.53)	(0.96)	(0.63)	(0.33)	(0.02)
σ	$\min\{0, \widehat{TPX}_{t-1}^{week}\} \times BOJ_{i,t}^{week}$	0.30 ***	0.18 ***	0.19 ***			
		(0.00)	(0.00)	(0.00)			
	$D_{t-1}^{week} \times VI_{t-1}^{week} \times BOJ_{i,t}^{week}$				-0.12 ***	-0.07 ***	-0.09 ***
					(0.00)	(0.00)	(0.00)
γ	$D_{t-1}^{week} \times BOJ_{i,t}^{week}$				1.79 ***	0.73 *	1.93 ***
					(0.00)	(0.05)	(0.00)
β_0	$Constant$	-0.15 ***	-0.15 ***	-0.15 ***	-0.15 ***	-0.15 ***	-0.15 ***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	$Time\ FE$	yes	yes	yes	yes	yes	yes
	$Individual\ FE$	yes	yes	yes	yes	yes	yes
	$Observation$	1,137,052	1,137,052	1,137,052	1,137,052	1,137,052	1,137,052
	$Within\ R^2$	0.02	0.02	0.02	0.02	0.02	0.02

Notes: 1. Numbers in parentheses are *p*-values. In (2), *p*-values are calculated based on the standard errors clustered by stocks.
2. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.
3. *X* denotes the window length of the moving average trend. The results for *X*=100 is the repost of the baseline results.
4. The sample period is from December 1, 2010 to December 30, 2020.

Table 6 Results of subsample analysis

(1) Dependent variable: Changes in the estimated ERP

Parameter	Explanatory variables	Estimation I-1	Estimation IIA-1	Estimation IIB-1	Estimation IIC-1	Estimation IID-1
$\theta,\ \alpha$	BOJ_t^{day}	-0.60 (0.77)	4.53 * (0.06)	2.40 (0.36)	-0.44 (0.84)	6.93 * (0.07)
σ	$\min\{0, \widehat{TPX}_{t-1}^{day}\} \times BOJ_t^{day}$		1.11 *** (0.00)			
	$D_{t-1}^{day} \times VI_{t-1}^{day} \times BOJ_t^{day}$			-0.67 *** (0.00)		
	$\min\{0, \Delta TPX_t^{AM}\} \times BOJ_t^{day}$				0.29 (0.85)	
	$BOJ_t^{day} \times BOJ_t^{day}$					-233.01 ** (0.02)
γ	$D_{t-1}^{day} \times BOJ_t^{day}$			11.09 ** (0.05)		
β	ΔTPX_t^{AM}	0.03 (0.23)	0.03 (0.31)	0.01 (0.79)	0.03 (0.36)	0.04 (0.13)
	ΔJPY_t^{AM}	0.09 ** (0.02)	0.13 *** (0.00)	0.13 *** (0.00)	0.09 ** (0.02)	0.11 *** (0.01)
	$\widehat{TPX}_{t-1}^{day}$		-0.01 *** (0.00)	0.00 (0.91)		
	VI_{t-1}^{day}			0.02 *** (0.00)		
β_0	$Constant$	0.02 (0.44)	0.02 (0.34)	-0.35 *** (0.00)	0.02 (0.42)	0.00 (0.89)
	$Observation$	1,057	1,057	1,057	1,057	1,057
	$Adjusted\ R^2$	0.01	0.04	0.05	0.01	0.02

(2) Dependent variable: Changes in the yield spreads of individual stocks

Parameter	Explanatory variables	Estimation I-2	Estimation IIA-2	Estimation IIB-2	Estimation IIC-2	Estimation IID-2
$\theta,\ \alpha$	$BOJ_{i,t}^{week}$	-1.10 *** (0.00)	-0.13 (0.39)	-0.06 (0.65)	-0.79 *** (0.00)	0.98 *** (0.00)
σ	$\min\{0, \widehat{TPX}_{t-1}^{week}\} \times BOJ_{i,t}^{week}$		0.20 *** (0.00)			
	$D_{t-1}^{week} \times VI_{t-1}^{week} \times BOJ_{i,t}^{week}$			-0.05 *** (0.00)		
	$\min\{0, \Delta TPX_{t-1}^{week}\} \times BOJ_{i,t}^{week}$				0.24 *** (0.00)	
	$BOJ_t^{week} \times BOJ_{i,t}^{week}$					-24.83 *** (0.00)
γ	$D_{t-1}^{week} \times BOJ_{i,t}^{week}$			-0.20 (0.56)		
β_0	$Constant$	-0.14 *** (0.00)	-0.15 *** (0.00)	-0.14 *** (0.00)	-0.14 *** (0.00)	-0.16 *** (0.00)
	$Time\ FE$	yes	yes	yes	yes	yes
	$Individual\ FE$	yes	yes	yes	yes	yes
	$Observation$	520,726	520,726	520,726	520,726	520,726
	$Within\ R^2$	0.10	0.10	0.10	0.10	0.10

Notes: 1. Numbers in parentheses are *p*-values. In (2), *p*-values are calculated based on the standard errors clustered by stocks.
2. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.
3. The sample period is from August 4, 2016 to December 30, 2020.

Table 7 Estimation results for the estimated ERP based on Duan and Zhang's (2014) method

Parameter	Explanatory Variables	Estimation I-1	Estimation IIA-1	Estimation IIB-1	Estimation IIC-1	Estimation IID-1
$\theta,\ \alpha$	BOJ_t^{day}	-6.23	1.61	-0.26	-7.00	24.10 *
		(0.39)	(0.85)	(0.98)	(0.41)	(0.07)
σ	$\min\{0, \widehat{TPX}_{t-1}^{day}\} \times BOJ_t^{day}$		2.02 **			
			(0.02)			
	$D_{t-1}^{day} \times VI_{t-1}^{day} \times BOJ_t^{day}$			-1.77 ***		
				(0.00)		
	$\min\{0, \Delta TPX_t^{AM}\} \times BOJ_t^{day}$				-1.03	
					(0.86)	
	$BOJ_t^{day} \times BOJ_t^{day}$					-1039.04 ***
						(0.01)
γ	$D_{t-1}^{day} \times BOJ_t^{day}$			40.04 *		
				(0.06)		
β	ΔTPX_t^{AM}	-0.05	-0.06	-0.08	-0.05	-0.02
		(0.39)	(0.31)	(0.20)	(0.48)	(0.75)
	ΔJPY_t^{AM}	-0.01	0.03	0.04	-0.02	0.02
		(0.90)	(0.76)	(0.72)	(0.89)	(0.88)
	$\widehat{TPX}_{t-1}^{day}$		-0.02 ***	-0.01		
			(0.00)	(0.36)		
	VI_{t-1}^{day}			0.04 ***		
				(0.00)		
β_0	$Constant$	0.15 ***	0.18 ***	-0.78 ***	0.15 ***	0.11 *
		(0.01)	(0.00)	(0.00)	(0.01)	(0.06)
	$Observation$	2,436	2,436	2,436	2,436	2,436
	$Adjusted\ R^2$	0.00	0.00	0.01	0.00	0.00

Notes: 1. Numbers in parentheses are *p*-values.

2. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.

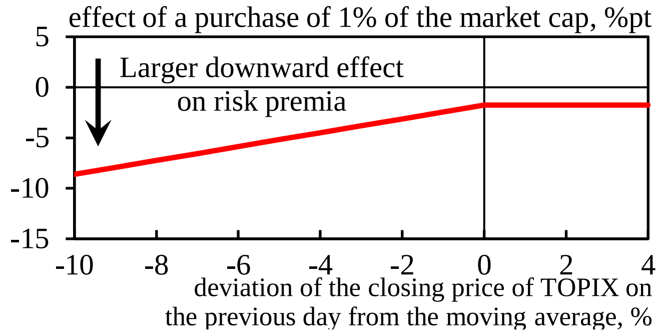
3. The sample period is from December 1, 2010 to December 30, 2020.

Figure 1 Effects of a purchase of 1% of the market capitalization

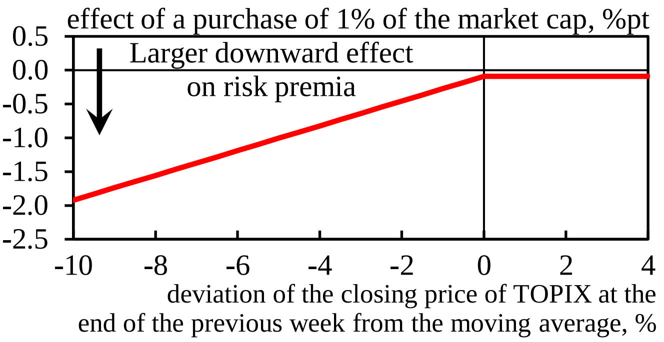
Dependent variable: Changes in estimated ERP

Dependent variable: Changes in yield spreads

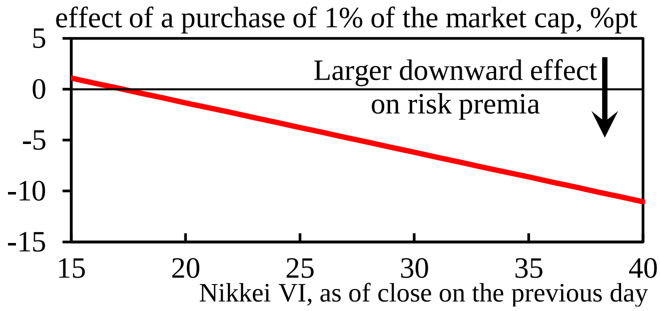
(1-1) Estimation IIA-1



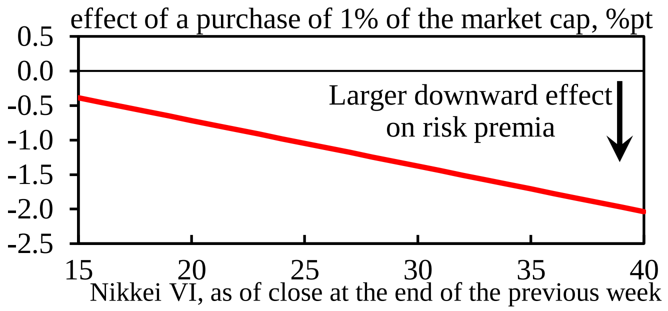
(1-2) Estimation IIA-2



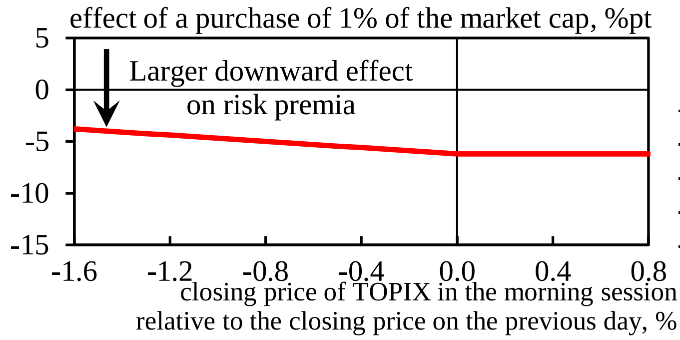
(2-1) Estimation IIB-1



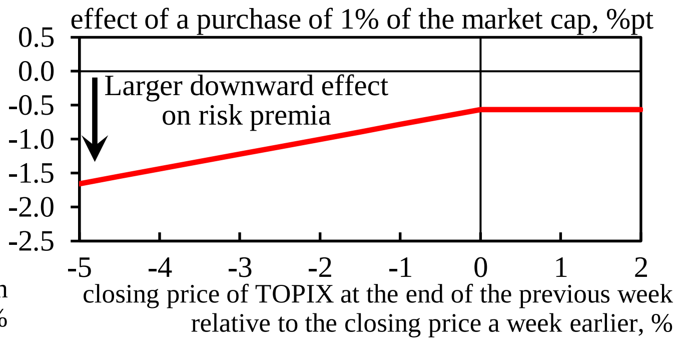
(2-2) Estimation IIB-2



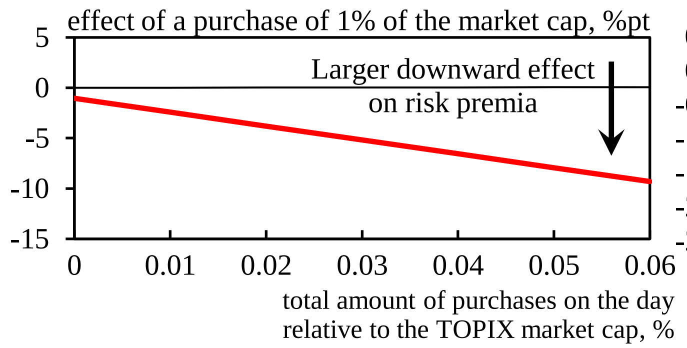
(3-1) Estimation IIC-1



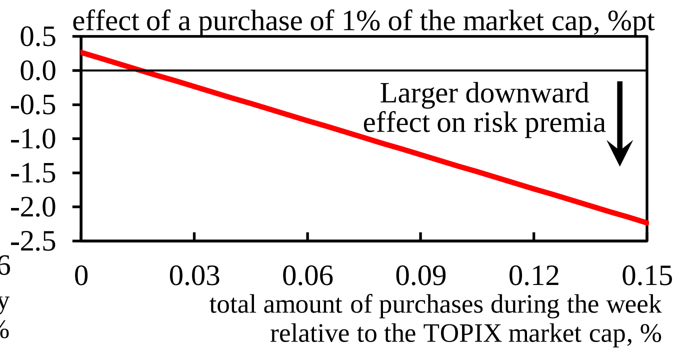
(3-2) Estimation IIC-2



(4-1) Estimation IID-1



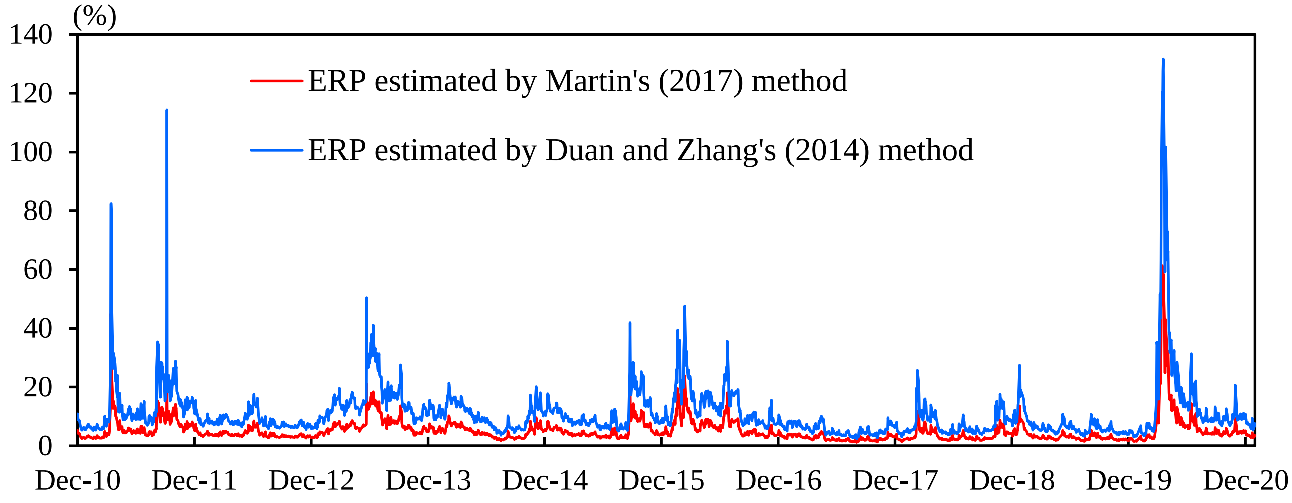
(4-2) Estimation IID-2



Note: Changes in estimated ERP are the changes in the afternoon session. Changes in yield spreads are the weekly changes.

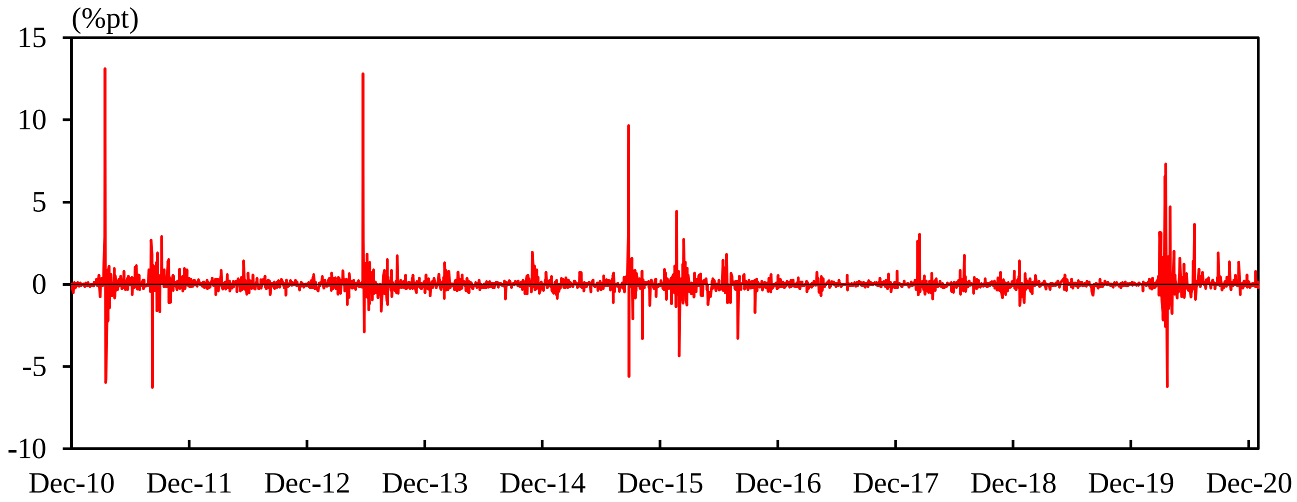
Figure A　Time-series of the estimated ERP

(1) Time-series of the estimated ERP (level)

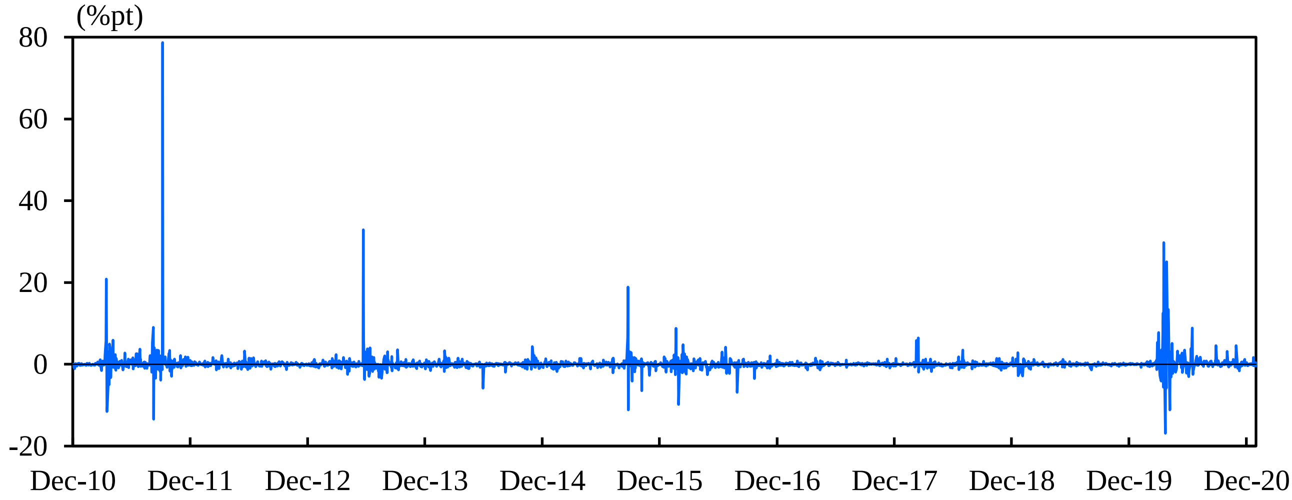


(2) Time-series of the estimated ERP (change)

(2a) Estimated ERP based on Martin's (2017) method



(2b) Estimated ERP based on Duan and Zhang's (2014) method



Note: The level of the estimated ERP in (1) is the level at the close of the afternoon session of the stock market.
The change in the estimated ERP in (2) is the change during the afternoon session of the stock market.