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Abstract

This paper provides a time series analysis of the Bank of Japan (BOJ)'s exchange traded fund (ETF) and real estate investment trust (REIT) purchase program. The program is a part of the BOJ's unconventional monetary policy introduced in December 2010 and the timing and quantity of purchases have changed substantially over time. To the best of our knowledge, the current study is the first attempt at investigating the purchase program from a dynamic viewpoint and developing a system that takes expert knowledge as input to analyze the BOJ's purchase program and outputs a trading strategy.

Firstly, to find factors underlying decisions of the BOJ's purchases, we apply a state space model with explanatory variables obtained by expert knowledge, which is an extension of a logistic regression and enables us to predict their timings with high accuracy throughout all periods. Secondly, we figure out the dynamics of the program's effect on equity and REIT prices by using a different type of state space model. Finally, we find a profitable trading strategy that incorporates the insights revealed in the above dynamic analysis and that focuses on an effect of the BOJ's purchase on the spread between the Tokyo Stock Price Index (TOPIX) and Nikkei225 Index (Nikkei225). In addition, we implement event studies, particularly the price dynamics of ETF and REIT just before and after the purchase.

Keywords: Time series analysis, State space model, Trading strategy, Central bank, Monetary policy, Stock market

1. Introduction and Related Works

1.1. Introduction

A central bank asset purchase program is important in terms of monetary policy and investment strategy. The Bank of Japan (BOJ) is the only central bank that has conducted the program to include stock exchange traded funds (ETFs) and real estate investment trusts (REITs) in its purchased assets to support the economy. Depending on the situation in the future, it is quite possible that the purchase of stock ETFs and REITs will be included in monetary policy when the central bank of each country is forced to purchase a wider range of assets. Hence, an analysis of Japan's experience will provide the other countries with important information and insights.

Since December 2010, the BOJ has been purchasing ETFs and REITs to lower risk premium in the market as a part of unconventional monetary policy. Initially, the maximum balance of this program was 450 billion yen and the expiration date was the end of December 2011. The target ETFs were limited to the ones linked to the Tokyo Stock Price Index (TOPIX)[1] and Nikkei225 Index (Nikkei225)[2]. The target REITs were limited to J-REITs whose issuers were sufficiently creditworthy.

After several rounds of increasing the purchase amount limit and extending the expiration date, in April 2013 Mr. Kuroda became the governor of the BOJ and introduced the Quantitative and Qualitative Easing (QQE) which increased the BOJ's ETF holdings by 1 trillion yen per year. Since then, the annual purchase amount has been increased to about 3 trillion yen in October 2014 and about 6 trillion yen in July 2016. This program makes the BOJ the only central bank that indirectly holds the stocks of many companies via ETFs. The BOJ's ETF holdings exceeded 36 trillion yen in May 2021, which means that the BOJ is the largest holder of Japanese equities, and such purchases may distort the market.

Under such circumstances, our study aims to (a) identify what factors determine the BOJ's ETF and REIT purchases, (b) quantify the impacts of the asset purchase on market equity and REIT prices, (c) examine whether the purchase causes some distortion in the market, and (d) develop a new trading strategy based on the analyses in (a), (b) and (c). To tackle the goal, this study applies a state space model with Markov Chain Monte Carlo (MCMC) method.

The contribution of this study is summarized as follows: (i) This study is the first application of a state space model with expert knowledge to analyze monetary policy in the form of purchases of

[1] Tokyo Stock Price Index is a Japanese stock market index calculated as a market capitalization-weighted average of about 2000 companies listed on the First Section of the Tokyo Stock Exchange (TSE).

[2] Nikkei225 Index is a Japanese stock index calculated as an average stock price index of 225 companies selected by Nikkei Inc. The constituents of this index are typically large blue-chip companies that account for roughly two-thirds of the market capitalization of the TSE First Section on aggregate.

stock ETFs and REITs. The state space models and complementary regression analyses enable us to identify what factors determine the purchases and accurately predict the purchase timings, which existing literature is unable to provide.

(ii) The results of our analysis have a wide range of implications. We show there is price distortion caused by the BOJ's ETF and REIT purchasing behavior with respect to the two indices, TOPIX and Nikkei225. This characteristic of the BOJ's behavior enables us to develop a new profitable trading strategy, which is an interesting result from a trader's viewpoint. However, it also conveys a warning sign to central banks that contemplate market intervention to stock and REIT markets, because the existence of price distortion and resulting exploitable profit opportunities are undesirable from the social point of view. None of the existing literature tackles this important issue.

Consequently, it can be said that this paper newly develops a system that takes expert knowledge as input to analyze the purchase program from a dynamic viewpoint and outputs a trading strategy.

The overview of our paper is as follows: The following subsection discusses related works.

Section 2 investigates factors underlying the decisions of the BOJ's purchases. Particularly, we use the following two steps. First, we estimate the dynamics of parameters using a state space model with time-varying parameters, which is an extension of a logistic regression model. Then we conduct a logistic regression analysis assuming that structural changes occurred when the parameters estimated by the state space model changed considerably. As a result, we identify the factors underlying the BOJ's purchase decision.

Section 3 provides an empirical analysis of the price impact of the purchase program. We implement a static regression analysis and then apply a state space model which is an extention of a linear regression model. The result shows that the effects of ETF and REIT purchases on their prices are about 13 basis points (bps) and 9bps, respectively. Moreover, we examine the dynamics of the price impact by a state space model. The estimated parameters show that the impact on equity is zero before 2013 but gradually goes up to about 20bps. On the other hand, the impact on REITs is around 10bps before 2020. However, it declines considerably to a level close to zero thereafter. Furthermore, we also analyze some impact on the difference between TOPIX and Nikkei225 return to find that the TOPIX return tends to be higher than the Nikkei225 when the BOJ purchases ETFs.

Section 4 implements a simulation of a trading strategy focusing on an effect of the BOJ's purchase on the TOPIX-Nikkei225 spread. The strategy is to construct TOPIX long and Nikkei225 short positions if the BOJ's purchase is predicted, which utilizes the insights obtained in Section 2 and Section 3. Then, the strategy yields non-negligible profits with low risks over around the past ten years.

Section 5 reports event studies, particularly price dynamics just before and after the BOJ's purchase. It turns out that the BOJ is likely to purchase ETFs if there is a sharp fall by about two percent on average. We also find that the current BOJ governor Mr.Kuroda aggressively bought ETFs even for smaller price declines. Finally, Section 6 provides a conclusion and discusses future research.

Figure 1 shows the structure of this paper, which also describes the research method used in each section.

Figure 1: The structure of this paper

Table 1 below explains the abbreviations used in this paper.

Table 1: Abbreviation List

Abbreviation	Description
BOJ	Bank of Japan. This bank is the central bank in Japan.
QQE	Quantitative and Qualitative Easing. In this paper, QQE refers to the BOJ's unconventional monetary policy since April 2013.
TSE	Tokyo Stock Exchange. This is a stock exchange located in Tokyo, Japan.
ETF	Exchange Traded Fund. This is a type of investment fund and is tradable on stock exchanges, such as TSE.
REIT	Real Estate Investment Trust. This is a type of investment fund. Although there are several types of REIT, in this paper, REIT refers to a publicly tradable one on TSE, which can be called J-REIT.
TOPIX	Tokyo Stock Price Index. This index is a Japanese stock market index calculated as a market capitalization-weighted average of about 2000 companies listed on the First Section of the TSE.
Nikkei225	Nikkei225 Index. This index is a Japanese stock market index calculated as an average stock price index of 225 companies selected by Nikkei Inc. The constituents of the Nikkei225 are typically large blue-chip companies that account for roughly two-thirds of the market capitalization of the TSE First Section on aggregate.
TSE-REIT	Tokyo Stock Exchange REIT Index. This index is a capitalization-weighted index based on all REITs listed on TSE.
VIX	Volatility Index. This is a popular measure of the stock market's expectation of volatility based on S&P 500 index options.
PER	Price to Earnings Ratio. This is the ratio for valuing a company that measures its current stock price relative to its earnings per share.
PBR	Price to Book Ratio. This ratio is calculated by dividing the company's stock price per share by its book value per share.

1.2. Related Works

As studies related to BOJ's purchase program which are different from our viewpoint, Serita & Hanaeda (2017) and Kobayashi (2017) point out that the purchase reduces the volatility of equity and REIT. Adachi et al. (2021) investigates the effects of the BOJ's ETF purchases on two types of risk premium, namely equity risk premium implied in Nikkei225 option prices and yield spreads of individual stocks. Their analysis shows that the BOJ's ETF purchases have lowering effects on the risk premium. Ide & Takehara (2020) finds that the purchase program lowers the default probability. Takahashi & Yamada (2021) reveals that indirect ownership through the ETF purchasing program by the BOJ has a positive impact on abnormal returns. Charoenwong et al. (2020) investigates the purchase program from a corporate governance perspective.

Other studies that have relatively similar interests to ours are the followings. Ide & Minami (2013) focuses on the return of ETFs linked to the Nikkei225 and conducts several event studies, which shows that ETFs prices on the day the BOJ purchases ETFs tend to go up compared with the prices on other days. Harada & Okimoto (2019) applies the difference-in-difference approach to individual stocks that constitute the Nikkei225 index against other stocks in the market and finds that the ETF purchases have a significant positive impact on those stocks' returns in the afternoon. Barbon & Gianinazzi (2019) constructs an asset pricing model and finds that the purchases of ETFs have a positive and persistent effect on individual stocks.

While the existing literature is short of providing comprehensive knowledge about the way the program is implemented and examining whether the program induces exploitable market distortion, our study based on expert knowledge finds the factors underlying the ETF/REIT purchase, which provide precise predictions of the purchase timing, and the price distortion of two different indices, namely TOPIX and Nikkei225, caused by the purchase. These analyses enable us to develop a profitable system that utilizes expert knowledge to create a trading strategy.

Moreover, from a methodological perspective, this study has an advantage because it adopts not only regression models with fixed coefficients of the explanatory variables which most of the existing studies use but also state space models that can incorporate the dynamic changes of the coefficients into the model. More concretely, we use two types of state space models, one that extends logistic regression and the other that extends normal regression analysis. Particularly, our approach is novel in the sense that it extends logistic regression within the framework of a state space model to estimate when the central bank implements the ETF and REIT purchases. As a result, several points are observed when the levels of the coefficients change significantly. Then, when regression analysis is also performed considering the structural changes in the time series, it is confirmed that the coefficients change significantly before and after specific time points.

Other related literature on the development of expert systems in finance includes the following works: Diaz et al. (2016) proposes a knowledge discovery methodology using several machine learning techniques, including decision tree and clustering, which enables us to discover and describe hidden patterns, economic cycle stages, and the historical relationships between interest rates and other relevant economic variables. Chatzis et al. (2018) examines crash event propagation and transmission mechanisms in international stock markets by leveraging bleeding-edge advances in deep learning, finding that stock market crises exhibit persistence. Lu et al. (2021) develops an early warning system for predicting stock market crisis via market indicators and mixed frequency investor sentiments employing artificial neural networks. Nishimura et al. (2019) and Nakatani et al. (2020) propose systems to estimate investor attitude factors through developing multi-factor interest rate models with natural language processing. Nakano et al. (2018) and Nakano & Takahashi (2020) propose trading strategies by developing deep neural networks for cryptocurrency markets. New investment models in state space frameworks utilizing machine learning techniques, such as anomaly detection and neural network, can be found in Nakano et al. (2017a, 2017c). Several papers develop investment schemes utilizing fuzzy systems composed of ”IF-THEN” rules ,e.g., (Dymova et al., 2012; Brzeszczyński & Ibrahim, 2019; Brzeszczyński et al., 2021b; Nakano et al., 2017b, 2017d, 2019; Takahashi & Takahashi, 2021).

As we see above, most of the existing works on finance applications of expert systems are related to asset price predictions, investment, risk management and an analysis of the economic environment using quantitative methods. However, there are few studies that investigate trading strategies based on monetary policy, except for Brzeszczyński et al. (2021b). In the paper, they apply traditional ”IF-THEN” rules to construct a trading strategy aimed at exploiting the central bank's announcements. Their strategy is based on the accumulation of their previous studies (Brzeszczyński et al., 2017; Brzeszczyński & Kutan, 2015; Brzeszczyński et al., 2021a) which investigate the National Bank of Poland (NBP)'s announcement effect on Poland markets and find out the existence of the statistically significant responses of the market. Their trading system captures announcements published by the NBP related to interest rate, money supply, official reserves, and current account data by dummy variables and then takes positions based on their ”IF-THEN” rules, which deliver profits. Our study takes a different approach. That is, we do not focus on the announcements but on the central bank's asset purchase. More precisely, we search for factors underlying the decisions of the purchases by applying a state space model and examine the market impact. The insights obtained from these analyses enable us to construct a system that utilizes expert knowledge to create a trading strategy by exploiting some distortion of the TOPIX-Nikkei225 spread at the timings of the BOJ's purchases.

2. Factors Underlying the BOJ's Purchase Decision

Before we examine the price impacts, this section discusses factors underlying the purchase decision by applying a state space model and a logistic regression. Specifically, we search for variables that are able to explain the BOJ's purchase.

2.1. State Space Model

2.1.1. State Space Model for TOPIX-linked ETFs

To analyze purchases of ETFs linked to TOPIX, we use the following state space model.

$$
\begin{aligned}
&\text{[observation equation]} \qquad Y_t^{ETF} \sim Bernoulli(p_t^{ETF}),\\
&\text{[state equations]} \qquad p_t^{ETF} = 1/\{1+\exp(-\alpha_t - \sum_{i=1}^{6}\theta_{i,t}x_{i,t}^{ETF})\},\\
&\qquad \theta_{i,t} \sim N(\theta_{i,t-1}, \sigma_i^2) \qquad (i=1,2,...,6),\\
&\qquad \sigma_i \sim t(3,0,10)^+.
\end{aligned} \tag{1}
$$

This state space model is an extension of the logistic regression model, where the parameters are time-varying. Although the distribution of the annual purchase amount to be used for TOPIX and Nikkei225 linked ETF are disclosed and the time series of ETF purchase volume is available at a daily frequency on the BOJ website, more detailed daily information such as the ratio of ETFs linked to TOPIX is not disclosed. Hence, the observation variable Y_t^{ETF} is an indicator variable which takes one if the BOJ purchases ETFs linked to TOPIX or Nikkei225 and zero otherwise. Moreover, we suppose that each Y_t^{ETF} follows a Bernoulli distribution with parameter p_t^{ETF}. It is expressed as a sigmoid function of six explanatory variables $\{x_{i,t}^{ETF}\}_{i=1,\cdots,6}$ selected by expert knowledge, five of which are related to TOPIX.

We also assume each coefficient $\theta_{i,t}$ is generated from a normal distribution with mean $\theta_{i,t-1}$ and variance σ_i^2, where σ_i is generated from a half-t-distribution. A half-t-distribution is well known as weakly informative prior and is used for parameters whose prior distribution we do not know very well. Based on these assumptions, we estimate the dynamics of state variables (p_t^{ETF} and $\theta_{i,t}$) and find out the key factors for the BOJ's purchase decision.

In reference to previous studies, comments from BOJ officials and several analysts' hypotheses, we take the following six variables as explanatory variables.

1. x_1^{ETF}: rate of change in TOPIX price in the morning session of the day
2. x_2^{ETF}: rate of change in TOPIX price from the closing of the previous business day to the opening of the day
3. x_3^{ETF}: deviation of TOPIX Price to Earnings Ratio (PER) from its previous 30 days moving average
4. x_4^{ETF}: deviation of TOPIX price from its previous 30 days moving average
5. x_5^{ETF}: number of consecutive days of TOPIX price decline as of the previous day
6. x_6^{ETF}: dummy variable that takes one if VIX index (for S&P500) in the previous day is greater than 20

The morning session of the Tokyo Stock Exchange (TSE) is from 9:00 to 11:30 and the afternoon session of the TSE is from 12:30 to 15:00 Japan time. Many analysts often state that TOPIX price changes in the morning session or/and price changes from the previous closing to the day's closing price in the morning session determines the BOJ's decision. For instance, Kobayashi (2017) and Hattori & Yoshida (2020) point out the validity of these variables. Reflecting the statements, we take x_1^{ETF} and x_2^{ETF} above. Amemiya, the deputy governor of the BOJ, said in the Diet speech[3] that the BOJ considered several factors such as PER, Price to Book Ratio (PBR) and VIX index. Based on this comment, we adopt x_3^{ETF}, x_4^{ETF} and x_6^{ETF}. On the contrary, we do not take other variables related to PBR or price deviation, which are strongly correlated with the above selected variables. In addition, we add x_5^{ETF} as an explanatory variable to reflect the market sentiment. Then, the state variable p_t^{ETF} can be regarded as the probability that the BOJ implements its purchase in the afternoon session at t.

The data used for this analysis is available on the BOJ website, Bloomberg[4] and Federal Reserve Bank of St. Louis. The data period is from December 15 2010 to July 31 2021.

The parameters are estimated by MCMC[5]. Figure 2 describes the time series of estimated p_t^{ETF} with the TOPIX price.

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[3] The 198th Session of the Diet on May 30, 2019

[4] TOPIX price, Price Earning Ratio and Price Book-Value Ratio are taken from Bloomberg. VIX data is available on the Federal Reserve Bank of St. Louis website.

[5] We use R and rstan package. Rstan config is as follows: seed = 1, iter = 20000, warmup = 10000, and thin = 20.

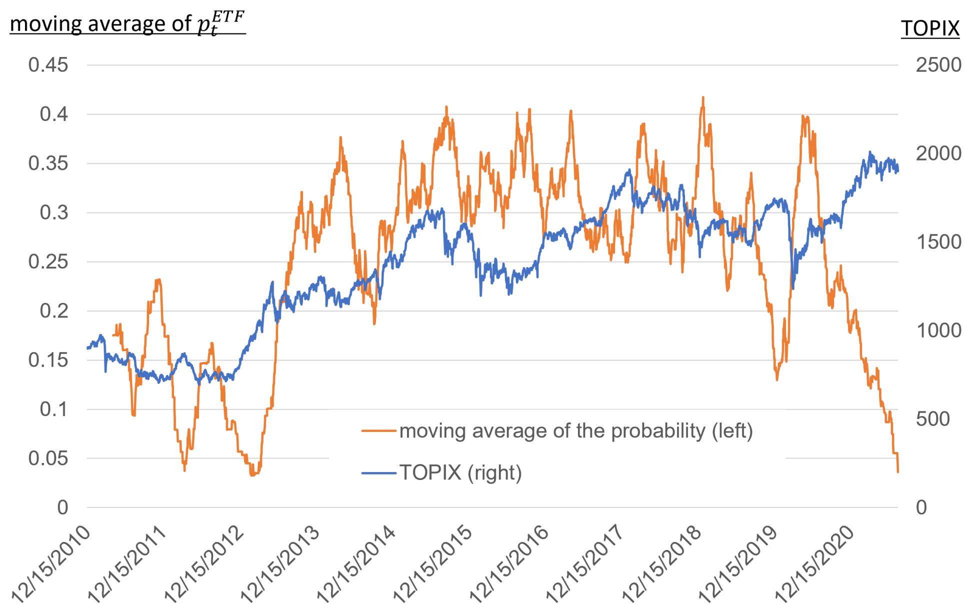


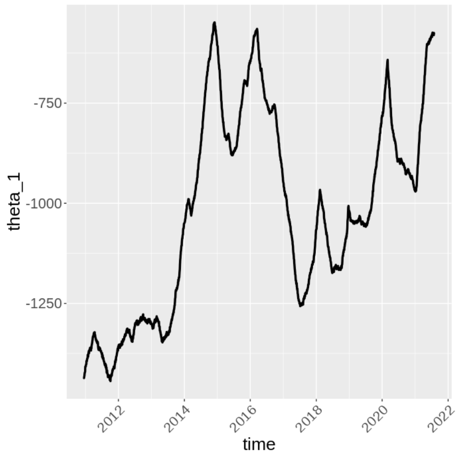
Figure 2: 90 days moving average of p_t^{ETF} and TOPIX

Since the original p_t^{ETF} is too volatile to see graphically, we use the moving average method in Figure 2. There are two features in Figure 2. Firstly, p_t^{ETF} rises rapidly around 2013. In April 2013 Mr. Kuroda became the governor of the BOJ and introduced QQE, which increased the BOJ's ETF holdings by 1 trillion yen per year. This monetary easing makes p_t^{ETF} higher. Another feature is that after p_t^{ETF} sharply went up when the covid-19 shock hit the Japanese equity market in early 2020, p_t^{ETF} has been decreasing, and currently it is at the same level as before 2013. It seems that the TOPIX price has recovered quickly after the covid-19 shock, which reduces p_t^{ETF}. Moreover, in March 2021 the BOJ expressed to refrain from purchasing and the decrease of p_t^{ETF} was accelerated.

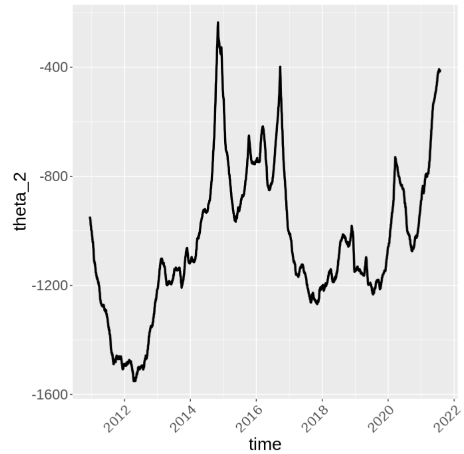
Next, we examine the coefficients of the explanatory variables. Figure 3 shows their dynamic behaviors: Overall most of the parameters change their levels substantially in 2013 or/and 2020. Seen individually, $\theta_{1,t}$ and $\theta_{2,t}$ are negative, which means that negative equity returns increase the BOJ's purchase probability p_t^{ETF}. On the contrary, it is difficult to interpret the time series of $\theta_{3,t}$, the coefficient of PER. In fact, as will be seen in Table 3 in Section 2.2, this parameter is not statistically significant (at the 5% level) throughout the entire period. As for $\theta_{4,t}$, its sign tends to be negative recently, which implies that a downward deviation of the TOPIX price from its trend for the previous 30 days increases p_t^{ETF}. We also note that in Table 3 below, this parameter is statistically significant only in the most recent period (period 3), namely after the covid-19 pandemic occurred.

It is observed that $\theta_{5,t}$ rises quickly in 2013. As the TOPIX price declines on consecutive days, the market sentiment becomes worse. We presume that after Mr. Kuroda became the BOJ governor, the

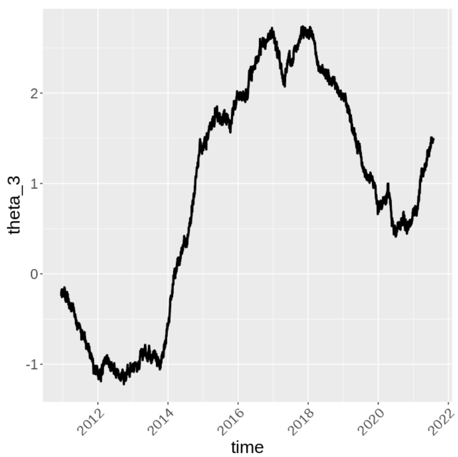
BOJ tends to purchase ETFs to improve the sentiment, which increases p_t^{ETF}. Although $\theta_{6,t}$ is close to zero until about 2020, it goes up quickly during the covid-19 period. Under the covid-19 pandemic, the BOJ seems to take the VIX index into account. We remark that in Table 3 below $\theta_{5,t}$ and $\theta_{6,t}$ are statistically significant in the periods 2 & 3 and only in the period 3, respectively.



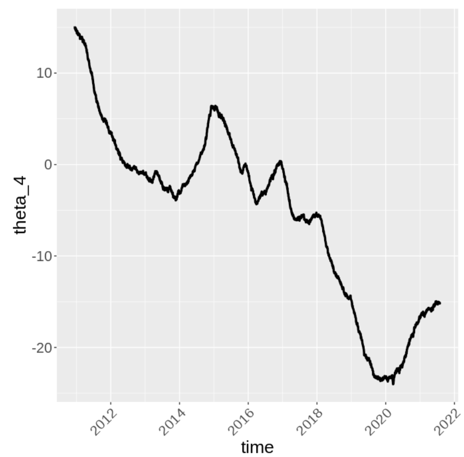
(a) $\theta_{1,t}$: the coefficient of x_1^{ETF}



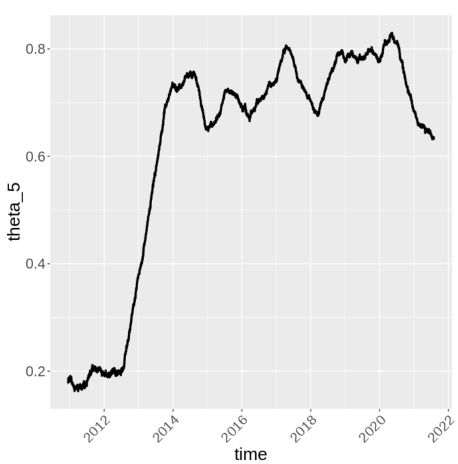
(b) $\theta_{2,t}$: the coefficient of x_2^{ETF}



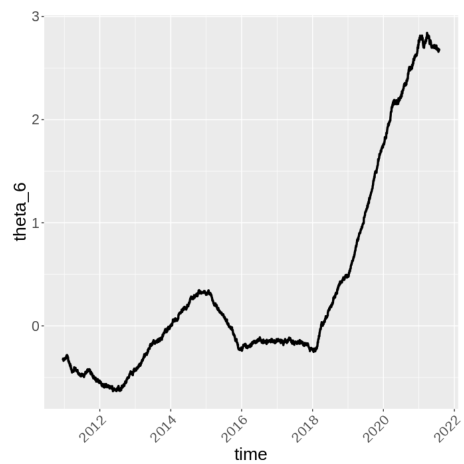
(c) $\theta_{3,t}$: the coefficient of x_3^{ETF}



(d) $\theta_{4,t}$: the coefficient of x_4^{ETF}



(e) $\theta_{5,t}$: the coefficient of x_5^{ETF}



(f) $\theta_{6,t}$: the coefficient of x_6^{ETF}

Figure 3: Coefficients of explanatory variables

2.1.2. State Space Model for Nikkei225-linked ETF

Moreover, we replace the explanatory variables $x_{1,t}^{ETF}, ..., x_{5,t}^{ETF}$ in the equation (1) by those for Nikkei225 to implement the same state space analysis. Table 2 compares the TOPIX and the Nikkei225 models, where we use accuracy and precision as evaluation metrics, because the output of each model is binary, 0 or 1. These metrics are statistical measures of how well a binary classification test works. We suppose that each model judges that the BOJ buys the corresponding ETF if estimated p_t^{ETF} is higher than 0.5, and vice versa.

There are four types of the estimation result: 1. estimates that correctly judge the BOJ's purchase decision (TP), 2. estimates that incorrectly judge the BOJ's purchase decision (FP), 3. estimates that correctly judge the BOJ's non purchase decision (TN), and 4. estimates that incorrectly judge the BOJ's non purchase decision (FN).

Then, *accuracy* is defined as the proportion of correct estimates among the total estimates: $(TP + TN)/(TP + FP + TN + FN)$, while *precision* is defined as the proportion of correct estimates for the purchases among all purchase estimates: $TP/(TP + FP)$.

Table 2: Comparison between Nikkei model and TOPIX model.

model	accuracy	precision
TOPIX model	0.96	0.93
Nikkei225 model	0.91	0.86

Table 2 shows the Nikkei225 model is inferior to the TOPIX model in accuracy and precision, which implies that the BOJ makes its purchasing decisions based on the information more from TOPIX than Nikkei225. Thus, we use variables relevant for TOPIX as the explanatory variables in the subsequent analyses of the BOJ's purchase of ETFs.

2.1.3. State Space Model for REIT

In a similar way to TOPIX linked ETFs, we construct the following state space model for REIT purchases.

$$\begin{aligned} &\text{[observation equation]} \qquad Y_t^{REIT} \sim Bernoulli(p_t^{REIT}), \\ &\text{[state equations]} \qquad p_t^{REIT} = 1/\{1 + \exp(-\alpha_t - \sum_{i=1}^{5} \theta_{i,t} x_i^{REIT})\}, \\ &\qquad \theta_{i,t} \sim N(\theta_{i,t-1}, \sigma_i^2) \quad (i = 1, 2, ..., 5), \\ &\qquad \sigma_i \sim t(3, 0, 10)^+. \end{aligned} \tag{2}$$

This model has the same structure as the ETF model, in which the observation variable Y_t^{REIT} is assumed to be generated from a Bernoulli distribution with probability p_t^{REIT}, and each p_t^{REIT} is calculated by a sigmoid function of the independent variables $x_{i,t}^{REIT}$. Also, $\theta_{i,t}$ and σ_i are parameters generated from normal and half-t-distributions, respectively.

In this model, we adopt the following five variables for explanatory variables.

1. x_1^{REIT}: rate of price change in Tokyo Stock Exchange REIT Index (TSE-REIT) price in the morning session of the day
2. x_2^{REIT}: rate of change in TSE-REIT price from the closing of the previous business day to the opening of the day
3. x_3^{REIT}: deviation of TSE-REIT price from its previous 30 days moving average
4. x_4^{REIT}: number of consecutive days of TSE-REIT price decline as of the previous day
5. x_5^{REIT}: dummy variable that takes one if VIX index (for S&P500) in the previous day is greater than 20

In particular, we use the variables calculated by TSE-REIT index data, which are available on Bloomberg and the data period is from December 15, 2010, to July 31, 2021. Figure 4 shows the time series of p_t^{REIT} estimated by MCMC[6] with the TSE-REIT index.

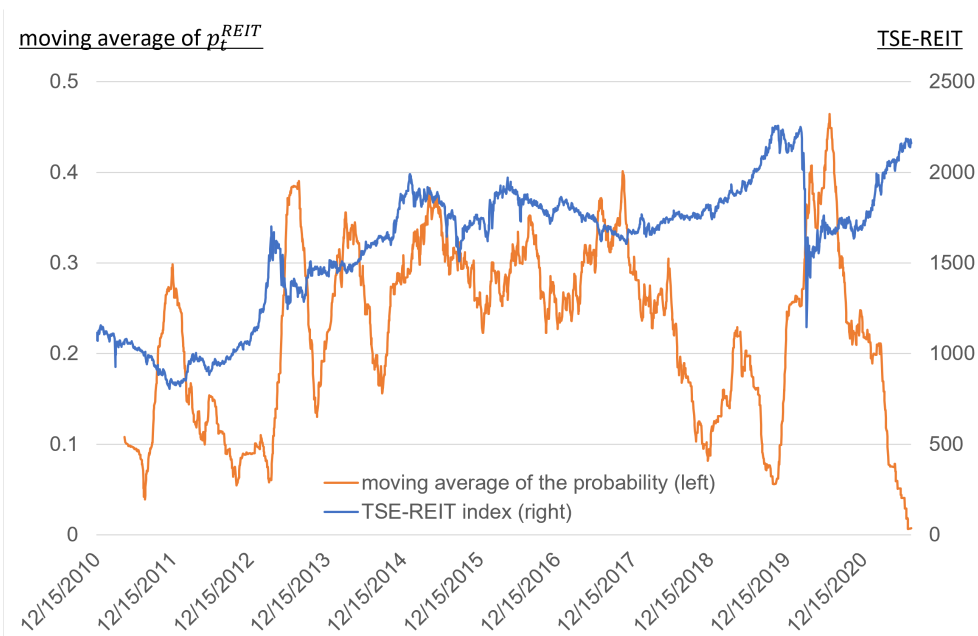
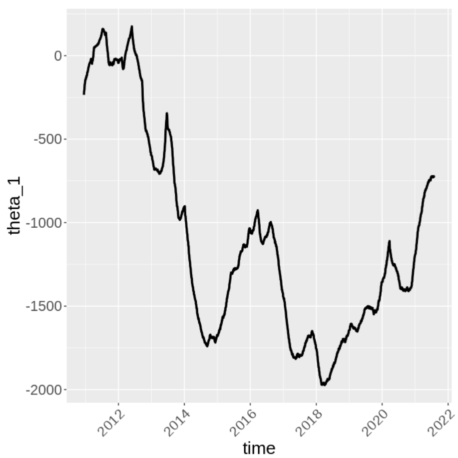


Figure 4: 90 days moving average of p_t^{REIT} and TSE-REIT index

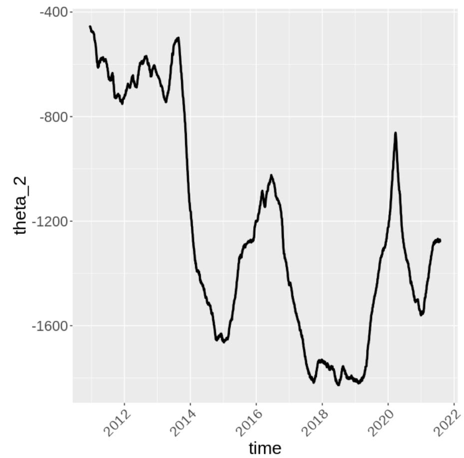
[6]Rstan config is as follows: seed = 1, iter = 20000, warmup = 10000, and thin = 20.

In Figure 4, p_t^{REIT} has characteristics similar to p_t^{ETF}: The level of p_t^{REIT} rises rapidly around 2013, which may be caused by QQE. Recently p_t^{REIT} declines to a level close to zero. In fact, after p_t^{REIT} sharply went up when the covid-19 shock hit the Japanese REIT market in early 2020, the quick recovery of the TSE-REIT index seems to reduce p_t^{REIT}. Moreover, in March 2021 the BOJ expressed to refrain from purchasing and the decrease of p_t^{REIT} was accelerated. The BOJ's announcement has a more powerful impact on REIT than ETF. As of the end of January 2022, the BOJ has never bought REITs since April 2021.

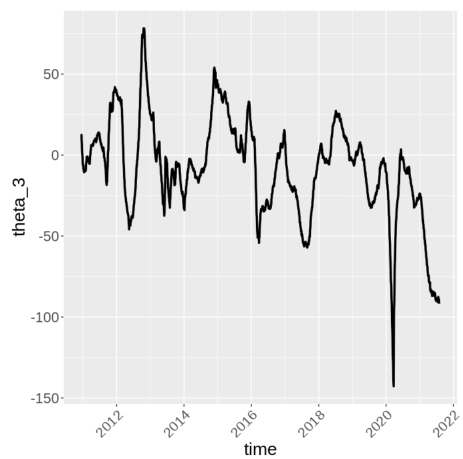
The coefficients of explanatory variables are shown in Figure 5. Overall most of the parameters change their levels substantially in 2013 or/and 2020, as in the ETF case. First, $\theta_{1,t}$ and $\theta_{2,t}$ decline after 2013. Although the BOJ has been aggressively purchasing REITs since declaring QQE, REITs do not have simple indicators such as PER and PBR, which increases the influence of x_1^{REIT} and x_2^{REIT}. Although $\theta_{3,t}$ changes its sign frequently until about 2020, the sign tends to be negative most recently, which indicates that a downward deviation of the TSE-REIT price from its trend during the previous 30 days increases p_t^{ETF}. In fact, as will be seen in Table 4 in Section 2.2, this parameter is statistically significant only in the period 3, namely, the covid-19 period. Also, it is observed that the sign of $\theta_{4,t}$ tends to be positive after Mr. Kuroda became the BOJ governor. As the REIT price declines on consecutive days, the market sentiment becomes worse. We again presume that the BOJ tends to purchase REITs to improve the sentiment, which increases p_t^{REIT}, but $\theta_{4,t}$ is statistically significant only during the period 2 in Table 4 below. Finally, $\theta_{5,t}$ is negative after the introduction of QQE, which is difficult to interpret, and this parameter is not statistically significant in the periods 2 and 3, namely after the introduction of QQE.



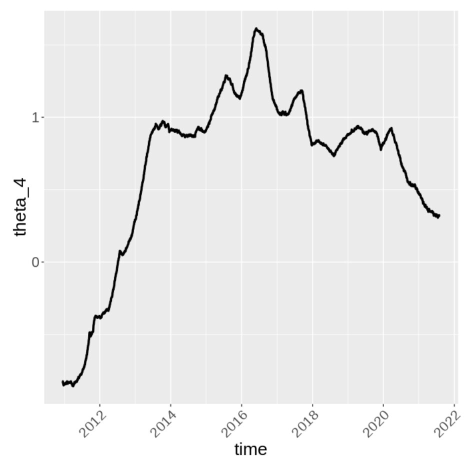
(a) $\theta_{1,t}$: the coefficient of x_1^{REIT}



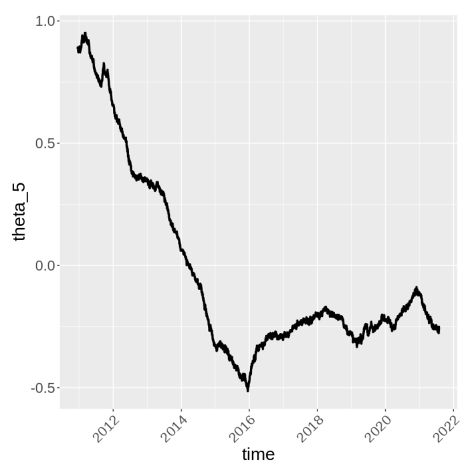
(b) $\theta_{2,t}$: the coefficient of x_2^{REIT}



(c) $\theta_{3,t}$: the coefficient of x_3^{REIT}



(d) $\theta_{4,t}$: the coefficient of x_4^{REIT}



(e) $\theta_{5,t}$: the coefficient of x_5^{REIT}

Figure 5: Coefficients of explanatory variables

2.2. Logistic Regression

According to the previous state space model analysis, the level of the parameters ($\theta_{i,t}$ and p_t) changed significantly at particular timings, namely those of the BOJ's governor change and the covid-19 pandemic. Taking these structural changes into account, we conduct a logistic regression to find the explanatory variables that determine the BOJ's purchase decision. Specifically, we apply the following logistic regression to the data split into three periods: (period 1) before March 19 2013, (period 2) from March 20 2013 to February 29 2020, and (period 3) after March 1 2020. The period 2 is the QQE period, and the period 3 is the covid-19 period in Japan.

$$\begin{aligned} Y_t^{ETF} &\sim Bernoulli(p_t^{ETF}), \\ p_t^{ETF} &= 1/\{1+\exp(-\alpha - \sum_{i=1}^{6} \theta_i x_{i,t}^{ETF})\}. \end{aligned} \tag{3}$$

The regression result is shown in Table 3.

Table 3: Regression results of (3).

	period 1			period 2			period 3		
	coefficient	t-value	p-value	coefficient	t-value	p-value	coefficient	t-value	p-value
α	-14.74	-4.92*	0.00	-2.57	-15.27*	0.00	-11.64	-5.25*	0.00
θ_1	-1473.68	-4.93*	0.00	-583.34	-16.04*	0.00	-480.67	-5.50*	0.00
θ_2	-1458.13	-4.90*	0.00	-592.53	-17.00*	0.00	-518.50	-6.39*	0.00
θ_3	-2.34	-0.65	0.52	-1.06	-0.35	0.72	2.75	0.98	0.33
θ_4	4.64	0.42	0.68	2.09	0.47	0.64	-19.48	-3.10*	0.00
θ_5	-0.07	-0.30	0.76	0.49	6.24*	0.00	0.49	2.20*	0.00
θ_6	-0.31	-0.39	0.70	-0.15	-0.37	0.71	8.61	4.35*	0.00

Note: * indicates the t-value is significant at the 5% level. Each parameter θ_i is the coefficient of x_i^{ETF}.

In Table 3, θ_1 and θ_2 are significant throughout the periods, which confirms that $x_{1,t}^{ETF}$ (rate of change in TOPIX price in the morning session of the day) and $x_{2,t}^{ETF}$ (rate of change in TOPIX price from the closing of the previous business day to the opening of the day) are consistently important for the BOJ's purchases throughout the periods. On the contrary, θ_5 is not significant in the period 1 but significant in the period 2. This suggests that after the governor changed, the BOJ's decision on purchases of ETFs is based on more diversified indicators including $x_{5,t}^{ETF}$ (number of consecutive days of TOPIX price decline). Moreover, θ_4 and θ_6 turn to be significant during the covid-19 period. This means that the BOJ is more careful about $x_{4,t}^{ETF}$ and $x_{6,t}^{ETF}$ (deviation of TOPIX price from its previous 30 days moving average and dummy variable that takes one if VIX index is greater than 20, respectively) under the covid-19 pandemic.

Also, we apply a logistic model to the REIT analysis with the following regression model as in the ETF case:

$$\begin{aligned} Y_t^{REIT} &\sim Bernoulli(p_t^{REIT}), \\ p_t^{REIT} &= 1/\{1+\exp(-\alpha - \sum_{i=1}^{5} \theta_i x_{i,t}^{REIT})\}. \end{aligned} \tag{4}$$

The regression result is shown in Table 4.

Table 4: Regression results of (4).

	period 1			period 2			period 3		
	coefficient	t-value	p-value	coefficient	t-value	p-value	coefficient	t-value	p-value
α	-3.31	-9.59*	0.00	-2.92	-17.80*	0.00	-26.70	0.00	1.00
θ_1	-37.12	-1.68	0.09	-589.57	-16.44*	0.00	-448.18	-6.03*	0.00
θ_2	-353.90	-7.75*	0.00	-647.51	-15.94*	0.00	-458.22	-6.04*	0.00
θ_3	10.31	1.82	0.07	-4.71	-1.19	0.24	-31.59	-4.01*	0.00
θ_4	-0.31	-2.17*	0.03	0.52	7.24*	0.00	0.01	0.04	0.97
θ_5	1.83	4.35*	0.00	-0.33	-1.02	0.31	24.39	0.00	1.00

Note: * indicates the t-value is significant at the 5% level. Each parameter θ_i is the coefficient of x_i^{REIT}.

In Table 4, θ_2 is significant throughout all periods and θ_1 is significant except for period 1. Although θ_4 is significant until period 2, its sign becomes reversed between periods 1 and 2, implying that the effect is unstable. Thus, we suppose that $x_{1,t}^{REIT}$ (rate of price change in TSE-REIT index in the morning session) and $x_{2,t}^{REIT}$ (rate of price change from the closing of the previous business day to the opening of the day) are the top two factors for the BOJ's decision of purchases.

2.3. Predictability of the BOJ Purchase

Based on the results in Section 2.2, we examine the predictability of the purchases. In fact, the high prediction ability of our model suggests that our finding factors are important for the BOJ's purchase decision. Concretely, we estimate our logistic regression model (3) every end of the year after 2015, where we fit our model to the data in each estimation period to make a prediction during the corresponding test period. In particular, we evaluate our prediction ability by accuracy and precision measures introduced in Section 2.1.2. Here, we do not apply the state space model in Section 2.1 to avoid substantial computational burdens.

Moreover, in this prediction we postulate that the BOJ's trading desk decides whether to purchase ETFs based on the information obtained by the day's morning session as in the previous studies including a recent BOJ's research (Adachi et al., 2021). The results are given as follows.

Table 5: Predictability of the BOJ's purchases

Predictability of the ETF purchases			
estimation period for the coefficients	test period	accuracy	precision
from December 15 2010 to December 31 2015	2016	0.85	0.94
from December 15 2010 to December 31 2016	2017	0.79	1.0
from December 15 2010 to December 31 2017	2018	0.87	0.96
from December 15 2010 to December 31 2018	2019	0.94	0.86
from December 15 2010 to December 31 2019	2020	0.86	1.0
from December 15 2010 to December 31 2020	2021	0.84	0.31
Predictability of the REIT purchases			
estimation period for the coefficients	test period	accuracy	precision
from December 15 2010 to December 31 2015	2016	0.80	0.96
from December 15 2010 to December 31 2016	2017	0.73	1.0
from December 15 2010 to December 31 2017	2018	0.84	1.0
from December 15 2010 to December 31 2018	2019	0.88	0.94
from December 15 2010 to December 31 2019	2020	0.88	0.97
from December 15 2010 to December 31 2020	2021	0.92	0.35

The data period is from December 15 2010 to July 31 2021, where we set the end of the initial period to be December 31 2015 to include a sufficient period after Mr. Kuroda became the BOJ governor. Table 5 shows high accuracy and precision, which implies that it is possible to predict purchases except for 2021. The 2021 result shows high accuracy and low precision, which means the non-purchase prediction is correct, but the purchase prediction is not. In March 2021, the BOJ stated they would refrain from purchasing; this lowers the BOJ's purchase probability and leads our model trained from past data to make incorrect predictions. However, once the data after March 2021 are accumulated, we expect the precision will increase again.

3. Price Impact of the BOJ's Purchase

By using the factors that are statistically significant in the analysis of Section 2.2, we examine the price impacts of the BOJ's purchases on TOPIX and TSE-REIT prices. First, our analysis employs a static regression model to estimate the price impact. Then, we apply a state space model to investigate the dynamics of the price impact.

3.1. Price Impact

We use the following linear regression model:

$$r_t^{TPX,pm} = \alpha + \sum_{i=1}^{5} \beta_i f_{i,t}^{TPX} + \epsilon_t, \quad (5)$$

where as the dependent variable $r_t^{TPX,pm}$ we take the rate of change in TOPIX between the closing prices in the day's morning and the afternoon sessions, because we postulate that the decision of the BOJ's trading desk depends on the information obtained by the day's morning session as in Section 2.3. Also, α and β_i are parameters, and ϵ_t is an error term generated from a normal distribution. In this model, we adopt the following five explanatory variables found in Section 2.2 and selected by expert knowledge, which are expected to affect the BOJ's purchases.

1. f_1^{TPX}: rate of change of TOPIX price in the morning session of the day
2. f_2^{TPX}: rate of change in TOPIX price from the closing of the previous business day to the opening of the day
3. f_3^{TPX}: previous 90 days TOPIX volatility as of the close of the previous day
4. f_4^{TPX}: rate of change in TOPIX price over the past 30 days as of the close of the previous day
5. f_5^{TPX}: dummy variable that takes one if the BOJ buys ETFs linked to TOPIX or Nikkei225

Here, f_1^{TPX} and f_2^{TPX} are the same variables as x_1^{ETF} (rate of change in TOPIX price in the morning session of the day) and x_2^{ETF} (rate of change in the price from the closing of the previous business day to the opening of the day) in Section 2, respectively. According to the results in Section 2.2, these variables are important for the BOJ's purchase decision throughout all periods. In addition, we take f_3^{TPX} and f_4^{TPX} as other important explanatory variables for TOPIX returns $r_t^{TPX,pm}$, which stand for the variation and trend of the price process, respectively. Finally, to capture the price impact of the BOJ's ETF purchase program, we include its dummy variable f_5^{TPX}. If the coefficient of f_5^{TPX} is positive, then the BOJ's ETF purchases have a positive impact on the TOPIX price. The data period is from December 15 2010 to July 31 2021. We also remark that since the correlations between these variables are not very high, we do not need to consider multicollinearity.

Table 6: Regression result of (5).

	coefficient	t-value	p-value
α	-0.0006	-1.490	0.136
β_1	0.0944	4.801*	0.000
β_2	0.0141	0.801	0.423
β_3	0.0327	1.092	0.275
β_4	-0.0041	-2.311*	0.021
β_5	0.0013	3.880*	0.000

Note: * indicates the t-value is significant at the 5% level. Each parameter β_i is the coefficient of f_i^{TPX}.

Table 6 shows the results estimated by Ordinary Least Squares (OLS) method, where β_1 indicates that the return in the morning session is positively correlated with the one in the afternoon session. On the contrary, β_4 implies the well-known short-term reversal effect, namely the phenomenon that stocks with relatively low returns over the past months earn positive returns. Finally, according to the estimation result for β_5, the BOJ's purchase affects the TOPIX return and the impact is about 13bps.

Next, we estimate the following REIT model:

$$r_t^{REIT,pm} = \alpha + \sum_{i=1}^{5} \beta_i f_{i,t}^{REIT} + \epsilon_t, \tag{6}$$

where $r_t^{REIT,pm}$ is the rate of change in TSE-REIT between the closing prices in the morning and afternoon sessions. Also, α and β_i are parameters, and ϵ_t is an error term generated from a normal distribution. In REIT analysis, we use the following explanatory variables found in Section 2.2 and selected by expert knowledge.

1. f_1^{REIT}: rate of change of TSE-REIT price in the morning session of the day
2. f_2^{REIT}: rate of change in TSE-REIT price from the closing of the previous business day to the opening of the day
3. f_3^{REIT}: previous 90 days TSE-REIT volatility as of the close of the previous day
4. f_4^{REIT}: rate of change in TSE-REIT price over the past 30 days as of the close of the previous day
5. f_5^{REIT}: dummy variable that takes one if the BOJ buys REITs

Here, f_1^{REIT} and f_2^{REIT} are the same variables as x_1^{REIT} and x_2^{REIT} in Section 2, respectively. According to the estimation result in Section 2.2, these variables are important for the BOJ's purchase decision and hence we take those variables. On the contrary, we do not include $x_{4,t}^{REIT}$, because its coefficient is unstable.

As in the TOPIX case, we also adopt f_3^{REIT} and f_4^{REIT} as other important explanatory variables for REIT returns $r_t^{REIT,pm}$, which represent the variation and trend of the price process, respectively. To capture the price impact of the BOJ's REIT purchase program, we take its dummy variable f_5^{REIT} as an explanatory variable.

The data period is from December 15 2010 to July 31 2021. Table 7 shows the estimated parameters.

Table 7: Regression result of (6).

	coefficient	t-value	p-value
α	-0.0004	-1.733	0.083
β_1	0.0017	0.104	0.917
β_2	0.0349	1.126	0.260
β_3	0.0530	2.663*	0.008
β_4	-0.0012	-0.616	0.538
β_5	0.0009	2.518*	0.012

Note: * indicates the t-value is significant at the 5% level. Each parameter θ_i is the coefficient of f_i^{REIT}.

It is observed that β_3 and β_5 are significant, while the other variables are not. Particularly, the result for β_5 indicates that the BOJ's purchase is effective and its impact on the REIT returns is about 9bps.

3.2. Dynamics of the Price Impact

This section employs a state space model to investigate the time series of the price impact of the BOJ's purchase program. The state space model is described as follows.

$$
\begin{aligned}
&\text{[observation equation]} \qquad && r_t^{TPX,pm} \sim N(\mu_t, \sigma^2),\\
&\text{[state equations]} && \mu_t = \alpha + \sum_{i=1}^{5} \beta_i f_{i,t}^{TPX},\\
& && \beta_{i,t} = N(\beta_{i,t-1}, \eta_i^2) \qquad (i = 1, 2, ..., 5),\\
& && \eta_i \sim t(3, 0, 10)^+,\\
& && \sigma \sim t(3, 0, 10)^+.
\end{aligned} \tag{7}
$$

We assume that each $r_t^{TPX,pm}$ is generated from a normal distribution with mean μ_t and variance σ^2, where μ_t is calculated as a linear combination of the independent variables $f_{i,t}^{TPX}$. Each coefficient, $\beta_{i,t}$

is generated from a normal distribution with mean $\beta_{i,t-1}$ and variance η_i^2. The σ and η_i are generated from a half-t-distribution. The data period is from December 15 2010 to July 31 2021.

The dynamics of parameters estimated by MCMC[7] are shown in Figure 6. β_5 expresses the effect of the BOJ's ETF purchases on the TOPIX, which is zero before 2013 but gradually goes up to about 20bps. The purchase amount has increased since Mr. Kuroda became governor, which makes the price impact larger.

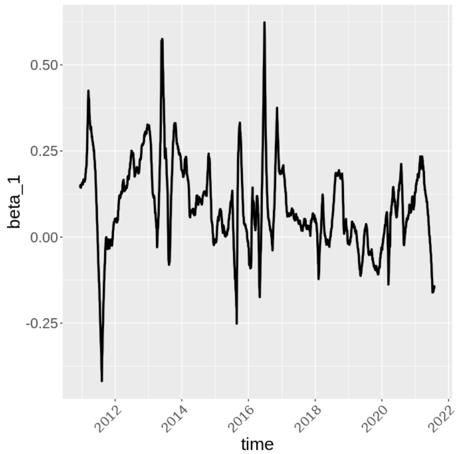
Next, we consider the following REIT model.

$$\begin{aligned}
\text{[observation equation]} \qquad & r_t^{REIT,pm} \sim N(\mu_t, \sigma^2), \\
\text{[state equations]} \qquad & \mu_t = \alpha + \sum_{i=1}^{5} \beta_i f_{i,t}^{REIT}, \\
& \beta_{i,t} = N(\beta_{i,t-1}, \eta_i^2) \quad (i = 1, 2, ..., 5), \\
& \eta_i \sim t(3, 0, 10)^+, \\
& \sigma \sim t(3, 0, 10)^+.
\end{aligned} \tag{8}$$

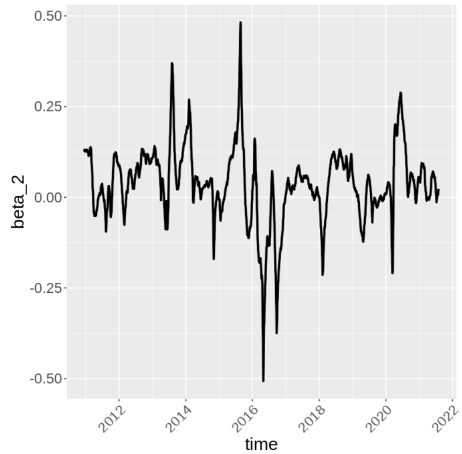
We suppose that each $r_t^{REIT,pm}$ is generated from a normal distribution with mean μ_t and variance σ^2, where μ_t is calculated as a linear combination of the independent variables $f_{i,t}^{REIT}$. Each coefficient, $\beta_{i,t}$ is generated from a normal distribution with mean $\beta_{i,t-1}$ and variance η_i^2. The σ and η_i are generated from a half-t-distribution. The data period is from December 15 2010 to July 31 2021.

The estimated parameters[8] are shown in Figure 7. The level of $\beta_{5,t}$ is around 10bps before 2020, however it declined to a level close to zero these days.

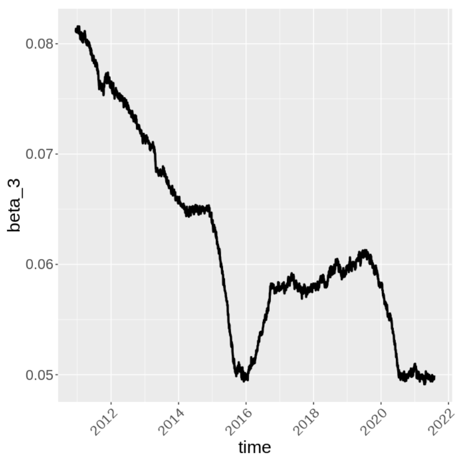
[7]Rstan config is as follows: seed = 1, iter = 20000, warmup = 10000, and thin = 20.
[8]Rstan config is as follows: seed = 1, iter = 30000, warmup = 10000, and thin = 20.



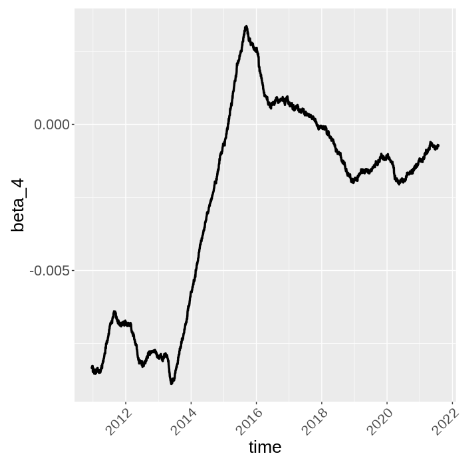
(a) $\beta_{1,t}$: the coefficient of f_1^{TPX}



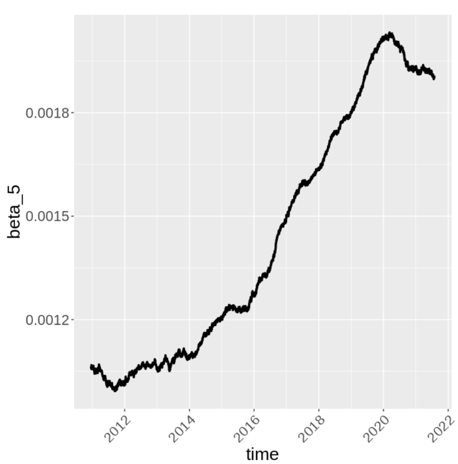
(b) $\beta_{2,t}$: the coefficient of f_2^{TPX}



(c) $\beta_{3,t}$: the coefficient of f_3^{TPX}

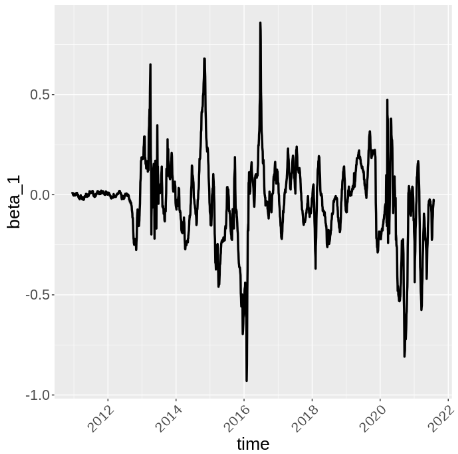


(d) $\beta_{4,t}$: the coefficient of f_4^{TPX}

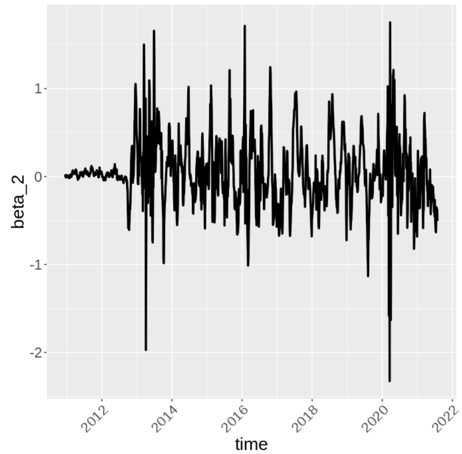


(e) $\beta_{5,t}$: the coefficient of f_5^{TPX}

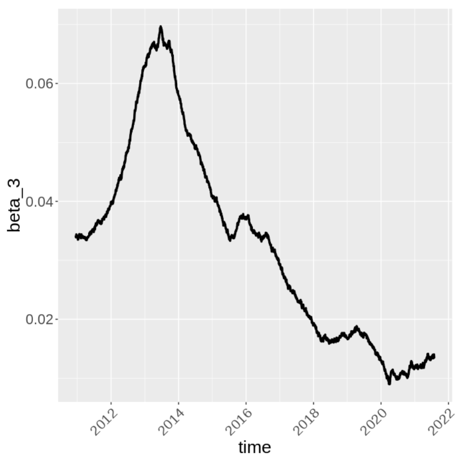
Figure 6: Coefficients of explanatory variables in (7)



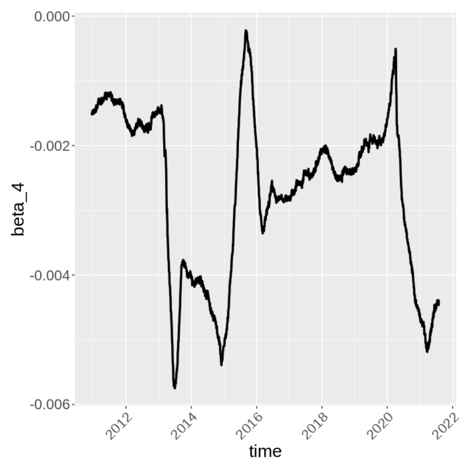
(a) $\beta_{1,t}$: the coefficient of f_1^{REIT}



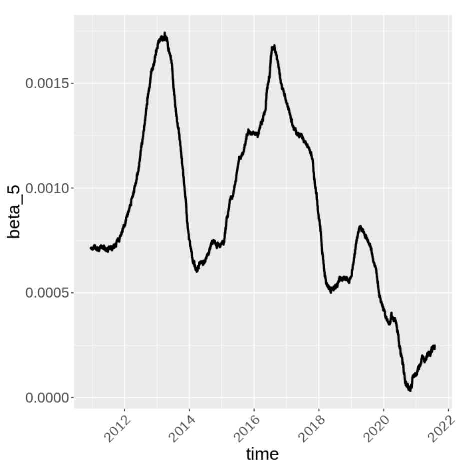
(b) $\beta_{2,t}$: the coefficient of f_2^{REIT}



(c) $\beta_{3,t}$: the coefficient of f_3^{REIT}



(d) $\beta_{4,t}$: the coefficient of f_4^{REIT}



(e) $\beta_{5,t}$: the coefficient of f_5^{REIT}

Figure 7: Coefficients of explanatory variables in (8)

3.3. Effect on TOPIX-Nikkei225 Spread

According to the analysis in Section 2.1.2, the BOJ makes its purchasing decisions based on the information more from TOPIX than Nikkei225, which enables us to conjecture there exist different price impacts on those indices. To see the difference, this section examines some effects of the BOJ purchases on the spread between TOPIX and Nikkei225. Specifically, we use the following OLS to investigate whether the purchases affect the spread between the afternoon returns of TOPIX and Nikkei225. We estimate the following model:

$$r_t^{pm} = \alpha + \sum_{i=1}^{5} \beta_i f_{i,t}^{TPX} + \epsilon_t, \tag{9}$$

where r_t^{pm} is the spread of afternoon return between TOPIX and Nikkei225 (i.e. $r_t^{pm} = r_t^{TPX,pm} - r_t^{NKY,pm}$), and $f_{i,t}^{TPX}$ are the same explanatory variables introduced in Section 3.1.

The data period is from December 15 2010 to July 31 2021. The regression result is shown as follows.

Table 8: Regression result of (9).

	coefficient	t-val	p-val
α	-0.0002	-1.580	0.114
β_1	-0.0133	-2.218*	0.027
β_2	-0.0044	-0.824	0.410
β_3	0.0154	1.678	0.093
β_4	0.0009	1.602	0.109
β_5	0.0004	3.762*	0.000

Note: * indicates the t-value is significant at the 5% level. Each parameter θ_i is the coefficient of f_i^{TPX}.

Here, β_5 is significant, which means the BOJ's purchase affects the return spread. Specifically, when the BOJ purchases ETFs, the afternoon return of TOPIX tends to be around 4bps higher than that of Nikkei225. This result implies the BOJ's purchases have a stronger impact on the smaller-cap equities that are not included in the Nikkei225. Since those equities are less liquid, the rates of changes in the prices might be greater than those for larger-cap equities.

4. Trading Strategy

This section discusses a trading strategy based on the BOJ's purchases. Our analysis so far has revealed the following two insights: (1) we can predict the BOJ's purchases accurately (Section 2.3) and (2) the BOJ's purchases cause the positive spread between the afternoon returns of TOPIX and Nikkei225 (Section 3.3). Hence, we conjecture that if the BOJ's ETF purchases are predicted, it may be possible to make a profit by constructing the TOPIX long and Nikkei225 short positions, which suggests the following strategy: First, using the state space model developed in Section 2.1, we predict whether the BOJ will purchase ETFs based on the information up to the morning session of the day. Particularly, we employ the equation (1) in Section 2.1 to estimate p_t^{ETF} from the entire period and suppose that our model predicts the BOJ's purchase if p_t^{ETF} is greater than 0.5. Second, if a purchase is predicted, we make a position of long TOPIX and short Nikkei225 at the beginning of the afternoon session, and then liquidate it at the end of the afternoon session. If the purchase is not predicted, we do not make any positions. We repeat this process every workday.

The simulation period is from December 15 2010 to July 31 2021 as in Section 2.

Figure 8: Simulation result

Figure 8 shows the equity curve of this strategy, which earns over 40 percent compound returns in around ten years with no trading costs. Its (i)annualized compound return, (ii)annualized risk (volatility) and (i)/(ii) return per risk are listed in (a) of Table 9 below.

Moreover, we also implement three simulations under more realistic settings using index futures as trading assets. The results are summarized as (b), (c), and (d) in Table 9.

Table 9: Annualized return and risk.

	Prediction Model	Trading Asset	Cost	(i)Annualized Compound Return	(ii)Annualized Risk (Volatility)	(i)/(ii)Return/Risk
(a)	State Space Model	Index	0bps	3.36%	1.71%	1.97
(b)	State Space Model	futures	2bps	2.27%	1.72%	1.32
(c)	Logistic Model	futures	0bps	2.75%	1.43%	1.92
(d)	Logistic Model	futures	2bps	1.81%	1.41%	1.28

Note: (a) is the simulation shown in Figure 8. Futures in the Trading Asset column are TOPIX and Nikkei225 futures.

In (b), we use TOPIX and Nikkei225 futures with 2bps costs for each spread trading [9]. In (c) and (d), as the prediction model we adopt the logistic regression model in Section 2.2. Then, we estimate the model parameters in the equation (3) every end of the year after 2015 to make out-of-sample predictions during the following year as in Section 2.3. Hence, the simulation period is from January 1 2016 to July 31 2021. The difference between (c) and (d) is the trading costs, which are 0bps in (c) and 2bps in (d).

Even in the most conservative simulation (d), the strategy earns 1.81% annualized compound returns with 1.41% annualized risk, which results in the return per risk 1.28, still high enough.

5. Event Study: Price Dynamics just before and after the BOJ's Purchase

In Section 3, we have observed how the BOJ's purchase affects the price on the event day. This section investigates the price dynamics just before and after the purchase event graphically.

5.1. Price Dynamics

We compare the price dynamics when the BOJ purchases ETFs (REITs) and when it does not. To control the market condition, we use the price data of ten days around the purchase event days, in which the sum of TOPIX (TSE-REIT) overnight and morning returns is below -1 percent. Note that our data is from December 15 2010 to July 31 2021. Then, we classify the data into two groups: the first one consists of the prices when the BOJ purchases ETFs (REITs) on the event day, and the second one consists of those when the BOJ does not. Figure 9 describes the comparison between those two groups. In Figure 9, we set the event day as $t = 0$ and all price data are scaled by the price at $t = 0$.

[9] We greatly appreciate Mr. Ryo Ishikawa for making and providing those futures data sets, of which original data are obtained from JPX Data Cloud. According to trading professionals, this assumption of transaction costs for futures is conservative enough.

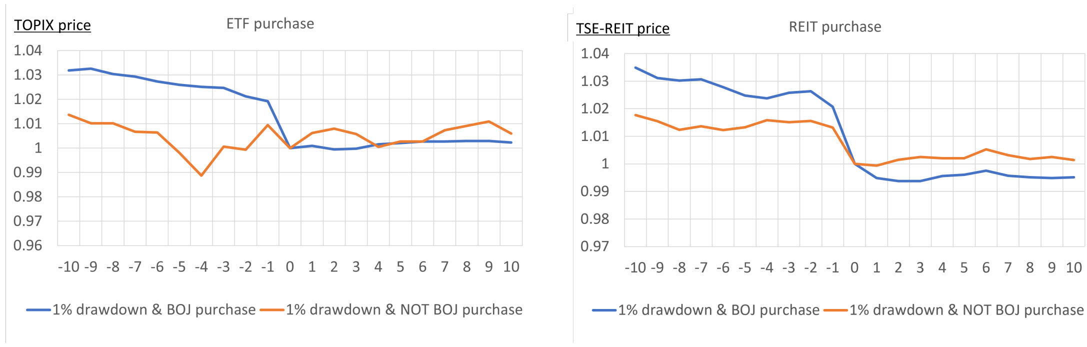


Figure 9: Price dynamics of the two groups

The figure on ETF shows that there is no difference after the purchase. However, the price trend is different before $t = 0$. The BOJ is likely to purchase ETFs if there is a sharp fall by about two percent on average at $t = 0$. Similarly, the figure on REIT indicates that the BOJ purchases REITs when the TSE-REIT index falls by about 2% on average. These observations support that the price dynamics in the last overnight and morning session are the factors in the purchase decision.

5.2. Effect of the BOJ Governor Change

The following analysis examines the difference due to the change of the BOJ governor. Particularly, we divide the data into two groups: the first is before March 19 2013, and the second is after March 19 2013. Figure 10 provides the difference between those two groups.

Figure 10: Price dynamics before and after the BOJ governor change

The figure on ETF shows a big difference, but does not on REIT. After March 19 2013 the BOJ aggressively intervenes in the equity market even for smaller declines. The result implies that the change of the governor affects a policy-making process.

6. Conclusion and Future Research

6.1. Conclusion

This paper has conducted a time series analysis of the Bank of Japan (BOJ)'s purchase program by applying two types of state space models with expert knowledge as well as logistic and linear regressions, where each state space model can be regarded as a dynamic extension of the corresponding logistic or linear regression model. Then we have developed a profitable trading strategy that incorporates the insights obtained from the dynamic analysis. To the best of our knowledge, the current analysis is the first attempt at investigating the purchase program from a dynamic viewpoint and developing a system that takes expert knowledge as input to analyze the BOJ's purchase program and outputs a trading strategy.

Concretely, we have found factors underlying the decisions of the BOJ's purchases, which enables us to predict their timings with high accuracy throughout all periods.

Moreover, our analysis has shown that the purchase program has certain impacts on the equity and REIT prices, but the effects are only about 13bps and 9bps, respectively. Also, we have examined the dynamics of the price impact by a state space model. The estimated parameters show that the impact on equity is zero before 2013 but gradually goes up to about 20bps. On the other hand, the impact on REITs is around 10bps before 2020. However, it declines to a level close to zero in 2021.

Furthermore, we have revealed some distortion of the TOPIX-Nikkei225 spread at the timings of the BOJ's purchases to develop a new investment strategy: Even in the most conservative out-of-sample simulation, the strategy earns 1.81% annualized compound returns with 1.41% annualized risk, which results in the return per risk 1.28.

In addition, we have implemented event studies, particularly the price dynamics of ETF and REIT just before and after the BOJ's purchase. It has turned out that on the days when BOJ purchases ETFs the closing price fell by about 2% on average in a single day, and that the current BOJ governor, Mr. Kuroda aggressively bought ETFs even for smaller price declines.

The method developed in this paper is shown to be capable of explaining the timing of the central bank's ETF and REIT purchases, which is not directly observable and changes over time as the perception of the central bank changes with respect to the economy. Hence, our result implies that such seemingly intractable large investors' behaviors can be analyzed by our proposed system incorporating state space models with expert knowledge. For instance, the current analysis may be applicable to other market interventions by central banks and governments. Namely, by a similar method we may find factors underlying interventions in foreign exchange or government bond markets and predicting their timings.

At the same time, this paper reveals the existence of a profitable trading strategy focusing on the BOJ's purchase program, which is practically interesting, especially for a certain type of traders. However, it also implies that central banks should be careful to design their asset purchase program to avoid benefitting only specific investors, who can exploit market distortion caused by the program.

6.2. Future Research

As tick-data are unavailable for us, we could not implement intraday analyses in this paper. If we obtain tick-data, where we observe all types of orders with trader IDs on a millisecond basis, we may identify the BOJ's trading activities for TOPIX and Nikkei225 ETFs, particularly their intraday purchase timings and amount, which are not disclosed by the BOJ. Moreover, we may observe how other market participants trade along with the BOJ's purchases, and thus investigate how the BOJ's purchases impact on returns of these ETFs on a short time scale in detail.

Furthermore, we may examine the purchase impact on stock returns on an individual security basis. As the stocks incorporated in TOPIX and Nikkei225 show high returns, arbitragers can profit by buying stocks in those indices and selling stocks in the same sector but not included in these indices. Since providing some entities arbitrage opportunities by a central bank is undesirable, we may investigate how a central bank effectively intervenes in the stock market without causing such a situation.

Also, the BOJ's purchase volume has declined since March 2021; this reduces the precision of our model in Section 2.3. Furthermore, after April 2021, the BOJ began buying mainly TOPIX-linked ETFs; this may change the purchase effect on the TOPIX-Nikkei225 spread examined in Section 3.3. Once the data after April 2021 are accumulated, examining the precision of our model and investigating whether the purchase impact on TOPIX-Nikkei225 spread changes are left for future research.

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