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Unconventional Monetary Policy through Open Market Operations: A Principal Component Analysis

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Abstract

This paper examines the unconventional monetary policies of the Bank of Japan from 2002 to 2019 with a focus on open market operations. We apply a principal component analysis to investigate the complexity of the operations. We find that four principal components (PCs) explain most of the variance of the Bank of Japan's operations of various facilities and measures. We are able to distinguish between 'quantitative easing policy', which is 'asset purchase measures' including JGBs, ETF and J-REIT (PC1), and different liquidity supply measures (PC2-4). The results are robust among different variable sets and time frames. We also find the complexity, measured by the number of PCs needed to explain the variance, differs substantially between three sub-periods of different governorships: Fukui (2003-2008), Shirakawa (2008-2013) and Kuroda (2013-present). We observe that open market operations of the Shirakawa era were the most complex, resulting in an increased number of PCs (five to seven depending on particular specifications). In contrast, the corresponding number in the other eras has been at most two (Fukui) and four (Kuroda).

Keywords: Unconventional Monetary Policies, Open Market Operations, Principal Component Analysis

JEL classification: E52, E58

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1. Introduction

The global financial crisis (GFC) of 2007-2008 has dramatically changed not only the role and function of central banks but also the implementation of monetary policy. Central banks have introduced so-called unconventional monetary policies (UMPs) – ranging from extremely low or negative interest rates to interventions in government bond markets, as well as other asset markets – which are considered potentially risky. At the start of the crisis, UMPs were introduced as emergency measures; however, not only have those policies remained, the scope of UMPs have in fact expanded to an unprecedented scale. So far, there are no signs of 'normalization' to the pre-crisis standard. Rather, it seems that 'unusual' times have become the 'new normal' for monetary policy (Kiley 2018; Panetta 2019). The crisis brought about by the Covid-19 pandemic has further expanded the scope while also entrenching them further.

Since the GFC, monetary policy has been not only unconventional but also more complex. Within conventional monetary policy, the policy rate is considered to be the primary signal of the central bank's monetary policy stance. The policy rate (which is usually the overnight rate on the interbank market) determines the shortest end of the yield curve, and the financial market determines the whole shape of the yield curve, which in turn reveals the market's expectations of the sustainable long-run levels of interest rates and of the short-run direction of monetary policy over business cycles.[2] However, when the policy rate becomes closer to or hits the effective lower bound, and the central bank adopts unconventional policies of various asset purchases, complexity increases substantially with respect to what assets are purchased or sold, of what maturity and for what period. Moreover, natural disasters and the resulting supply-chain disruptions and sudden evaporation of final demand creates regional and, in some cases, global issues, and the central bank is obliged to cope with these problems. These 'local-economy supporting measures' are also a component of UMPs that further increase their complexity, especially through open market operations.[3]

The Bank of Japan (BOJ) was the earliest adopter of UMPs and remains the central bank most actively implementing the policies. The BOJ hit the effective lower bound in 1999, much earlier than other countries, due to prolonged economic stagnation caused by the asset market bubble collapse of the 1990's – one of the most severe collapses in modern economic history – which followed an unprecedented asset market boom in the late 1980s. Moreover, Japan's nascent recovery was shattered by the global economy's sharp downturn caused by the GFC and the European sovereign debt crisis that started in 2008. These economic issues were compounded by Japan's triple disasters of 2011: a devastating earthquake, a tsunami, and the Fukushima Nuclear Plant Accident. Facing these extreme crises, the BOJ reinstituted and restarted various unconventional policies in the form of new facilities and measures of its open market operations. As the crisis deepened, the complexity

[2] This function is often called a part of price discovery functions of the markets.

[3] There are other unconventional policies which are outside of open market operations, such as collateral policies. The complexity is also increased with respect to them, and they have influenced the effectiveness of monetary policy as a whole (see Section 2). However, we concentrate our analysis on the complexity of open market operations since they are the most important route through which the central bank directly influences the financial markets regardless of whether it is a normal time or crisis time.

of monetary policy increased. Between 2002 and 2019, we can find at least thirty-nine different facilities and measures of its open market operations.[4] [5]

The purpose of this this paper is twofold. First, we examine this complexity of unconventional policies through open market operations to reduce the variables and distil the most important objectives and/or targets of these open market operations. Our chosen time frame is a very turbulent period, and the purpose of monetary policy is not simply to set the policy rate at a targeted level but also to include other considerations, such as supplying emergency liquidity to the financial market to cope with crises of various kinds.

Second, we explore differences between central bank governors with respect to unconventional policies. The conventional wisdom (at least in economic theory) is that central banking can be seen as a 'reaction function' that may be derived as the optimal response maximizing the central bank's objective function. That is, by applying simple rules, the conduct of monetary policy becomes almost systematic and 'mechanical'. This becomes evident, for example, in the frequently referenced Taylor rule, which demystifies monetary policy. With the introduction of UMP, these kinds of simple rules fell out of favour, and monetary policy became much more complex.

With such a wide array of alternatives and possible overlaps of policy measures, it is difficult to derive or even conceive the reaction function, regardless of whether it is optimal or not. Thus, the central bank governor's preferences[6] (or the collective preferences of the Policy Board under the leadership of the governor) in the literal sense come forward for policy discussion and analysis. We examine how data-determined characteristics of unconventional policies differ between three consecutive governorships of the BOJ (Fukui 2003-2008, Shirakawa 2008-2013 and Kuroda 2013-present) and tentatively explore how the varying degrees of complexity.[7]

The results are encouraging and surprising. The principal component analysis (PCA) of the BOJ's market operations of the whole period (2002-2019) [8] shows that there are four principal components (PC) of significance. The first PC explains 37% of the variation and can be characterized as '(broadly-defined) quantitative easing policy' which is 'asset purchase measures'. This reveals that the main objective or goal of the BOJ is to reduce long-term risk-free rates, risk premiums of stock and related markets and risks in corporate finance. In contrast, PCs 2, 3, and 4 are liquidity supply measures. PC2 is mainly liquidity supplying aimed at the funding of longer-term investors such as securities houses, insurance companies and investment trusts, including funding in

[4] In fact, we found seventy-one labels of instruments in various parts of the BOJ's home pages. We combine some of them to form one category of instruments. For example, outright purchases of JGBs of maturity 1-2 years, 2-3 years, and so on up to 10 years are added to get 'outright purchases of JGBs of maturity 1-10 years'. This reduction of instruments yields thirty-nine names of facilities and measures.

[5] See for detailed accounts of Tokyo money markets, Totan Research (2019).

[6] The same argument also applies to other members of the Policy Board, though to a substantially lesser degree. The importance of the governor should be taken into consideration in a de-facto hierarchical central bank, of which the BOJ is one example.

[7] Our aim is not to assess monetary policy per se of a particular period but find complexity of market operations of that period.

[8] Our data is from March 2002 to December 2019. The choice of this period was dictated by the availability of data on the homepages of the BOJ. See,
https://www.boj.or.jp/en/statistics/boj/fm/ope/m_release/index.htm/ (English)
https://www.boj.or.jp/statistics/boj/fm/ope/m_release/index.htm/ (Japanese)

corporate finance during the crisis situation. PC3 is liquidity supply aimed at the short-term segment of the markets. PC4 refers to the funding of financial institutions in interbank markets and the T-bills market to control the policy rate and keep these institutions' current account at high levels.

The surprising part of the results is the stark difference in the number and nature of principal components between governors. The cumulative variance of the first two PCs is enough to capture the monetary policy of the Fukui and Kuroda period. Thus, the complexity is substantially less than for the whole period, although in the Fukui period, traditional measures including Funds Supplying Operations against Pooled Collaterals are the most important, while in the Kuroda period, (broadly defined) quantitative easing measures are the most prominent. In contrast with the periods prior and following, the Shirakawa period is the most complicated: we need five principal components in the mainline case and seven in the alternative cases, whereas we only have four in both the mainline and alternative cases during the whole period. Although this is beyond the scope of this paper, such great complexity may pose a serious communication problem for central banks. Present-day central banking is complicated, and present-day central banking communication is even more complicated to accomplish with both the financial markets and the public.

The rest of the paper is organized as follows: Section 2 reviews the related literature about the complexity of UMP and application of PCA in the financial markets to show the difference between our approach and traditional approaches. Section 3 presents the method we apply and the data we use. Results for the whole period are presented in Section 4, and Section 5 reports the results under different governors according to subsample analyses. Section 6 presents some concluding remarks.

2. Related Literature

The former Chair of the US Federal Reserve (Fed), Alan Greenspan argues that the problem of monetary policy in times of crises is not its complexity and the policy-making process, but rather the increased complexity of a continuously changing world economy (Greenspan 2004: 38-40). However, this statement was before the GFC, and we are now in a 'normal' zero-interest rate environment which requires unconventional measures. After the GFC, central banks were challenged with an unprecedented crisis and introduced various kinds of new operations called unconventional monetary policies (UMP), for example negative interest rate policies, new lending operations, large-scale asset purchase programmes, and forward guidance (Potter and Smets 2019). An introduction to quantitative easing and UMP can be found in Joyce et al. (2012). Chen et al (2012) analyse macroeconomic effects of large-scale asset purchase programmes with a DSGE model. Other strands of literature focus on the optimal monetary policy (Benhima and Blengini 2020; De Fiore and Tristani 2013) or the transmission of quantitative easing (Christensen and Krogstop 2019).

After the GFC many economists acknowledge the issue of an increased uncertainty and complexity of monetary policy (e.g., Rudebusch 2013). Some theoretical discussions about the increased complexity of monetary policy include Orphanides and Wieland (2013) and Gai, Haldane and Kapadia (2011), concerning model and data uncertainty and network complexity.

The complexity is found in various asset purchase programmes which are a part of the central bank's open market operations. An analysis of the asset purchase programmes by the European Central Bank (ECB) can be found in Altavilla et al. (2015), Ayuso and Repullo (2003), Claeys and Leandro (2016), De Santis (2020), Fève et al. (2010), Fratzscher et al. (2016) and Hammermann et al. (2019).

Other authors analysed the APP and open market operations of the Fed (D'Amico et al. 2012; Fratzscher et al. 2018; Van Dijk et al. 2016), or the Bank of England (Kapetanios et al. 2012; McLaren et al. 2014). An assessment of the monetary policy of the BOJ include the Bank of Japan (2016), Hausman and Wieland (2015), Lam (2011), and Ueda (2012).

Lenza at al. (2010) describe monetary policy of the ECB, the Fed and the Bank of England since the beginning of the GFC. They show that both quantitative easing and other non-standard measures have had different effects on money markets. The increased complexity of monetary policy resulted from the diversity and interrelation among different central bank instruments, which then challenged central bank communication. Smales and Apergis (2017) focus on the complexity of monetary policy announcements (linguistic complexity) and the impact of the language used within the Fed System. The effectiveness of monetary policy during financial and other crises might be limited due to the increased complexity of monetary policy and language. Based on a sample of 24 developed countries, Bech et al. (2014) argue that monetary policy is less effective in financial crises as the monetary transmission mechanism is weakened and not fully functioning.

Open market operations, however, are not solely confined to asset purchases. They also include liquidity provisions.[9] Acharya et al. (2012) show the importance of central banks providing sufficient liquidity during crises to avoid inefficiencies in financial markets and interbank lending. During the crisis of 2007-10, the Fed implemented substantial modifications to its lender-of-last-resort function, for example, by extending maturities of the discount window and open market operations, as well as extending eligible collateral to include investment-grade debt securities. Cecchetti and Disyatat (2010) provide a summary of liquidity operations by central banks during crises, offering examples for the US, Euro area and UK. De Grauwe (2013) analyses the ECB's decision to provide unlimited liquidity in the government bond markets of the Eurozone and argues that this is a necessary condition to prevent European countries from falling into undesirable equilibria. Coenen et al. (2017) analyse communication by central banks during times of crises.

In this paper, we take a different approach to the issue of complexity in monetary policy. We apply the method of a principal component analysis (PCA) to open market operations whose components are increasingly complicated, including both asset purchases and various liquidity provision measures. To our knowledge, this paper is the first to apply PCA to open market operation of central banks. We adopt the number of principal components needed to explain the variation[10] as a measure of complexity and try to find the objective or goal of each principal component by examining its composition.

Although PCA has been utilized in the economic and financial literature, these applications are different from our analysis. For example, Angelopoulou et al. (2014) analyse the impact of monetary policy on financial conditions in the euro area using data from 2003 to 2011. They construct financial conditions indices (FCIs) which include, among others, monetary policy variables. Out of 24 variables, they use three principal components which explain more than 70% of the total variance. Their results suggest that the newly constructed index offers a more comprehensive framework of

[9] Earlier theoretical works on the importance of liquidity provision include Freixas et al. (2000) who model systematic risks in interbank markets and liquidity provision by central banks, and Martin (2006) who shows that central bank liquidity policy can prevent bank panics without moral hazard problems.

[10] The number of principal components whose eigenvalue exceeds some threshold. Details are given in Section 3.

financial conditions than solely analysing interest rates. Another example is found in Giannone et al. (2004) who apply PCA for monetary policy of the Fed. Their empirical analysis show only two PCs explain more than 70% of the variance of major macroeconomic aggregates such as the interest rate, output and inflation.

In the case of central bank communication, Boyarchenko et al. (2017) use PCA to measure the impact of announcements by the Fed on asset prices. The time period of the sample is from 1994 to 2007 and has 113 announcement days. They create monetary policy shocks as the PCs of the excess variation in yields during times of Federal Open Market Committee meetings and show that Federal Reserve announcements have effects on the markets regardless of the direction of monetary policy.

In sum, these existing applications use PCA to reduce the complexity of a vast number of macroeconomic economic variables (including some policy variables) to a few principal components that explain most of the total variation and to extract and interpret the most important underlying factors determining these variables. In contrast, our approach is much more targeted to policy complexity. We apply PCA to only one set of monetary policy variables: those in the form of open market operations. PCA is utilized to assess the complexity of open market operations' measures by the number of principal components necessary to explain the variation and to find the objective or target of each principal component by examining the characteristics of its composition. In this way, we can get a clearer picture of unconventional policies through open market operations.

3. Method and Data

Many times, economists are confronted with large, complex, and high-dimensional datasets of correlated economic variables. Principal component analysis (PCA) is a widely used technique for dimensionality reduction. PCA transforms the original variables into a smaller number of artificial variables, the so-called principal components (PC). The advantage is that this technique reduces the original datasets to components that are uncorrelated with each other without losing much information. Principal components are projected as linear lines which point out where the data is scattered and PC account for most of the variance in the data set. In short, PCA reduces the complexity and dimension of the original data to a large extent (Angelopoulou et al. 2014: 394-395; James et al., 2017, p. 374-375). We consider the number of the representative variables from the PCA analysis as a measure of complexity.[11]

PCA is useful for our analysis of the BOJ because the central bank has increased the number of measures in open market operations considerably over time, and the implementation of these operations has become complicated.[12] Thus, how to measure the complexity and its change over time is an important issue for understanding the BOJ's monetary policy. The academic literature on central bank policy and central bank communication usually focusses only on a few variables (e.g., interest rates and/or government bond purchases). In contrast, we examine monetary policy in a

[11] In typical applications to economic variables, key features in the data can be extracted from only the first two or three PCs (Wilke, 2019). In contrast, this is not the case in our examination of policy complexity.

[12] It can be argued that BOJ policies are manifested through numerous monetary operations. In historical perspective, there are periods in which it is problematic to interpret their complete functions. Our argument is that, in fact, these operations serve only a few very distinct purposes, and that PCA is the suitable method for identifying them.

comprehensive way by focussing on all open market operations. This approach is an important contribution of our paper.[13]

For determining the number of principal components, which is a measure of complexity in our analysis, we adopt the method of Horn's parallel analysis (1965),[14] rather than the Kaiser criterion (Kaiser 1960). [15] Hayton et al. (2004) argue that there is evidence that parallel analysis is one of the most precise methods for identifying the number of variables (e.g., Velicer et al., 2000; Zwick and Velicer, 1986). However, despite its advantages parallel analysis was not used that often (e.g., Fabrigar et al., 1999; Ford et al. 1986). In Horn's parallel analysis, similar to the Kaiser criterion, a component is kept if the eigenvalue is greater than 1, and it is dropped if the eigenvalue is less than 1. In contrast to the Kaiser criterion, parallel analysis corrects for the effect of sampling errors and consequently can be regarded as the preferable alternative (Zwick and Velicer 1986).[16]

By using parallel analysis, we avoid an arbitrary selection of operations (thus avoiding a selection bias). Rather we adopt a strategy of including all policy measures (according to the statistical data) and letting the data reveal the objective of these policy measures. Central banks usually make announcements of their intention for each measure they implement. The market and the public may take it at face value. However, the actual implementation of the unconventional policies may change as time passes to eventually have different policy implications. The unconventional policies are often introduced as 'emergency measures' but subsequently become permanent, or at least long-lasting [17] (even if unintentionally). Thus, financial markets should not take central banks' announcements for granted but rather let their actual deeds speak for themselves. PCA may be helpful and informative for revealing the hidden objectives of extremely complicated market operations, which is encouraging in showing the usefulness of the approach.

Our data set of the BOJ's open market operations builds on the time period of 2002 (March) to 2019, resulting in a total of 71 variables (operation measures) which are first reduced to 39 variables in

[13] We concentrate our focus on open market operations and exclude policy rate changes and communication policy in the form of forward guidance. The BOJ hit the effective lower bound in most intervals in our sample period (2002-2019), so our approach of concentrating attention on open market operations may be justified as the first attempt to examine the complexity of unconventional quantity policy measures.

[14] For an update of Horn's parallel analysis, see e.g. Glorfeld (1995).

[15] Fabrigar et al. (1999) argue that the Kaiser criterion is rather arbitrary, as this criterion just distincts between factors based on whether their eigenvalue is above or below one.

[16] Our PCAs were conducted with *R* (see R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/) within the *R Studio* environment (see RStudio Team 2020) and by drawing on specialized R packages. After feeding each of the 72 data sets to the *FactoMineR* package (see Le et al. (2008), a list of elements was compiled among which there are the principal components and other related metrics such as eigenvalues and contributions of the variables to principal components. Figures were created with the help of the packages *ggplot2* (see, Kassambara 2019) and *factoextra* (see Kassambara and Mundt 2020) and then the correlation matrix plots were generated using the *ggcorrplot* package. Finally, we conducted Horn's parallel analysis with the *paran* package (Dinno (2018) to determine the optimal number of principal components to be retained. The scores of the principal components were generated and stored in an Excel-file.

[17] In this regard, it is interesting that the President of the Deutsche Bundesbank, Jens Weidmann, stated that the current pandemic emergency purchase programme (PEPP) of the ECB should be temporary and not permanent (Weidmann 2020).

Variable Set 1 (See footnote 5). Table 1 shows Variable Set 1 (including its Japanese expressions).[18] We used further variable reductions by combining some operation measures into one category, which is explained in Tables 2 and 3. This procedure resulted in Variable Sets 2 and 3, respectively (Table 1). Variable Set 3 is our baseline case. Later in this paper, we examine the robustness of the results obtained in the baseline case when Variable Sets 1 and 2 are used instead of the baseline case of Variable Set 3.

In total, we ran 72 separate analyses to account for the 72 different data set combinations conceivable by spanning a three-dimensional field consisting of three different variable set compositions (see above), four different time periods (whole data set 2002M3 – 2019M12 and subsamples of the Fukui, Shirakawa and Kuroda era), and six different aggregation levels (weekly, bi-weekly, monthly, bi-monthly, regular monetary policy meeting intervals, and monetary policy meeting intervals (including emergency meetings)).

For our data, we use the date of offer (and not date of exercise) and the amounts offered. For some cases such as purchases of Exchange Traded Funds there is no data about the amounts offered and we use the amounts of the successful bid instead[19]. In the baseline case reported in this section (see Table 4 for details), we aggregate all offers of each variable for each period between regularly scheduled monetary policy meetings. For example, if quantity X is offered ten days after the i-th regular monetary policy meeting and quantity Y is offered ten days before the i+1-th regular monetary policy meeting, then X+Y is the quantity of this variable for the period (interval) from the i-th to i+1-th meeting. We take the period (interval) between regularly scheduled monetary policy meetings as the basic time unit for the baseline case since it is policies announced in the monetary policy meeting that introduce, continue or abolish both conventional and unconventional policies through open market operations.[20]

Table 4 shows time frames (baseline and alternatives) and the number of observations under those time frames. As with the choice of the variable set, we examine whether the result of the baseline

[18] Our data of operations is based on Statistics of Market Operations by the BOJ: https://www.boj.or.jp/en/statistics/boj/fm/ope/index.htm/. They correspond to 'Operations' in: https://www.boj.or.jp/en/mopo/measures/mkt_ope/index.htm/, and they do not include 'Lending Facility', and in particular 'Loan Support Program'. The 'Fund-Provisioning Measure to Support Strengthening the Foundations for Economic Growth Conducted through the Loan Support Program' from June 2010 and 'Fund-Provisioning Measure to Stimulate Bank Lending Conducted through the Loan Support Program' from December 2012 are offered quarterly and more like institutional facilities. For this reason, we exclude them from our data set of operations that are far more frequent.

[19] The whole list of operations, for which there is no data for the amounts offered and we took the amounts of successful bids, include ETF, JGB (F), J-REIT, SFSOFCF, and USD-FSOPC (F).

[20] There are also unscheduled emergency meetings between regularly scheduled meetings. Although we also consider the time frame incorporating these unscheduled emergency meetings, the results qualitatively do not change much.

case changes or not if we control for weekly and monthly aggregation rather than the monetary-policy-meeting-interval aggregation.[21] [22]

Our chosen research methodology – the principal component analysis – allows us to 'obtain' from these complex unconventional policies a few significant policy combinations on the basis that if two unconventional policies move significantly in the same direction during each period then they are considered to achieve the same 'objective', and if two differ considerably, they have different 'objectives'. Thus, we conduct a PCA of the BOJ's market operations, which are principal routes of conducting unconventional policies.

[21] Although inter-meeting intervals seem appropriate when examining these unconventional measures, as policy changes are determined in the monetary policy meeting, it might be desirable to examine our results' robustness with respect to monthly and, in some cases, weekly frameworks. This is because many relatively high frequency economic data are monthly (or weekly, in some cases). These relatively high frequency economic data include Indices of Industrial Production (IIP) and other real economic indexes (for example, sentiment surveys such as Economy Watcher's Survey).

[22] We have also examined other time frames for variable aggregation, namely, bi-weekly, bi-monthly, and interval-between policy meetings including unscheduled (emergency) meetings. In most cases, the results do not change substantially compared with weekly and monthly time frames. These results are available upon request from the authors.

Table 1 Variable Sets 1-3 of the BOJ's Open Market Operations

	Var Set 1	Var Set 1 in Japanese Terms	Var Set 2	Var Set 3
1	ABCP_op	ABCP 買入オペレーション	ABCP_op	CB_op
2	Bills_os	手形売り出しオペ（資金吸収）	CB_op	CP_repo
3	Bills-All_op	手形買入・全店	CP_op	ETF
4	Bills-Head_op	手形買入・本店	CP_repo	ETF2
5	CB_op	社債買入（資金供給）	ETF	FSO-Disaster
6	CP_op	CP 買入（資金供給）	ETF2	FSO-Kumamoto
7	CP_repo	CP 買現先オペ（資金供給）	FSO-Disaster	JGB-0-1_op
8	ETF	指数連動型上場投資信託受益権買入	FSO-Kumamoto	JGB-10-30_op
9	ETF2	設備投資および人材投資に積極的に取り組んでいる企業を支援するための ETF 買入	FSOPC	JGB-1-10_op
10	FSO-Disaster	被災地金融機関を支援するための資金供給オペ	JGB-0-1_op	JGB-float_op
11	FSO-Kumamoto	平成二十八年熊本地震にかかる被災地金融機関を支援するための資金供給オペレーション	JGB-10-30_op	JGB-I_op
12	FSOPC	共通担保資金供給オペ（資金供給）	JGB-1-10_op	JGB_op
13	FSOPC-All	共通担保資金供給オペ・全店	JGB-float_op	JGS-Collateral-USDFSOPC
14	FSOPC-All-F	共通担保資金供給オペ・全店(固定金利)	JGB-I_op	J-REIT
15	FSOPC-All-M	共通担保資金供給・全店(金利入札)	JGB_op	SFSOFCF
16	FSOPC-Head	共通担保資金供給・本店	JGB_repo	Bills_op-FSOPC
17	FSOPC-Head-F	共通担保資金供給・本店(固定金利)	JGS-Collateral-USDFSOPC	T-Bills_repo
18	FSOPC-Head-M	共通担保資金供給・本店(金利入札)	J-REIT	T-Bills_op2
19	JGB-0-1_op	国債買入(残存期間 1 年以下)	SFSOFCF	USD-FSOPC2
20	JGB-10-30_op	国債買入(残存期間 10 年超 30 年以下)	Bills_op (net)	CP_op2
21	JGB-1-10_op	国債買入(残存期間 1 年超 10 年以下)	T-Bills_repo (net)	JGB-JGS_repo
22	JGB-F_op	国債買入(固定)	T-Bills_op2 (net)	
23	JGB-float_op	国債買入(変動利付債)	USD-FSOPC2	
24	JGB-I_op	国債買入(物価連動債)	FSOPC-AllHead	
25	JGB_op	国債買入（資金供給）	FSOPC-AllHead_F	
26	JGB_repo	国債借入	FSOPC-AllHead_M	
27	JGS-Collateral-USDFSOPC	米ドル資金供給用担保国債供給	JGS_repo (net)	
28	JGS-purchases_repo	国債買現先オペ（資金供給）		
29	JGS-sales_repo	国債売現先オペ（資金吸収）		
30	J-REIT	不動産投資法人投資口買入		
31	SFSOFCF	企業金融支援特別オペ		
32	TB-FB_op	短期国債買入		
33	TB-FB_os	短期国債売却		
34	TB-FB-purchases_repo	短期国債買現先		
35	TB-FB-sales_repo	短期国債売現先		
36	T-Bills_op	国庫短期証券買入		
37	USD-FSOPC	米ドル資金供給オペ		
38	USD-FSOPC-F	米ドル資金供給オペ（固定金利）		
39	USD-FSOPC-M	米ドル資金供給オペ（金利入札）		

Notes: (1) op = outright purchases; os = outright sales in Var. Set 1. op (net) = op – os in Var. Set 2.
(2) '(net)' is not shown in Var. Set 3 in Table 1 for notational simplicity.
Source: The authors' construction based on the List of Market Operations by the Bank of Japan (Monthly);

In English: https://www.boj.or.jp/en/statistics/boj/fm/ope/m_release/index.htm/
In Japanese: https://www.boj.or.jp/statistics/boj/fm/ope/m_release/index.htm/

Table 2: Variable Reduction (Combining Variables) to Get Variable Set 2

New Variable	Combination of Former Variables
Bills_op (net)	Bills-All_op + Bills-Head_op – Bills_os
T-Bills_repo (net)	TB-FB-purchases_repo – TB-FB-sales_repo
T-Bills_op2 (net)	TB-FB_op + T-Bills_op – TB-FB_os
USD-FSOPC2	USD-FSOPC + USD-FSOPC(F) + USD-FSOPC(M)
FSOPC-AllHead	FSOPC-All + FSOPC-Head
FSOPC-AllHead_F	FSOPC-All(F) + FSOPC-Head(F)
FSOPC-AllHead_M	FSOPC-All(M) + FSOPC-Head(M)
JGS_repo (net)	JGS-purchases_repo – JGS-sales_repo

Table 3: Variable Reduction (Combining Variables) to Get Variable Set 3 (Baseline Model)

New Variable	Combination of Former Variables
CP_op2	ABCP_op + CP_op
Bills_op-FSOPC	Bills_op (net) + FSOPC + FSOPC-AllHead + FSOPC-AllHead_F + FSOPC-AllHead_M
JGB-JGS_repo	JGB_repo + JGS_repo

Table 4: Time Frames and Number of Observations

Time Frame	**Number of Observations Scheduled MPM** (1)	**Number of Observations: Monthly Data** (2)	**Number of Observations: Weekly Data** (3)
Whole data set (March 1, 2002 – Dec. 31, 2019)	232	214	929
Fukui (March 20, 2003 – March 19, 2008)	74	61	262
Shirakawa (April 9, 2008 – March 19, 2013)	70*	60	256
Kuroda (March 20, 2013 – Dec. 31, 2019)	71**	82	353

Notes: *Technically, Shirakawa was not Governor on the monetary policy meeting on April 9, but he was appointed on that day, so we count it. Between March/April 2008, there was a leadership vacuum in the BOJ. Statistically, it makes no difference.
** Our data is only until end of 2019. Therefore, we do not count Kuroda's MPM after 2019.
(1) MPM. Fukui: "2003-04-08" - "2008-03-07"; Shirakawa: "2008-04-09" - "2013-03-07", Kuroda: "2013-04-04" - "2019-12-19".

(2) Monthly. Fukui: "2003-Mar" - "2008-Mar"; Shirakawa: "2008-Apr" - "2013-Mar"; Kuroda: "2013-Mar" - "2019-Dec".
(3) Weekly. Fukui: "3/17/2003 - 3/23/2003" - "3/17/2008 - 3/23/2008"; Shirakawa: "4/7/2008 - 4/13/2008" - "3/11/2013 - 3/17/2013"; Kuroda: "3/18/2013 - 3/24/2013" - "12/23/2019 - 12/29/2019".

As is evident in Table 1, the BOJ's open market operations are complicated: thirty-nine variables in Variable Set 1, twenty-seven in Variable Set 2, and twenty-one in the baseline case of Variable Set 3. Some are conventional open market operation instruments, such as FSOPC (Funds-Supplying Operations against Pooled Collaterals), which are supply or absorption of funds intended to control the policy rate in the interbank markets. However, many of these variables are introduced as emergency measures to cope with specific distress in financial markets and bank lending at the time of their introduction. SFSOCF (Special Funds-Supplying Operations to Facilitate Corporate Financing) is one example of this kind. Although not stated directly, the very unconventional outright purchases of ETF (Exchange Traded Funds) and J-REIT (Japanese Real Estate Investment Funds) are considered to be emergency measures to cope with excessive pessimism about stock and related markets.

Open market operations include measures for disasters, such as FSO-Disaster (Funds-Supplying Operation to Support Financial Institutions in Disaster Areas) for the Earthquake, Tsunami and Fukushima crisis[23] starting in May 2011 and the FSO-Kumamoto (Funds-Supplying Operation to Support Financial Institutions in Disaster Areas) for the 2016 Kumamoto Earthquake which are specific operations to deal with regional crises in specific areas of Japan.[24]

4. Revealed Objectives of Unconventional Measures (2002-2019)

We divide our analysis between the whole dataset 2002-2019 in this Section and a subsample analysis of three different BOJ governors in Section 5: Toshihiko Fukui (2003-2008), Masaaki Shirakawa (2008-2013) and Haruhiko Kuroda (2013- to present).

When we consider the whole period, we implicitly assume that the BOJ has a contingency plan for each unconventional measure for the whole period. In case there is no such contingency (event) to trigger a particular unconventional measure, the quantity of this unconventional measure is zero. When such contingency (event) occurs, then the quantity of the corresponding unconventional policy becomes positive. The quantity is then dependent on the magnitude of the negative effects on economic activities caused by the contingency (event). To take the whole period as our sample period means that at the outset of the period (March 2002), the BOJ is anticipating the possibility of contingencies (events) during the whole period. Since the Bank is always examining and preparing various possibilities, this assumption may not be totally unrealistic.

However, it might be argued that some contingencies that trigger corresponding unconventional measures are not conceived in advance. For example, some may argue that the contingency caused by the GFC of 2008 might not have been on the menu of policy options before 2007. With this

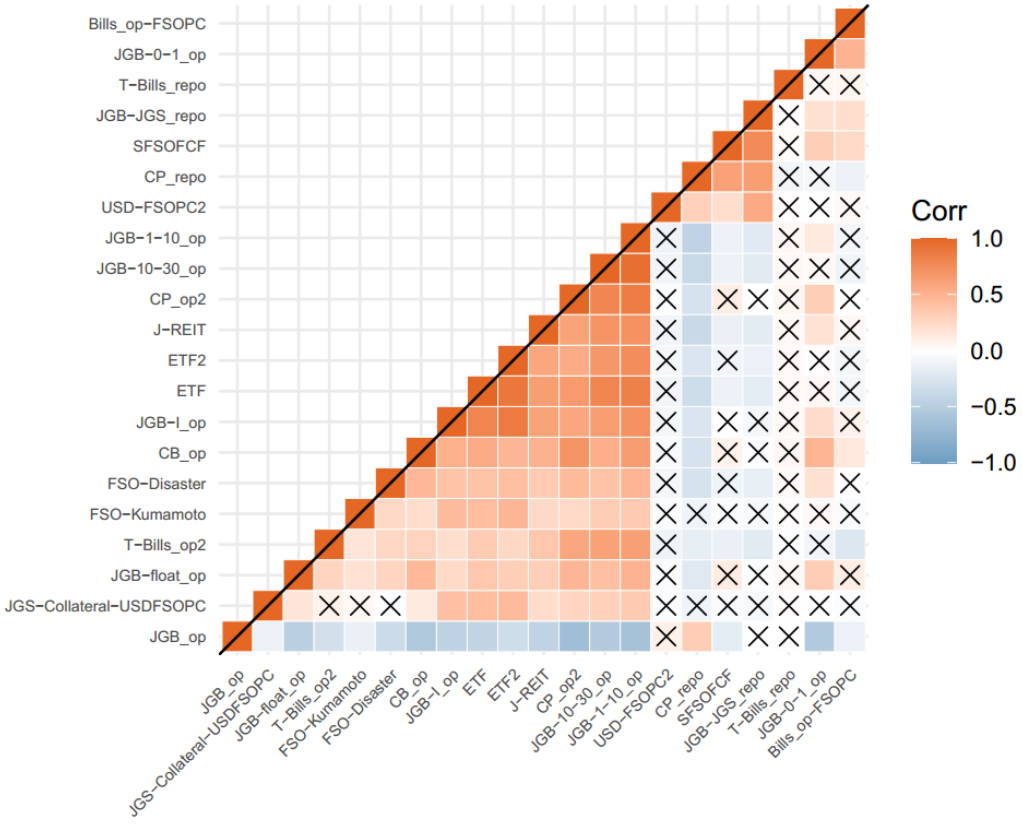
[23] See Yamaguchi (2011) for details about challenges to monetary policy after the earthquake.
[24] However, as already mentioned in the paper, both measures became permanent, although they were originally planned as an emergency measure for a specific crisis/disaster.

possibility in mind, we divide the whole sample period into three periods of different governors and apply PCA to each period independently. This procedure may reveal the difference between the governors in devising and implementing unconventional measures during their term.

4.1. Whole Data Set 2002-2019: Four Principal Components Representing Four 'Objectives'

The number of observations total 232 in the whole sample period (2002-2019) in the baseline case (Table 4). Figure 1 below shows the correlation of the 21 variables in the baseline case. Here the variables are of Variable Set 3, and each variable's quantities are aggregated for each regularly scheduled monetary policy meeting interval. This Figure shows correlations among these variables, each of which is aimed for specific policy needs.[25]

Figure 1: Correlation Table: Baseline Case of Variable Set 3 (21 variables) for the whole sample period (2002-2019) (p26-32 of New Columns Data (3))



Note: [X] shows that the correlation is not significant at the 5% level.
Source: Authors' calculation based on *R*.

[25] Ideally, we would like to see the correlation of the identified PCAs with some market-based measures, such as spreads in different market segments etc. However, we unfortunately do not have such detailed information about the 'functioning metric' of each market. We thank Katrin Assenmacher for hinting at this point.

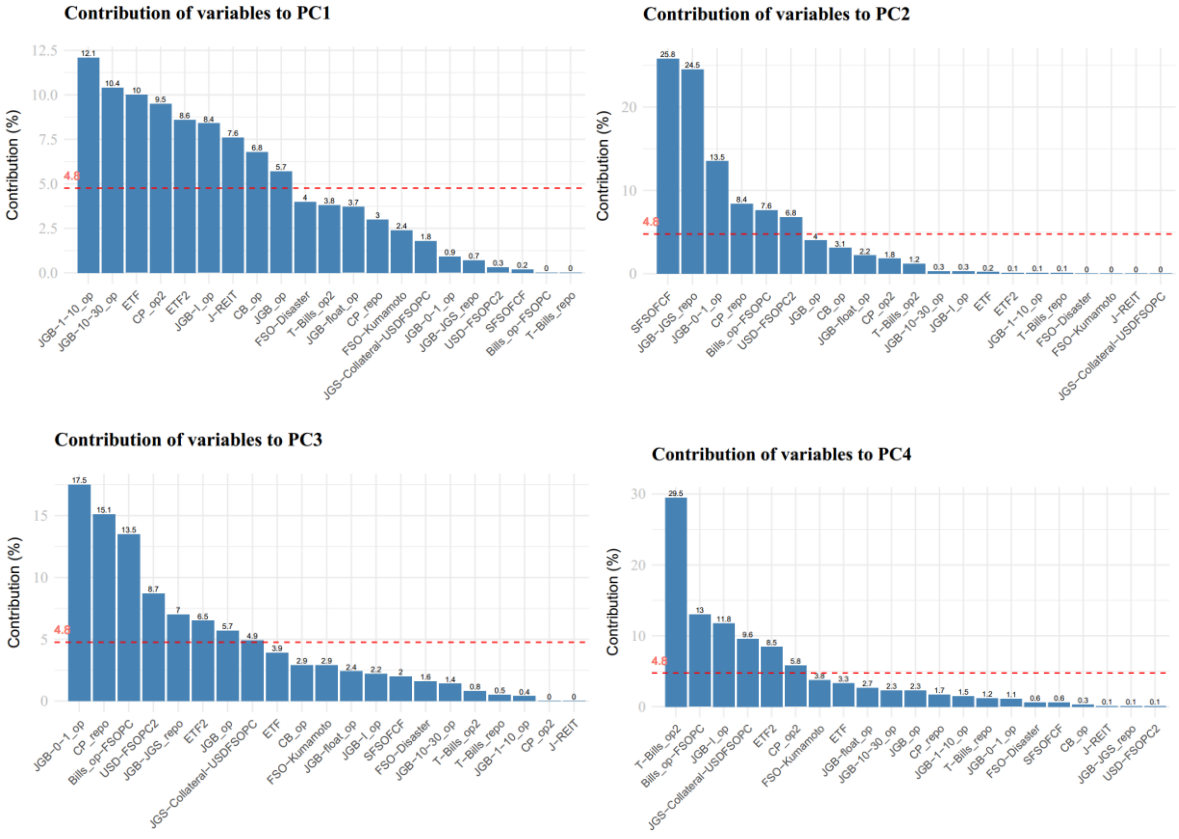
In the baseline case of Variable Set 3 for the regularly scheduled monetary policy meeting interval, we can identify four principal components under our criterion of Horn's parallel analysis.[26] The following Figure 2 shows the contribution and composition of Principal Components 1, 2, 3, and 4 for the whole data set 2002-19.

Figure 2: Contribution and composition of PC 1-4 for whole data set 2002-19

(1) Eigenvalues and Percentage of Variance Explained (comp = Principal Component)

	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	7.67	36.54	36.54
comp 2	2.82	13.42	49.97
comp 3	1.86	8.85	58.82
comp 4	1.39	6.63	65.45

(2) Contribution and composition of Principal Components



Source: Authors' calculation based on *R*.

[26] For details, see section 3.

The results show first that PC1 explains 37% of the variation and can be characterized as quantitative easing policy which consists of asset purchase measures. It includes outright purchases of medium-term (1y-10y) and long-term (10y-30y) JGBs (Japanese Government Bonds), which are risk-free assets as well as ETF (Exchange-Traded Funds), ETF2 (ETF of Firms Investing in Equipment, Structure and Human Capital) and J-REIT (Japanese Real Estate Investment Trusts), which are risky financial assets. It also contains outright purchases of commercial papers (CP) and corporate bonds (CB), which are also risky assets. This indicates that the main objective or goal of PC1 is to reduce long-term risk-free rates, risk premiums of stock and related markets, and risks in corporate finance.

It should be noted that the BOJ makes it clear in its policy statement that the purpose of JGB purchases and those of ETF and J-REIT are different: the former is the core of quantitative easing – increasing quantity (balance sheets) and reducing risk free rates – while the latter is more like so-called credit easing – reducing risk premiums. Although the stated purposes are different, they constitute of the same principal component. Thus, quantitative easing in the Japanese case includes credit easing as an integral part. By combining the two, the Bank has made portfolio rebalance effects stronger than otherwise.

Second, PC2 explains 13% of the variation. PC2, to which SFSOCF (Special Funds-Supplying Operations to Facilitate Corporate Financing) and JGB-JGS (Japanese Government Securities) repos are major contributors, is mainly liquidity supplying aimed at the funding of longer-term investors, such as securities houses, insurance companies and investment trusts. It also aimed at funding needs of corporate finance in crisis situations.

Third, PC3, explaining 9%, is dominated by outright purchases of short-term (0-1y) JGBs and is liquidity supply aimed at the short-term segment of the markets. Finally, PC4 explains 7% of the variation and consists of T-bills (Treasury bills) and FSOPC (Funds Supplying Operations against Pooled Collateral). These operations influence the funding of financial institutions in interbank and T-bills markets to control the policy rate and keep these institutions' current account at high levels.[27] The difference between PC3 and PC4 may also reflect differences in the market structure. Although there may be some arbitrage between them, the arbitrage is known to be rather weak. Short-term (0-1y) JGB markets are relatively illiquid markets in which domestic investors buy and hold, while T-bills markets are more liquid with frequent offers as well as the presence of foreign investors[28].

Thus, our PCA of open market operations identifies four objectives or targets of unconventional policies:[29] (1) quantitative easing policy to reduce both long-run rates of riskless assets and risk premiums of risky financial assets and to ease market conditions of corporate finance, (2) liquidity supply to longer-term investors, (3) liquidity supply to shorter-term markets, and finally (4) to control overnight policy rates and maintain financial institutions' current account at elevated levels.

[27] The BOJ has maintained the position to keep these financial institutions' current account at the Bank at an elevated level.

[28] We owe this interpretation to Seiichi Shimizu (Bank of Japan).

[29] It may be possible that some operations have multiple purposes. For example, while outright purchases of short-term (0-1y) JGBs is the dominant component of PC3, it is also a small-contribution component of PC2. Thus, outright purchases of short-term (0-1y) JGBs is likely to be more focused on PC3, though both PC3 and PC2 are liquidity supply in different segments of financial markets.

This demonstrates that the BOJ's open market operations cannot be reduced to a single dimension, and quantitative easing policies are mingled with various liquidity provisions.

It should be noted that we do not use any information other than the data regarding the quantity of open market operation measures. In particular, we do not include the central bank's announced intention to take particular actions. These findings are what quantitative data tell us about the central bank's 'revealed' objectives (or targets).

4.2. Robustness Checks

In this section, we examine the robustness of the results obtained in the section above. The number of observations is 214 for monthly data and 929 for weekly data (see Table 4).

In the baseline case, we have examined 21 variables (Variable Set 3) aggregated in the period (interval) between regularly scheduled monetary policy meetings. In the following, we show that the basic results obtained in the previous section still hold true even if (1) the variable sets are changed from the baseline Variable Set 3 to more detailed variable sets (that is, Variable Sets 1 and 2), and (2) the time frame is changed from monetary policy meeting intervals to a monthly frame or even a weekly frame.

Figure 3a shows the principal components in the case of Variable Set 1 (39 variables) and Variable Set 2 (27 variables), alongside the baseline case of Variable Set 3 (21 variables) for reference. Our methodological framework requires two more principal components in Variable Sets 1 and 2.

It is evident from the figures that by comparing large-contribution variables (indicated by a tilted red box) in different variable sets, the results of the baseline case are robust with respect to variable selection. The interpretation of the first principal component as quantitative easing policy in the form of 'asset purchases' is the same in the more detailed variable cases as in the baseline case. The same is true for PC2, which is a liquidity supplying scheme aimed at funding longer-term investors, including corporate finance. It is also to a lesser extent the case for PC3, which is liquidity supply aimed at short-term markets. In addition, PC4 can still be considered liquidity supply aimed at short-term markets in Variable Set 2.

In contrast, it is not clear what PC4 implies in the most detailed Variable Set 1. Regarding the new components PC5 and PC6, though their importance is less than the other four principal components, it is not easy to discern the objective of these policy measures. However, as PC5 and PC6 do not contribute much to the explanation of variation (that is, their Eigenvalue is not much higher than 1 in our Parallel Analysis), they can be ignored.

The time frame comparison is presented in Figure 3b. We compare principal components in different time frames. As in Figure 3a, we juxtapose the baseline case of the monetary policy meeting intervals as a frame of reference.

The results are remarkable. The large-contribution components of the principal components are very similar within different time frames. Thus, the results of principal components are robust with respect to time frames for all PC (PC1, 2, 3, and 4). The difference between time frames lies in the number of principal components. We have an additional PC (PC5) in the weekly data which reveals some particularly interesting results. It should be noted that in the weekly data set, PC5 appears to

represent disaster relief measures. Disaster relief measures are truly emergency measures that should have desirable effects immediately after the disaster. Thus, it is no surprise that the objective of these disaster relief measures should appear in the weekly framework.[30] It may be the case that when aggregated in a month or longer, these disaster relief measures are buried in other longer-lasting measures.[31]

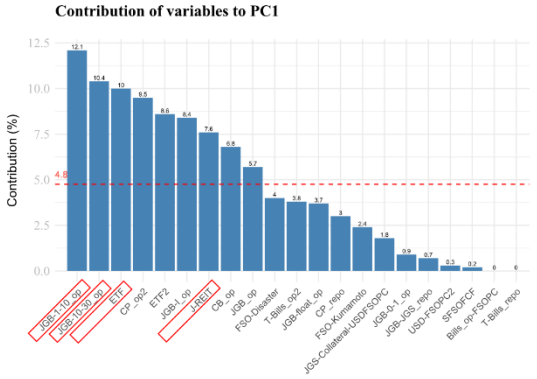
[30] However, as the variance is only 6.22%, the explanatory capacity is not very high (Figure 3b).

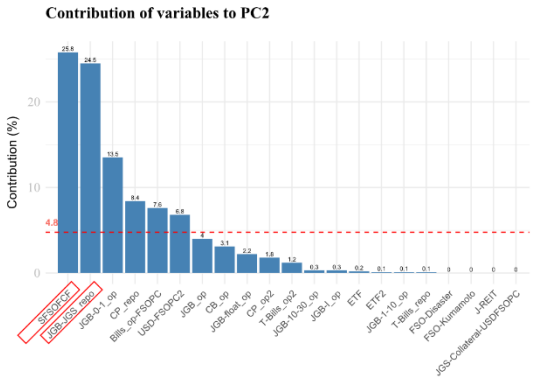
[31] Results from other time frames (bi-weekly, bi-monthly, etc.) are available from the authors upon request. There are some subtle differences, but qualitatively the results do not change much.

Figure 3a: Robustness Checks: Choice of Variable Sets

Baseline: Var. Set 3 (4 PC)

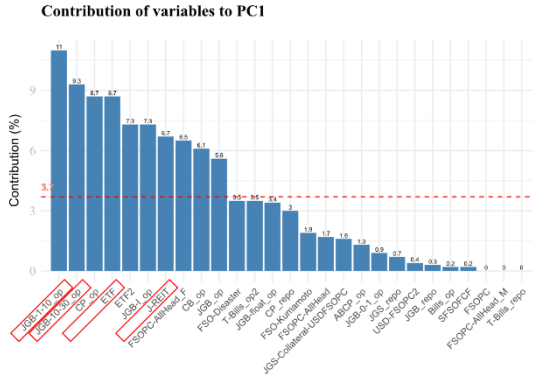
	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	7.67	36.54	36.54
comp 2	2.82	13.42	49.97
comp 3	1.86	8.85	58.82
comp 4	1.39	6.63	65.45

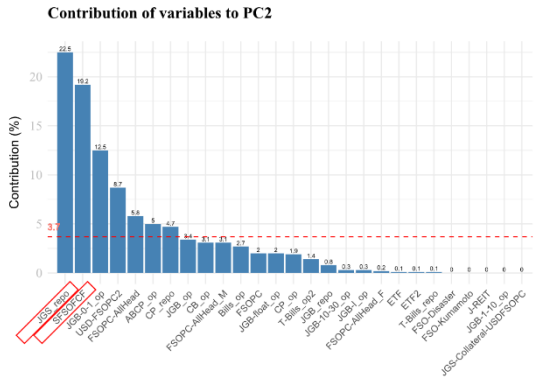




Var. Set 2 (6 PC)

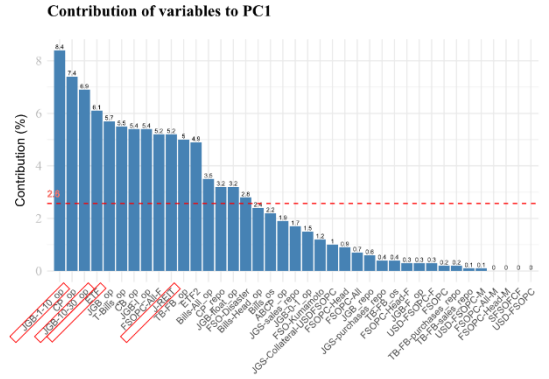
	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	8.47	31.38	31.38
comp 2	3.07	11.36	42.74
comp 3	2.66	9.84	52.58
comp 4	1.53	5.66	58.24
comp 5	1.47	5.46	63.7
comp 6	1.33	4.91	68.61

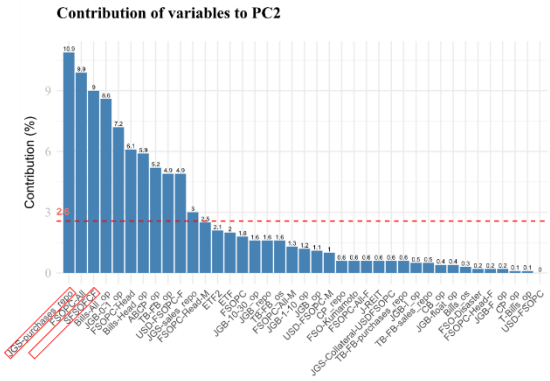


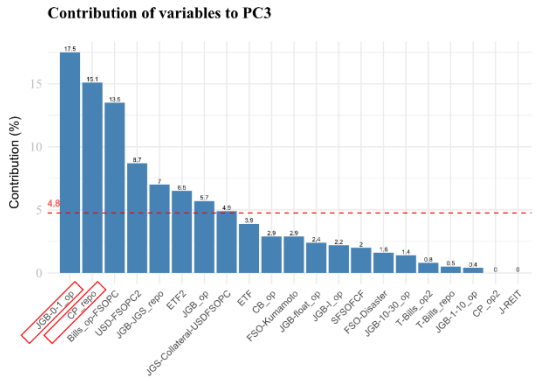


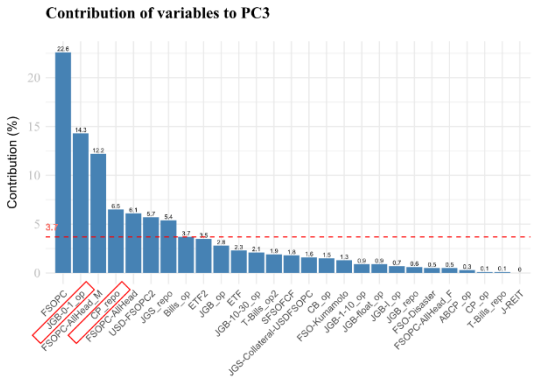
Var. Set 1 (6 PC)

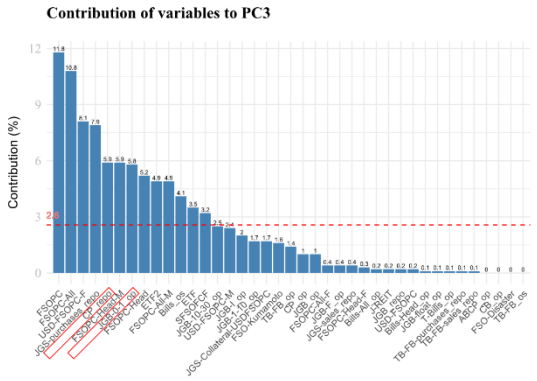
	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	10.13	25.97	25.97
comp 2	4.26	10.92	36.88
comp 3	3.18	8.15	45.03
comp 4	2.27	5.81	50.84
comp 5	2.05	5.26	56.1
comp 6	1.55	3.97	60.07

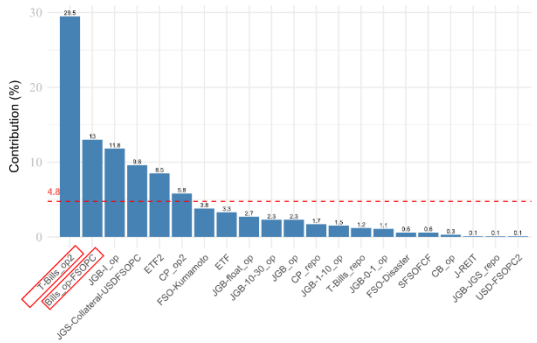


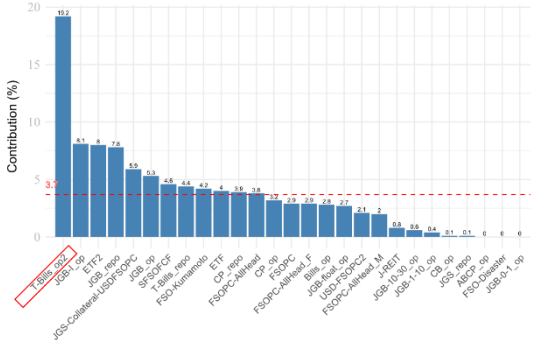


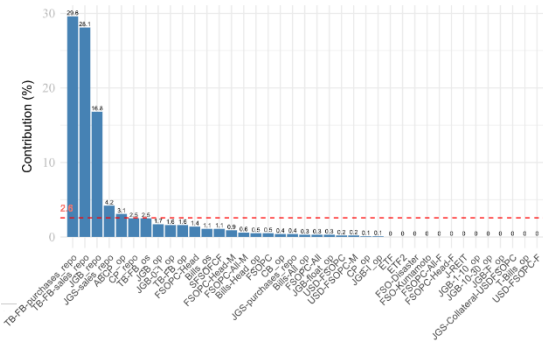

Contribution of variables to PC3
Contribution (%)
JGB-0.1_op
CP_repo
Bills_op+FSOPC
USD-FSOPC2
JGB-JGS_repo
ETF2
JGB_op
JGS-Collateral-USDFSOPC
ETF
CB_op
FSO-Kumamoto
JGB-float_op
JGB-I_op
SFSOFCF
FSO-Disaster
JGB-10-30_op
T-Bills_op2
T-Bills_repo
JGB-1-10_op
CP_op2
J-REIT

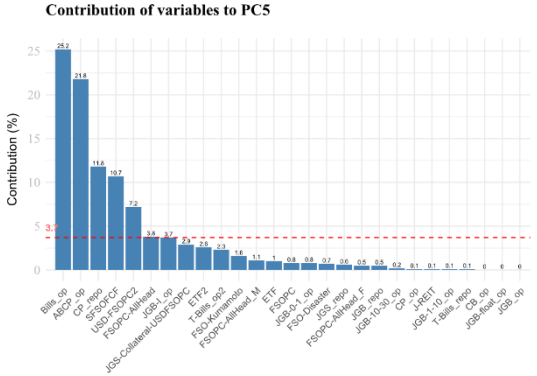

Contribution of variables to PC3
Contribution (%)
FSOPC
JGB-0.1_op
FSOPC-AllHead_M
CP_repo
FSOPC-AllHead
USD-FSOPC2
JGS_repo
Bills_ op
ETF2
JGB_ op
ETF
JGB-10-30_op
T-Bills_op2
SFSOFCF
JGS-Collateral-USDFSOPC
CB_op
FSO-Kumamoto
JGB-1-10_op
JGB-float_op
JGB-I_op
JGB_repo
FSO-Disaster
FSOPC-AllHead_F
ABCP_op
CP_op
T-Bills_repo
J-REIT

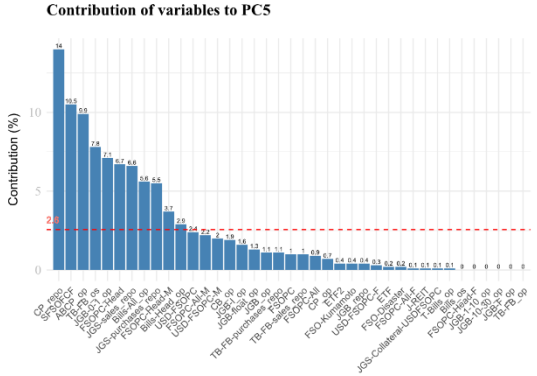

Contribution of variables to PC3
Contribution (%)
FSOPC
FSOPC-All
FSOPC-FSOPC-F
USD-FSOPC-F
JGS-Collateral-USDFSOPC
JGB-0.1_op
FSOPC-AllHead_M
JGB-JGS_repo
FSOPC-AllHead_F
ETF2
FSOPC-AllHead
Bills_ op
ETF
SFSOFCF
JGB-1-10_op
USD-FSOPC2
JGB-10-30_op
JGS-Collateral-USDFSOPC
FSO-Kumamoto
TB-FB_op
CB_op
JGB-I_op
FSOPC-Head_F
JGS-sales_repo
Bills-All_op
JGB_op
USD-FSOPC_op
Bills-Head_op
JGB-float_op
TB-FB-purchases_repo
T-Bills_op2
ABCP_repo
CB_repo
FSO-Disaster
TB-FB_op

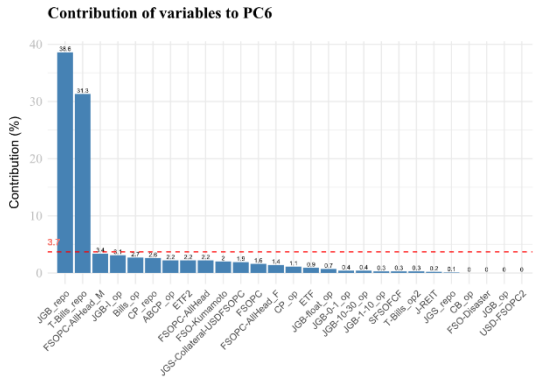

Contribution of variables to PC4
Contribution (%)
T-Bills_op2
Bills_op+FSOPC
JGB-I_op
JGS-Collateral-USDFSOPC
ETF2
CP_op2
FSO-Kumamoto
ETF
JGB-float_op
JGB-10-30_op
JGB_op
CP_repo
JGB-1-10_op
T-Bills_repo
JGB-0-1_op
FSO-Disaster
SFSOFCF
CB_op
J-REIT
JGB-JGS_repo
USD-FSOPC2


Contribution of variables to PC4
Contribution (%)
T-Bills_op2
JGB-I_op
ETF2
JGB_repo
JGB_op
JGS-Collateral-USDFSOPC
SFSOFCF
T-Bills_repo
FSO-Kumamoto
ETF
CP_repo
FSOPC-AllHead
CP_op
FSOPC
FSOPC-AllHead_F
Bills_op
JGB-float_op
USD-FSOPC2
FSOPC-AllHead_M
J-REIT
JGB-10-30_op
JGB-1-10_op
CB_op
JGS_repo
ABCP_op
FSO-Disaster
JGB-0-1_op


Contribution of variables to PC4
Contribution (%)
TB-FB-purchases_repo
TB-FB-sales_repo
JGS-sales_repo
JGB_repo
ABCP_op
CP_repo
TB-FB_op
JGB-0-1_op
TB-FB_op
FSOPC-Head_F
Bills-Head_op
FSOPC-AllHead_M
Bills-Head_op
CB_op
JGS-purchases_repo
Bills-All_op
JGB-float_op
FSOPC-All_op
JGB-I_op
USD-FSOPC_op
FSOPC-Head_M
JGB-1-10_op
ETF
FSO-Disaster
FSO-Kumamoto
FSOPC-Head_F
JGB-10-30_op
JGB-1-10_op
JGS-Collateral-USDFSOPC
USD-FSOPC_F


Contribution of variables to PC5
Contribution (%)
Bills_op
ABCP_op
CP_repo
SFSOFCF
USD-FSOPC2
FSOPC-AllHead
JGB-I_op
JGS-Collateral-USDFSOPC
ETF2
T-Bills_op2
FSO-Kumamoto
FSOPC-AllHead_M
ETF
FSOPC
JGB-0.1_op
FSO-Disaster
JGS_repo
FSOPC-AllHead_F
JGB_repo
JGB-10-30_op
CP_op
J-REIT
JGB-1-10_op
T-Bills_repo
CB_op
JGB-float_op
JGB_op


Contribution of variables to PC5
Contribution (%)
CP_repo
SFSOFCF
ABCP_op
TB-FB_op
JGB-0.1_op
FSOPC-Head_F
JGS-sales_repo
JGS-purchases_repo
Bills-Head_op
FSOPC-Head_M
Bills-Head_op
USD-FSOPC_op
FSOPC-All_M
CB_op
JGB-float_op
JGB-I_op
TB-FB-purchases_repo
FSOPC
TB-FB-sales_repo
FSOPC_op
CP_op
ETF2
FSO-Kumamoto
USD-FSOPC_F
ETF
FSO-Disaster
FSOPC-All_F
JGS-Collateral-USDFSOPC
T-Bills_op
FSOPC-Head_F
JGB-1-10_op
JGB-10-30_op
JGB_op
TB-FB_op


Contribution of variables to PC6
Contribution (%)
0
10
20
30
40
3.2
38.6
31.3
3.4
3.1
2.7
2.6
2.2
2.2
2.2
2
1.8
1.6
1.4
1.1
0.9
0.7
0.4
0.4
0.3
0.3
0.3
0.2
0.1
0
0
0
JGB_repo
T-Bills_repo
FSOPC-AllHead_M
JGB-1_op
Bills_op
CP_repo
ABOP_op
_ETF2
FSOPC-AllHead
FSO-Kumamoto
JGS_Collateral-USDFSOPC
FSOPC
FSOPC-AllHead_F
CP_op
ETF
JGB-float_op
JGB-0-1_op
JGB-10-30_op
JGB-1-10_op
SFSOFCF
T-Bills_op2
J-REIT
JGS_repo
CB_op
FSO-Disaster
JGB_op
USD-FSOPC2

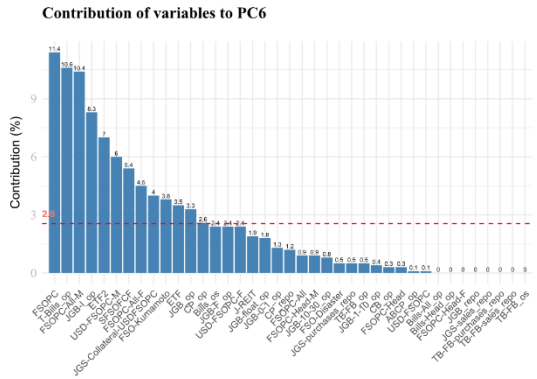

Contribution of variables to PC6
Contribution (%)
0
3
6
9
2.3
11.4
10.5
10.4
8.3
7
6
5.4
4.6
4
3.6
3.5
3.3
2.6
2.4
2.4
2.4
1.8
1.8
1.3
1.2
0.9
0.9
0.8
0.5
0.5
0.5
0.4
0.3
0.3
0.1
0.1
0
0
0
0
0
0
0
FSOPC
FSOPC-AllHead_M
FSOPC-AllHead_F
JGB_op
ETF2
USD-FSOPC_M
SFSOFCF
FSOPC-AllHead
USD-FSOPC_F
JGS_Collateral-USDFSOPC
FSO-Kumamoto
ETF
JGB_repo
CP_op
Bills_op
USD-FSOPC_REIT
J-REIT
JGB-0-1_op
CP_repo
FSOPC-AllHead_F
FSOPC-Head_M
JGB-10-30_op
FSO-Disaster
JGS-purchase_repo
JGB-1-10_op
FSOPC-Head_F
CB_op
USD-FSOPC
ABOP_op
Bills-All_op
Bills-Head_op
FSOPC-Head_op
JGS_op
JGS-reverse_repo
TB-FB-swaps_repo
TB-FB-swaps_op
TB-FB_op

Figure 3b: Robustness Checks: Choice of Aggregation Levels

Baseline MPM Interval (4 PC)

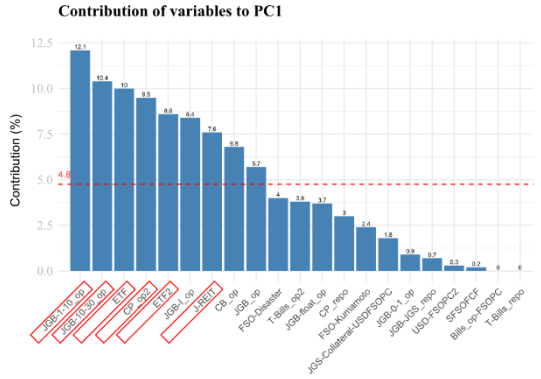
	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	7.67	36.54	36.54
comp 2	2.82	13.42	49.97
comp 3	1.86	8.85	58.82
comp 4	1.39	6.63	65.45

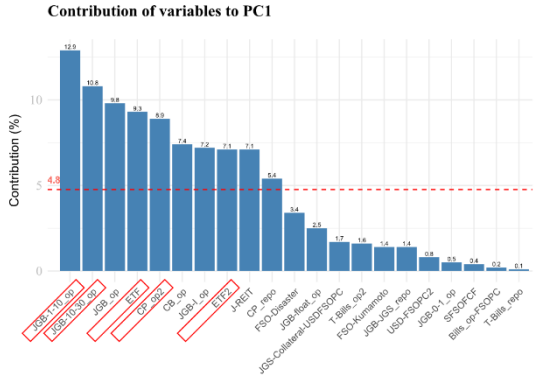
Monthly (4 PC)

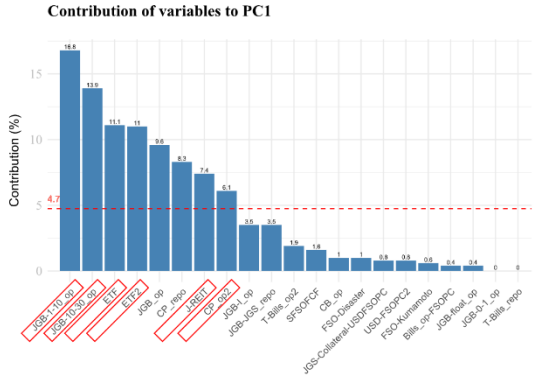
	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	6.88	32.76	32.76
comp 2	3.01	14.34	47.1
comp 3	1.99	9.47	56.57
comp 4	1.69	8.02	64.59

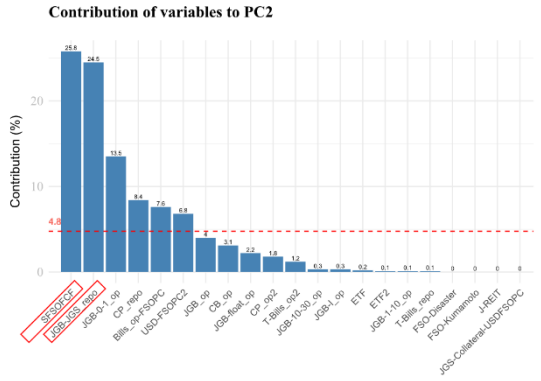
Weekly (5 PC)

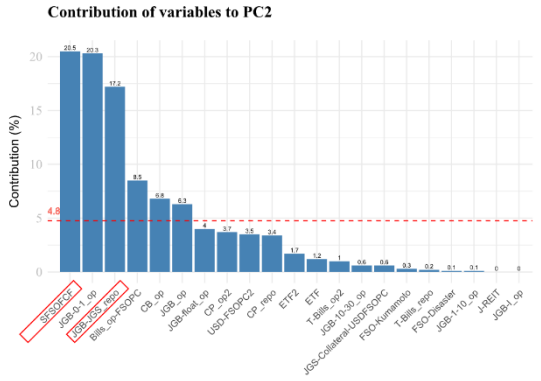
	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	4.55	21.66	21.66
comp 2	2.18	10.36	32.02
comp 3	1.51	7.2	39.22
comp 4	1.32	6.28	45.5
comp 5	1.31	6.22	51.72

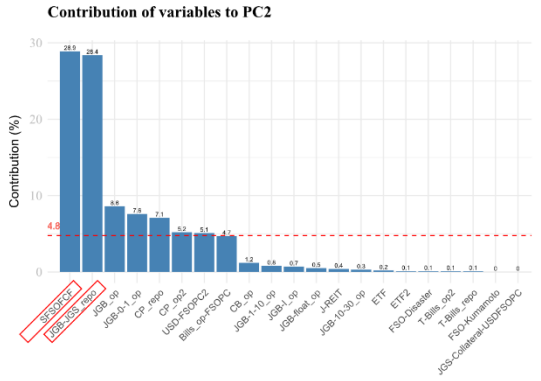


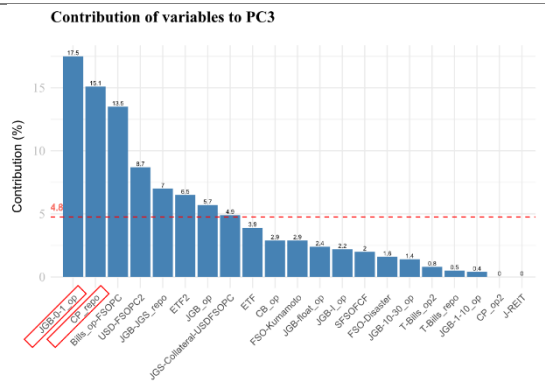


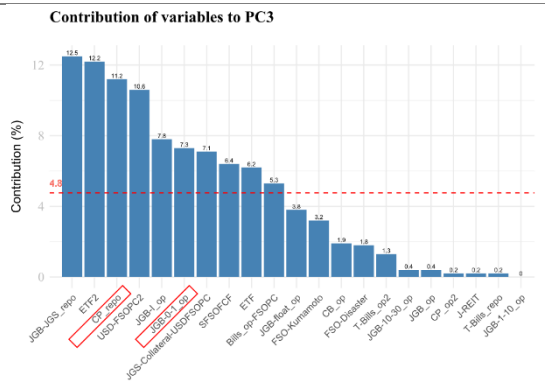


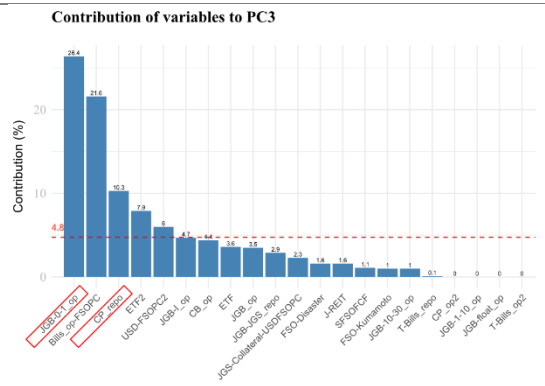


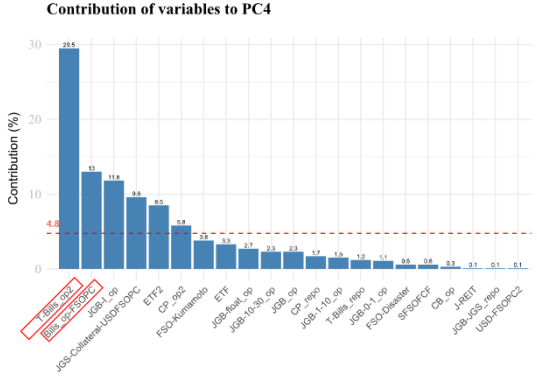


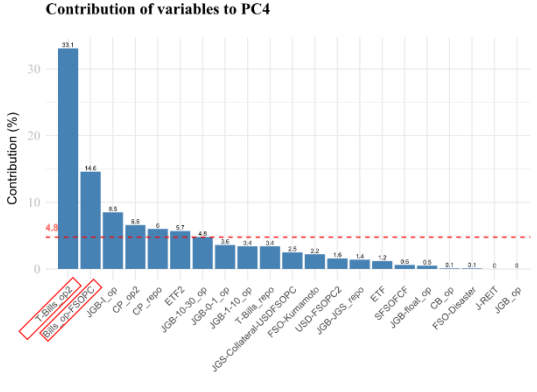


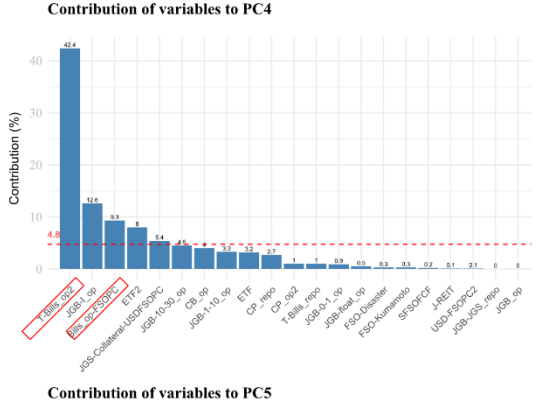

Contribution of variables to PC3
Contribution (%)
JGB-0-1_op
CP_repo
Bills_op-FSOPC
USD-FSOPC
JGB-JGS_repo
ETF2
JGB_op
JGS-Collateral-USDFSOPC
ETF
CB_op
FSO-Kumamoto
JGB-float_op
JGB-1_op
SFSOFCF
FSO-Disaster
JGB-10-30_op
T-Bills_op2
T-Bills_repo
JGB-1-10_op
CP_op2
J-REIT

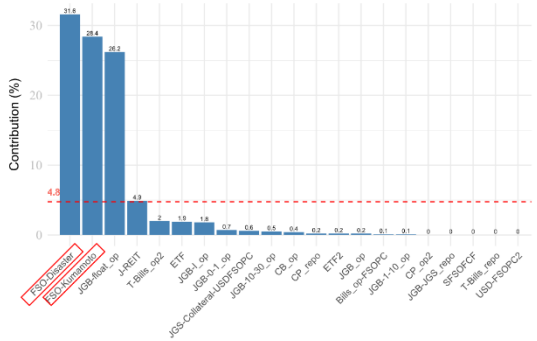

Contribution of variables to PC3
Contribution (%)
JGB-JGS_repo
ETF2
CP_repo
USD-FSOPC2
JGB-1_op
JGB-0-1_op
JGS-Collateral-USDFSOPC
SFSOFCF
ETF
Bills_op-FSOPC
JGB-float_op
FSO-Kumamoto
CB_op
FSO-Disaster
T-Bills_op2
JGB-10-30_op
JGB_op
CP_op2
J-REIT
T-Bills_repo
JGB-1-10_op


Contribution of variables to PC3
Contribution (%)
JGB-0-1_op
Bills_op-FSOPC
CP_repo
ETF2
USD-FSOPC2
JGB-1_op
CB_op
ETF
JGB_op
JGB-JGS_repo
JGS-Collateral-USDFSOPC
FSO-Disaster
J-REIT
SFSOFCF
FSO-Kumamoto
JGB-10-30_op
T-Bills_repo
CP_op2
JGB-1-10_op
JGB-float_op
T-Bills_op2


Contribution of variables to PC4
Contribution (%)
T-Bills_op2
Bills_op-FSOPC
JGB-1_op
JGS-Collateral-USDFSOPC
ETF2
CP_op2
FSO-Kumamoto
ETF
JGB-float_op
JGB-10-30_op
JGB_op
CP_repo
JGB-1-10_op
T-Bills_repo
JGB-0-1_op
FSO-Disaster
SFSOFCF
CB_op
J-REIT
JGB-JGS_repo
USD-FSOPC2


Contribution of variables to PC4
Contribution (%)
T-Bills_op2
Bills_op-FSOPC
JGB-1_op
CP_op2
CP_repo
ETF2
JGB-10-30_op
JGB-0-1_op
JGB-1-10_op
T-Bills_repo
JGS-Collateral-USDFSOPC
FSO-Kumamoto
USD-FSOPC2
JGB-JGS_repo
ETF
SFSOFCF
JGB-float_op
CB_op
FSO-Disaster
J-REIT
JGB_op


Contribution of variables to PC4
Contribution (%)
T-Bills_op2
JGB-1_op
Bills_op-FSOPC
JGS-Collateral-USDFSOPC
ETF2
JGB-10-30_op
CB_op
JGB-1-10_op
ETF
CP_repo
CP_op2
T-Bills_repo
JGB-0-1_op
JGB-float_op
FSO-Disaster
FSO-Kumamoto
SFSOFCF
J-REIT
USD-FSOPC2
JGB-JGS_repo
JGB_op


Contribution of variables to PC5
Contribution (%)
FSO-Disaster
FSO-Kumamoto
JGB-float_op
J-REIT
T-Bills_op2
ETF
JGB-1_op
JGB-0-1_op
JGS-Collateral-USDFSOPC
JGB-10-30_op
CB_op
CP_repo
ETF2
JGB_op
Bills_op-FSOPC
JGB-1-10_op
CP_op2
JGB-JGS_repo
SFSOFCF
T-Bills_repo
USD-FSOPC2

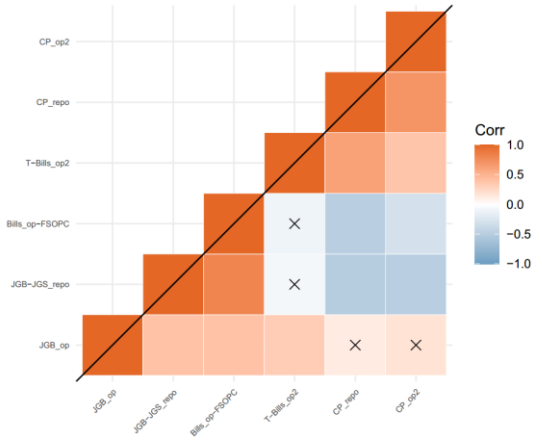
5. Similarities and Differences Between Three Governors

In this section, we construct sub-samples and divide our analysis between three BOJ governors, Fukui (2003-08), Shirakawa (2008-13) and Kuroda (2013-present).

5.1. The Fukui Period 2003-2008

The number of observations is 74 in the Fukui period (2003-2008) (see Table 4). In retrospect, the era of Governor Fukui is characterized by relatively simple monetary policy measures compared with his successors. There are only six variables in the mainline case of Variable Set 3, and they are relatively conventional measures compared with the variables in the later stage (Shirakawa and Kuroda periods).

Figure 4: Correlation Table:
Baseline Case of Variable Set 3 for the Fukui period (2003-2008)



Note: [X] shows that the correlation is not significant at the 5% level.
Source: Authors' calculation based on *R*.

Figure 4 shows the correlation table of six variables (open market operation measures). Although it is markedly simpler than the whole period, it is evident the policy is still complicated, reflecting the existence of outright purchases of commercial papers.

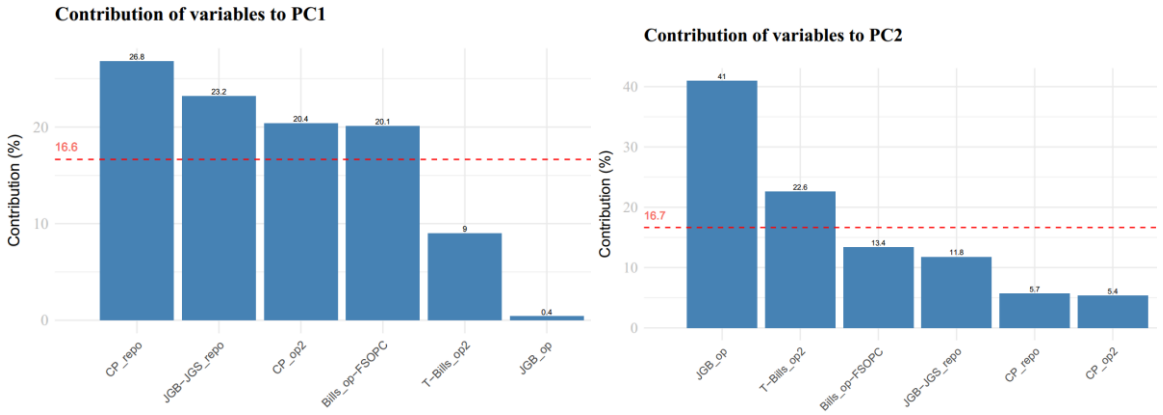
Figure 5 shows that PC1 accounts for 48% of the variation, and it consists of commercial paper (CP) and Japanese government bonds repos (CP_repo and JGB-JGS_repo) and traditional Funds Supplying Operations against Pooled Collaterals (FSOPC), which can be characterized as liquidity supply at the short-end of the interbank markets to keep the BOJ current accounts at the target level and thus to keep the policy rate effectively at zero. The BOJ current accounts are the policy target of quantitative easing at that time. PC2, explaining 30% of the variation, is dominated by Japanese government bond (JGB) and T-bill purchases, which can be considered to be a precursor to the quantitative easing policy of various asset purchase programmes in the later periods.

Figure 5: Baseline Case (Variable Set 3 and Monetary Policy Meeting Intervals)

(1) Eigenvalues and Percentage of Variance Explained (comp = Principal Component)

	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	2.87	47.83	47.83
comp 2	1.80	30.04	77.87

(2) Contribution and composition of Principal Components



Source: Authors' calculation based on *R*.

Figure 6: Robustness Check (Variable Set 3 and monthly data)

(1) Eigenvalues and Percentage of Variance Explained (comp = Principal Component)

	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	3.25	65.06	65.06

(2) Contribution and composition of Principal Components

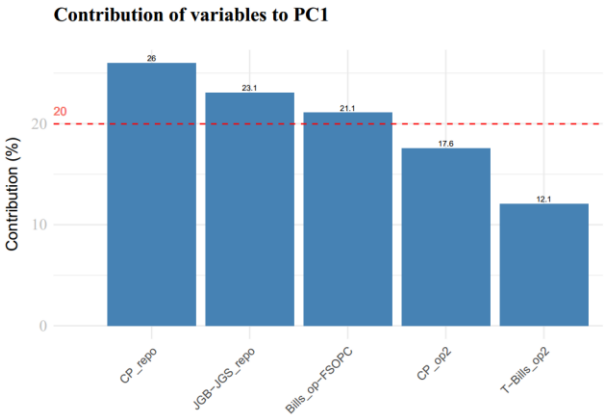
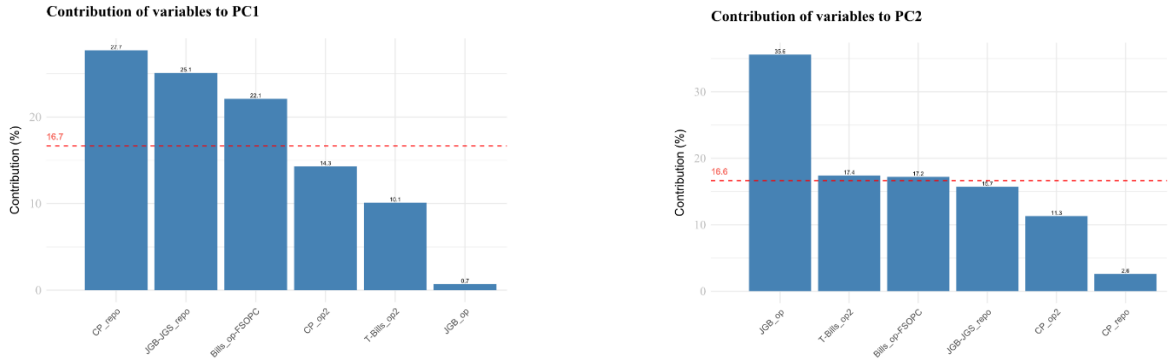


Figure 7: Robustness Check (Variable Set 3 and weekly data)

(1) Eigenvalues and Percentage of Variance Explained (comp = Principal Component)

	Eigenvalue	Percentage of Variance	Cumulative Percentage
comp 1	2.33	38.84	38.84
comp 2	1.27	21.11	59.95

(2) Contribution and composition of Principal Components



Source: Authors' calculation based on *R*

The robustness check of Figures 6 and 7 reveals an interesting twist concerning JGB purchases. The number of observations is 61 for monthly data and 262 for weekly data (see Table 4). When we use the monthly time frame instead of the baseline case of monetary policy meeting intervals, PC2 disappears (Figure 6). JGB purchases are the most important factor in the baseline case. However, in monthly data there is no variance in JGB purchases. This might reflect the fact that the Bank announced its intention of buying a fixed amount of JGB each month, and the amount did not change under the Fukui governorship. The JGB purchase is explained as a steady source of 'growth money' to make market operations as smooth as possible. In addition, there is a so-called bank note rule which limits the amount of JGB purchases to avoid possible criticism of money financing of government debts. However, if we switch to the weekly framework (Figure 7), PC2 resurfaces again, and JGB purchases are the most important component.

Thus, there are two points we should keep in mind about the Fukui period. First, even though 'monthly JGB purchases' remain constant, the within-the-month allocation of purchases is not. Intentionally or unintentionally, the Bank can influence the market significantly by 'fine tuning' JGB purchases. Second, by making the monthly purchase amount fixed, the burden of implementing quantitative easing is solely born by the PC1, the short-term liquidity supply. It is increasingly clear that in order to achieve the quantitative easing target, the short-run liquidity supply is obliged to be supplemented by longer-term liquidity supply.

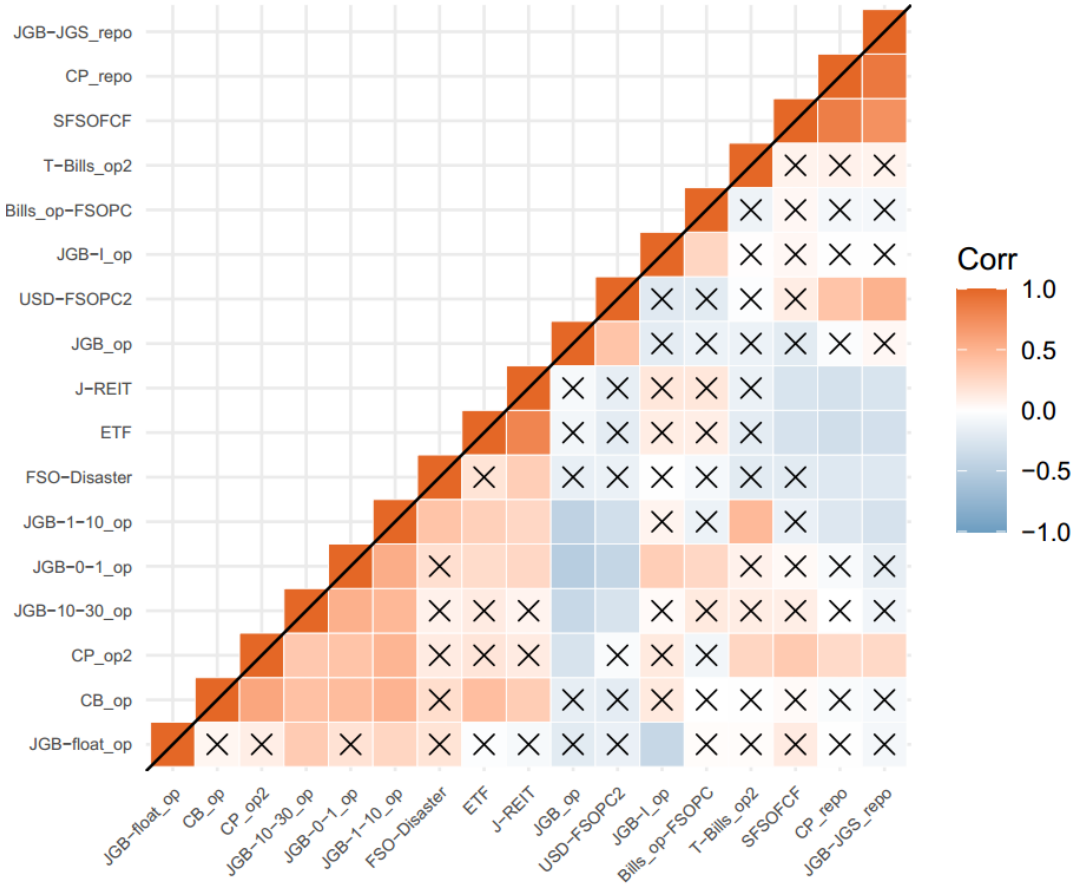
However, this is a narrowly focused explanation. Looking more broadly, the PCA of the Fukui era remains consistent with the results of the whole period: PC2 of the Fukui era corresponds to PC1 of the whole data set (Section 4), and thus the Fukui era is a harbinger of events to come. PC1 of the

Fukui era corresponds to PC3 of the whole period in regard to liquidity supply to short-term money markets.

5.2. The Shirakawa Period 2008-2013

Let us now turn to the Shirakawa period. Unconventional policy measures are expanded significantly in the Shirakawa period: from seven to seventeen in the mainline case. The complexity is increased considerably. Figure 8 shows the correlation table of the baseline case of Variable Set 3, consisting of seventeen variables. This figure shows a very high correlation between ETF and J-REIT purchases, and among SFSOFCF (Special Funds-Supplying Operations to Facilitate Corporate Financing), CP repo, and JGB-JGS (Japanese government securities) repo. ETF and J-REIT purchases and SFSOFCF are introduced as emergency measures to cope with severe problems in the stock and other capital markets (in the case of the former) and in corporate finance (in the case of the latter) of the time. Otherwise, correlation among variables is low and insignificant in many cases.

Figure 8: Correlation Table:
Baseline Case of Variable Set 3 (17 variables) for the Shirakawa period (2008-2013)

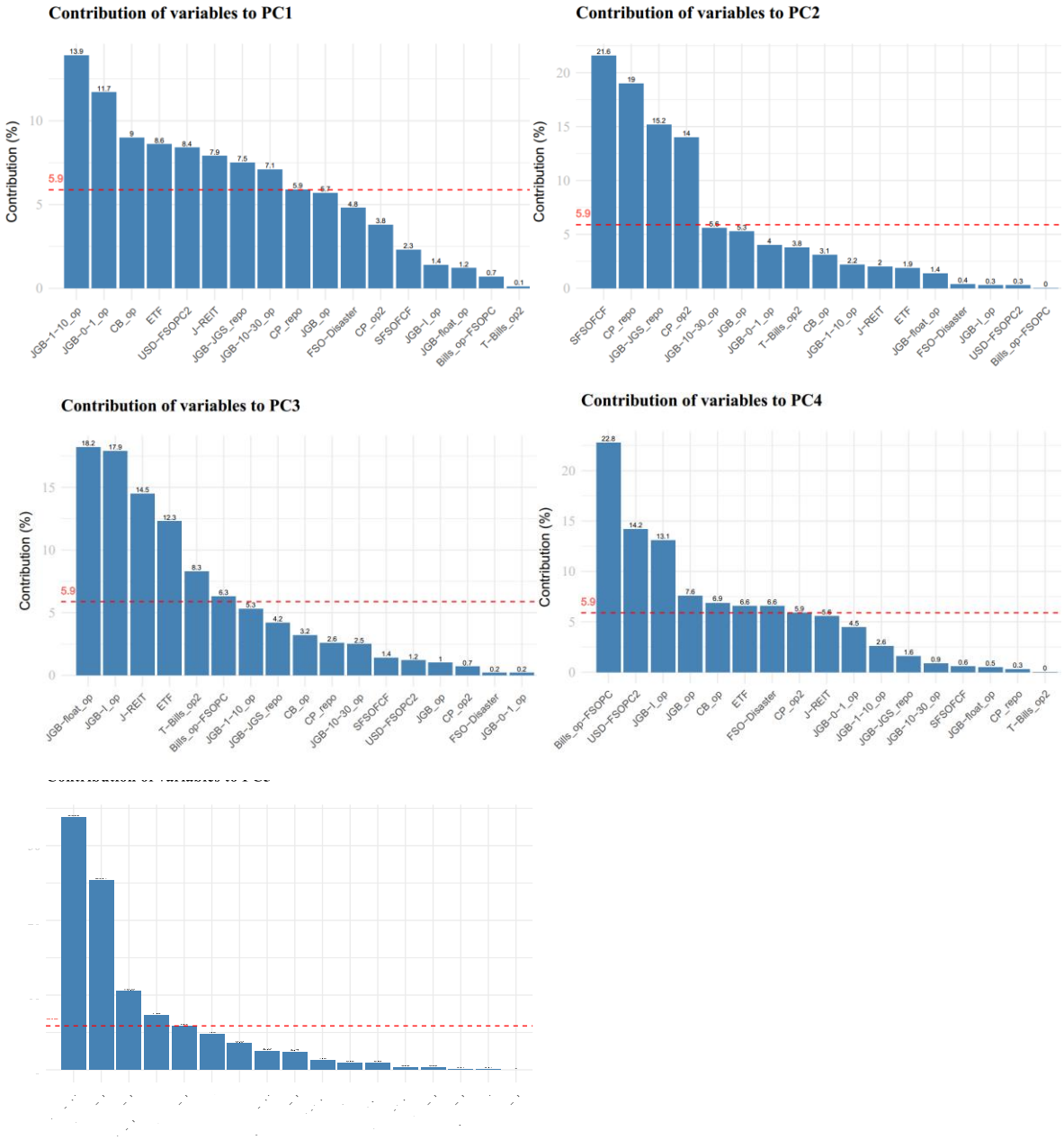


Note: [X] shows that the correlation is not significant at the 5% level.
Source: Authors' calculation based on *R*.

Figure 9: Baseline Case (Variable Set 3 and Monetary Policy Meeting Intervals)
(1) Eigenvalues and Percentage of Variance Explained (comp = Principal Component)

	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	4.25	25.03	25.03
comp 2	3.11	18.32	43.34
comp 3	1.78	10.45	53.8
comp 4	1.59	9.37	63.16
comp 5	1.34	7.85	71.02

(2) Contribution and composition of Principal Components



Source: Authors' calculation based on R.

Figure 9 shows the baseline case for 17 variables in Variable Set 3 and for the time frame of monetary policy meeting intervals for the Shirakawa period. The number of observations is 70 in the Shirakawa period (2008-2013) (see Table 4). Compared with the baseline case in the whole period (Figure 2), the percentage of variance explained by the first principal component is significantly smaller. Instead, the second, third, and fourth principal components' percentage in the Shirakawa period is greater than that of the whole period. In addition, we have a fifth principal component in the Shirakawa period, which is absent in the whole period. Thus, the first principal component is not as dominant, and the number of principal components explaining the variance is increased, suggesting more complexity in comparison to the whole period.

Moreover, interpretation of each principal component is not as clear as in the whole period. As in the whole period, PC1 in the Shirakawa period can be interpreted as the (broadly defined) quantitative easing policy since it includes JGB (1-10y, 10-30y) purchases, ETF, J-REIT, and CB outright purchases. However, it also includes short-term JGB (0-1y) purchases, which is the major component of PC3 (whole period). Thus, the quantitative easing policy looks to be still in the making, mingled with short-term liquidity supply measures terms in the market. This 'still in the making' nature can also be reflected in its smaller percentage of variations as the first component.

An interesting point is found in PC3, which is not liquidity supply, but direct interventions into stock and related markets (purchases of ETF and JREIT), alongside outright purchases of JGB-float and JGB-indexed.[32] Thus, in the Shirakawa period there is a distinction between a quantitative easing policy of asset purchases, and specific involvement and intervention of stock and related markets to directly influence resource allocations of private enterprises. Later we will see this distinction disappears in the Kuroda period, and ETF and J-REIT purchases are firmly incorporated into 'normal unconventional monetary policy'. This seems another indication that quantitative easing policy is still in the making in the Shirakawa period.

In contrast, PC2 is characterized by emergency liquidity. It is dominated by Special Funds-Supplying Operations to Facilitate Corporate Financing (SFSOFCF) and corresponds to PC2 (whole period). PC4 is characterized by Funds-Supplying Operations against Pooled Collaterals [FSOPC] (and their predecessor, bills outright purchases [Bills-op]). Finally, PC5 is dominated by T-bills and floating-rate JGB purchases. In fact, both PC4 and PC5 in the Shirakawa period correspond to PC4 (whole period). In addition, there is no counterpart of PC3 (whole period); that is, liquidity supply measures aimed at the short-term segment of the markets.

The 'still-in-the-making' nature of the '(broadly-defined) quantitative easing policy' of the Shirakawa period creates these complexities in the policy measures. Shirakawa made it clear from the beginning of his tenure that he was rather sceptical about the effectiveness of quantitative easing, especially regarding the purchasing of longer-term JGBs.[33] However, various crises hit the Japanese economy, including the Global Financial Crisis, the European Sovereign Bond Crisis,[34] and the triple

[32] Although the presence of JGB-Indexed and floating-rate bond purchases (JGB-I op and JGB-float op) is somewhat enigmatic, it can be ignored because it is not considered as important as other factors.
[33] See Shirakawa (2018).
[34] Since the financial markets are globally connected, the European Sovereign Crisis also affected the Japanese financial markets, especially foreign exchange markets.

disasters of the earthquake, tsunami and Fukushima Nuclear Power Plan Accident of 2011. These particular events (crises) trigger various unconventional measures.

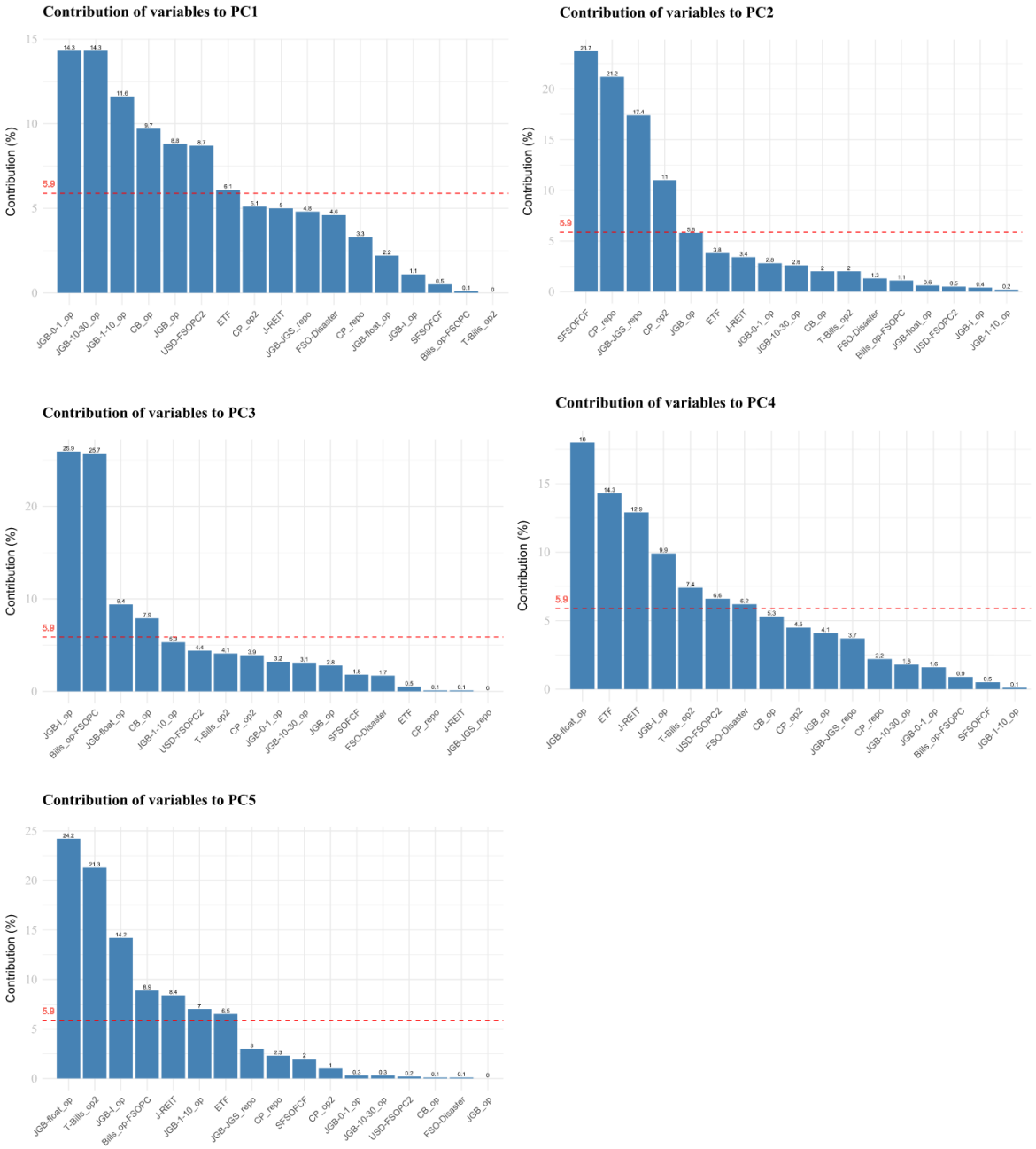
Robustness checks are presented in Figures 10 and 11. The number of observations is 60 for monthly data and 256 for weekly data (see Table 4). It can be observed that the change from monthly to weekly data increases complexity considerably: the number of principal components expands from five to seven. One possible explanation for the difference between monthly and weekly cases is that since new measures are introduced rather frequently in the Shirakawa period, and adjustments have to be made for their implementation, this causes volatility in weekly quantities. Thus, this is another manifestation of the 'still in the making' characteristics of unconventional policies in the Shirakawa period.

During this period, there are fourteen regularly scheduled monetary policy meetings per year (two in April and October, and one in other months); therefore, monetary policy meeting intervals roughly correspond with monthly data.[35] It is thus not surprising that in Figure 10, the time frame change from monetary policy meeting intervals to the monthly framework does not affect the number of principal components, which remain at five. Furthermore, the characteristics of major principal components (the first four components) do not change much except for their ordering between the mainline case of Figure 9 and the monthly frame case of Figure 10.

[35] The number of monetary policy meetings is reduced to eight from fourteen in the subsequent Kuroda period from 2016 on. The decision to hold eight monetary policy meetings per year – starting from 2016 – was decided under the *New Framework for Monetary Policy Meetings* June 19, 2015. https://www.boj.or.jp/en/mopo/mpmsche_minu/m_ref/index.htm/

Figure 10: Robustness Check (Variable Set 3 and monthly data)

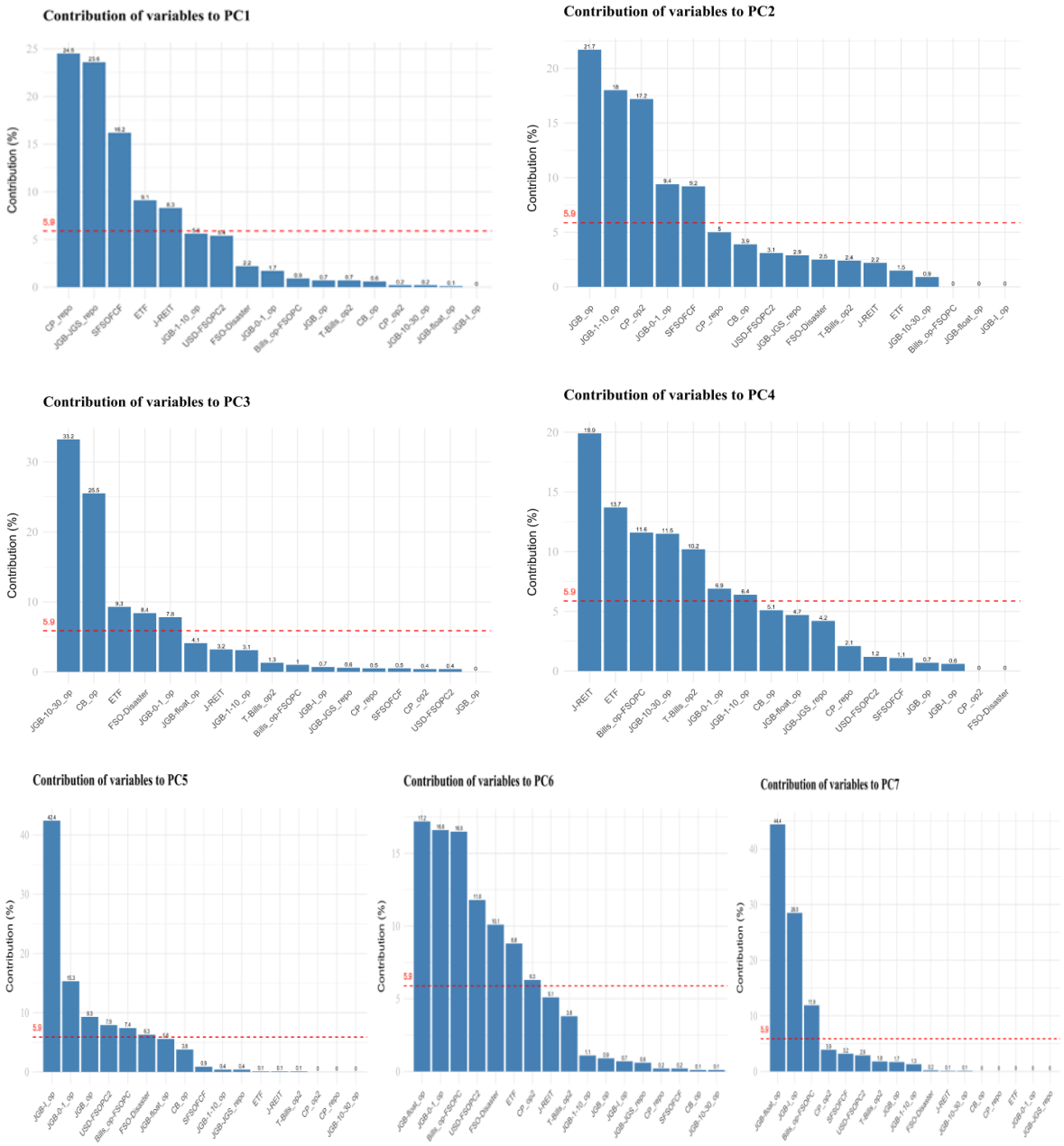
	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	5.13	30.2	30.2
comp 2	3.2	18.81	49.01
comp 3	1.99	11.72	60.73
comp 4	1.76	10.36	71.09
comp 5	1.38	8.11	79.21



Source: Authors' calculation based on *R*.

Figure 11: Robustness Check (Variable Set 3 and weekly data)

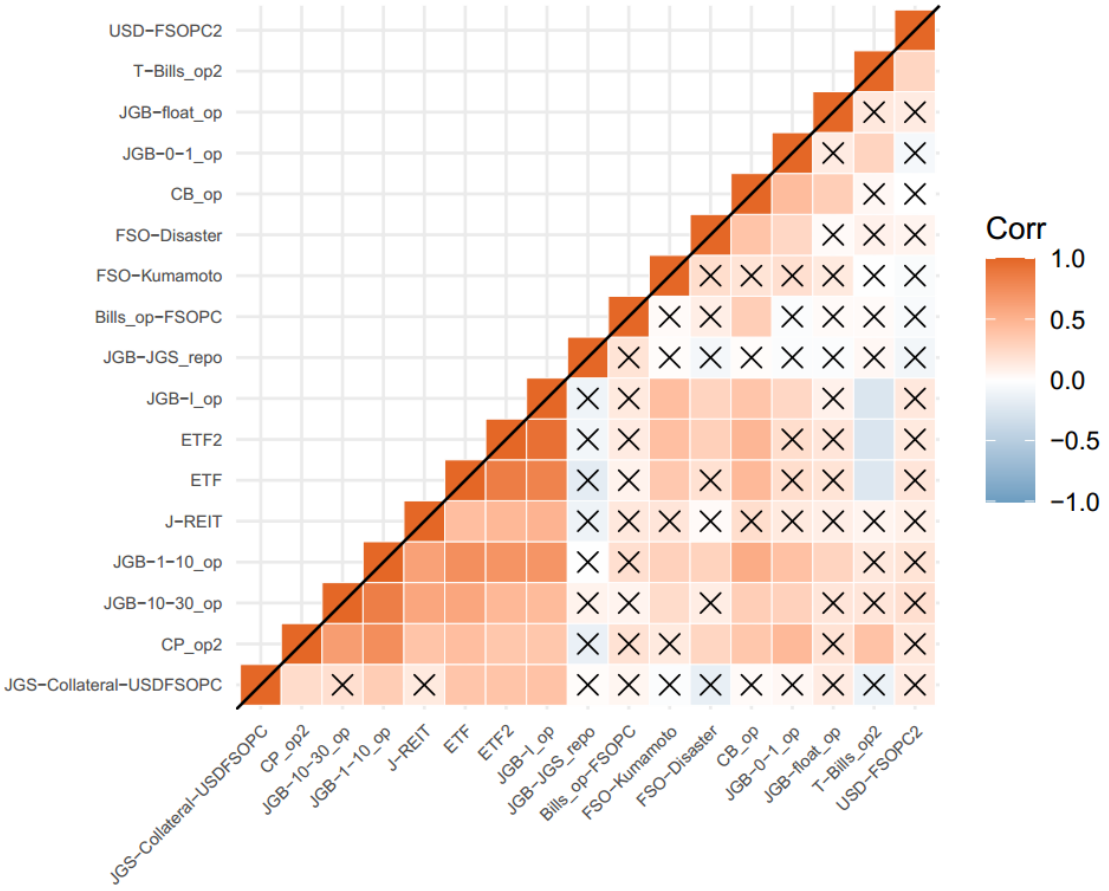
	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	3.00	17.67	17.67
comp 2	2.05	12.06	29.73
comp 3	1.67	9.84	39.57
comp 4	1.49	8.79	48.36
comp 5	1.26	7.42	55.78
comp 6	1.15	6.75	62.53
comp 7	1.08	6.36	68.88



5.3. The Kuroda Period 2013-2019

The number of observations is 71 in the Kuroda period (2013-2019) (see Table 4). It should be noted that in the Baseline Case (Variable Set 3), the number of variables in the Kuroda period is seventeen, exactly the same as in the Shirakawa period. Figure 12 shows the correlation table for the baseline case of 17 variables. Although Kuroda abolished some policy measures of the Shirakawa period, he retained many and added some other disaster relief measures, which makes the overall number of variables unchanged. However, we find higher correlation between certain variables in the Kuroda period than in the Shirakawa period.

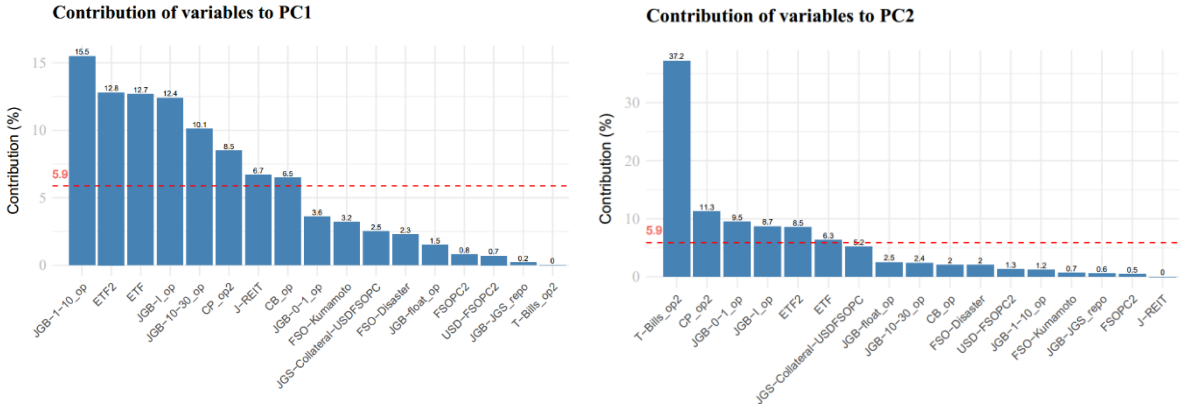
Figure 12: Correlation Table:
Baseline Case of Variable Set 3 for the Kuroda period (2013-2019)



Note: [X] shows that the correlation is not significant at the 5% level.
Source: Authors' calculation based on *R*.

Figure 13: Baseline Case (Variable Set 3 and Monetary Policy Meeting Intervals)

	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	5.7	33.5	33.5
comp 2	1.96	11.51	45.01



When comparing the baseline case of the Kuroda period in Figure 13 and that of the Shirakawa period in Figure 9, the most striking observation is that the complexity is substantially reduced in the Kuroda period from the Shirakawa period, even though the number of variables is the same. The number of principal components are reduced from four to two.

As expected, PC1, accounting for 34% of the variation, is characterized as (broadly defined) quantitative easing policy. In contrast to his predecessor Shirakawa, the Kuroda-led BOJ incorporated ETF and J-REIT into quantitative easing policy, as in the whole period case of Figure 2. PC2, on the other hand, accounting for 12% of the variation, is dominated by a single operation: T-bills. T-bills are very short-term liquidity measures. This corresponds to PC4 in the whole period case of Figure 2.

An important result is that Funds Supplying Operations against Pooled Collateral (FSOPC), which are very important for conventional monetary policy, are absent for relevant PC in the Kuroda era. This can be interpreted as monetary policy becoming increasingly quantitative in the Kuroda period.

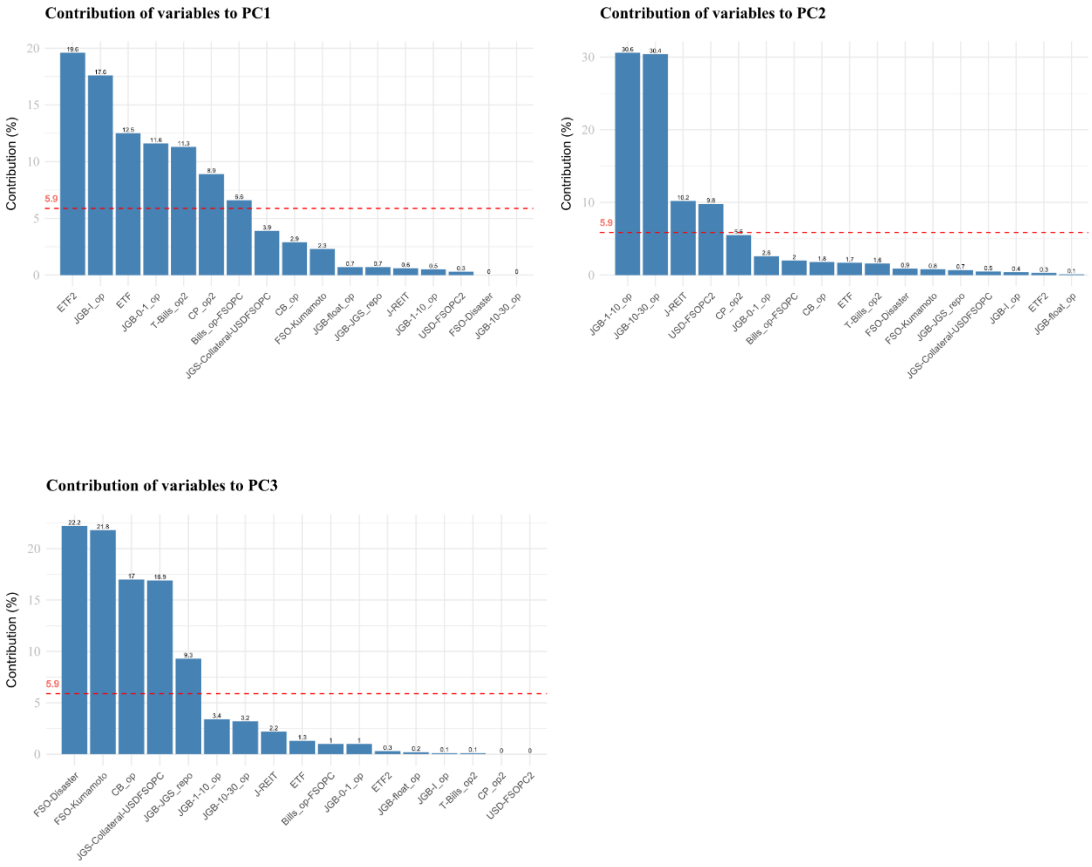
Robustness checks are reported in Figure 14 (monthly data) and Figure 15 (weekly data). The number of observations is 82 for monthly data and 353 for weekly data (see Table 4). The number of principal components (that is, complexity) is increased from two in the mainline case of monetary policy meeting intervals to three for the monthly data in Figure 15, while from three in the monthly data to four in the weekly data. However, they are substantially fewer than the corresponding number of principal components in the Shirakawa period. In addition, they are comparable to the number of principal components during the whole period (which is four). Therefore, the complexity does not increase in the Kuroda period, which is a major difference to the Shirakawa period.

The composition of the principal components changes between the baseline case and the monthly and weekly data. PC1 (quantitative easing policies) in the mainline case is now divided into two: PC1 dominated by ETF and ETF2, and PC2 dominated by JGB purchases (1-10y, 10-30y) and J-REIT. In addition, disaster relief measures (FSO-Disaster and FSO-Kumamoto) appear as PC3 in the monthly

framework and PC4 in the weekly one. Thus, qualitative results do not change significantly among different time frames. That is, the results are robust.

Figure 14: Robustness Check (Variable Set 3 and monthly data)

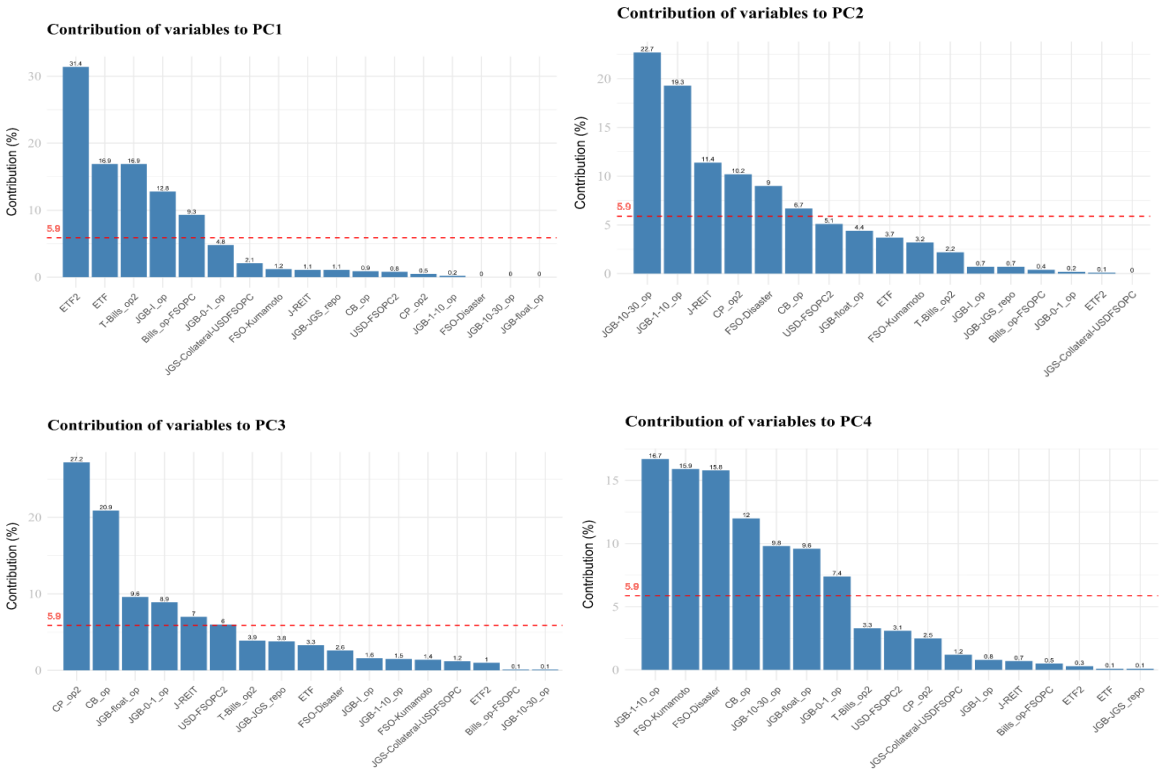
	Eigenvalue	Percentage of Variance	Cumulative Percentage
comp 1	4.28	25.16	25.16
comp 2	2.67	15.7	40.86
comp 3	1.56	9.18	50.04



Source: Authors' calculation based on *R*.

Figure 15: Robustness Check (Variable Set 3 and weekly data)

	Eigenvalue	Percentage of variance	Cumulative percentage
comp 1	2.20	12.94	12.94
comp 2	1.77	10.43	23.37
comp 3	1.63	9.6	32.98
comp 4	1.42	8.36	41.34



Source: Authors' calculation based on *R*.

5.4. Discussion: Communication with the Markets

The most striking results of the comparison between the three governors' periods are (1) the complexity of the Shirakawa period, which needs five principal components in the mainline case and seven in the weekly time frame, and (2) the simplicity of the Kuroda period, which needs only two in the mainline case and three and four in the monthly and weekly time frame, respectively, even though the number of variables (measures) in open market operations is the same – seventeen – as in the Shirakawa period. The number of principal components is the same as in the Fukui period, which is characterized by relatively simple monetary policy.

The Shirakawa period (2008-13) is plagued by various crises, including the Global Financial Crisis, the European Sovereign Bond Crisis, and the triple disasters of the earthquake, tsunami and Fukushima Nuclear Power Plan Accident of 2011. These crises require significant fine-tuning and innovation of monetary policy. The fine-tuning of open market operations is done by the BOJ's Financial Markets Department, which has certain leeway in conducting open market operations. Our results showing extreme complexity at weekly levels may suggest attempts by the financial market department to conduct new policy under the mandate of the policy-making board, while at the same time trying to interfere with the markets' functioning as little as possible.

With respect to innovations of policy measures, Shirakawa and his policy board introduce many new open-market operations. Quantitative easing measures are a distinct example of new unconventional measures initiated during the Shirakawa governorship. New quantitative easing measures are first introduced on a rather small scale and then gradually expanded. If the strengthening of quantitative easing measures is implemented without significant changes in the Bank's statement of its assessment of economic conditions, financial markets might find it difficult to react properly. Moreover, gradual quantitative easing might be regarded as the central bank giving in to pressure from financial markets and politicians.

That is, the complexity brought by monetary policy innovations might pose serious problems for financial markets if new policy measures are misinterpreted or not well communicated. Markets ultimately assess central bank policy through what the central bank does rather than what it says. A dramatic increase in the complexity of monetary policy can create difficulties for markets to discern the objectives of the Bank's policies.

The Kuroda period is characterized by a relatively stable economic environment, although the level of economic activity is not as high as the BOJ was hoping to achieve. In fact, Kuroda inherits and keeps many of the innovations implemented during the Shirakawa period. This economic stability helps the BOJ streamline its policy to reduce complexity and thereby communicate its intentions in a straightforward manner to financial markets.[36]

[36] One exception is the introduction of negative interest rates in January 2016.

6. Concluding remarks

Applying a principal component analysis, we have examined the complexity of unconventional monetary policy through open market operations in Japan. Although existing literature points out that many macroeconomic variables (including some traditional monetary policy variables) are explained by a small number (one or two) of principal components, this is not the case with the Japanese unconventional policies through open market operations. In the whole period (2002-2019), we have found at least four components: one is quantitative easing policies and the other three are liquidity provisions to different segments of the financial markets.

The complexity, moreover, has been found to change from one governor to the next. In particular, the complexity increased substantially under the governorship of Shirakawa. Our findings suggest that crises, such as the Global Financial Crisis, and natural disasters, such as the earthquake, tsunami and Fukushima Nuclear Plant Accident, can greatly increase the complexity of monetary policy, as they require special disaster measures by the monetary authorities in order to guarantee sufficient liquidity in the markets locally and nationwide. In fact, we have found a stark difference between Shirakawa and Kuroda eras despite the number of their policy variables being almost equal. The analysis of this difference is the subject of future work,[37] though we have suggested that this might be the central bank's communication challenge when facing unexpected large shocks both globally and locally, and this difference in communication policies matters significantly for the effectiveness of monetary policy.

Finally, the research question can also be broadened to an international perspective. This paper's results are useful for future research on monetary policy and central bank communication. Future research should focus on comparisons with other central banks. In particular, the comparison of the BOJ's market operations with the European Central Bank's may produce interesting insights. The European Central Bank has expanded its operations substantially since the Global Financial Crisis and the subsequent sovereign crisis in Europe. With the famous 'whatever it takes' speech[38] on July 26, 2012, then-ECB Governor Mario Draghi showed the power of bold monetary policy measures in combination with a strong commitment via central bank communication.[39] [40]

Linking our results to the topic of central bank communication, especially with financial markets, should also bring new insights. Our data reveals what the Japanese central bank really did (via open market operations), and not what it said. Linking two datasets (deeds vs. words) might lead to a better understanding of central bank communication and its effectiveness. Finally, adding data from the current Covid-19 crisis, including the massive reaction from central banks to support governments and fiscal policy, to the analysis should bring additional insights to central banking, the complexity of monetary policy and central bank communication.

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[37] One possible line of research is to find the number of principal components of many real, market and financial variables and compare the number of principal components of market operations for each period. This is the subject of future research.

[38] The verbatim speech can be found at https://www.ecb.europa.eu/press/key/date/2012/html/sp120726.en.html

[39] For a recent assessment of major central bank interventions and Draghi's speech, see Alcaraz et al. (2019).

[40] It should be noted that BOJ Governor Kuroda tried to echo Draghi's 'whatever it takes' speech in April 2020.

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