IMPACT OF QUANTITATIVE TIGHTENING ON INFLATION IN THE US

A Thesis

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Abstract

The aim of this thesis is to examine the effects of quantitative tightening (QT) on inflation. Literature analysis has shown that it is challenging to estimate the potential impact of QT due to varying factors in the historical data and changing market conditions. VAR methodology employs the data from the United States over the period from 2000 to 2022. In addition, econometric analysis is complemented with a qualitative system dynamics model to provide visual representation of the underlying causal relationships between contractionary monetary policy and inflation. Findings of VAR indicate that QT reduces inflation through asset price and portfolio balancing channels in the short-term. The causal loop diagrams provide additional insights into the complex interdependencies of monetary policy transmission mechanism. (19476 words)

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Introduction

During the last few years, the global economy has experienced a number of shocks such as the unprecedented COVID-19 pandemic, the ongoing war in Ukraine, and the slowdown in China. These events combined have caused an increase in inflation levels that were not seen in several decades, and in 2022, it has reached the highest point since 1982. Therefore, to combat continuous and widening inflation pressures, tightening of the financial conditions is evident in most regions. An increasing number of countries are experiencing a slowdown in growth or even straightforward contraction. Thus, the successful alignment of the monetary policy regime is a fundamental factor for the future health of the global economy (IMF, 2022).

The graph in Figure 1, depicts the development in the personal consumption expenditure index and unemployment rate in the United States from 2007 to 2023. Varying market conditions have been experienced during the last 15 years. In order to ensure the price stability and maximum employment – Federal Reserve's (FED) dual mandate – the central bank has to constantly adjust its monetary policy stance. Unemployment has experienced a sudden shock when pandemic restrictions were introduced. That, accompanied by various other factors, has led to the vast monetary accommodation cycle. Since then, unemployment rate has come back to the pre-crisis level. Inflation has been rather steady without exceeding the 2% threshold for a prolonged period of time since the Global financial crisis (GFC). Although, the clear shift is visible since 2021, when inflation has started to increase.

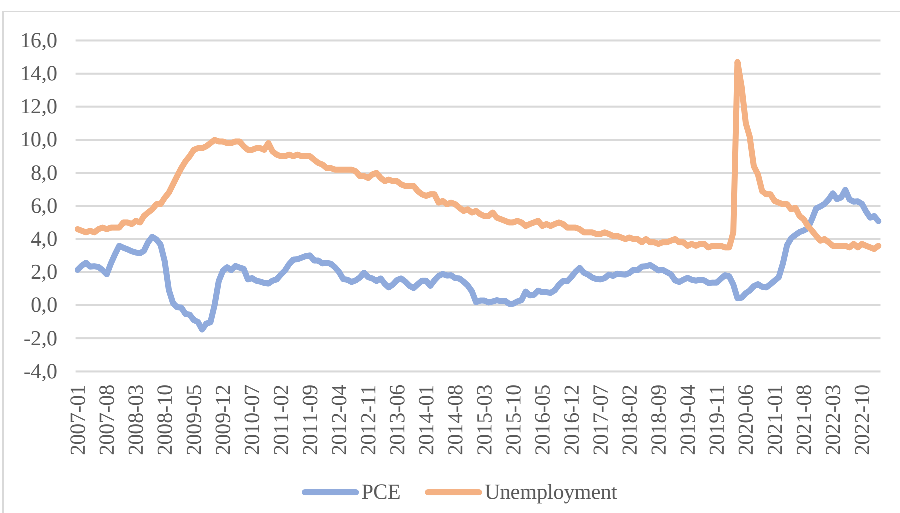


Figure 1. Developments of PCE and unemployment in the US

To lower the inflation back to its target, the FED has been rapidly raising its nominal policy rate since the beginning of 2022, and has communicated that further hikes are likely (IMF, 2022). Moreover, in January 2022, the United States Federal Open Market Committee (FOMC) has announced that, in order to promote maximum employment and price stability goals, it has planned to significantly decrease its purchases of securities (Board of Governors of the FED, 2022a). Additionally, the actual reductions of security holdings have taken place from June 1st, 2022. Initially, the monthly reduction for US Treasury securities was capped at $30 billion, and after three months the cap was raised to $60 billion per month. Regarding agency debt and mortgage-backed securities (MBS), the cap for the first three months was set at $17.5 billion and was expanded to $35 billion per month afterwards (Board of Governors of the FED, 2022b).

QT is a relatively new monetary policy tool that, before its comeback in 2022, had been introduced only once in the period between October 2017 and July 2019 in the US. Therefore, the possible outcomes of such a policy regime are less well understood as there is a lack of experience and a scarcity of empirical research related to this topic.

For the reasons mentioned above, the research question that is attempted to answer in this thesis is: what is the impact of quantitative tightening on inflation in the US?

The thesis employs a dual methodology approach and consists of econometrics analysis as well as qualitative system dynamics modeling. In the majority of academic research that was reviewed, for econometrics testing Vector Autoregressive (VAR) model was employed. Therefore, to test impulse responses related to the changes in the central bank’s holdings of securities VAR methodology is applied. Since there is very little experience with the QT and the time frame during which this method was approached is very short, the main assumption of this research related to empirical analysis is that QT works as a quantitative easing (QE) in reverse. The dataset consists of the main macroeconomic indicators of the US as well as monetary policy indicators such as FED funds rate, purchases of MBS and US Treasury securities. The time frame for the econometrics testing spans from 2000 to 2022. Gretl software is used to conduct econometrics modeling.

Qualitative system dynamics model is constructed using the Stella Architect modeling tool. It visualizes how contractionary monetary policy could affect inflation. System dynamics methodology allows to capture intrinsic details of how the change is transmitted through the monetary system more precisely. Literature regarding the system dynamics approach and its advantages related to macro and monetary economics and policy will be covered in the methodology section.

The following work adds to the scarce empirical literature that is the analysis of quantitative tightening and its impact. It could serve as a tool to provide relevant insights into the subjects of unconventional monetary policy such as QT as well as insights about the interaction between inflation and changes in the size and composition of the central bank's balance sheet. Moreover, the relevance of this type of empirical research becomes even more important as the number of countries that follow the route of QT might increase even further. Having knowledge of the potential impact on inflation – one of the major issues that disrupts the worldwide economy since the beginning of 2022 – would allow policymakers to steer the monetary policy strategy in the right direction.

Literature review

First of all, to understand the need for the implementation of QT and how this type of monetary tightening could be beneficial in fighting heightened inflation, it is essential to analyze the mechanism and the effects of QE, which was introduced to combat the ongoing crisis by providing additional liquidity and encouraging aggregate demand. The following part will cover the main principles of QE, followed by its transmission channels and influence on the economy. It will lay the foundation for the introduction of QT, its working mechanism, the effect on the financial system as well as the impact on inflation.

Quantitative easing

Basic principles and transmission channels

The outset of the GFC has led to the situation in the financial markets where interest rates have hit zero lower bound and where conventional monetary policy was not a sufficient tool to lower policy rates and stimulate aggregate demand. Therefore, to ensure both financial and price stability as well as economic growth, central banks had to employ unconventional monetary policies. One of the most prominent and widely used was quantitative easing. QE is considered as an unconventional monetary policy where the money supply is increased by employing open-market operations. Since the GFC, the central banks of leading economies – the United States, United Kingdom, Japan, and the Euro area –have expanded their balance sheets by undergoing large-scale asset purchase programs in order to improve distressed market conditions (Gern et al., 2015). The assets that were usually bought are private and public sector securities, although the major share of purchases are of long-term government bonds (Cui & Sterk, 2018). The purpose was to directly affect longer-term market rates when short-term money market rates were near zero and could not be lowered further.

The asset purchase programs were started more than a decade ago. However, according to, at the time Chairman of the FED, Bernanke (2014) “the problem with QE is it works in practice, but it doesn’t work in theory” (p. 14). A similar view was expressed by Cei and Sterk (2018) since it is argued that the use of QE is not fully understood as there is no certainty when or how to use it, as well as questions being raised of how aggressively, and when to slow it down. Moreover, according to D’Amico and Seida (2020), QE is mainly used only in periods of distress because it is not considered as a part of regular monetary policy. To understand the benefits of QE, it is important to analyze what was the impact on the economy and the transmission channels through which the effect could be felt by the general public. As stated by Stefanski (2021) there are four main transmission channels – price, portfolio rebalancing, signaling, and bank lending channels.

First of all, the price channel. When asset purchase programs are employed the demand for the securities that are being bought increases. Also, the increase in demand is accompanied by the shrinking market supply. Hence, there are changes in both the demand and supply sides of the purchased assets, thus their price increases (Stefanski, 2021). Second, the portfolio rebalancing channel is related to the yield decreases of the acquired security. Also, it is closely linked to the price channel mentioned above due to the inverse relationship between a bond's price and yield. Gern et al. (2015) argue that "the relative supply of short-term and long-term bonds affects the yield curve" (p. 208). Consequently, central banks' purchases of long-term bonds lower the term premium of such bonds. The expected returns of similar assets are also affected via arbitrage processes. Therefore, the decrease in returns may encourage investors to substitute to riskier assets with higher yields. Rather than purchasing government bonds, central banks can acquire private sector assets such as corporate bonds, mortgage-backed securities or asset-backed securities. The latter assets could be considered as imperfect substitutes for government bonds. All in all, an investment in private sector securities directly lowers market risk premiums.

Asset purchases by the central banks can act as a signaling channel. It can be considered as a form of forward guidance communication strategy. Central banks have used this strategy to shape the expectations about future short-term policy rates. The central banks achieve that by announcing their commitment to keep interest rates at the zero lower bound, and thus to uphold loose monetary policy for a prolonged period of time. In this context, an earlier withdrawal from the QE strategy would result in losses for the central bank as their credibility would suffer. On the contrary, extensive asset purchase programs could also be understood as a signal of a deteriorating economic situation and that the expansionary monetary policy will be employed for an extended period of time (Gern et al., 2015).

Lastly, the bank lending channel. The expansion of the central bank's reserves and the increase in prices of purchased assets raise the bank's liquidity and net worth. Thus, it allows them to issue more loans to the real economy (Stefanski, 2021). According to Grab and Zokowski (2017), traditional bank lending channel works slightly differently compared to bank lending channel when unconventional monetary policy is employed. The latter for the most part functions via an increase in money supply and the flattening of the yield curve. After the expansion of the bank's balance sheet, interest rates decline and the money supply increases. This positive shock, in turn, enables banks to raise the level of lending and thus leads to an increase in both consumption and investment.

Stefanski (2021) points out that the aforementioned are not the only channels. It is important to note that in times of market distress QE could increase market liquidity, and hence lower liquidity premium. Christensen and Gillan (2022) point out that the liquidity premium can be understood as "investors' required compensation for assuming the risk of having to liquidate a long position in the security prematurely at a potentially depressed price" (p. 7), and under unfavorable market conditions when capital constraints are present. The effect of the liquidity channel was one of the main arguments among numerous central banks to launch QE programs during the recent COVID-19 pandemic (Stefanski, 2021).

Also, these channels may have a confidence effect that improves economic outlook, diminishes financial market volatility, and lessens uncertainty. It could also encourage business confidence which leads to a strengthening in investment spending and contributes to a downturn in risk premiums (Gern et al., 2015).

Effect on the economy

Having an overview of the broad principles of QE, it is evident that monetary accommodation through asset purchase programs has a considerable effect on the economy. In general, Gern et al. (2015) argue that QE has an impact both on GDP and inflation. It was estimated that the introduction of the QE program combined with further announcements have increased GDP between 0.3% to 3%, and inflation between 0% and 1% in the US. Moreover, Reis (2016) indicated, that with a conventional monetary policy it was thought that the push for an increase in reserves would lead to lower short-term interest rates and higher inflation because the size of the central bank's balance sheet was tied to an overnight interest rate. Thus, the banks could not freely choose between the target rate and the volume of their balance sheet. However, as the balance sheet of a central bank significantly expands and reserves become greater than it was initially required, the balance sheet is not an appropriate measure to predict inflation anymore. Also, once the economy is saturated with reserves, following QE announcements do not have any or only a minor effect on inflation. It is only the news about the changes in policy rates on reserves that have an impact on inflation.

Quantitative tightening

Basic principles

The monetary base expansion is a relatively understood subject and has been widely studied. Although, the reverse contractionary policy of QT is less familiar. According to Honig et al. (2017), there is no credible experience from the past, therefore it is hard to understand what will likely effects of QT be on the economy.

After the decade has passed since the expansion of the monetary base begun, the FED and other central banks have started to undo QE when previously acquired bonds were left to mature without replacing them (Honig et al., 2017). Letting bonds to mature allows the central bank to reduce its balance sheet gradually and predictably over an extended period of time. Thus, it is expected that no significant disruptions will be caused in the market (Yellen, 2017). As Yellen (2017) has stated “it will be like watching paint dry” (p. 17). However, this strategy can be implemented only in normal market conditions because the pace at which the balance sheet shrinks is limited to the pace of asset redemption (Tanaka, 2022).

On the contrary, if the economy recovers faster than expected, the bank must react and absorb excess liquidity created by QE. Therefore, a strategy that reduces the pace of accommodation more rapidly is required. An alternative way how QT can be carried out is through active sales. The bonds held by the bank are sold before the maturity (Tanaka, 2022; Wei, 2022). However, the rapid sale of assets can cause major disruption for the bank itself. Tanaka (2022) indicates that this active strategy “imposes a large capital loss on the bank because interest rates rise and asset prices fall at and after the exit” and the loss is reported on the balance sheet once the assets are sold (p. 91). Also, a sale of this scale may as well cause turmoil in the respective markets. Therefore, completely committing to the active strategy might not be preferable (Tanaka, 2022).

Another possible solution to diminish excess liquidity is to use reverse repos or pay elevated interest on the excess reserves. This way, it is possible to significantly reduce liquidity without rapidly decreasing bank’s balance sheet. Despite the fact that this strategy does not cause capital loss or stir up related markets, it still requires to pay high interests that lower profit and may jeopardize bank’s solvency in case the burden of interest payments is too large (Tanaka, 2022).

Transmission channels

Similarly to QE, understanding the effects of QT and its transmission channels is essential. To be able to make insights into the effect of QT, it is necessary to analyze FED's experience with contractionary monetary policy during the period of 2014-2019. Despite the fact, that the FED was shrinking its reserve balances, the income received from the securities that were maturing was reinvested during the period of 2014-2017, thus the overall size of its balance sheet remained mostly unchanged. Then, every month the share of owned assets was allowed to come to the end of its maturity since 2017, and the reserves began to shrink together with the size of the balance sheet. In the following 2 years, the bank reserves have declined from about $2 trillion to about $1.4 trillion. In particular, it has contracted mainly in holdings of the assets such as US Treasury and MBS (Lee Smith & Valcarcel, 2022).

QT might push the short-term interest rates up through the liquidity effect. According to the study by Lee Smith and Valcarcel (2022), the liquidity effect might have had a more distinguished role during the times of QT compared to the times of QE. This can be associated with the way the FED manages short-term interest rates. Amid the period of accommodative monetary policy, zero lower bound has supported short-term interest rates from below while the reverse-repo facility deployed by FED acted the same in favor of the federal funds rate. Therefore, the amount by which short-term interest rates could decline was limited. On the contrary, there were no such measures that could prevent the upward push on short-term interest rates during the period of QT. Hence, the extent of the pass-through from reserves to interest rates is potentially larger when the QT period is considered (Lee Smith & Valcarcel, 2022).

The decline in asset holdings during the QT period is believed to also affect asset prices via similar channels as do asset purchases, which include signaling and duration channels. According to Bauer and Rudebusch (2014), the signaling channel is one of the most important factors that pushed down long-term interest rates after QE announcements. Market expectations of the upcoming policy rates have been altered as it was believed that an expansionary policy will be maintained for a longer period than it was expected. Therefore, the reverse effect could be present under the period of QT. The expectations of the future path of policy rate could be adjusted to an upward trajectory because it could suggest that the tighter monetary policy is approaching as well as drive long-term yields higher (Lee Smith & Valcarcel, 2022).

Moreover, as proposed by Gagnon et al. (2011) the reduction in yields following QE announcements was also derived from duration effects. During the periods of QE, by obtaining long-term assets, the FED has shortened the duration that the private sector had to endure. When assets are sold or allowed to mature, the duration of those assets is transferred back from FED's balance sheet onto investors', which might increase term and risk premiums. Furthermore, an increased supply of MBS and US Treasury securities in the public market could cause a reversal of some portfolio rebalancing effects (D'Amico & King, 2013). Hence, the tightening and transfer of duration back to the private investors could raise long-term interest rates through duration-linked portfolio balance effects (Lee Smith & Valcarcel, 2022).

However, D'Amico and King (2013) indicate that diminishing asset holdings might have smaller and more restricted effects compared to asset purchases. Implementing QT under improved market conditions might lead to the dilution of the portfolio balancing effect. Additionally, the effects that arise from the sale of past assets should be restricted only to those assets that FED has purchased. Moreover, the signaling effect is less pronounced in the period of QT compared to QE as well. Lee Smith and Valcarcel (2022) demonstrate that the FED's announcements of QE have led to substantial declines in long-term interest rates. Whereas, announcements of QT in which the FED disclosed the timeline and plans for slowing and eventually unwinding assets purchases have made no meaningful increases. The differences in these effects would suggest that QT is not entirely a reversal of QE as it transmits differently to the financial markets. Additionally, Riley (2022) presents a similar view to Lee Smith and Valcarcel (2022) as the author suggests that QT should have opposite effects compared to QE but not necessarily of the same degree.

Quantitative tightening and inflation

At first, the surge in price levels in 2022 was believed to be related to supply chain issues as well as pandemic-related problems and was understood as transitory by the major central banks such as FED and European central bank (ECB). However, the assumption turned out to be incorrect since the policymakers had to implement continuous adjustments in the key policy rates. The rapid increase of interest rates combined with the increasing QT measures was the answer to fight inflation which has shot up as a result of the stimulus that was injected into the global economy since Covid-19 has begun (Minerd, 2022).

Minerd (2022) suggests that inflation as well as economic output and asset prices are significantly influenced by the changes in the money supply. Similarly, interest rates substantially depend on the level of monetary liquidity and inflation expectations. Therefore, by changing the amount of money the central bank can affect short-term rates. The amount of money that is available in the market today is immense, thus the FED had to boost its reverse repo facility (RRP) operations to gather cash that would have caused short-term interest rates to fall below zero. The RRP is designed to provide a cushion for the short-term rate and federal funds rate, and it is one of the tools to achieve the inflation mandate. At the end of 2022, the FED’s RRP has hit its record intake of $2.5 trillion (Derby, 2022). This way the FED can establish a rate that is not set by the forces of the market. Hence, this makes the FED unable to recognize what the real demand for money would be if the policy rates would be free-floating. Also, it losses the ability to create a signaling mechanism to display the interest rate equilibrium. If inflation falls below the target, a free-floating short-term interest rate would signal that the monetary policy had become too tight, thus the FED would expand its balance sheet. Otherwise, if inflation rises above the target, it would show that the policy is too accommodative, and therefore the QT is necessary. Therefore, it is proposed that the FED should quit setting ranges for short-term interest rates and allow the market to regulate the rates while it monitors the level of inflation and adjusts its pace of asset purchases to control the money supply (Minerd, 2022).

The famous quote by Milton Friedman (as cited in Leeson and Palm, n.d.) states that “inflation is always and everywhere a monetary phenomenon”. In his work Adrogue (2022) proposes that, under the assumption that inflation is a monetary phenomenon, it is unnecessary to analyze supply and demand dynamics and rather more beneficial to put focus on the global money supply. The FED has started QT in 2022, therefore it is expected that the global money supply is going to significantly decrease in the upcoming periods. It is also anticipated that the effects of recent monetary accommodation will be reversed and that inflation should recede.

The first rounds of QE that occurred since 2008 did not have a meaningful impact on increasing the rate of inflation. However, the latest round of QE that happened in 2020 was more impactful. It was measured that the global money supply has risen by 10% in 2008, while it expanded by 15% in 2020. The difference between the first and the latest QE rounds was that in 2020 commercial banks were not in the middle of the crisis. Therefore, the expansion which took place in 2020 was more effective in increasing the money supply as the banks did not wipe out their reserves. Hence, it is expected that reversing QE will possibly result in a gradual decrease in inflation and economic growth (Adrogue, 2022). Adrogue (2022) predicts that under given assumptions, QT that the FED has started in 2022 will shrink the size of global reserves by 5%. Thus, inflation is expected to fall below 2% at the end of 2023.

Moreover, Riley (2022) proposes that the speed at which the FED wants to employ monetary tightening is much quicker compared to what it did in 2017-2019. It can shrink at a maximum pace of around $90 billion per month starting from July 2022. Hence, at this pace, the reserves would drop off by $775 billion. Given that the same pace is maintained throughout 2023 and 2024, the FED's balance sheet would reduce by around $2.6 trillion, from $8.8 trillion at its peak to $6.2 trillion at the end of 2024. It would result in the decrease from 36% to around 22% of GDP, which is still higher compared to a pre-pandemic level of around 18%, but lesser than a post-GFC level of 25% to GDP. A research paper published by the FED in July 2019 (as cited in Riley, 2022) estimated that "a 2% of GDP reduction in the Fed's balance sheet was equivalent to about 20bps increase in the Fed funds rate in terms of the impact on growth and inflation" (p. 5).

However, it is important to note, that there is a lack of academic literature that could measure the effects of QT. It is a very recent phenomenon and the effects are not well understood (Adrogue, 2022). A similar view is put forth by Riley (2022) as well as Lee Smith and Valcarcel (2022) as the latter argue that "there is scant empirical analysis of the broad financial market effects of unwinding the central bank's balance sheet" (p. 2) and that the knowledge of the effects of QT is essential for central banks to be able to make informed decisions regarding introduction and withdrawal of monetary policy accommodation.

System dynamics literature

Overview of system dynamics modeling

System dynamics is a modeling technique based on computer simulations. It enables the analysis of complex dynamic feedback systems in order to generate fundamental insights and facilitate policy design. One of the main building blocks of system dynamics is the feedback theory. It depicts how certain decisions and the principle methods of implementation induce the dynamic behavior of modeled systems. System dynamics can be used to investigate a wide variety of problems in a number of academic disciplines that include economics as well (Forrester et al., 1976). Modularity of system dynamics models and ability to incorporate multitude of factors like economics, production, environment and social behavior allow to extend the scope of studied interactions, and enhance the assessment of the impact of policy decisions (Kontogiannis, 2021).

Structurally system dynamics models consists of stocks, flows and feedback loops. Stocks accumulate over time and are quantities that the researcher is interested in studying, i.e. money in a circulation in an economic system. Flows are the rates of movement into or out of the stock over time, thus flows are considered as either inflows or outflows. For example, if a stock is a bank account, inflows can be described as income, while outflows reflect spending. Furthermore, feedback loops represent the mutual causation of the system over time. Also, the endogenous dynamic behavior of the model is solely determined by the feedback loops. Feedback loops are categorized to positive and negative loops. In general, positive loops amplify the change in the system and cause self-reinforcing behavior. Thus the latter can also be called reinforcing loops as the change in one part leads to further changes in the same direction in the other part of the system, and in turn, reinforce the initial change. Contrary, negative loops are the ones in which the change leads to a change in the other part of the system in the opposite direction, and then counteracts the initial change. This way it helps to maintain equilibrium in the system. Negative feedbacks loops depict self-regulating and goal-seeking processes that are in charge of stabilizing the system and preventing it from getting into a vicious cycle, thus are also called balancing loops (Wheat, 2017; Radzicki, 2020).

The findings of system dynamics modeling are focused on identifying set of policies that can improve the performance of the system and make it more resilient to unexpected shocks. The latter policies are usually based on feedback loops and do not require to accurately predict the points in the system (Forrester, 2013; Radzicki, 2020). Moreover, according to Forrester (1985) the real value of system dynamics comes not only from the final model itself, but from the iterative process of modeling. In other words, modeler should be learning how the system is working.

Another important tool of system dynamics are causal loop diagrams (CLDs). CLD is a qualitative model, that provides a visual representation of the dynamic interactions between the main balancing and reinforcing feedback loops that generate the behavior of the system. Simplification of the underlying system dynamics model is one of the main benefits of a CLD as the insights can be drawn from the model used as the basis for policy development and implementation (Lin et al., 2020; Kontogiannis, 2021).

Monetary policy in system dynamics

System dynamics approach has been used to study various relationships and policy implementation effects in macroeconomics. A research conducted by John (2012) is an example of how SD improves economic models of monetary policy, financial crises and macroprudential regulation. According to John, financial turmoil by itself is an intricate dynamic event, therefore the capabilities provided by the system dynamics tools should facilitate the understanding of the fundamental feedbacks. The study combines economic reasoning and SD approach by introducing financial behavior model that was developed by Stein (2012), and adopting it to create the fundamentals for a simple dynamic model. The main idea of the model presented by Stein was to capture the integral feedback effects of central banks and to portray that unregulated commercial banks tend to provide excessive amounts of short-term debt, thus this results in the heightened exposure of the economic system to financial crisis. The analysis has focused on a qualitative approach in order to demonstrate the benefits of adding the dynamics into the model (John, 2012).

A study completed by Tauheed and Wray (2006) has analyzed the effects of interest rate changes to aggregate demand using system dynamics methodology. The authors investigated the possibility that the effect of lowering the interest rates would lead to lower aggregate demand and vice versa, which is opposite to common beliefs. This was based on the idea that lower interest rates would result in a decrease in government interest payments, and thus lead to lower government deficit. Aggregate demand/GDP model was used to measure the effects of interest rates on debt service, investment, and GDP, as well as the combined effect of latter variables on aggregate demand in both static and dynamic modes. The authors claimed that under specific conditions aggregate demand could be boosted by raising interest rates, and that it is achieved through government's debt service payments on its unsettled liabilities. Additionally, it was shown that the pace of how changes in the interest rate transmit to government spending could be affected by the reset period of government debt (Tauheed & Wray, 2006).

System dynamics monetary policy feedback model was introduced by Neugebauer in 2011. The author builds a Taylor rule system dynamics model for the economy of Brazil, and examines endogenous feedback among interest rate changes, GDP growth and inflation variables during the period from 2004 to 2011. The results of the model present a strong endogenous feedback for inflation and monetary policy, whereas GDP growth is shown to be defined by the exogenous economic factors. Moreover, it indicated that the majority of monetary policy decisions during the research period were taken with regards to GDP growth rather than following inflation movements, despite inflation having higher coefficients in the Taylor rule. Also, it was argued that Taylor rule model emphasizes the advantages of system dynamics methodology with regard to stock and flow method and nonlinear policies (Naugebauer, 2011).

System dynamics and unconventional monetary policy

The effect of unconventional monetary policy has also been studied using system dynamics methodology. Research conducted by Jančiauskaitė in 2022 analyzed the impact of expansionary conventional and unconventional monetary policy on income inequality. Euro area economy during the period from 1999 to 2019 was studied. Her model shows how expansionary monetary policy has a positive impact in decreasing inequality gap in the short-run, while it has no observable effect in the long-run (Jančiauskaitė, 2022). A significant part of the model incorporates the fundamentals of unconventional monetary policy and its transmission channels. Hence the model presented by Jančiauskaitė (2022) is used as a reference model in this thesis for further research into the effects of unconventional monetary policy.

Methodology

This section provides the fundamentals of the empirical research related to unconventional monetary policy as well as an understanding of the research design that will be carried out in this paper. An overview of comparable empirical studies is presented. Additionally, this section outlines the main assumptions related to the differences between QE and QT that are necessary to undergo this study. Lastly, research hypotheses are listed and are followed by the description of the chosen variables.

Methodology of econometric analysis

The research question that this thesis aims to answer covers a particularly new subject, thus there is no significant amount of empirical research that was conducted in the past. Although, the main principles of the econometric analysis of QT are based on the research works that addressed questions related to QE policy. The main assumptions and limitations of econometric research are presented in the following sections. Moreover, to complement econometric analysis, system dynamics (SD) approach which has not been extensively employed in the field of unconventional monetary policy is used. It enables the visual representation and causal interpretation of the relationship between QT and inflation.

Overview of comparable studies

Fundamentally the concepts of QE and QT are quite similar, and are often referred to as being reverse of one another. There is a significant amount of empirical studies that focus on questions addressing various QE-related topics. However, QT-related research is highly limited as this is a very recent phenomenon. Therefore, analysis of previously conducted QE studies is presented in this section to understand the underlying principles of unconventional monetary policy research and to determine the most appropriate approach for the empirical part of this thesis.

Research on the macroeconomic effects of asset purchase programs was conducted by Weale and Wieladek in 2016. The authors have focused on the impact of QE on real GDP and consumer price index (CPI) both in the United Kingdom and the United States. Researchers have employed Bayesian Vector autoregression (VAR) to study both economies in the period from 2009 to 2014. For GDP and CPI variables, monthly GDP and seasonally adjusted monthly CPI measures were used respectively. To estimate the extent of QE, the variable was constructed by taking asset purchase announcements from Federal Reserve Board as well as Monetary Policy

Committee for US and UK, respectively. The effect of different transmission channels was captured by including particular variables that represent each channel. Portfolio rebalancing channel is the main transmission channel in this study and is represented by the yield on the 10-year government bonds as well 20 and 30 year bonds. For signaling channel variable, interest rate futures were used. In particular, Overnight Index Swap futures for 3-month and 6-month interest rates together with 1 and 2 years ahead. Moreover, investors' risk appetite and economic uncertainty were tested by taking the two volatility indices VIX and MOVE, for volatility of a stock market and bond market, respectively. The study has concluded that an economy affected by an asset purchase shock will experience a rise in real GDP and the CPI. It was estimated that the impact of asset purchases worth 1% of nominal GDP in both US and UK would lead to a rise of 0.62% and 0.25% in real GDP, respectively. While the CPI would increase by 0.58% and 0.32% accordingly. Moreover, authors have found that portfolio rebalancing channel has rather significant effect while signaling channel is less important (Weale & Wieladek, 2016).

Another study on the macroeconomic effects of QE in the US was conducted by Stefanski (2021). The analysis was based on quarterly data that ranges from 1966 to the end of 2019. Thus, the dataset includes the period of QT that took place from 2017 to 2019. The author uses VAR model and argues that it is a primary tool to analyze macroeconomic effects of QE. Moreover, this study adds to the literature that study effects of QE (Weale & Wieladek, 2016; Hesse et al. 2018) by using larger model which employs 15 variables. Also, due to dataset being that long and reaching beyond GFC, it allows to make a comparison between the effects of QE and conventional monetary policy. Variables are split into 4 groups – macroeconomic, monetary policy, transmission channel and control. Key macroeconomic variables are GDP, PCE deflator and unemployment. Furthermore, monetary policy variables include FED funds rate as well as US Treasury and MBS purchases, and Operation Twist. Inclusion of Treasury and MBS variables facilitates the comparison between the effects of purchases of various assets. Financial variables such as 10-year Treasury yield, S&P 500, bank credit and others were used to capture the impact of transmission channels. Lastly, import prices together with housing starts and primary surplus were included as a control. The research has found that QE had a strong influence on unemployment. Purchases of Treasury bonds during first round of QE were estimated to reduce unemployment by 0.7%. However, there were no statistically significant effects on GDP as well as no effect on inflation (Stefanski, 2021).

Research analyzing the role of monetary policy and other determinants of aggregate demand on inflation in Japan was conducted by Hayo and Ono in 2015. The research focuses on the period from March 2001 to March 2006 during which the Bank of Japan has employed QE. Impulse response analysis was employed to understand "the dynamic nature of the effects" (p. 3). Authors have used monthly data and VAR method to estimate the dynamics between demand, supply and monetary shocks. For the supply-side variable producer price index was used, while for the demand-side Industrial Production Index provided by the Ministry of Economy, Trade and Industry was employed. Monetary policy variable was constructed by taking total current accounts held at the Bank of Japan and subtracting reserve requirements. This has allowed to capture the effect of the excess reserves that is the one of the fundamental measures for QE. The study has shown that during the period of QE the shock on the demand-side had a significant effect on the price developments, while neither changes in excess reserves nor supply-side developments did not result in having significant effect on inflation in Japan (Hayo & Ono, 2015).

A similar study on the macroeconomic effects of quantitative easing was implemented by Koeda in 2019. The research uses structural VAR model and Japanese financial as well as macroeconomic data from 1995 to 2016 to estimate the effect of Bank of Japan's quantitative and qualitative easing. Similar to Stefanski (2021), there are 3 distinct groups of variables that are present in the model – macroeconomic, monetary policy and financial. First, consistent with previously investigated studies, monthly inflation and output gap are used as macroeconomic variables. Furthermore, policy rate and excess reserve rate are employed to capture the changes in the monetary policy regime. Lastly, financial variables such as 10-year term spread, changes in stock prices, change in yen/dollar exchange rate, and changes in bank loans are introduced to analyze possible effects of monetary policy transmission channels. The findings of this study conclude that Bank of Japan's QE policy has increased output. However, analysis of the financial variables has shown that there is no "strong monetary policy transmission to macroeconomic variables" (p. 122) through respective transmission channels (Koeda, 2019).

The scope of the empirical analysis

Time period and scope. Empirical part of thesis focuses only on the data from the United States. US was chosen as a primary subject of thesis because it has one of the longest histories of employing unconventional monetary policy tools. The FOMC decided to employ QE in 2008 in the US to achieve its dual mandate targets after the FED funds rate has reached its zero lower bound as a result of an ongoing GFC. There were several stages of QE programs that were mainly built on large-scale asset purchases that consisted of long-term Treasury bonds and MBS. During the period from 2008 to 2014, FED's holdings of the latter securities have risen from about $500 billion to around $4 trillion (Engen et al., 2015). Furthermore, after the QE cycle has ended, the FED has raised its policy rate from the lower bound, and has implemented QT from 2017 to 2019. Similar to other countries like UK and Euro area, large scale asset purchase programs were reintroduced with the outbreak of a recent Covid-19 pandemic in 2020 (Stefanski, 2021). Even though the period is relatively short, but US is the only country that has carried out unconventional contractionary policy before the recent QT announcements in 2022 and 2023. Moreover, since the mid-2022s the FOMC has started to reduce the holdings of securities on its balance sheet. The planned monthly reduction for Treasury securities is capped at $60 billion, while the cap for MBS is $35 billion (Board of Governors of the FED, 2022b). Only a year later, the president of ECB has announced the plans to reduce Eurosystem's monetary policy security holdings starting from March 2023 (Lagarde, 2022). The data for this period is not available yet, therefore the inclusion of other countries and regions is not considered. Additionally, there is a fundamental difference in the construction of the unconventional monetary policy programs, i.e. QE in US has consisted of only 2 assets (Treasury bonds and MBS), while in the euro area or Japan it was at least 4 (Stefanski, 2021).

The research aims to analyze and estimate the effect of the contractionary monetary policy measures taken by the FED, specifically QT. Econometric analysis of the latter concept is particularly challenging subject because, as was mentioned previously, the data span during which QT was adopted is limited. Therefore, econometrics modeling is focused on the data ranging from 2000 to 2022 that covers different monetary policy regimes. The chosen timespan covers both expansionary and contractionary cycle, therefore conclusions about the effect of QT can be made. In particular, the period could be separated in 5 distinct time frames that have underlying differences. First, the cycle from 2000Q1 to 2008Q3, which covers conventional monetary policy period and involves both contractionary cycle that occurred during the Dotcom crisis as well the period of growth that lasted up until the onset of GFC (Farrell et al., 2005). Furthermore, GFC and the recovery that lasted from 2008Q4 to 2017Q2. These times have seen the introduction of unconventional monetary policy and have experienced the period of sharp decline and slow recovery (Antoshin et al., 2017). Next, is the tightening cycle that was present from 2017Q3 up until 2019Q4. This was followed by the vast expansionary period of QE due to the recent pandemic that lasted from 2020Q1 to 2022Q1. Lastly, the analyzed timespan also covers the comeback of QT that was announced in 2022Q1 and begun in the second quarter of 2022 (Riley, 2022).

Econometric analysis is separated into three parts. First, the baseline model is constructed using full period data to capture intrinsic effects of unconventional monetary policy. Furthermore, full period model is adjusted to analyze possible transmission channels. The third part examines the period from 2009 to 2022 when mainly unconventional monetary policy measures were taken, that include QT as well, to achieve FED's dual mandate. The study uses quarterly data that is separated into 3 types – macroeconomic, monetary policy and transmission channel variables.

Main assumption for econometrics testing. The econometric estimation of QT is based on the main assumption that the effect of such contractionary policy is, with several exceptions, the reverse of the effect that QE brings to the economy. In simplified terms, the effects of QT can be measured by flipping the sign of the likely impact of QE (Clemens et al., 2017). The study conducted by Clemens et al. (2017) aimed to estimate the potential effects of QT for Euro area while studying three different scenarios using Dynamic Stochastic General Equilibrium model. The authors have distinguished three types of QT that are: reduction of expansionary pace by diminishing net purchases of securities; reduction of the amount of long-term debt held by the ECB; and a faster exit which is selling securities before maturity. The research has shown that the reduction of the expansionary pace has resulted in an annualized impact on inflation and real GDP growth of only 0.005% lower compared to the baseline scenario, thus it has only moderate negative impact. Furthermore, it was found that if the central bank acquires less long-term bonds compared to the amount that matures and this way reduces the amount of held securities, then both GDP growth and inflation decrease at the initialization of the program. It was estimated that the GDP growth would fall by 0.2% in the initial year, while inflation would decrease by 0.3%. Looking from the qualitative perspective these effects can be viewed as the reverse compared to the ones caused by asset purchase programs. Also, it is important to note that the negative impact on inflation was present throughout the whole simulation period. Lastly, the third scenario focuses on how quickly the balance sheet shrinks and what effect it has for the economy. Similar to previously discussed scenarios, it was concluded that output growth and inflation would contract in this case as well. However, the reduction in macroeconomic indicators is less evident compared to the second scenario in which the central bank reduces the amount of securities held at a slower pace. Quantitatively, the effect on GDP growth was estimated to be -0.08% on an annual basis at the start of the program. Regarding the impact on inflation, it was assessed to be negative as well, although less pronounced (Clemens et al., 2017).

A similar view was expressed by Wieladek (2022) in his analysis on the impact of QT. Wieladek argues QT affects an economy in fewer aspects and therefore is a more limited monetary policy tool compared to QE. The author claims that the effects of QT only transmit through portfolio rebalancing, exchange rate, and bank lending channels, while QE additionally influences markets through signaling, market stabilization, and reduction of uncertainty channels. The study analyzes the effects of QT by examining pre-pandemic differences in QE multipliers. This allows to measure the effects of three QT channels separately. The results show that the QT multiplier is approximately 70% smaller in contrast to QE. The author explains the findings by analyzing FED’s QT plan in which the regulator intends to shrink central bank’s balance sheet by $900 billion per year. It is estimated that such reduction would result in a downturn of about 0.6% in GDP, 0.36% in CPI as well as a 0.3% increase in the 10-year US Treasury yield. Similar results are presented for both UK’s and ECB’s potential QT policies (Wieladek, 2022).

Isabel Schnabel, Member of the Executive Board of the ECB, in her speech in March 2023, has also argued that the ECB’s “QT will not be simply a reversal of QE” (Schnabel, 2023). In a case where QT is QE in reverse, monetary tightening would result in a raise in term premium in order to make up for the risk of holding long-term securities. However, QT that was employed in 2017 in US had no distinct effect on term premium. Schnabel has expressed similar opinion to Wieladek (2022), as she stated that the effects of QT could be less pronounced. Although, a lot of focus is put on the portfolio balancing channel and its reversal. It is evident that there were significant shifts in the portfolio composition which have resulted in considerable amount of securities being sold in the secondary market in 2022. Therefore, it suggests that it is possible to consider that QT is QE in reverse when taking into account portfolio rebalancing effects. Also, it is estimated that 10-year GDP-weighted risk premia of four largest euro area countries has decreased by about 0.4% since 2021 due to the revised expectations of the market about the development of ECB's balance sheet size (Schnabel, 2023).

As was discussed before, the data set for this thesis spans from 2000 to 2022. Therefore, it incorporates the period of QT that occurred in 2017-2019 as well as the most recent measures that were taken in 2022 in the US. The fundamental effects of QT are incorporated in the employed data, thus conclusions about plausible effects can be made.

Econometric method specification

Transmission of the unconventional monetary policy impact to the economy is empirically tested with a VAR model using Gretl econometrics modeling software. VAR enables the analysis of dynamic interrelationships between multiple variables employing time-series data. Several different VAR model specifications are used to estimate the impact of unconventional monetary policy on macroeconomic variables that are present in the covered literature (Weale & Wieladek, 2016; Hesse et al., 2018; Koeda, 2019; Stefanski, 2021). Moreover, VAR methodology provides impulse response functions that depict the dynamic effects of shocks to the system, and that are imperative for heterogeneity in the field of monetary policy research (Dieppe et al., 2016; Papadamou et al., 2019).

In this research, VAR methodology enables to examine potential heterogeneous responses of the main macroeconomic and monetary measures of the US to monetary policy shock.

The structural form of VAR model is presented below:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + C x_t + \varepsilon_t$$

Where t stands for time (t=1,2,…,T), and p stands for lag. y_t indicates $n\ x\ 1$ vector that consists of n endogenous variables at time t. $A_1, A_2, \dots, A_p$ are $n\ x\ n$ matrices that determine the relationship between the n variables in the system across the p lags. C is a $n\ x\ m$ matrix that specifies the responses of endogenous variables to exogenous variables. x_t is a $m\ x\ 1$ vector of exogenous variables. ε_t is a residuals vector which follows a multivariate normal distribution (Dieppe et al., 2016).

A general VAR model used in this thesis has its advantages as well as drawbacks. First, the model allows to examine interdependencies and interactions among multiple endogenous variables simultaneously. Second, VAR does not require to distinguish between endogenous and exogenous variables as all can be analyzed as endogenous. Third, the value of a particular variable is determined not only by its own lags or error terms, thus it is capable to provide more insights about the data. Regarding the drawbacks of the VAR modeling, it requires all variables in model to be stationary. Furthermore, the interpretation of VAR coefficient estimates is often not particularly clear. Moreover, to estimate VAR a lot of parameters are necessary, thus for models with small sample size this leads to increased standard errors and wide confidence intervals (Dieppe et al., 2016; Brooks, 2019).

Methodology of system dynamics approach

System dynamics modeling is used to explore plausible causal structures of QT. The qualitative causal model is created by determining and linking behavioral hypothesis about the given system to analyze the dynamics of that structure. It is used as a tool to help understand how the structure of a system can cause certain behavior and to redesign particular system's structure so that it would improve its performance.

Literature on the comparable topics in monetary policy that has employed system dynamics approach has been examined previously in the "System dynamics literature" section. The aim of SD is to build a plausible, causal model that enhances the understanding of the studied economic system and provides a causal interpretation of the behavior that is identified in the results of the econometrics testing. A thesis done by Jančiauskaitė (2022) analyzed the effect of both conventional and unconventional monetary policy on inequality. The author used system dynamics modeling to build a quantitative causal model in order to estimate the main factors that determine the impact of monetary policy on inequality. The part of the model that simulates the effect of unconventional monetary policy to the economy was used as reference point, and studied to familiarize with the fundamental logic and the causal relationships of the transmission mechanism.

The qualitative model presented in the empirical part further develops and expands monetary policy transmission mechanism observed in the model presented by Jančiauskaitė (2022). The CLD illustrates additional hypothesis on the mutual causation between monetary policy and inflation. In addition, transmission mechanism is further improved by introducing new monetary pass-through channels. The aim of qualitative SD model is to visually represent the causal links between the key variables that are used in the system. It also complements and simplifies the understanding of the correlations observed in the VAR analysis.

Research hypotheses

The hypotheses that are raised and tested in this thesis are:

1. Quantitative tightening leads to an increase in long-term interest rates.
2. A rise in long-term interest rates leads to a decrease in inflation.

Data selection

This part depicts the variables and statistical data aspects that are relevant for the empirical analysis part. The comparison of the possible alternatives and the chosen variables that are employed is presented as well as the reasoning behind selecting particular data is explained. The data for the preferred variables is portrayed graphically in order to examine the trends, movements and shocks, and to yield potential insights for the empirical analysis.

Monetary policy variables

Measures of unconventional monetary policy. The determinant of unconventional monetary policy is the key aspect in order to evaluate its impact on inflation. Therefore, it is important to understand how the latter policy can be quantifiable. Probably one of the most frequently used methods to build QE variable is to take the asset purchase announcements by FOMC. Previously analyzed studies by Weale and Wieladek (2016) and Stefanski (2021) have employed this method. The announcements presented by FOMC include the type of securities that are purchased as well as the monetary value of planned purchases over the specified period of time. Moreover, as argued by Stefanski (2021) the latter method of variable composition allows to build separate variables in order to distinguish the effect between MBS and US Treasury securities. Although, reviewed literature (Krishnamurthy & Jorgensen, 2012; Hesse et al., 2018; Kim et al., 2020) suggests that one of the dominant transmission channels of QE is signaling. Therefore, the expected size of the FED's balance sheet, which can be induced by the market from the FOMC announcements, have a more defined effect than the actual purchases. However, the same channel does not have a particularly strong or any effect when QT is considered (Lee Smith & Valcarcel, 2022).

Alternative to following FOMC announcements, several studies have used the Survey of Primary Dealers performed by Federal Reserve Bank of New York. It shows the expectations for the change in holdings of US Treasury securities and MBS in the FED's balance sheet. However, this method has similar drawbacks to the one discussed above.

Published data series related to the central bank's balance sheet is another possibility to analyze monetary policy. It has several advantages over the previous methods of monetary policy quantification. First, the data is easily accessible, thus the data set is more accurate, reliable and the model has better comparability. Second, balance sheet-related data can be adapted not only to the models studying expansionary monetary policy, but also to tightening-related research. Moreover, this type of data also allows to separate monetary policy variables into two categories for varying effects depending on the type of the securities that are either purchased, sold or let to mature. Additionally, it is important to note that the balance sheet size and composition has changed significantly since the GFC, hence MBS and Treasury securities amount to around 90% of the total FED's balance sheet (Carpenter et al., 2013; Ihrig et al., 2012).

In this study, the outstanding amount on the FED's balance sheet of both MBS and US Treasury securities are used to represent monetary policy variables. Data has been retrieved from Federal Reserve Economic Data (FRED) database. The shortest frequency available for the latter datasets as well as several other variables that will be discussed in the following paragraphs is quarterly. Therefore, the empirical analysis will be conducted on a quarterly basis.

In Figure 2, data shows quarter-over-quarter changes in the FED's holdings of US Treasury securities from 2000 to 2022. Data is illustrated in millions of US dollars and is not seasonally adjusted. It is evident that there were no significant fluctuations during the period leading up to GFC. Although, since the onset of GFC there are distinct spikes visible that correspond to different QE programs that were employed throughout the given period. Furthermore, the graph clearly portrays that the scope of asset purchase program that was employed during the recent pandemic was significantly broader compared to the one during GFC. Moreover, the negative changes can also be visible around 2017 – 2019 when it was decided to shrink the balance sheet. Also, the same tendency albeit in larger volume is present since the mid-2022s. Data is retrieved from FRED database.

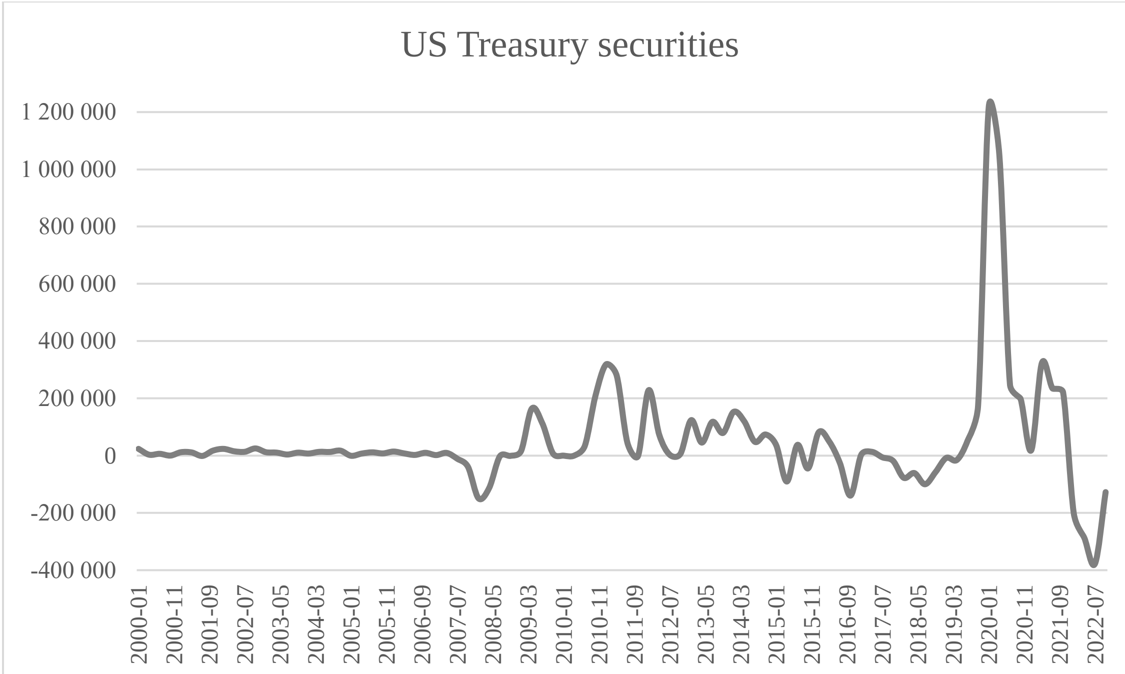


Figure 2. FED's holdings of US Treasury securities

In Figure 3, data shows quarter-over-quarter changes in the FED's holdings of MBS from 2000 to 2022. Data is illustrated as quarter-over-quarter change in millions of US dollars and is not seasonally adjusted. Contrary to the holdings of Treasury securities, initial purchases of MBS have occurred only during the GFC with the first QE program. The graph in Figure 3 depicts variations in the level of MBS that correspond to different QE or tightening programs. The exception is the second QE program in the of 2010, in which MBS were not purchased. Moreover, the most significant acquisitions of MBS have occurred since the onset of Covid-19, and hence the holdings have started to decrease since the announcement of QT in the first quarter of 2022. Retrieved from FRED database.

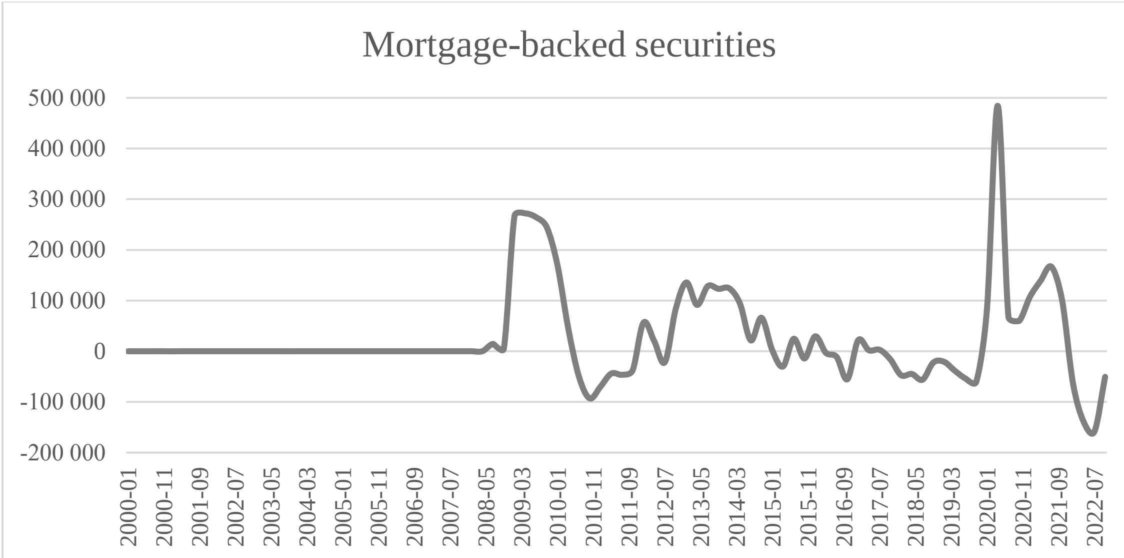


Figure 3. FED's holdings of mortgage-backed securities

Conventional monetary policy measure. Conventional monetary policy measures will be controlled by employing effective federal funds rate (FFR). Federal funds rate is considered as the main tool to achieve FED's dual mandate, and is set by FOMC. Effective FFR is a rate paid by the borrowing institutions to the lending institutions, and it is the weighted average of all these transactions, while FFR is set as a range. Figure 4 shows the development of effective FFR. FFR trends clearly correspond to the economic cycles that were present during particular time span. It is evident that during the periods of crises – Dotcom, GFC and Covid-19 – FFR is significantly lowered to boost the liquidity in the economy. Also, GFC and Covid-19 levels of FFR represent the zero lower bound that was reached, and was one of the reasons to utilize unconventional monetary policy measures. In contrast, the sharp rises correspond to the periods of high economic growth. Data of effective FFR is from 2000 to 2022, and is represented in percentage points. Data series is available on a monthly basis, therefore it was aggregated to quarterly data using 3-month average. Data is not seasonally adjusted. Retrieved from FRED database.

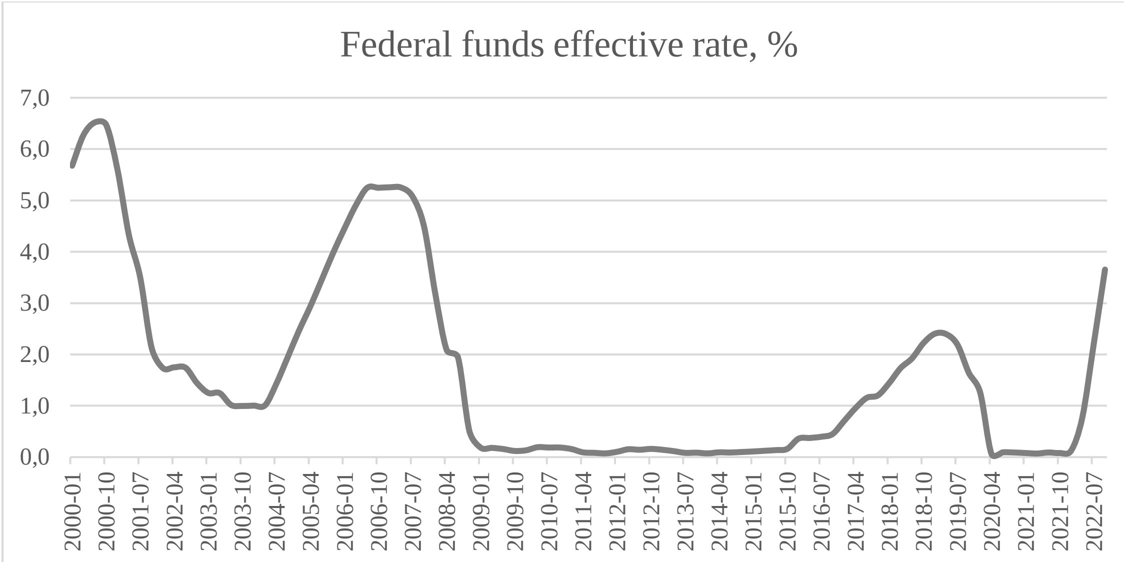


Figure 4. Federal funds effective rate

Macroeconomic variables

Inflation. The level of inflation in this analysis is measured by the personal consumption expenditure index (PCE). PCE is the preferred index by the FED to track inflation level, therefore it was chosen as the main indicator. PCE takes into account the change in prices of all consumption items, not only the items that have been paid for by the consumers themselves. PCE is a chained index, thus its formula uses updated data and it evaluates the substitution among comparable items when one of the items becomes more expensive. Therefore, PCE is thought to be a more reliable and precise reflection of changes in prices.

Alternatively, changes in prices can also be measured by the consumer price index (CPI). CPI is meant to reflect the price change which is felt by urban consumers, that represent around 90% of total US population. CPI takes into account a fixed basket of goods and services that are purchased “out-of-pocket” by the consumers. CPI is the most extensively used standard of inflation.

Although the CPI and PCE are likely to follow similar patterns, the latter is a more conservative measure as it tends to increase by around 0.2 – 0.3% less compared to CPI (Salwati & Wessel, 2021). Moreover, in this analysis, PCE is a preferred indicator as it takes into account not only the costs that were directly incurred by the consumers, is a chained index, and is used by the FED. PCE consists data from 2000 to 2022, and is measured in percentage points. Quarterly inflation in the majority of the observed period has been in the range from 1% to 3%. There were only several periods where clear inflationary or deflationary cycles were experienced. Similar to other indicators, these relate to crises. Throughout the last two decades economic contraction was encountered only in the three quarters in 2009. On the contrary, the apparent rise of inflation that started since the second quarter of 2021 is the key reason why the FED had to introduce QT measures (Figure 5). Data for PCE is retrieved from FRED database.

Figure 5. Personal consumption expenditure

GDP. The level of economic output in the US is measured by the real GDP. Real GDP is used as a control variable to account for the changes in aggregate demand which, in theory, should have an impact on the changes in price level. The graph in Figure 6 indicates that the aggregate demand in the US has been rising at a consistent pace throughout the last couple of decades. Although, there have been several exceptions during the previously discussed crises, therefore the stimulus for the economy in both fiscal and monetary form was required. Data for real GDP is seasonally adjusted annual rate and is measured in billions of chained 2012 dollars. Retrieved from FRED database.

Figure 6. Real gross domestic product

Transmission channel variables

US Treasury yield. The effects of unconventional monetary are transmitted through several channels. Data on the market yield on US Treasury securities at 10-year constant maturity is used to evaluate the impact of portfolio balancing channel. An increase (decrease) in the yield on 10-year US Treasury securities plays an important role when portfolio allocation is considered by the investors as the shift leads to an increase in demand for safer (riskier) assets.

Moreover, for the purpose of this analysis, market yield on US Treasury securities at 10-year constant maturity represents long-term interest rates. The yield on 10-year Treasury securities is a benchmark for various other interest rates prevalent in the market, such as yields on corporate bonds or mortgage rates, and is often used a proxy for long-term interest rates. 10-year US Treasury yield indicates investors' expectations on the future growth and health of an economy.

Figure 7 shows the changes on market yields on US Treasury securities at 10-year constant maturity throughout the period from 2000 to 2022. The lowest points in the yield are experienced during expansionary monetary policy cycles. Latest occurrence where the yield dropped below 1% was experienced during the vast QE program that was employed to counter the negative effects of the recent pandemic. Data on market yield on US Treasury securities is quoted on an investment basis and is not seasonally adjusted. Retrieved from FRED database.

Figure 7. Market yield on US Treasury securities at 10-year constant maturity

Asset prices. Asset prices are closely linked with several transmission channels that were discussed in the "Literature review" chapter. Therefore, to capture the transmission of monetary policy through the changes in the prices of assets S&P 500 index is used as a representative variable. S&P 500 tracks the performance of 500 large capitalization enterprises that are listed on US stock exchanges. Companies from variety of sectors such as technology, financial services, healthcare, consumer goods and others are included in the index. S&P 500 is considered a benchmark index for the general performance of the US stock market, and is extensively used by financial professionals to track the direction of the economy. During the last couple of decades the value of S&P 500 has almost tripled. The index shows evident downward trends during the crisis periods. Index has recovered to the initial level before the GFC after it has fallen amidst Dotcom bubble. After the GFC has passed, the steep expansionary trend is visible with several minor adjustments in 2018 and 2020. Distinctively sharp rise is visible since the second quarter of 2020, which is related to the massive monetary easing program employed by the FED. Data series is available on a monthly basis, therefore it was aggregated to quarterly data using 3-month average closing price. Measured in US dollars. Data on S&P 500 is retrieved from Yahoo finance (Figure 8).

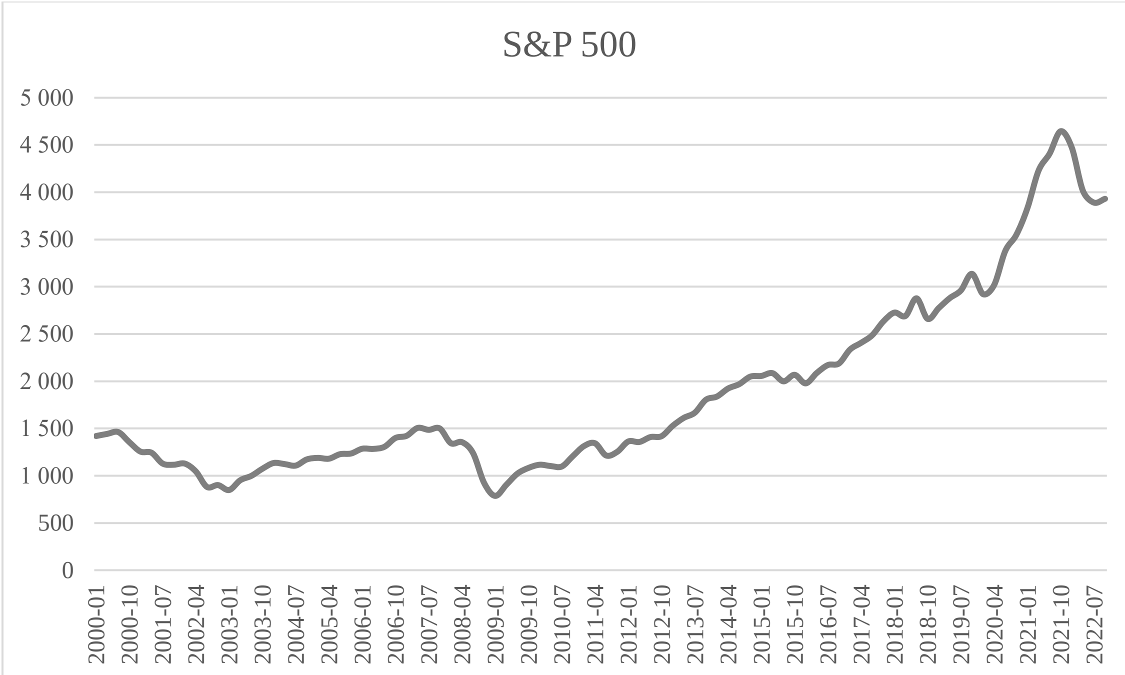


Figure 8. S&P 500 index

Possible weaknesses of the research design

The plausible weaknesses of the presented research design are related to the econometric analysis. VAR model that is used to measure the impact of QT is based on the data which does not specifically include extensive periods of contractionary monetary policy. The major part of the researched period consist of the expansionary policy data. Therefore, in order to make conclusions about the QT, assumptions listed in the “Main assumption for econometrics testing” section had to be made. However, it could be argued, that it is not guaranteed that the FED will ever employ its contractionary policy for the prolonged period of time to be sufficient for the econometric research.

Empirical Analysis Results and Discussion

Dual methodology approach is employed to conduct empirical analysis of this study, thus it consists of VAR econometric modeling as well as system dynamics modeling technique. First, VAR model is created and the relationship between monetary policy, long-term interest rates, and inflation is examined using data that was presented in the “Data selection” section. The main purpose of econometric analysis is to identify the correlations between monetary policy, long-term interest rates, inflation and transmission channels. Second, a qualitative approach of system dynamics model is presented. This allows to visualize transmission channels of monetary policy decisions. System dynamics model builds on the findings of econometric analysis and expands the understanding by portraying key causal relationships. Furthermore, identified limitations of this thesis are presented in the following chapter.

Econometric analysis – VAR modeling

VAR econometrics model estimation on the effects of monetary policy on inflation is presented in the following section. Quantitative research is performed in order to assess whether the effects and transmission channels that were specified in the literature review could be estimated using the actual data. Also, it is checked if the formulated hypotheses can or cannot be rejected. Moreover, several VAR models are built to check and ensure the robustness of the results. Econometric analysis is performed using Gretl software.

Data inspection and preparation

Data inspection is performed before VAR model is created. In general, time-series models, including VAR, require that all used variables are stationary, therefore the variables were checked for stationarity. Augmented Dickey-Fuller and KPSS tests were used to test stationarity. Results of both tests have indicated that all variables, except for MBS and Treasury securities (denoted TREAS), are non-stationary (Appendix 1). To solve non-stationarity problem the data were transformed. Quarter-over-quarter percentage change was introduced for S&P 500 variable, and others were transformed into first differences. The latter change did not make inflation (denoted PCE) and effective FFR (denoted FFR) stationary. To make PCE and FFR stationary, other forms of variable conversions were tested, of which quarter-over-quarter annualized percentage change has helped. However, such transformation significantly distorts the data and makes interpretation especially complicated because the variables in question are denominated in percentage terms. Therefore, it was decided that the first differences of PCE and

FFR will be employed for the empirical research (Appendix 2).

Non-stationary data can cause spurious regressions and biased results, therefore cointegration of residuals was tested to ensure that the use of non-stationary PCE and FFR variables would not result in such issues. Cointegration analysis enables to examine the model even if multiple variables within the model exhibit non-stationarity. If the test results confirm that cointegration is present, it indicates that the given model as a unit is stationary, regardless of any non-stationarity amidst the individual variables (Sims et al., 1990). Engel-Granger test for cointegration was used. The null hypothesis of cointegration test, which assumes time-series non-stationarity is rejected, thus the model is stationary (Appendix 3). Therefore, it is confirmed that the use of PCE and FFR determinants in the form of first differences is appropriate for further research.

Using first differencing has its shortcomings as well. According to Sims et al. (1990) transforming variables to first differences makes the interpretation of the results a bit more complex and less obvious, hence requires more effort to understand. Moreover, using levels of variables would allow to isolate the trends that are present in the data more effectively as well as more information could be retained compared to using first differences (Harvey, 1980).

In addition, an important point to note is that in the majority of analyzed cases the changes that are displayed in the impulse response functions are expansionary policy related since the standard errors in the models are positive. For the ease of communication, the changes are analyzed as shown in the impulse response graphs, but it is assumed that the effects of QT are in reverse.

Estimation of the baseline model

To start with, the baseline model is constructed following the logic behind the analyzed theory, which states that the monetary policy measures taken by the FED aim to affect long-term interest rates that, in turn, have an impact on inflation. Therefore, the initial model includes MBS, Treasury securities, market yield on US Treasury securities (denoted Yield), and inflation as endogenous variables, while others (S&P500, GDP, and FFR) are kept as exogenous. The inclusion of exogenous variables means that these variables are neither explained nor determined by the model, although have a causal effect on endogenous variables. To proceed with the VAR model, VAR lag selection was applied to check the appropriate lag length. According to the test results, the most fitting lag order is one by BIQ and HQC criterions, and four by AIC criterion

(Appendix 4). Therefore, VAR models with different lag lengths have been built. The length of four lags has been chosen as it produced the lowest score of AIC, while BIQ and HQC criterions have displayed almost identical figures between separate models. Moreover, heteroscedasticity and autocorrelation tests were completed to check whether there is no serial correlation and the variance of the residuals is constant (Appendix 5). Results have shown that these issues are present, thus HAC robust standard errors were used. In addition, graph of VAR inverse roots indicates that the dynamic system of the baseline model is stable and will converge to a steady-state solution as all the values lie inside the unit circle (Appendix 5).

Impulse responses displayed in Figure 9 show the effect of a unit of shock, which is equal to one standard error, in MBS, Treasury securities, Yield, and PCE to each of the mentioned variables and itself. First of all, one standard error shock in monetary policy variables is equal to a period to period change of $42.055 billion in the amount of MBS held, and $141.14 billion in Treasury securities held. Also, a shock in 10-year US Treasury yield is equal to a quarter-over-quarter change of 0.3 percentage points, which is used to investigate the impact of long-term interest rates as well transmission channel effects on inflation. Depending on the sign of the change the impact can be attributed as being either contractionary or expansionary.

When a positive shock in MBS is introduced to the system, yield decreases by 0.04 percentage points in the first period, which leads to an immediate easing conditions as, for example, long-term interest rates drop from 3.92% to 3.88%. However, it is estimated that starting from the second period the yield would start to increase and it would rise above the initial level. The effect of an increase in MBS dies out in the 5th period since the quarter-over-quarter change is around 0. Conversely, the change in yield does not significantly affect the change in the amount of MBS held. If a negative shock of a similar size in MBS would be introduced to the system, under the assumptions presented in the “Methodology” section, the effects would be opposite, and thus it would lead to temporary contractionary environment.

Furthermore, a positive shock of $141 billion in Treasury securities would cause the yield to decrease by 0.15 percentage points in the first period, and 0.02 percentage points in the third period. Although, the effect would be opposite, but minor from 5th to 9th periods, and it would eventually die out beginning with the 10th. On the contrary, a positive shock, which reflects contractionary monetary policy, in the US Treasury yield would lead to a quarter-over-quarter decrease in the holdings of US Treasury securities ranging from $6.7 to $36.8 billion throughout the first 6 periods. In the long run, after the 6th period, the effect starts to diminish as the changes are minor. Likewise, a negative shock in the Treasury securities would cause the yield to increase in the short-run, which supports the main goals of QT.

Another important aspect is the transmission of monetary policy measures to inflation, therefore an impact on PCE has to be analyzed as well. First, an unexpected result is visible when a shock in MBS is initiated into the system. A positive change in MBS leads to a period to period decrease in PCE by 0.1 percentage points in the first period. A negative change is visible in the third period as well, as PCE decreases by 0.02 percentage points. Although, after the 3rd period a positive change in PCE of around 0.03 percentage points stays until the period 7, and when the impact dissipates. Furthermore, similarly to the impact on yield, the shock of one standard error in Treasury securities has a bigger impact on PCE compared to MBS. A $141 billion change in US Treasury securities induces a 0.18 percentage point rise in PCE in the 2nd period after the shock is introduced. The effect starts to deplete afterwards as the change in 4th period is 0.05 percentage points. After the 5th period the price level starts to decline by 0.03-0.07 percentage points until period 9 and then starts to fluctuate around zero.

Contrary, according to the given results, a negative shock of one standard error in US Treasury securities would lead to a slowdown in price growth, while the impact of MBS is ambiguous. Moreover, the effect of a 0.3 percentage points increase in US Treasury yield at 10-year maturity would drive inflation up by 0.02 percentage points in the first period. Although, it would generate a negative impact of 0.05 percentage points in the 2nd period, and would continue to negatively affect PCE through 4th to 6th periods by 0.01, 0.07, and 0.04, respectively. Eventually, the impact becomes positive and dissipates after the 9th period.

Nevertheless, a reaction to a shock in PCE is worth analyzing as well. One standard error shock in PCE is equal to the quarter-over-quarter change of 0.49 percentage points. First, the response of both MBS and Treasury securities to a change in PCE is similar. Both MBS and Treasury securities decrease in the first 6 periods after a positive shock in PCE is introduced. The largest changes for both MBS and US Treasury securities are during the 2nd and 4th periods. MBS shrinks by $14.388 and $21.179 billion, respectively, while Treasury securities are reduced by $22.646 and $28.907 billion, respectively. Second, the market yield on US Treasury securities is also affected by the change in the price level. The yield rises by 0.09 and 0.03 percentage points in the 1st and 2nd period, respectively, after a shock is generated. There is a reduction by 0.3

percentage points in the 3rd period. Afterwards the rise is present for three periods which is followed by the decrease that balances out from the 10th period. The dynamic behavior of MBS, Treasury and yield supports the theory of employing unconventional contractionary monetary policy measures in order to lower inflation.

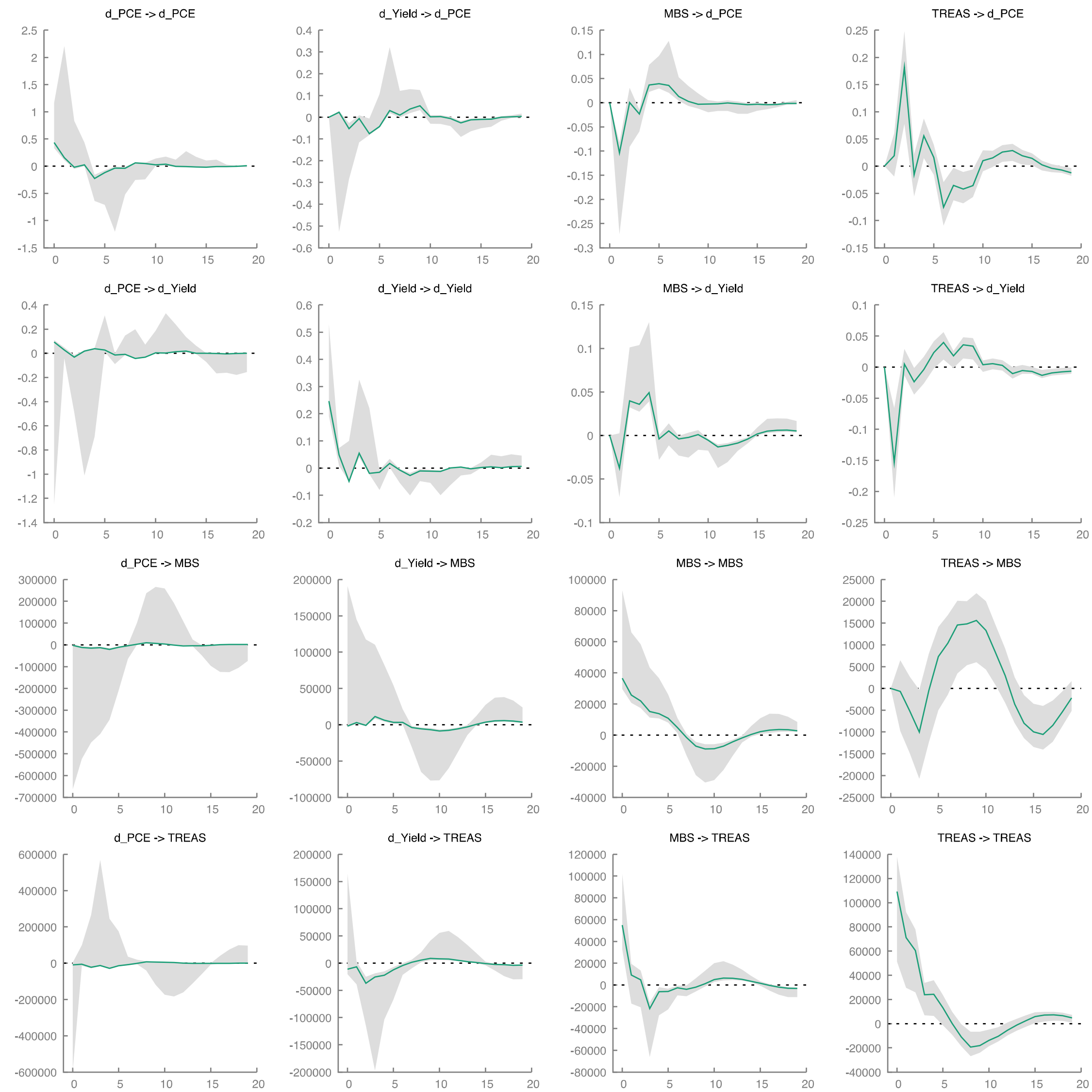


Figure 9. Baseline VAR impulse responses

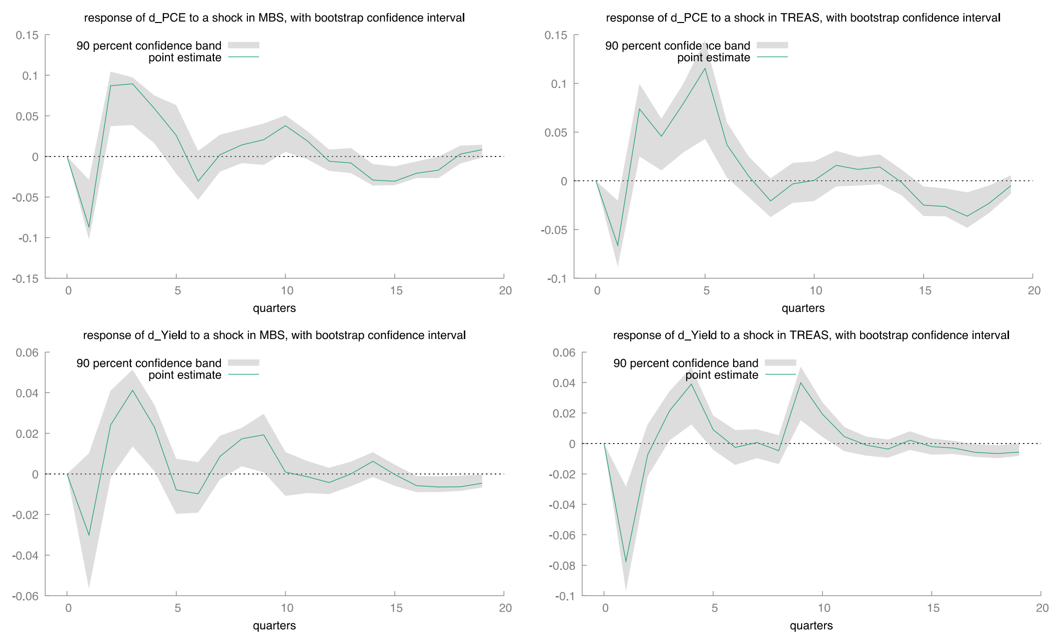
Results of the alternative model – full period

Alternative models are created to analyze whether the treatment of exogenous variables as endogenous would have an impact and change the results of the VAR model. Addition of endogenous variables means that the variables are jointly determined in the VAR system, and that the value of a particular variable is determined by its own lag, and by the lags of other endogenous variables. All variables that were described in the "Methodology" part are included as endogenous – d_PCE, d_Yield, d_FFR, p_SP500, d_GDP, MBS, and TREAS. Stationarity-corrected form of all variables is used. VAR lag selection (Appendix 4) does not yield concrete results as all the criterions display different lag orders, therefore VAR with lag order of 4, which produces the lowest Akaike criterion, is used. Moreover, the graph of VAR inverse roots indicates that the model is stable since all the values lie inside the unit circle (Appendix 5).

Figure 10 portrays impulse responses of the main variables of interest – d_PCE, and d_Yield – to the monetary policy shock, which is caused by the $52.162 billion increase in MBS, or a rise in the holdings of US Treasury securities by $146.433 billion. When a positive shock in MBS or Treasury securities is introduced, full period alternative model provides similar results comparing to the baseline model. The yield decreases in the first period following the shock in both MBS and Treasury securities. Although, the impact of MBS is slightly lower – 0.03 versus 0.04, while the impact of Treasury securities diminishes significantly, and is only 0.08 compared to 0.15 percentage points in the baseline model. Moreover, the yield increases in varying amounts in the upcoming periods, which is comparable to the baseline model as well. In the long run, after the 10th period, the impact of monetary policy dissipates as the period to period change stays around zero. In general, the results indicate that the impact of unconventional monetary policy on long-term yield is transitory since there is no meaningful effect in the long-run.

In addition, comparable trends are present when an impact on inflation is considered. A positive change in MBS results in a decrease of 0.09 percentage points in the first period, which is marginally lower than in the baseline model. Although, it is followed by a 0.09 increase in PCE in the two following periods, and 0.06 percentage points in the 4th period. The effect that is visible from 2nd to 5th period is slightly stronger than the one observed in the baseline model, although the overall trend is analogous. In the long-term, in both models inflation tends to fluctuate around zero. Furthermore, a positive one standard error shock in Treasury securities generates a 0.07 percentage point reduction in the price level in the 1st period, which follows the trend of MBS that was not seen in the baseline model. Though, starting from the 2nd period, PCE starts to increase by 0.07, and reaches its peak of quarter-over-quarter change of 0.12 percentage points in the 5th period. In the long-run, starting from period 7, the direction of change becomes cyclical, while the magnitude of the effect becomes negligible. Therefore, taking into account both the effect of MBS and Treasury securities, the cumulative positive change that is present since the 2nd period, offsets the negative drop in the 1st period, hence leads to an overall increase in PCE, when positive shock is considered.

Contrary, reverse dynamics on the proportionate level are expected when the tightening shock is introduced. The positive shock in US Treasury yield displays the contractionary effect of long-term interest rates as well as the transmission of monetary policy to inflation. In addition, a positive one standard error shock in 10-year US Treasury yield, equal to period to period change of 0.33 percentage points, causes cyclical dynamic behavior in the price level. In the 1st period inflation increases by 0.03, which is followed by the 0.05 percentage points decrease. In the next periods inflation starts to increase again. Until the period 6, the growth varies between 0.01 and 0.09 percentage points. The most notable shock occurs, which causes a period to period decrease of 0.15, 0.09, and 0.06 percentage points from period 8 to 10. Then, the effect starts to diminish as the change reaches close to zero. The impact of yield on PCE is felt stronger in the alternative model, although it takes more time to transmit through the system. Alternative model results suggest that a QT shock increases long-term interest rates, and decreases inflation in the short-term, albeit in the long-term there is no lasting effect.



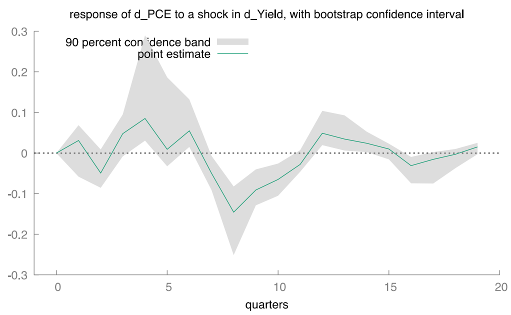


Figure 10. Impulse responses of alternative model – full period

Inclusion of exogenous variables allows to analyze the impact of monetary policy shock on transmission channel variables (Figure 11). First, arguably the largest effect is felt on the asset price channel after expansionary shock in MBS. S&P 500 index experiences a rise of 1.6 percent in the 1st period, which is followed by another increase of 0.74 percent in the 2nd period. There is a slight decrease of 0.2, 0.5, and 0.15 percent in the respective periods from 4 to 6, and the change balances out around zero afterwards. Similarly, the impact on S&P 500 is significant when Treasury securities are considered. In the 1st period, the index rises only by 0.05 percent, but it starts to grow rapidly by 1.2 percent in the period 2, and continues the growth cycle, 0.45 percent on average, until period 6. The effect becomes negative in the following three periods, on average 0.3 percent, and dissipates since the 12th period. Secondly, the change in real GDP is estimated to be negative in the 1st period after unconventional monetary policy shock. When the holdings of MBS and US Treasury securities rise, economic output decreases by $15 and $145 billion on an annual basis (annualized quarter-over-quarter change, 2012 chained dollars), respectively. Then, considering MBS shock, GDP growth varies from $7 to $33 billion in the upcoming three periods. In the long-term, the impact on GDP growth is not present. Regarding the shock in Treasury securities, GDP is projected to rebound by $95 billion in the 2nd period. However, the effect starts to significantly diminish in the upcoming periods and is not visible in the long-term.

Moreover, the reaction of FFR and the relationship between FFR, MBS, and TREAS variables is analyzed. The model projects that conventional and unconventional monetary policy measures show similar dynamic behavior then the shock is introduced. In the expansionary policy environment, an increase in the assets on the central bank's balance sheet leads to an immediate decrease in FFR, and vice versa when contractionary shock is introduced. The graphs in Figure 11 display that FFR is reduced in the first couple of periods. However, it is expected to increase from 5th to 12th period, while in the long-run there is no likely effect. Also, it is worth mentioning that the changes are marginal – 0.06% or lower.

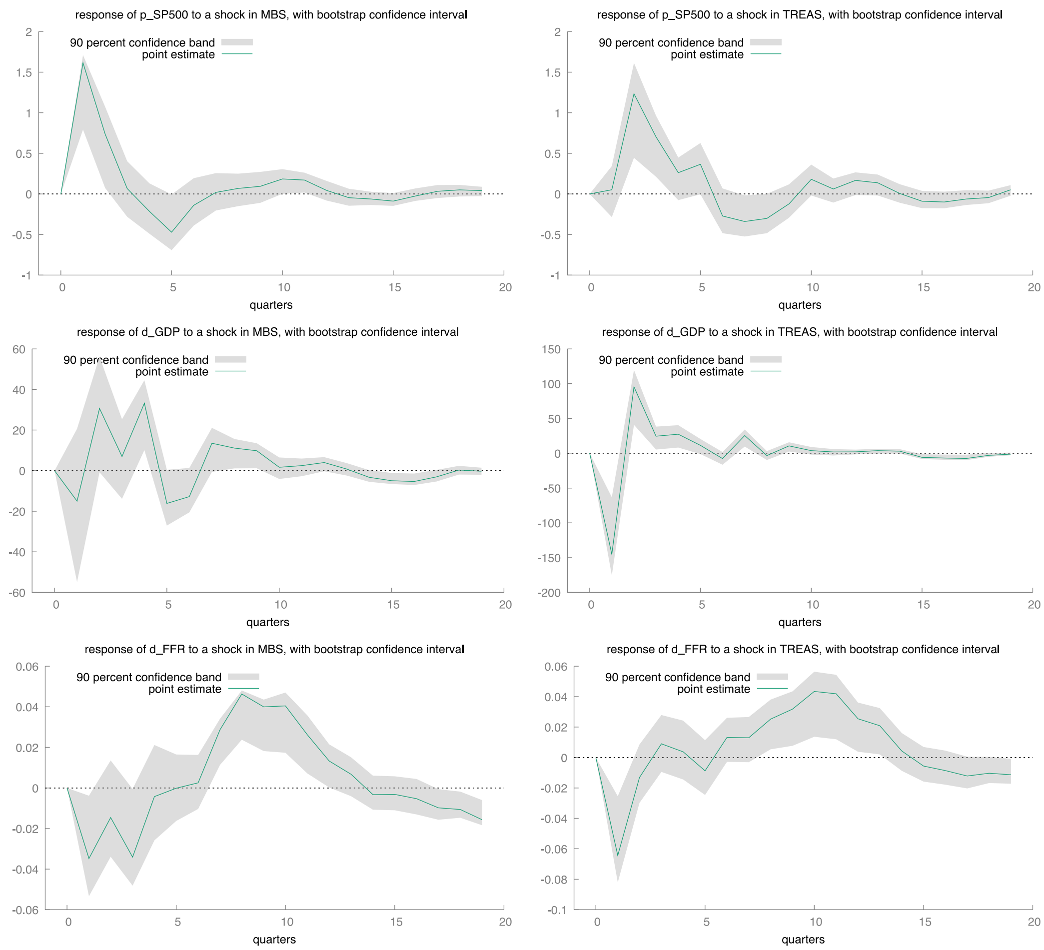


Figure 11. Impulse responses of transmission channel variables – full period

Alternative model – unconventional monetary policy period

Previously analyzed models have covered the period where both unconventional and conventional monetary policy tools were used. However, since the GFC when the policy rate has reached zero lower bound, the effect of conventional monetary policy by keeping the rates low was marginal, and thus could be considered negligible. Therefore, the period from 2008Q4 to 2022Q4, during which unconventional policy measures, such as QE or QT, could have been considered as the main monetary policy tool, is studied separately. Despite the fact that the sample size is significantly reduced, this allows to analyze the impact of unconventional monetary policy without diluting it with the period where the policy rate was the main and only instrument to achieve FED’s dual mandate.

The range employed for unconventional monetary policy period is significantly reduced, therefore Engel-Granger cointegration test was performed (Appendix 3). Results indicate that the model is stationary. Similarly to full period, all the variables are included as endogenous. Lag order determination using VAR lag selection yields ambiguous results (Appendix 4), therefore different lag lengths have been tested. Due to the reduced sample size, VAR system with the lag order of 4 is unstable, thus the model with 2 lags is employed since it yields the lowest combination of AIC, BIC, and HQC scores. Moreover, VAR inverse roots confirm that VAR dynamic system is stable as all the values are inside the unit circle (Appendix 5).

Impulse responses of the main indicators are presented in the Figure 12. A one standard error shock in MBS is equal to $69.318 billion. First, the graph portrays that a shock in MBS leads to an immediate decrease in 10-year US Treasury yield as the negative change from period 0 to 1 is 0.04 percentage points. Although, the impact is reversed in 2nd and 3rd periods with the growth in yield of 0.05 and 0.02, respectively. The biggest negative impact of MBS shock is felt on period 5 since the yield decreases by 0.05 percentage points. Nevertheless, periods 7 to 9 show an increase again, after that, in the long-run, the impact of MBS shock becomes zero. Next, PCE experiences a rise in the first four periods, with the largest quarter-over-quarter changes of 0.2 and 0.16 percentage points visible from periods 2nd to 3rd and 3rd to 4th, respectively. PCE decreases in the upcoming two periods by 0.1 and 0.15 percentage points, but there is no MBS effect on PCE in the long-term.

Next, the shock in US Treasury securities is equal to $180.623 billion. 10-year US Treasury yield is more significantly impacted by the change in holdings of Treasury securities rather than MBS. Yield declines by 0.09 percentage points in the 1st period after the introduction of Treasury shock. Although, after the initial change, the impact is significantly reduced. It goes through both expansionary and contractionary cycles in the periods from 2 to 6, while in the longer term the effect dies out. Furthermore, reaction of PCE in the first period after the shock is consistent with the full period model as the change in holdings leads to a decline of 0.1 percentage points. Despite the fact, the effect on PCE is positive from the 2nd to 5th period with the changes of 0.15, 0.09, 0.06, and 0.02 percentage points quarter-over-quarter. The effect diminishes in the following periods, hence in the long-term it is not present.

In addition, a one standard error shock in US Treasury yield is equal to quarter-over-quarter change of 0.32 percentage points. The graph displays unexpected results. An increase in long-term Treasury yield, which represents contractionary monetary policy, leads to a rise in PCE in the first 6 periods, which results in a cumulative change of 0.4 percentage points over the given time frame. Even though the PCE starts to decrease afterwards, but the effect is significantly smaller compared to the initial shock. In the long-term, yield has no effect on PCE.

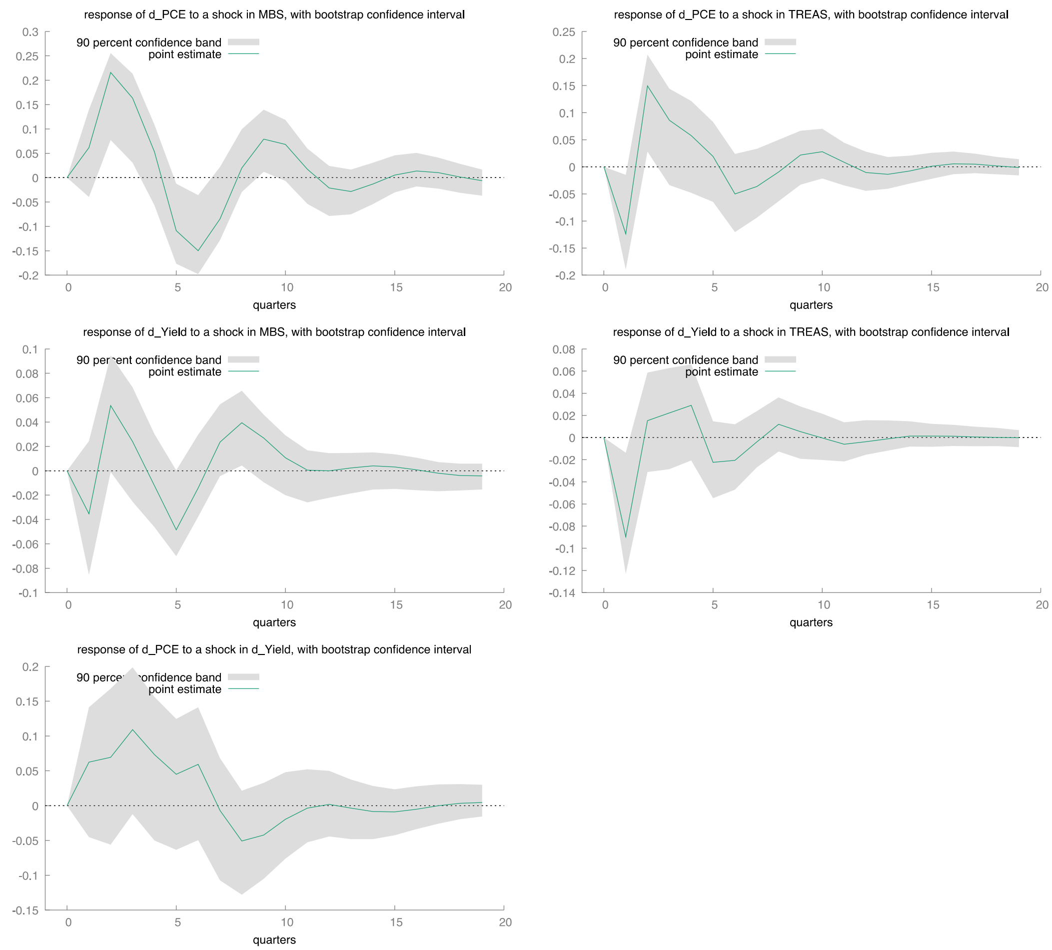


Figure 12. Impulse responses of alternative model – unconventional MP

The impact on transmission channel variables in displayed in the Figure 13. S&P 500 is significantly affected by the change in holdings of both MBS and US Treasury securities. MBS shock leads to 3.3 and 1.7 percent increase in the first 2 periods, while US Treasuries raise the index by 0.72 and 1.13 percent quarter-over-quarter. In the long-term, there is no meaningful impact of both MBS and US Treasury securities on S&P 500. GDP reacts by growing by $13 and $93 billion after the MBS shock on an annual basis. Even though GDP decreases around the period 5, the long-term effect becomes zero. The results are ambiguous when US Treasury impact on GDP is evaluated. Initially, GDP decreases by $160 billion, but the accumulated growth impact over the 3 upcoming periods adds up to the same amount. Starting from the 4th period, the effect on GDP is insignificant and fluctuates around zero.

Furthermore, the relationship between conventional and unconventional monetary policy is visible when FFR responses are considered. A positive shock in MBS leads to a slight decrease in FFR by 0.06 percentage points. Notably, there is a delay in the FOMC decision as the effect is present only since the 3rd period. On the contrary, the shock in US Treasury leads to an immediate decline in FFR since it shrinks by 0.07 percentage points in the first period.

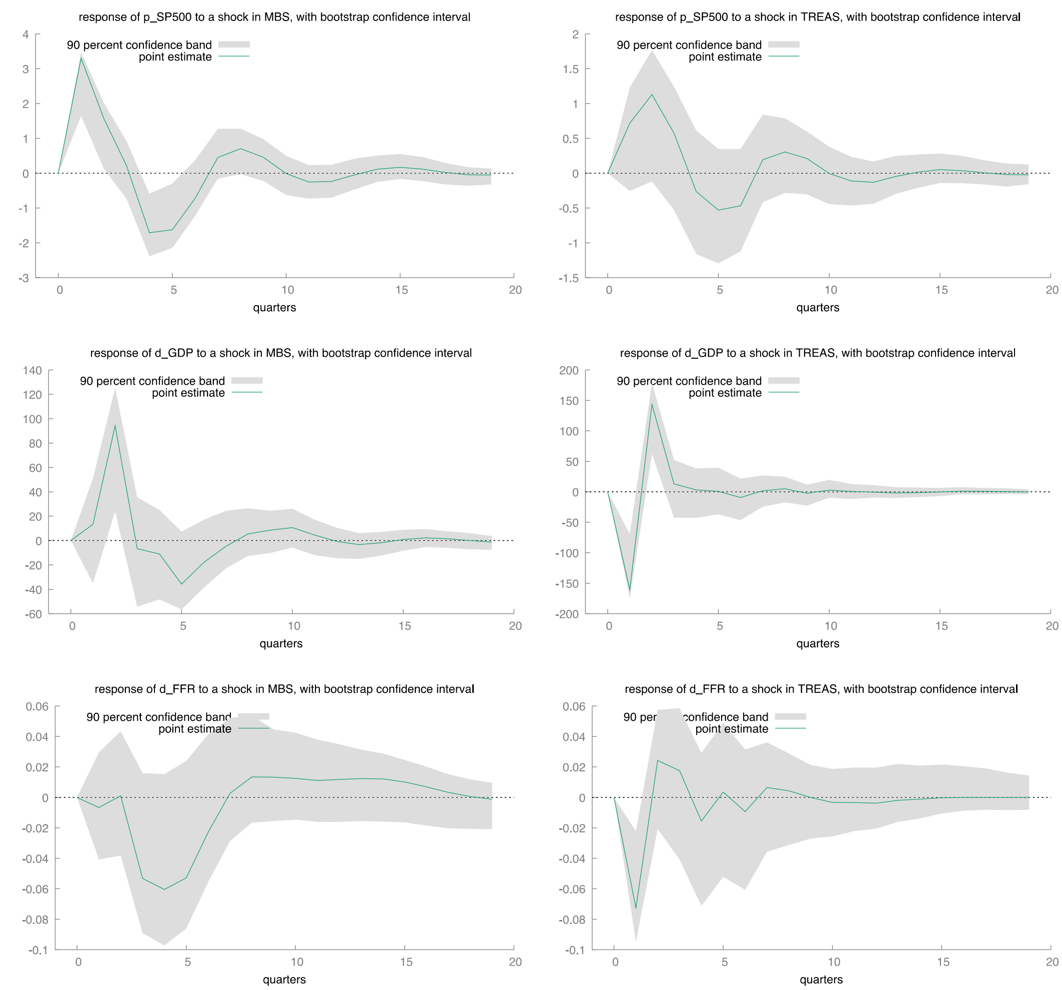


Figure 13. Impulse responses of transmission channel variables – unconventional MP

Comparison of different model results

The dynamic behavior that was observed in the baseline and both alternative models is analyzed and compared in the following section. First of all, Figure 14 shows the response of 10-year US Treasury yield to a shock in US Treasury securities and MBS. In general, when US Treasury shock is considered, the observed trend among the three models is similar. The yield decreases in the 1st period after the monetary policy shock is introduced. The impact of both alternative models is of a similar size, with the largest effect predicted by baseline model. The impact significantly decreases in the upcoming periods after the initial shock. Although, both alternative models predict that the yield will increase from period 3 to 5, while the difference in baseline is that the increase is estimated only from the 6th period. In the long-term, change in holdings of US Treasury securities does not have an impact on yield. On the contrary, in the short-term, a reduction of US Treasury securities would lead to an increase in the long-term yield. Second, all three models estimate that a shock in MBS would be felt in the 1st period after the introduction as the yield would fall down. The yield would increase in the periods from 3 to 4 in all the models. Unconventional monetary policy model predicts that the yield would start to shrink again in the period 5, and the impact would be more pronounced, while the baseline and full period models predict the slight decrease from the period 6. There is no meaningful impact estimated since the 6th period in the baseline model, while after increasing again from 8th to 11th periods, the effect also dissipates in both alternative models.

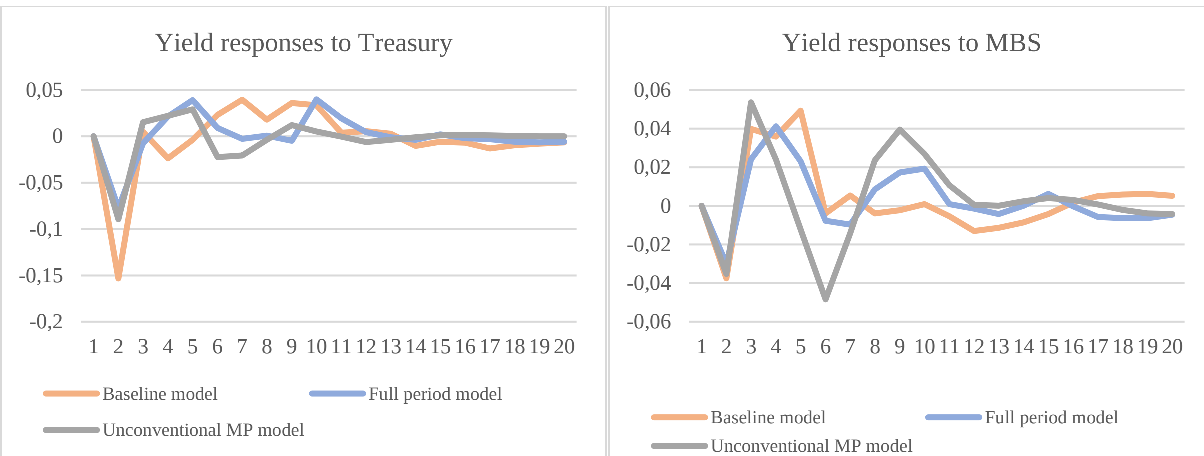


Figure 14. 10-year US Treasury yield responses to a shock in US Treasury securities and MBS

Furthermore, the graph in Figure 15 shows the dynamic behavior of the PCE when a shock in holdings of US Treasury securities or MBS is introduced. First, regarding a shock in US Treasury securities, the baseline model predicts the increase in PCE in the first 3 periods, while both alternative models suggest that there would be a decrease in the 1st period, which would then be followed by a rise of a similar magnitude. The results show that the trend is varying among the models from 4th to 6th period, but it stays on the positive side. From 7th to 9th periods there is a slight decrease estimated in the baseline and unconventional monetary policy models.

Although, it is evident that in the long-run, there is no significant effect on PCE. Furthermore, The trend of PCE response to MBS shock is quite similar to the one observed when a shock in US Treasury securities is introduced. Alternative models predict an increase in the price level from 3rd to 5th periods. On the other hand, the baseline model predicts a slight increase only from the 5th period. The negative impact on inflation is present from the 6th to 9th period only in unconventional monetary policy model, while the remaining two already display the diminishing trend in the long-run.

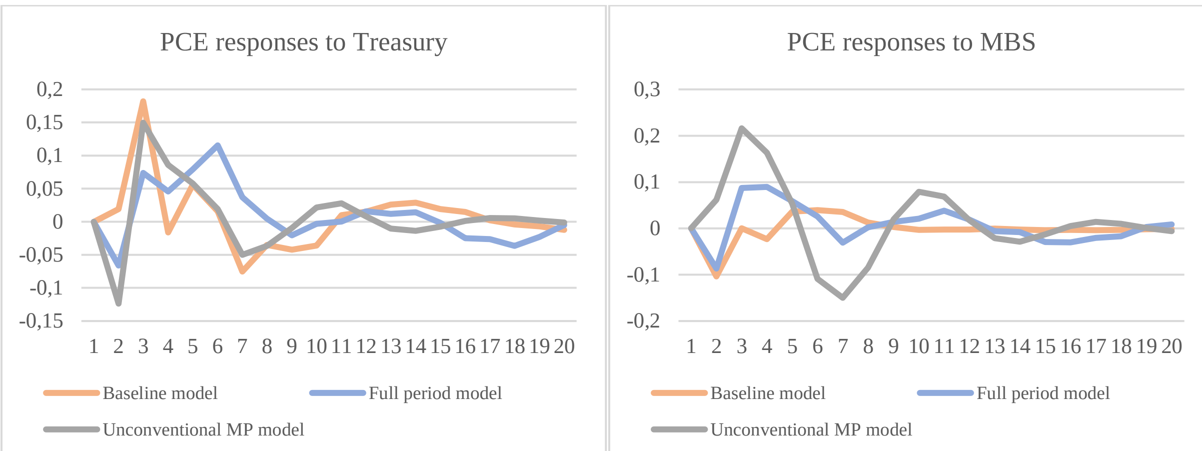


Figure 15. PCE responses to a shock in US Treasury securities and MBS

Moreover, Figure 16 portrays the responses of PCE to a shock in 10-year US Treasury yield. All three models estimate quite distinct trends of PCE development. It is evident that when a shock in long-term yield occurs, there are periods of significant changes in the PCE. The two largest negative impacts on the price level are observed in period 5 of the baseline model, and 9th of the alternative full period model. However, the results of the three constructed models are too ambiguous to come to one general conclusion on the timing and size of a change in the inflation. Although, it is evident that long-term rates do not have a significant effect on the price level in the long-run.

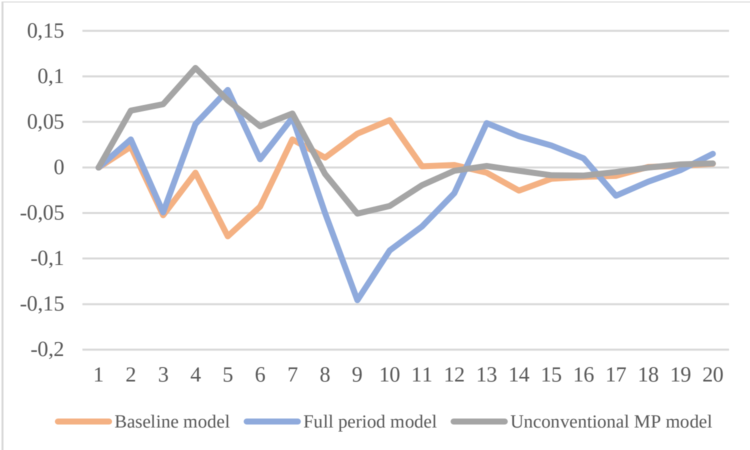


Figure 16. PCE responses to a shock in 10-year US Treasury yield

Monetary policy transmission is an important subject that helps to understand how the effect is felt throughout the system. Therefore, it is beneficial to compare the reaction of the variables in both alternative models when a shock is introduced (Figure 17). Both alternative models display similar trend when S&P 500 is considered. The index has a major surge in the first 4 periods when a shock in US Treasury securities and MBS is induced. Also, reaction is more pronounced when MBS shock is felt rather than US Treasury securities. S&P 500 slightly decreases from the 5th to 7th periods, and the effect in the long-term is negligible. Likewise, reaction of GDP is quite unexpected as it shrinks in the first period after the US Treasury shock. Even though the negative effect is negated in the upcoming periods, the positive accumulated change throughout the examined time frame is minor. On the contrary, GDP experiences growth cycle when positive MBS shock is introduced. GDP growth stays positive until 4th period in the unconventional monetary policy model, while it is positive until the 6th period in the full period model. However, unconventional monetary policy induces only a short-term effect on GDP, as there is no significant impact observed after the 8th period.

Dynamics between conventional and unconventional monetary policy can be examined when FFR responses to unconventional monetary policy are analyzed. The results show that when expansionary unconventional monetary policy is employed, it is complemented with the lowering of policy rate as well. However, the magnitude of change in the policy rate is reasonably small, and the shock does not yield any impact in the long-run.

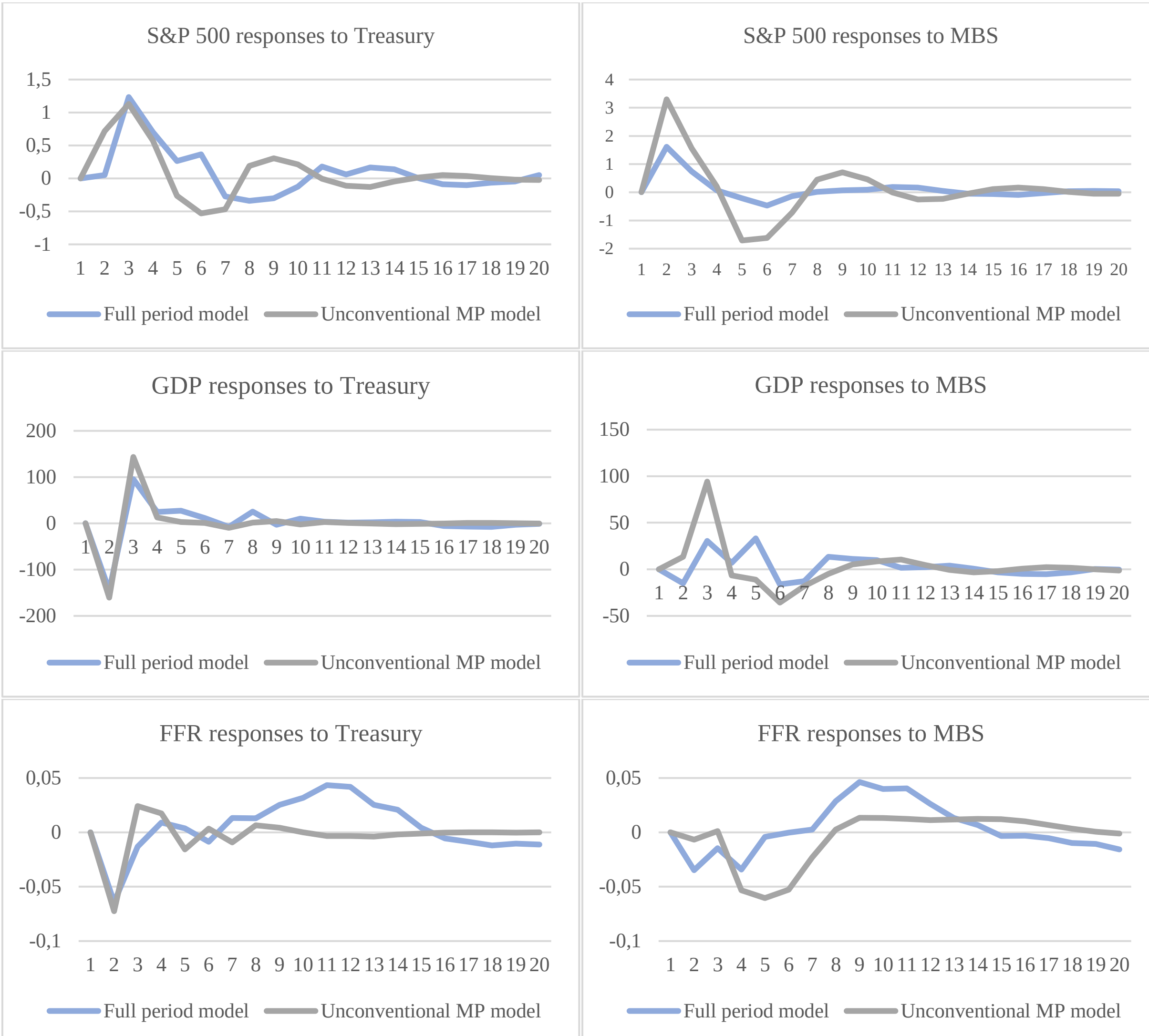


Figure 17. Responses of transmission channel and conventional MP variables

Discussion and policy implications

Unconventional monetary policy effects on long-term interest rates and inflation were studied and results were analyzed. Impulse response functions indicate dynamic behavior that is important to address. Even though the aforementioned findings were mostly illustrated as the effects of expansionary monetary policy, the impact of contractionary policy is estimated to be the opposite. Moreover, monetary policy shock in MBS varies between $42 and $69 billion, while US Treasury shock is between $141 and $180 billion. These amounts correspond to two month reduction in MBS and a single quarter reduction in US Treasury securities since the FED declared that capped monthly reduction is $35 and $60 billions in 2022, respectively. Therefore, the identified impact would be accumulated throughout the contractionary cycle.

First, empirical analysis has shown that contractionary monetary policy reduces inflation in the short-term. It is understood that the change does not occur instantly, therefore the transmission of monetary policy was examined. However, VAR methodology does not allow to segregate net impact of QT on inflation by different transmission channels, hence the effect of each channel is evaluated separately.

Contractionary monetary policy has a positive impact on long-term interest rates. This supports the hypothesis raised in this thesis that QT raises long-term interest rates, thus the hypothesis cannot be rejected. Also, the results suggest that the portfolio balancing channel is one of the main transmission channels through which QT affects inflation. In the short-run, decrease in the securities held by the central bank or reduction in the pace of purchases raises long-term rates, therefore the borrowing conditions deteriorate for both households and businesses. Furthermore, an increase in long-term rates leads to worsening economic outlook that results in the upturn in the savings rate, and lower spending. However, in the longer period there was no impact of contractionary monetary policy on long-term interest rates observed.

It was estimated that QT has a significant negative impact on asset prices. Asset prices channel is closely related to several other transmission channels such as portfolio rebalancing or bank lending. A decrease in asset prices affects inflation through the impact on long-term rates since the price and yield are inversely related. It also reduces banks' liquidity, which leads to a downturn in lending availability. Moreover, it was found that QT leads to a reduction in the economic output. This contributes to the decrease in overall expectations about the health of the economy as well as to the diminishing demand.

The effect of long-term interest rates on inflation yields ambiguous results. It is evident that increase in long-term rates has an impact on the price level, however the significance and the direction of change is varying across the constructed models. Therefore, the econometric findings do not support the hypothesis, that the rise in long-term interest leads to reduction in inflation, with high degree of confidence.

Lastly, the effect on policy rate suggests that conventional and unconventional monetary policy measures are employed collectively. In the case of QE, when policy rate has reached zero lower bound, conventional policy did not yield any additional impact. Therefore, QE has become the main policy tool to achieve FED's dual mandate. This is particularly important point when QT is considered. There is no upper policy rate limit when contractionary measures are employed. The FED raises its policy rate alongside QT, which aims to lower long-term interest faster. Therefore, the FED has to be especially cautious in measuring the extent of QT since the actual effect of both policies takes time to occur.

The findings of econometric analysis suggest that QT affects the economy in a numerous ways. It is a particularly important topic nowadays since at least one of the largest economies is already in the contractionary monetary policy period. Analysis shows that QT is an important tool to combat heightened inflation levels. Although, the policy makers should carefully assess the impact of QT since the actual implications of such measures and possible side effects are yet unknown.

System dynamics approach

This part presents the qualitative SD model used to facilitate understanding of the complex relationship between unconventional monetary policy and inflation. The model represents the causal hypotheses for the behavior observed in VAR analysis. The qualitative model constructed by Jančiauskaitė (2022) is used as a reference model. Additional hypotheses have been added to the reference model in order to illustrate the monetary policy transmission from QT to inflation.

A constructed CLD illustrates the feedback loops that are imperative for the purpose of this thesis. For the ease of understanding, unconventional monetary policy variable is setup as “securities purchased” (measured in US dollars per year), which represents QE when the amount increases, and is treated as QT when the pace of purchases drops, becomes zero or negative. To facilitate the understanding of all the relationships and transmission channels, the model is presented here in several steps. The model is shown in a way that firstly the general idea of how to read a CLD is displayed. Next, the full CLD is built in step-by-step process. Stella Architect modeling tool is used for model creation and visualization.

Monetary policy transmission CLD

Figure 18 displays the common understanding of the relationship between monetary policy and inflation. The links that are marked in red are called positive, while the blue are negative. The link from FFR variable to inflation is negative and indicates that, when FFR is raised it affects inflation in the opposite direction, lowers it. Next, the positive link from inflation to FFR, which implies that a decrease in inflation causes FFR to decline as well. The latter loop is a negative loop (N1) since it has an odd number of negative links. Another loop is between securities purchased variable and inflation. It shows that reduction in the purchases causes inflation to decrease, and leads to a decrease in FFR in the future, if and when inflation gap becomes negative; in the meantime, the increases in FFR will be smaller than they otherwise would be. This loops is also negative (N2).

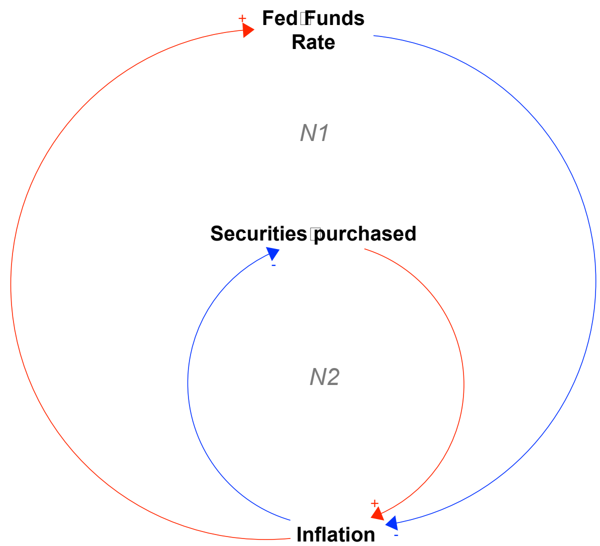


Figure 18. Monetary policy transmission to inflation – general idea

In Figure 19, long-term interest rates are inserted to provide more details to the model. Long-term rates are emphasized in this thesis as being part of the channels, through which the impact of monetary policy is transmitted. Addition of long-term interest rates portrays the transmission in more detail than Figure 18, and facilitates the understanding that the effect on inflation is not instant and takes time to occur. The two loops are as follows. First, the loop N3 from FFR, long-term interest rates, inflation and back to FFR. The rise in policy rate causes long-term rates to increase, therefore the link between these variables is positive. Rise in the long-term rates is expected to lower inflation, which, in turn, leads to a reduction in the policy rate. Note that loop N3 in Figure 19 is a more detailed version of N1 loop in Figure 18. Also, the effect of change from one variable to another is not immediate and takes time to occur, therefore the delays (marked || on the links) are introduced. Second, N4 (more detailed version of N2) is the unconventional monetary policy loop. By reducing the amount of securities purchased, the FED expects to increase long-term rates faster than by only employing conventional policy. Then, rise in the long-term rates lowers inflation, and thus adjustment in the pace of purchases occurs. It is noted, that long-term rates are affected by both conventional and unconventional policy. Therefore, the cumulative impact is more pronounced compared to employing only one branch of policy.

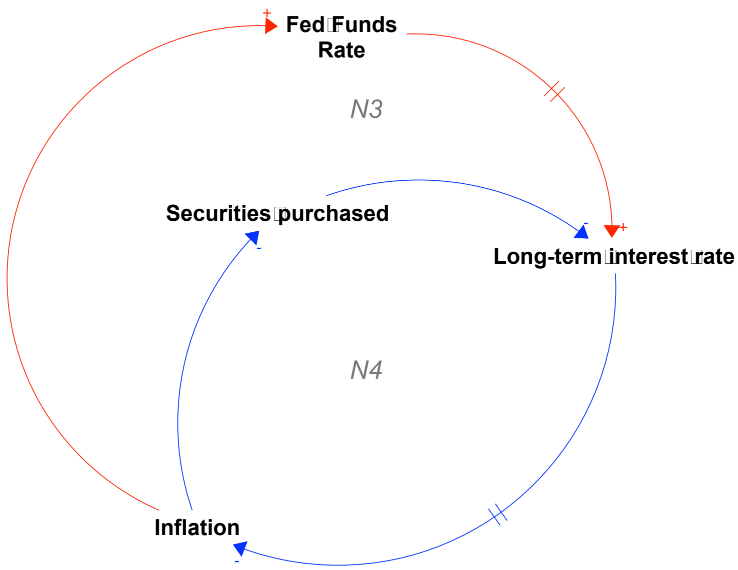


Figure 19. Introduction of long-term interest rates to model

In Figure 20, short-term interest rates, asset prices, bond yields, and bank's cost of fund variables are introduced to the model in order to explain how decisions taken by the FED affect long-term rates. The loops N5 and N6 that are presented in Figure 20 are more detailed versions of N3 and N4 in the Figure 19, respectively. Note the loop N6 from securities purchased, asset prices, bond yields, long-term rates, inflation, and back to securities purchased. When QT is employed, the demand for securities in the open market decreases, thus it leads to a downturn in asset prices – positive link means that they move in the same direction. The inverse price and yield relationship is represented by the negative link from asset prices to bond yields. The behavioral assumption of reinforcing link from bond yields to interest rates is that yields represent risen market expectations for long-term interest rates, therefore long-term rates are raised. Next, in a loop N5 a rise in FFR directly affects short-term interest rates since these are the rates used for banking operations within the banking sector. An increase in short-term rates affects long-term rates through a rise in bank's cost of funds. Higher short-term rates make interbank operations more expensive which translates to the rise in the rates on commercial loans. In a loop N7, an increase in short-term rates adds to the cumulative effect on the asset price, and, in turn, long-term rates. The impact through the asset prices, similarly to the loop N6, is related to the inverse price and yield relationship.

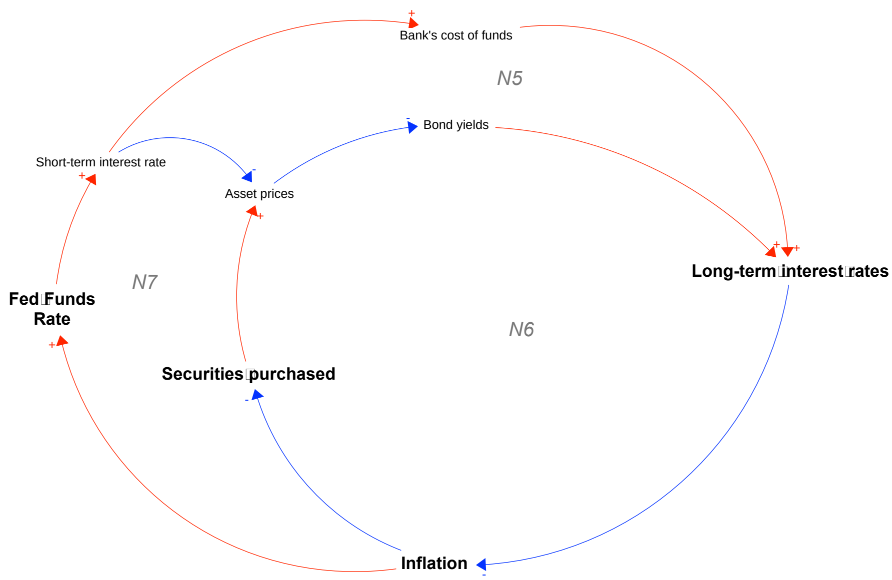


Figure 20. Monetary policy transmission to long-term interest rates

Figure 21 focuses on the dynamics of the changes in long-term rates and its effect on demand and supply sides of the economy. Loop N8 presented in Figure 21 is a more detailed explanation version of loop N5 in Figure 20. The assumed behavior is that long-term rates would affect aggregate demand through changes in investment and consumption components. First, high interest rates discourage investment for both households and businesses. Investment is discouraged due to increased borrowing costs. Also, the access to credit is reduced as lenders become increasingly cautious about the non-repayment risks by the borrowers. Second, higher interest rates lead to lower consumption as any purchases that are made on credit become more expensive. Moreover, higher interest rates act as an economic outlook, hence it could lower market confidence which in turn leads to increased savings rate and lower consumption.

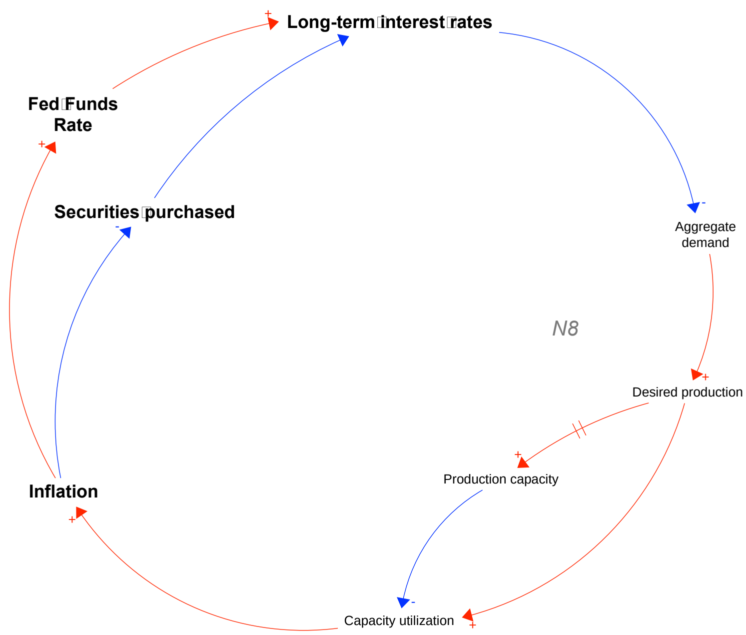


Figure 21. Transmission from long-term rates to inflation

As was discussed, a reduction in both consumption and investment affects aggregate demand. Hence lower demand causes a reduction in desired production, which leads to a decrease in the supply side through lowering capacity utilization and reducing inflation. In order to balance the effects, self-regulating loop is created that includes capacity utilization. Capacity utilization is the ratio of desired production to production capacity. An increase in desired production would cause capacity utilization to rise since more production is demanded and the available output changes slowly (as displayed by the delay mark in Figure 21). Capacity utilization could be lowered by increasing production capacity when additional resources are demanded and introduced to raise the potential of the system, but the process is rather slow. Dynamics between desired production and production capacity are particularly import as it can lead to inefficiencies due to excess production capacity or in the rise of prices due to the lack of supply.

Change in the level of capacity utilization is hypothesized to be the main driver of the changes in inflation. When capacity utilization rises that brings the economy closer to the maximum output that it is able to produce, which could lead to an increase in inflation. When QT is employed, aggregate demand is reduced through the channels that were previously discussed, hence capacity utilization is expected to fall, and cause a downturn in inflation as well.

Figure 22 adds bank lending channel to the model. Loop N9 portrays bank lending channel that works through the change in asset prices, which, as it was examined previously, is affected by both conventional and unconventional monetary policy. A decline in asset prices negatively affects the value of assets that are held by the bank, thus leads to a downturn in net capital and liquidity. This results to diminishing lending due to various restrictions imposed on banks such as capital adequacy ratios. The effect is further transmitted through consumption and investment that were analyzed above.

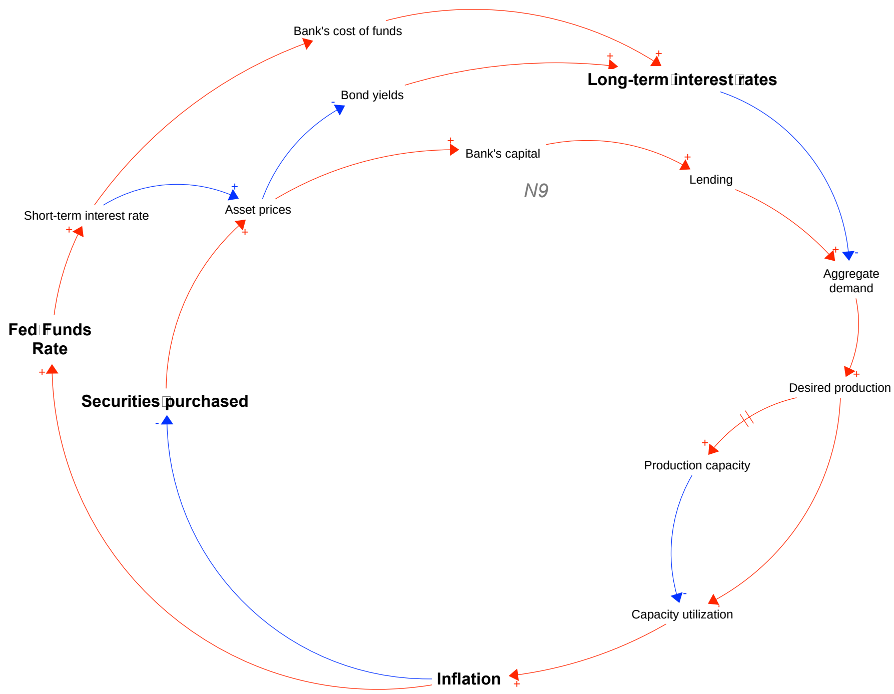


Figure 22. Transmission from monetary policy to inflation

A small addition is made in Figure 23. It emphasizes that the FED's monetary policy behavior is based on the gap between inflation and the inflation goal. Inflation goal is an exogenous parameter and is understood as the FED's 2% inflation target. Inflation gap is defined as current inflation minus inflation goal. A rise in inflation contributes to an increase in the inflation gap. The behavioral assumption for FED's decision about the stance of monetary policy and whether tightening or accommodation is necessary, is that it examines the inflation gap, and adjust the policy accordingly. Hence, heightened inflation results in bigger inflation gap, which in turn encourages increase in the policy rates and decline in the securities purchased. However, the timing or delays on these decisions are not subjects of this thesis.

Additionally, for further research into the impact of QT on inflation, CLD presented in Figure 23 could be converted to stock and flow equations to create a dynamic SD model that simulates the causal links between the variables of interest.

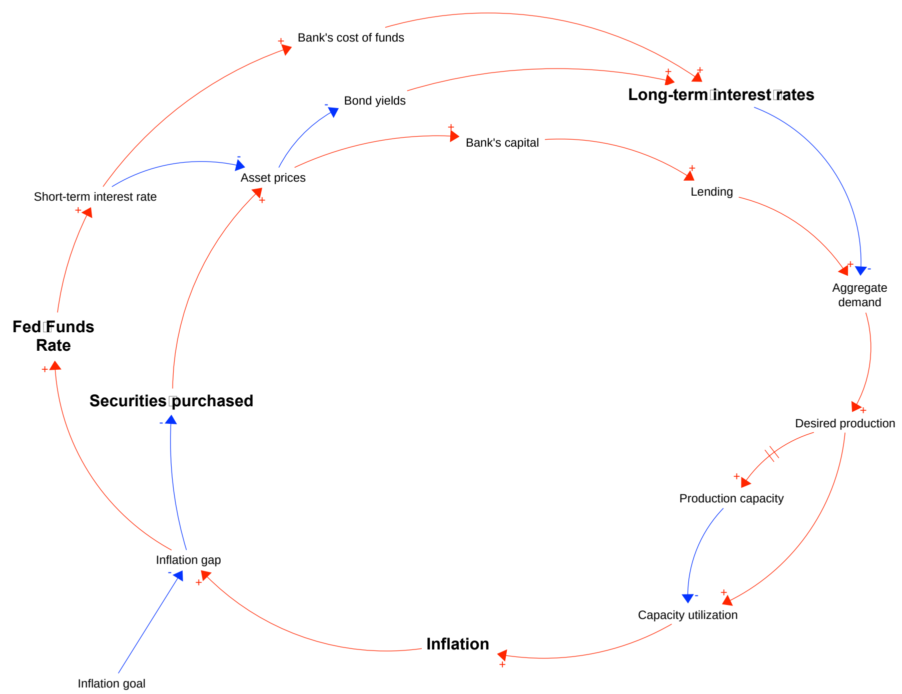


Figure 23. Final CLD of monetary policy transmission

Comparison with VAR analysis results

Implicit causal relationships suggested by the results of VAR analysis are explicit in the CLD. Variables, such as asset prices, long-term interest rates, or economic output, that are crucial in explaining monetary policy transmission in the CLD, have also been employed in the VAR analysis. Expansionary monetary policy was the main instrument to achieve price stability since GFC. Although, inflation has not risen to level that was expected, which has caused a debate whether transmission mechanism that was implicit before the crisis still holds. Recent developments in the financial markets to fight the pandemic and in the post-pandemic period have proved otherwise. The vast accommodation accompanied by the supply chain disruptions has resulted in the significant rise of prices. Therefore, the main transmission channels of monetary policy – asset prices, portfolio rebalancing, bank lending – that were reviewed in the literature part are considered in the analysis. Of course, the strength of causal relationships presented in the CLD could only be explored in a quantitative SD model.

SD analysis implies that the effect of QT on long-term interest rates is relatively quick compared to the slow effect of changes in the short-term rates in conventional monetary policy.

This behavior is supported by VAR modeling as well since it is able to capture the transmission from QT to long-term rates rather accurately. The findings have shown that one of the largest effects of QT was felt on asset prices which has a direct impact on the long-term rates. VAR analysis has shown that contractionary monetary policy measures were estimated to have a significant impact on inflation. However, the transmission from long-term rates to inflation is rather intricate. For long-term rates to have an impact on inflation, the effect has to go via consumption or investment, aggregate demand, desired production, production capacity, and capacity utilization. Therefore, inconclusive results obtained from VAR about the impact of long-term rates on the price level can be explained by the complexity of the monetary policy transmission channels. Also, this suggests that using only econometric analysis might not be sufficient enough tool to precisely evaluate underlying causal relationships between QT and inflation.

All in all, SD approach supports the outcome of VAR modeling which shows that QT has a meaningful impact on inflation. It also facilitates the understanding of monetary policy transmission mechanism to inflation by visualizing it as well as makes the interpretation of VAR results more straightforward and easier understood.

Limitations and recommendations

There are particular areas of this thesis that contribute to the limitations of the empirical research. First, one of the main issues is related to data availability. QT is a very recent phenomenon, therefore the span during which monetary tightening was employed is relatively short compared to QE. For this reason, comparative literature was reviewed in order to establish plausible assumptions of the relationship between QE and QT. Therefore, it is challenging to estimate the actual strength of QT impact on inflation with high degree of confidence. Furthermore, several of the key indicators such as GDP, MBS or Treasury securities holdings, are available only in quarterly or broader frequencies. Hence, inclusion of monthly data could provide more accurate results.

Next, different methods to quantify QT could be employed. The variable could be constructed by analyzing FED’s announcements of the future policy related to QT. It would be beneficial to examine whether the announcements and the size of planned monthly reduction do have an impact on the market, and its expectations. This would allow to compare expansionary and contractionary monetary policy effects through the signaling channel and evaluate whether the latter channel plays a significant role when QT is employed. Similarly, different inflation measure could have been chosen. CPI is presumably one of the most commonly used indices among the researchers. Since CPI is not as conservative as PCE, it could results in more pronounced effects. The basket of measured goods and services does not change when CPI is measured, therefore it could also lead to a more comparable data throughout the extended time frame. Moreover, inclusion of more control variables would allow to examine monetary policy transmission more precisely, especially the transmission from long-term interest rates to inflation since it is one the most complex parts of the model. One of the possibilities is to introduce the determinants that represent supply side effects that would capture the changes in capacity utilization. Last, the outcome of VAR modeling is highly theoretical and the interpretation of generated coefficients is limited. Therefore, the option for supportive econometrical methods to allow for the analysis of both the impulse response functions and the coefficients of the variables could be considered.

In the system dynamics part, a qualitative model that was built visualizes hypotheses of the dynamic interactions between the reinforcing and balancing loops of the system. CLD of this thesis includes the main channels of monetary policy transmission, therefore analysis of the additional factors that could have an impact on inflation could yield further insights into the behavior of the system. Moreover, the confidence of the causal behavior presented in CLD can be strengthened by constructing quantitative SD model. Calibrating the model to the actual data would allow to examine the inherent trends and dynamics that are present in the economic system. Lastly, there is no empirical work on contractionary monetary policy effect on inflation in the field of system dynamics, hence the quantitative SD model would add imperative fundamental knowledge.

For the future research that aims to estimate QT effect on inflation it would be beneficial to included other countries. Since the beginning of 2023, ECB’s conventional monetary policy of raising the euro area interest rates has been complemented with QT as well. Therefore, the relevance of this topic becomes even more important since major economies are likely to follow the route of QT.

Conclusions

The vast liquidity that was created in the financial markets during the recent asset purchase programs accompanied by geopolitical and supply chain factors has sparked the sudden jump in the levels of inflation since the beginning of 2022. The policymakers had to adjust their monetary policy stance in order to achieve the price stability goals. Central banks have employed the combination of both conventional and unconventional contractionary monetary policies to bring down inflation to a desired level. Therefore, the plausible impact of quantitative tightening on inflation is examined. This research studies Federal Reserve's monetary policy actions that were adopted from 2000 to 2022.

Reviewed literature has disclosed that unconventional monetary policy, both contractionary and expansionary, transmits via distinct channels. The main transmission channels, such as asset price, portfolio balancing, signaling, bank lending, and liquidity, were introduced and the effects were discussed. Several key challenges to measure the effects of QT transmission have been identified. First, it is hard to evaluate the significance of QT impact since the historical contractionary period is particularly short. Second, varying market conditions and dominant transmission channels between the first and the recent cycles of QT make the analysis of the effect especially complex. Finally, impact of QT is estimated to be the reverse of the effect of the most recently employed asset purchase programs that had a significant influence on inflation.

Econometric analysis is performed using VAR modeling which is complemented with a system dynamics causal loop diagram. The aim of CLD is to provide visual description of monetary policy transmission. It simplifies and emphasizes the main transmission channels and the causal links between the variables of interest. The model facilitates the understanding of dynamic behavior implicit in the findings of econometric research. Quantitative research is done using quarterly data from the US. Variables for VAR model are grouped into three categories – macroeconomic, monetary policy and transmission channel. PCE was used as an inflation measure. MBS and US Treasury security holdings on the FED's balance sheet were included to account for the QT shock. Three separate models were constructed to check the robustness of the results.

Two hypotheses were raised for the purpose of this thesis. First, that QT causes long-term interest rates to rise. Second, that an increase in long-term interest rates leads to a reduction in inflation. The first hypothesis cannot be rejected based on the findings of econometric modeling. Although, there is not enough significant evidences to confidently support the second hypothesis. The results imply that a contractionary unconventional monetary policy shock weakens inflation. It was estimated that QT significantly raises long-term interest in the short-term. The negative impact on asset prices and economic output supports the results of monetary policy transmission to inflation as well. Although, the pass through from long-term interest rates to inflation has yielded inconsistent results. In general, econometrics outcome suggests that inflation can be affected through asset price and portfolio balancing channels.

In conclusion, particular aspects can be improved that could provide additional insights into this research. Inclusion of supply side related variables would enable to more accurately evaluate the link from long-term interest rates to inflation. Also, the effects of QT could be estimated for an alternative financial system. Additionally, building a quantitative SD model would allow a more confident determination of the relative strength (i.e. importance) of the feedback loops in the CLD, that would further contribute to the scarce literature on underlying principles of QT.

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Appendices

Appendix 1.

Initial stationarity tests

```
Augmented Dickey-Fuller test for GDP
testing down from 11 lags, criterion AIC
sample size 92
unit-root null hypothesis: a = 1

  with constant and trend
  including 0 lags of (1-L)GDP
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
  estimated value of (a - 1): -0.227059
  test statistic: tau_ct(1) = -3.28253
  asymptotic p-value 0.0691
  1st-order autocorrelation coeff. for e: -0.098


KPSS test for GDP (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.218451

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value < .01

Augmented Dickey-Fuller test for Yield
testing down from 11 lags, criterion AIC
sample size 92
unit-root null hypothesis: a = 1

  with constant and trend
  including 3 lags of (1-L)Yield
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.151165
  test statistic: tau_ct(1) = -2.25287
  asymptotic p-value 0.4594
  1st-order autocorrelation coeff. for e: -0.024
  lagged differences: F(3, 86) = 3.865 [0.0121]

KPSS test for Yield (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.180292

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
Interpolated p-value 0.031

Augmented Dickey-Fuller test for SP500
testing down from 11 lags, criterion AIC
sample size 88
unit-root null hypothesis: a = 1

  with constant and trend
  including 7 lags of (1-L)SP500
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.00342728
  test statistic: tau_ct(1) = -0.107041
```

```
  asymptotic p-value 0.9948
  1st-order autocorrelation coeff. for e: 0.018
  lagged differences: F(7, 78) = 3.285 [0.0041]

KPSS test for SP500 (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.498079

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value < .01

Augmented Dickey-Fuller test for FFR
testing down from 11 lags, criterion AIC
sample size 92
unit-root null hypothesis: a = 1

  with constant and trend
  including 2 lags of (1-L)FFR
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.0670786
  test statistic: tau_ct(1) = -2.89352
  asymptotic p-value 0.1645
  1st-order autocorrelation coeff. for e: -0.008
  lagged differences: F(2, 87) = 48.167 [0.0000]

KPSS test for FFR (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.180874

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
Interpolated p-value 0.031

Augmented Dickey-Fuller test for PCE
testing down from 11 lags, criterion AIC
sample size 86
unit-root null hypothesis: a = 1

  with constant and trend
  including 9 lags of (1-L)PCE
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.14571
  test statistic: tau_ct(1) = -1.43117
  asymptotic p-value 0.8521
  1st-order autocorrelation coeff. for e: 0.032
  lagged differences: F(9, 74) = 7.446 [0.0000]

KPSS test for PCE (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.206743

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
Interpolated p-value 0.015

Augmented Dickey-Fuller test for MBS
```

```
testing down from 11 lags, criterion AIC
sample size 92
unit-root null hypothesis: a = 1

  with constant and trend
  including 0 lags of (1-L)MBS
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
  estimated value of (a - 1): -0.374552
  test statistic: tau_ct(1) = -4.49204
  asymptotic p-value 0.001501
  1st-order autocorrelation coeff. for e: 0.049

KPSS test for MBS (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.0677593

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value > .10

Augmented Dickey-Fuller test for TREAS
testing down from 11 lags, criterion AIC
sample size 92
unit-root null hypothesis: a = 1

  with constant and trend
  including one lag of (1-L)TREAS
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.491459
  test statistic: tau_ct(1) = -5.32455
  asymptotic p-value 3.98e-05
  1st-order autocorrelation coeff. for e: 0.004

KPSS test for TREAS (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.0399401

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value > .10
```

Appendix 2.

Fixed variable stationarity

```
Augmented Dickey-Fuller test for d_GDP
testing down from 11 lags, criterion AIC
sample size 91
unit-root null hypothesis: a = 1

  with constant and trend
  including 0 lags of (1-L)d_GDP
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
  estimated value of (a - 1): -1.23088
  test statistic: tau_ct(1) = -11.866
  asymptotic p-value 8.372e-28
  1st-order autocorrelation coeff. for e: -0.019

KPSS test for d_GDP (including trend)
```

```
T = 92
Lag truncation parameter = 3
Test statistic = 0.0401214

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value > .10

Augmented Dickey-Fuller test for d_Yield
testing down from 11 lags, criterion AIC
sample size 91
unit-root null hypothesis: a = 1

  with constant and trend
  including 0 lags of (1-L)d_Yield
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
  estimated value of (a - 1): -0.817462
  test statistic: tau_ct(1) = -7.73218
  asymptotic p-value 1.452e-11
  1st-order autocorrelation coeff. for e: 0.040

KPSS test for d_Yield (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.0652889

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value > .10

Augmented Dickey-Fuller test for p_SP500
testing down from 11 lags, criterion AIC
sample size 92
unit-root null hypothesis: a = 1

  with constant and trend
  including 0 lags of (1-L)p_SP500
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
  estimated value of (a - 1): -0.725034
  test statistic: tau_ct(1) = -7.17552
  asymptotic p-value 7.604e-10
  1st-order autocorrelation coeff. for e: 0.020

KPSS test for p_SP500 (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.0506117

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value > .10

Augmented Dickey-Fuller test for d_FFR
testing down from 11 lags, criterion AIC
sample size 92
unit-root null hypothesis: a = 1

  with constant and trend
  including 0 lags of (1-L)d_FFR
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
```

```
  estimated value of (a - 1): -0.277303
  test statistic: tau_ct(1) = -3.46723
  asymptotic p-value 0.04294
  1st-order autocorrelation coeff. for e: -0.058


KPSS test for d_FFR (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.0549321

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value > .10

Augmented Dickey-Fuller test for d_PCE
testing down from 11 lags, criterion AIC
sample size 83
unit-root null hypothesis: a = 1

  with constant and trend
  including 11 lags of (1-L)d_PCE
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -1.63217
  test statistic: tau_ct(1) = -3.67607
  asymptotic p-value 0.02388
  1st-order autocorrelation coeff. for e: 0.007
  lagged differences: F(11, 69) = 5.911 [0.0000]

KPSS test for d_PCE (including trend)

T = 92
Lag truncation parameter = 3
Test statistic = 0.0470333

                   10%      5%      1%
Critical values: 0.120   0.148   0.215
P-value > .10
```

Appendix 3.

Cointegration

Full period:

```
Step 1: cointegrating regression

Cointegrating regression -
OLS, using observations 2000:1-2022:4 (T = 92)
Dependent variable: d_GDP

             coefficient     std. error    t-ratio    p-value
  -----------------------------------------------------------
  const       88.9305        42.8503        2.075     0.0410  **
  d_Yield    -54.5491        67.4072       -0.8092    0.4207
  p_SP500     13.2115         3.66692       3.603     0.0005  ***
  d_FFR       43.5194        51.2419        0.8493    0.3981
  d_PCE       97.3199        34.0775        2.856     0.0054  ***
  MBS         -0.000712545    0.000275390  -2.587     0.0114  **
  TREAS       -0.000356529    0.000133797  -2.665     0.0092  ***
  time         0.0745205      0.822311      0.09062   0.9280
```

```
Mean dependent var   79.33928   S.D. dependent var   244.5734
Sum squared resid     3197296   S.E. of regression   195.0975
R-squared            0.412615   Adjusted R-squared   0.363666
Log-likelihood      -611.5196   Akaike criterion     1239.039
Schwarz criterion    1259.214   Hannan-Quinn         1247.182
rho                 -0.311612   Durbin-Watson        2.619606

Step 2: testing for a unit root in uhat

Augmented Dickey-Fuller test for uhat
testing down from 4 lags, criterion AIC
sample size 91
unit-root null hypothesis: a = 1

  test without constant
  including 0 lags of (1-L)uhat
  model: (1-L)y = (a-1)*y(-1) + e
  estimated value of (a - 1): -1.31161
  test statistic: tau_ct(7) = -13.1187
  asymptotic p-value 2.865e-19
  1st-order autocorrelation coeff. for e: 0.023

There is evidence for a cointegrating relationship if:
(a) The unit-root hypothesis is not rejected for the individual variables, and
(b) the unit-root hypothesis is rejected for the residuals (uhat) from the
    cointegrating regression.
```

Unconventional monetary policy period:

```
Step 1: cointegrating regression

Cointegrating regression -
OLS, using observations 2008:4-2022:4 (T = 57)
Dependent variable: d_GDP

             coefficient     std. error     t-ratio   p-value
  -----------------------------------------------------------
  const      159.949        149.446         1.070    0.2897
  d_Yield    -98.1872       109.710        -0.8950   0.3752
  p_SP500     14.1274         5.85169       2.414    0.0195  **
  d_FFR       89.4973       117.972         0.7586   0.4517
  d_PCE      117.321         51.8036        2.265    0.0280  **
  MBS         -0.000739625    0.000371495  -1.991    0.0521  *
  TREAS       -0.000344594    0.000190349  -1.810    0.0764  *
  time        -0.985252       2.28335      -0.4315   0.6680

Mean dependent var   78.56023   S.D. dependent var   306.2958
Sum squared resid     2950232   S.E. of regression   245.3748
R-squared            0.438453   Adjusted R-squared   0.358232
Log-likelihood      -390.2283   Akaike criterion     796.4565
Schwarz criterion    812.8010   Hannan-Quinn         802.8085
rho                 -0.264400   Durbin-Watson        2.501944

Step 2: testing for a unit root in uhat

Augmented Dickey-Fuller test for uhat
testing down from 4 lags, criterion AIC
sample size 56
unit-root null hypothesis: a = 1

  test without constant
  including 0 lags of (1-L)uhat
  model: (1-L)y = (a-1)*y(-1) + e
```

```
  estimated value of (a - 1): -1.2644
  test statistic: tau_ct(7) = -9.86495
  asymptotic p-value 6.873e-12
  1st-order autocorrelation coeff. for e: -0.006

There is evidence for a cointegrating relationship if:
(a) The unit-root hypothesis is not rejected for the individual variables, and
(b) the unit-root hypothesis is rejected for the residuals (uhat) from the
    cointegrating regression.
```

Appendix 4.

VAR lag selection

Baseline model:

```
VAR system, maximum lag order 8

The asterisks below indicate the best (that is, minimized) values
of the respective information criteria, AIC = Akaike criterion,
BIC = Schwarz Bayesian criterion and HQC = Hannan-Quinn criterion.

lags        loglik    p(LR)       AIC          BIC          HQC

   1   -2216.51523             53.631315    54.673094*   54.050101*
   2   -2206.77935  0.24496   53.780461    55.285252    54.385374
   3   -2188.87575  0.00308   53.735137    55.702941    54.526178
   4   -2148.09658  0.00000   53.145157*   55.575973    54.122325
   5   -2134.56973  0.04089   53.204041    56.097871    54.367336
   6   -2123.22387  0.12223   53.314854    56.671696    54.664276
   7   -2110.95070  0.07823   53.403588    57.223443    54.939138
   8   -2089.13979  0.00023   53.265233    57.548101    54.986910
```

Alternative model – full period:

```
VAR system, maximum lag order 8

The asterisks below indicate the best (that is, minimized) values
of the respective information criteria, AIC = Akaike criterion,
BIC = Schwarz Bayesian criterion and HQC = Hannan-Quinn criterion.

lags        loglik    p(LR)       AIC          BIC          HQC

   1   -3021.33933             73.436651    75.259763*   74.169527
   2   -2941.92197  0.00000   72.712428    75.953517    74.015318*
   3   -2896.01905  0.00021   72.786168    77.445233    74.659073
   4   -2825.93495  0.00000   72.284165    78.361207    74.727085
   5   -2783.96282  0.00139   72.451496    79.946514    75.464430
   6   -2740.74338  0.00077   72.589128    81.502123    76.172077
   7   -2680.18445  0.00000   72.313916    82.644887    76.466879
   8   -2601.78235  0.00000   71.613865*   83.362813    76.336844
```

Alternative model – unconventional monetary policy period

```
VAR system, maximum lag order 4

The asterisks below indicate the best (that is, minimized) values
of the respective information criteria, AIC = Akaike criterion,
BIC = Schwarz Bayesian criterion and HQC = Hannan-Quinn criterion.

lags        loglik    p(LR)       AIC          BIC          HQC
```

1	-2057.07109		74.388459	76.646569*	75.266038
2	-1965.38117	0.00000	72.890567	76.904984	74.450706
3	-1906.20077	0.00000	72.533360	78.304084	74.776060
4	-1792.96617	0.00000	70.279515*	77.806546	73.204775*

Appendix 5.

Autocorrelation and heteroscedasticity

Test for autocorrelation of order up to 4

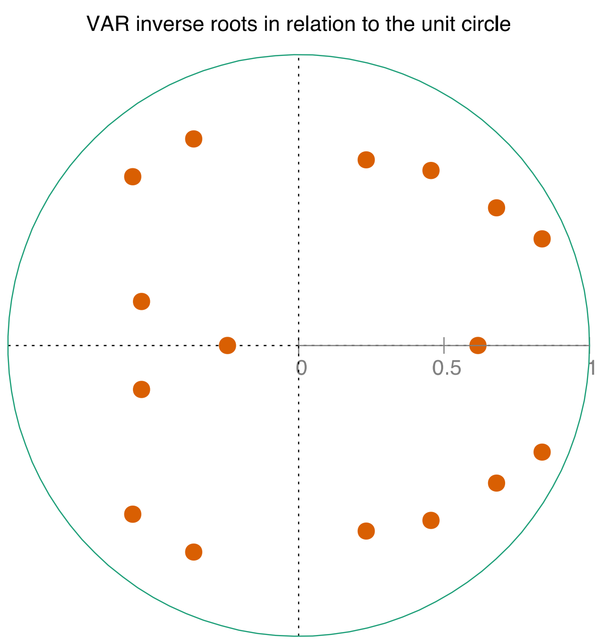
	Rao F	Approx dist.	p-value
lag 1	1.444	F(16, 196)	0.1248
lag 2	1.069	F(32, 222)	0.3748
lag 3	0.849	F(48, 217)	0.7469
lag 4	0.941	F(64, 205)	0.6044

Test for ARCH of order up to 4

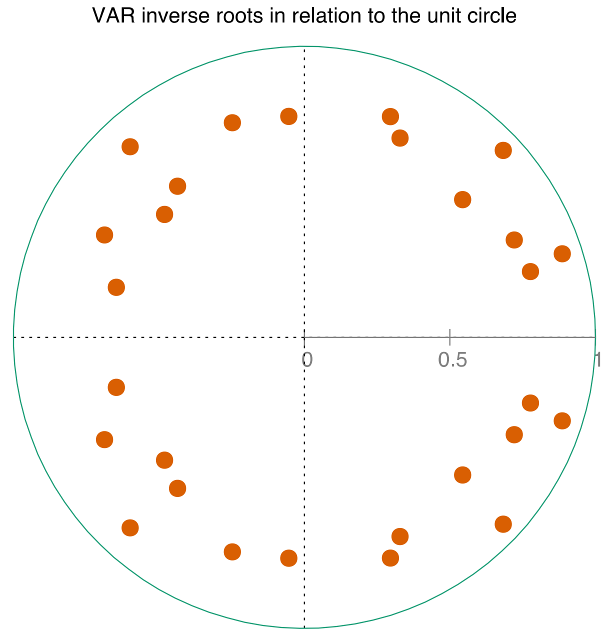
	LM	df	p-value
lag 1	102.314	100	0.4170
lag 2	187.288	200	0.7311
lag 3	277.566	300	0.8192
lag 4	371.388	400	0.8445

VAR inverse roots

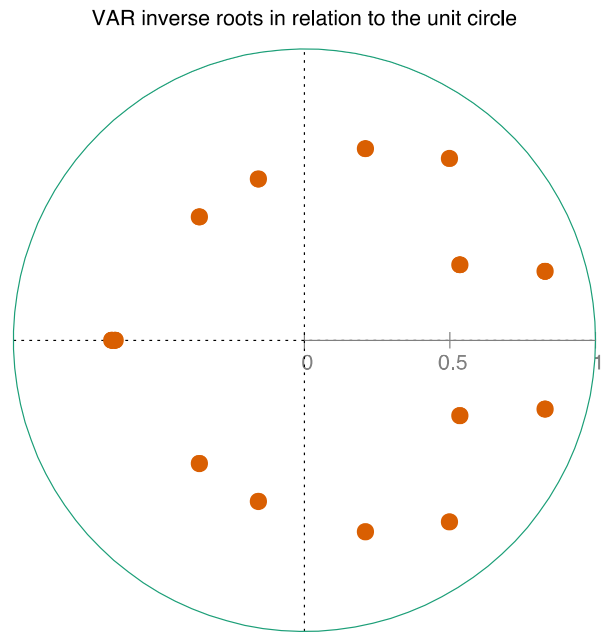
Baseline model:



Alternative model – full period:



Alternative model – unconventional monetary policy period:



Appendix 6.

Baseline model

```
VAR system, lag order 4
OLS estimates, observations 2001:1-2022:4 (T = 88)
Log-likelihood = -2248.2056
Determinant of covariance matrix = 1.8223508e+17
AIC = 53.0047
BIC = 55.3694
```

HQC = 53.9574
Portmanteau test: LB(22) = 309.736, df = 288 [0.1810]

Equation 1: d_PCE
HAC standard errors, bandwidth 3 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−0.0594083	0.0864499	−0.6872	0.4943	
d_PCE_1	0.328988	0.0785623	4.188	<0.0001	***
d_PCE_2	−0.186668	0.0881279	−2.118	0.0379	**
d_PCE_3	0.0596226	0.118365	0.5037	0.6161	
d_PCE_4	−0.488354	0.129050	−3.784	0.0003	***
d_Yield_1	0.0753180	0.140889	0.5346	0.5947	
d_Yield_2	−0.138494	0.199599	−0.6939	0.4902	
d_Yield_3	0.0810665	0.204641	0.3961	0.6933	
d_Yield_4	−0.0489071	0.168936	−0.2895	0.7731	
MBS_1	−3.10014e-06	8.53349e-07	−3.633	0.0005	***
MBS_2	7.83263e-07	9.40882e-07	0.8325	0.4081	
MBS_3	2.70212e-06	8.44685e-07	3.199	0.0021	***
MBS_4	−9.97742e-07	1.05879e-06	−0.9423	0.3494	
TREAS_1	1.74593e-07	5.23583e-07	0.3335	0.7398	
TREAS_2	1.58154e-06	6.59834e-07	2.397	0.0193	**
TREAS_3	−2.12749e-06	5.89108e-07	−3.611	0.0006	***
TREAS_4	1.23891e-06	4.74575e-07	2.611	0.0111	**
d_GDP	0.000436956	0.000273955	1.595	0.1154	
p_SP500	0.0229706	0.0133438	1.721	0.0898	*
d_FFR	0.109413	0.146875	0.7449	0.4589	
time	7.29470e-05	0.00172939	0.04218	0.9665	

Mean dependent var	0.035907	S.D. dependent var	0.652948
Sum squared resid	16.58551	S.E. of regression	0.497539
R-squared	0.552851	Adjusted R-squared	0.419374
F(20, 67)	27.60593	P-value(F)	8.24e-25
rho	0.032357	Durbin-Watson	1.906257

F-tests of zero restrictions:

All lags of d_PCE	F(4, 67) =	20.78	[0.0000]
All lags of d_Yield	F(4, 67) =	0.16931	[0.9533]
All lags of MBS	F(4, 67) =	5.4663	[0.0007]
All lags of TREAS	F(4, 67) =	5.569	[0.0006]
All vars, lag 4	F(4, 67) =	6.3996	[0.0002]

Equation 2: d_Yield
HAC standard errors, bandwidth 3 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−0.0595070	0.0568957	−1.046	0.2994	
d_PCE_1	0.00551604	0.0498488	0.1107	0.9122	
d_PCE_2	−0.00241025	0.0525491	−0.04587	0.9636	
d_PCE_3	−0.0131659	0.0625639	−0.2104	0.8340	
d_PCE_4	0.156744	0.0445656	3.517	0.0008	***
d_Yield_1	0.141305	0.113158	1.249	0.2161	
d_Yield_2	−0.230123	0.0892830	−2.577	0.0122	**
d_Yield_3	0.120985	0.112111	1.079	0.2844	
d_Yield_4	−0.219508	0.100495	−2.184	0.0324	**

MBS_1	1.08478e-06	5.74915e-07	1.887	0.0635	*
MBS_2	−9.13874e-07	6.84564e-07	−1.335	0.1864	
MBS_3	1.20805e-06	4.29756e-07	2.811	0.0065	***
MBS_4	−4.13306e-07	5.46838e-07	−0.7558	0.4524	
TREAS_1	−1.40475e-06	3.37891e-07	−4.157	<0.0001	***
TREAS_2	1.16281e-06	4.69594e-07	2.476	0.0158	**
TREAS_3	−4.89617e-07	4.48640e-07	−1.091	0.2790	
TREAS_4	2.32115e-07	2.87123e-07	0.8084	0.4217	
d_GDP	−0.000512262	0.000215367	−2.379	0.0202	**
p_SP500	0.0211576	0.00468334	4.518	<0.0001	***
d_FFR	0.156641	0.0830379	1.886	0.0636	*
time	0.000737111	0.00118392	0.6226	0.5357	

Mean dependent var	−0.019735	S.D. dependent var	0.359063
Sum squared resid	6.100939	S.E. of regression	0.301760
R-squared	0.456080	Adjusted R-squared	0.293715
F(20, 67)	29.35523	P-value(F)	1.38e-25
rho	−0.148682	Durbin-Watson	2.259348

F-tests of zero restrictions:

All lags of d_PCE	F(4, 67) =	3.2231	[0.0176]
All lags of d_Yield	F(4, 67) =	2.8179	[0.0318]
All lags of MBS	F(4, 67) =	4.2164	[0.0042]
All lags of TREAS	F(4, 67) =	7.7067	[0.0000]
All vars, lag 4	F(4, 67) =	3.9819	[0.0059]

Equation 3: MBS
HAC standard errors, bandwidth 3 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	26337.6	7828.73	3.364	0.0013	***
d_PCE_1	−27730.6	17475.9	−1.587	0.1173	
d_PCE_2	−1372.46	10361.0	−0.1325	0.8950	
d_PCE_3	−14492.4	6787.71	−2.135	0.0364	**
d_PCE_4	−19316.3	5744.79	−3.362	0.0013	***
d_Yield_1	17231.0	15150.7	1.137	0.2595	
d_Yield_2	−12769.1	11494.3	−1.111	0.2706	
d_Yield_3	44870.6	17160.2	2.615	0.0110	**
d_Yield_4	−17778.6	16318.3	−1.089	0.2798	
MBS_1	0.714526	0.0826644	8.644	<0.0001	***
MBS_2	0.0523991	0.129143	0.4057	0.6862	
MBS_3	−0.0556612	0.111336	−0.4999	0.6188	
MBS_4	−0.153211	0.0855470	−1.791	0.0778	*
TREAS_1	−0.00624675	0.0579873	−0.1077	0.9145	
TREAS_2	−0.0100040	0.0863542	−0.1158	0.9081	
TREAS_3	−0.0198783	0.0738516	−0.2692	0.7886	
TREAS_4	0.151261	0.0522418	2.895	0.0051	***
d_GDP	−264.059	37.3348	−7.073	<0.0001	***
p_SP500	1895.16	894.163	2.119	0.0378	**
d_FFR	1851.97	8155.45	0.2271	0.8211	
time	5.50738	138.429	0.03978	0.9684	

Mean dependent var	25795.61	S.D. dependent var	93475.14

Sum squared resid	1.18e+11	S.E. of regression	42055.09
R-squared	0.844116	Adjusted R-squared	0.797584
F(20, 67)	301.3131	P-value(F)	1.10e-57
rho	−0.081706	Durbin-Watson	2.124695

F-tests of zero restrictions:

All lags of d_PCE	F(4, 67) =	3.6912 [0.0089]
All lags of d_Yield	F(4, 67) =	2.0534 [0.0968]
All lags of MBS	F(4, 67) =	62.285 [0.0000]
All lags of TREAS	F(4, 67) =	16.498 [0.0000]
All vars, lag 4	F(4, 67) =	12.475 [0.0000]

Equation 4: TREAS
HAC standard errors, bandwidth 3 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−5572.82	34790.9	−0.1602	0.8732	
d_PCE_1	−2210.72	13635.1	−0.1621	0.8717	
d_PCE_2	−33969.4	17148.9	−1.981	0.0517	*
d_PCE_3	−1143.34	17317.4	−0.06602	0.9476	
d_PCE_4	−63321.8	33016.6	−1.918	0.0594	*
d_Yield_1	−3993.22	40601.6	−0.09835	0.9219	
d_Yield_2	−113966	83530.8	−1.364	0.1770	
d_Yield_3	−1838.27	34440.3	−0.05338	0.9576	
d_Yield_4	4629.51	43361.9	0.1068	0.9153	
MBS_1	−0.730004	0.353215	−2.067	0.0426	**
MBS_2	0.293598	0.328275	0.8944	0.3743	
MBS_3	−0.0831789	0.212847	−0.3908	0.6972	
MBS_4	0.183410	0.201505	0.9102	0.3660	
TREAS_1	0.650671	0.118953	5.470	<0.0001	***
TREAS_2	0.119202	0.136069	0.8760	0.3841	
TREAS_3	−0.401395	0.193561	−2.074	0.0420	**
TREAS_4	0.280557	0.117261	2.393	0.0195	**
d_GDP	−235.928	69.3725	−3.401	0.0011	***
p_SP500	4446.37	2405.09	1.849	0.0689	*
d_FFR	−16079.2	28296.7	−0.5682	0.5718	
time	870.695	991.570	0.8781	0.3830	

Mean dependent var	51676.86	S.D. dependent var	200205.3
Sum squared resid	1.33e+12	S.E. of regression	141140.4
R-squared	0.617257	Adjusted R-squared	0.503005
F(20, 67)	42.80763	P-value(F)	1.79e-30
rho	−0.034328	Durbin-Watson	2.063095

F-tests of zero restrictions:

All lags of d_PCE	F(4, 67) =	1.7609 [0.1471]
All lags of d_Yield	F(4, 67) =	1.2038 [0.3174]
All lags of MBS	F(4, 67) =	2.2668 [0.0711]
All lags of TREAS	F(4, 67) =	36.329 [0.0000]
All vars, lag 4	F(4, 67) =	8.481 [0.0000]

For the system as a whole
Null hypothesis: the longest lag is 3
Alternative hypothesis: the longest lag is 4
Likelihood ratio test: Chi-square(16) = 81.6247 [0.0000]

Appendix 7.

Alternative model – full period

```
VAR system, lag order 4
OLS estimates, observations 2001:1-2022:4 (T = 88)
Log-likelihood = -2973.858
Determinant of covariance matrix = 5.3166377e+20
AIC = 72.3604
BIC = 78.2722
HQC = 74.7421
Portmanteau test: LB(22) = 903.908, df = 882 [0.2970]
```

Equation 1: d_PCE
HAC standard errors, bandwidth 3 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−0.203778	0.130554	−1.561	0.1240	
d_PCE_1	0.128752	0.0846986	1.520	0.1339	
d_PCE_2	−0.139915	0.0722104	−1.938	0.0575	*
d_PCE_3	0.0523897	0.0894492	0.5857	0.5604	
d_PCE_4	−0.456897	0.137738	−3.317	0.0016	***
d_Yield_1	0.0308603	0.142557	0.2165	0.8294	
d_Yield_2	0.0527510	0.221886	0.2377	0.8129	
d_Yield_3	0.181369	0.214327	0.8462	0.4009	
d_Yield_4	0.199398	0.198326	1.005	0.3189	
d_FFR_1	−0.101146	0.188634	−0.5362	0.5939	
d_FFR_2	−0.0141016	0.133210	−0.1059	0.9161	
d_FFR_3	0.462873	0.248343	1.864	0.0674	*
d_FFR_4	−0.408057	0.155188	−2.629	0.0109	**
p_SP500_1	0.0336617	0.00980802	3.432	0.0011	***
p_SP500_2	−0.00921349	0.0107151	−0.8599	0.3934	
p_SP500_3	−0.0142606	0.0120795	−1.181	0.2426	
p_SP500_4	−0.0251142	0.0108926	−2.306	0.0247	**
d_GDP_1	−0.000236706	0.000540577	−0.4379	0.6631	
d_GDP_2	0.00131116	0.000373233	3.513	0.0009	***
d_GDP_3	0.000764975	0.000409692	1.867	0.0669	*
d_GDP_4	0.000502770	0.000187498	2.681	0.0095	***
MBS_1	−1.42746e-06	1.11543e-06	−1.280	0.2057	
MBS_2	2.91676e-07	1.81273e-06	0.1609	0.8727	
MBS_3	1.43779e-07	1.66872e-06	0.08616	0.9316	
MBS_4	6.91262e-07	1.38706e-06	0.4984	0.6201	
TREAS_1	−6.80192e-07	3.20897e-07	−2.120	0.0383	**
TREAS_2	1.66365e-06	7.75463e-07	2.145	0.0361	**
TREAS_3	5.59151e-07	8.46356e-07	0.6607	0.5114	
TREAS_4	7.25535e-08	6.67091e-07	0.1088	0.9138	
time	0.000657152	0.00170238	0.3860	0.7009	

Mean dependent var	0.035907	S.D. dependent var	0.652948
Sum squared resid	13.18038	S.E. of regression	0.476705
R-squared	0.644654	Adjusted R-squared	0.466982
F(29, 58)	48.57520	P-value(F)	5.50e-31
rho	0.040072	Durbin-Watson	1.905179

F-tests of zero restrictions:

All lags of d_PCE	F(4, 58) = 7.3561	[0.0001]
All lags of d_Yield	F(4, 58) = 0.41542	[0.7968]
All lags of d_FFR	F(4, 58) = 2.0055	[0.1057]
All lags of p_SP500	F(4, 58) = 3.4935	[0.0127]
All lags of d_GDP	F(4, 58) = 5.7702	[0.0006]
All lags of MBS	F(4, 58) = 0.88692	[0.4776]
All lags of TREAS	F(4, 58) = 8.543	[0.0000]
All vars, lag 4	F(7, 58) = 9.4982	[0.0000]

Equation 2: d_Yield
HAC standard errors, bandwidth 3 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−0.121411	0.0785605	−1.545	0.1277	
d_PCE_1	−0.0836140	0.0697056	−1.200	0.2352	
d_PCE_2	−0.0103945	0.0683591	−0.1521	0.8797	
d_PCE_3	−0.0308019	0.0664849	−0.4633	0.6449	
d_PCE_4	0.151849	0.0643584	2.359	0.0217	**
d_Yield_1	0.104358	0.104302	1.001	0.3212	
d_Yield_2	−0.0896781	0.131176	−0.6837	0.4969	
d_Yield_3	0.242340	0.139867	1.733	0.0885	*
d_Yield_4	−0.159077	0.112400	−1.415	0.1623	
d_FFR_1	0.0923837	0.120419	0.7672	0.4461	
d_FFR_2	−0.223844	0.116996	−1.913	0.0607	*
d_FFR_3	0.296101	0.176691	1.676	0.0992	*
d_FFR_4	−0.0347117	0.103031	−0.3369	0.7374	
p_SP500_1	0.0165383	0.00545467	3.032	0.0036	***
p_SP500_2	−0.00851496	0.00758773	−1.122	0.2664	
p_SP500_3	−0.00712621	0.00661997	−1.076	0.2862	
p_SP500_4	−0.00531320	0.00835069	−0.6363	0.5271	
d_GDP_1	−0.000198395	0.000256772	−0.7727	0.4429	
d_GDP_2	0.000237055	0.000315920	0.7504	0.4561	
d_GDP_3	0.000103136	0.000253227	0.4073	0.6853	
d_GDP_4	7.13699e-05	0.000190551	0.3745	0.7094	
MBS_1	5.12800e-07	8.59869e-07	0.5964	0.5532	
MBS_2	−2.66266e-07	1.29245e-06	−0.2060	0.8375	
MBS_3	6.19333e-07	9.42677e-07	0.6570	0.5138	
MBS_4	1.94935e-07	7.60707e-07	0.2563	0.7987	
TREAS_1	−7.96020e-07	3.87196e-07	−2.056	0.0443	**
TREAS_2	2.76749e-07	5.19426e-07	0.5328	0.5962	
TREAS_3	4.42037e-07	6.38706e-07	0.6921	0.4916	
TREAS_4	2.62152e-08	4.93842e-07	0.05308	0.9578	
time	0.00148065	0.00156841	0.9440	0.3491	

Mean dependent var	−0.019735	S.D. dependent var	0.359063
Sum squared resid	6.451757	S.E. of regression	0.333522
R-squared	0.424803	Adjusted R-squared	0.137205
F(29, 58)	16.09059	P-value(F)	1.80e-18
rho	−0.096494	Durbin-Watson	2.136356

F-tests of zero restrictions:

All lags of d_PCE	F(4, 58) = 4.9391	[0.0017]
All lags of d_Yield	F(4, 58) = 1.7975	[0.1417]

```
All lags of d_FFR        F(4, 58) =   1.3699 [0.2556]
All lags of p_SP500      F(4, 58) =   5.1927 [0.0012]
All lags of d_GDP        F(4, 58) =  0.45232 [0.7703]
All lags of MBS          F(4, 58) =  0.74279 [0.5668]
All lags of TREAS        F(4, 58) =   2.1441 [0.0868]
All vars, lag 4          F(7, 58) =    2.064 [0.0621]
```

```
For the system as a whole
Null hypothesis: the longest lag is 3
Alternative hypothesis: the longest lag is 4
Likelihood ratio test: Chi-square(49) = 148.738 [0.0000]
```

Appendix 8.

Alternative model – unconventional monetary policy period

```
VAR system, lag order 2
OLS estimates, observations 2008:4-2022:4 (T = 57)
Log-likelihood = -1965.3812
Determinant of covariance matrix = 2.0986964e+21
AIC = 72.8906
BIC = 76.9050
HQC = 74.4507
Portmanteau test: LB(14) = 642.885, df = 588 [0.0579]
```

Equation 1: d_PCE

HAC standard errors, bandwidth 2 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−0.468713	0.333985	−1.403	0.1680	
d_PCE_1	0.207975	0.150313	1.384	0.1740	
d_PCE_2	−0.310985	0.116398	−2.672	0.0108	**
d_Yield_1	0.201956	0.221607	0.9113	0.3675	
d_Yield_2	0.140618	0.224645	0.6260	0.5348	
d_FFR_1	−0.461519	0.198444	−2.326	0.0251	**
d_FFR_2	1.08051	0.529552	2.040	0.0478	**
p_SP500_1	0.0171790	0.0137235	1.252	0.2177	
p_SP500_2	0.0137804	0.0207115	0.6653	0.5096	
d_GDP_1	0.000416004	0.000512650	0.8115	0.4218	
d_GDP_2	0.000328929	0.000195724	1.681	0.1005	
MBS_1	2.61338e-06	2.02738e-06	1.289	0.2046	
MBS_2	−1.14243e-06	1.49966e-06	−0.7618	0.4505	
TREAS_1	−1.01104e-06	4.82695e-07	−2.095	0.0424	**
TREAS_2	1.64397e-06	5.00152e-07	3.287	0.0021	***
time	0.00499742	0.00479565	1.042	0.3035	

Mean dependent var	0.030780	S.D. dependent var	0.743090
Sum squared resid	12.37496	S.E. of regression	0.549389
R-squared	0.599804	Adjusted R-squared	0.453391
F(15, 41)	32.67021	P-value(F)	5.03e-18
rho	0.054527	Durbin-Watson	1.789689

F-tests of zero restrictions:

```
All lags of d_PCE        F(2, 41) =   4.0067 [0.0257]
All lags of d_Yield      F(2, 41) =  0.84207 [0.4381]
All lags of d_FFR        F(2, 41) =   3.6989 [0.0334]
All lags of p_SP500      F(2, 41) =  0.78392 [0.4633]
```

```
All lags of d_GDP        F(2, 41) =   1.4874 [0.2379]
All lags of MBS          F(2, 41) =   1.0269 [0.3671]
All lags of TREAS        F(2, 41) =   7.6121 [0.0015]
All vars, lag 2          F(7, 41) =   7.2009 [0.0000]
```

Equation 2: d_Yield
HAC standard errors, bandwidth 2 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−0.386455	0.183157	−2.110	0.0410	**
d_PCE_1	0.00411034	0.0649532	0.06328	0.9498	
d_PCE_2	−0.146742	0.0666578	−2.201	0.0334	**
d_Yield_1	0.208334	0.102572	2.031	0.0488	**
d_Yield_2	−0.167901	0.141566	−1.186	0.2424	
d_FFR_1	0.324050	0.144066	2.249	0.0299	**
d_FFR_2	−0.0152830	0.210623	−0.07256	0.9425	
p_SP500_1	−0.00185140	0.00881109	−0.2101	0.8346	
p_SP500_2	−0.00791804	0.00955983	−0.8283	0.4123	
d_GDP_1	−0.000198108	0.000257447	−0.7695	0.4460	
d_GDP_2	0.000428614	0.000151054	2.837	0.0070	***
MBS_1	2.45911e-07	8.57149e-07	0.2869	0.7756	
MBS_2	7.75829e-07	7.52682e-07	1.031	0.3087	
TREAS_1	−7.32080e-07	2.71216e-07	−2.699	0.0100	**
TREAS_2	6.41861e-07	2.84998e-07	2.252	0.0297	**
time	0.00560890	0.00318418	1.761	0.0856	*

Mean dependent var	−0.000585	S.D. dependent var	0.373495
Sum squared resid	4.109123	S.E. of regression	0.316579
R-squared	0.473994	Adjusted R-squared	0.281553
F(15, 41)	15.70747	P-value(F)	1.97e-12
rho	0.032595	Durbin-Watson	1.884791

F-tests of zero restrictions:

```
All lags of d_PCE        F(2, 41) =    3.062 [0.0576]
All lags of d_Yield      F(2, 41) =   2.6407 [0.0834]
All lags of d_FFR        F(2, 41) =    2.685 [0.0802]
All lags of p_SP500      F(2, 41) =  0.34412 [0.7109]
All lags of d_GDP        F(2, 41) =    4.306 [0.0201]
All lags of MBS          F(2, 41) =   2.4931 [0.0951]
All lags of TREAS        F(2, 41) =   5.8904 [0.0056]
All vars, lag 2          F(7, 41) =   4.0991 [0.0017]
```

```
For the system as a whole
Null hypothesis: the longest lag is 1
Alternative hypothesis: the longest lag is 2
Likelihood ratio test: Chi-square(49) = 183.38 [0.0000]
```