UNIVERSITY OF LJUBLJANA
SCHOOL OF ECONOMICS AND BUSINESS

MASTER'S THESIS

THE IMPACT OF MONETARY POLICY ON THE US EQUITY MARKET DURING COVID-19 PANDEMIC

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AUTHORSHIP STATEMENT

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LIST OF ABBREVIATIONS

repo – repurchase agreement
SVAR – structural vector autoregressive model
CPFF – commercial paper funding facility
VAR – vector autoregressive model
QE – quantitative easing
FED – Federal Reserve System
BHC – bank holding company
TALF – term asset backed security loan facility
FIMA – foreign and international monetary authority
DCF – discounted cash flow model
FCF – free cash flow
M&A – mergers and acquisitions
FFR – Federal Funds rate
LBO – leverage buyouts
IRF – impulse response function
IPO – initial public offering
WACC – weighted average cost of capital
FOMC – Federal Open Market Committee
FEVD – forecast error variance decomposition
CAPM – capital asset pricing model
GMM – generalized method of moments
MBS – mortgage backed securities

INTRODUCTION

Volatile equity markets force central banks to intervene with monetary policy to prevent adverse effects for the economy. Central bank initially changes the Federal Funds rate target to stabilize equity market, because it directly influences real interest rates expectations. Such two-way causal effects of the stock prices and monetary policy measures were also emblematic during the Covid-19 pandemic. While initially we could observe sharp decline of the stock prices due to increased uncertainty, the US Federal Reserve System took aggressive steps to stimulate US economy and reverse market trend. The purpose of this thesis is to identify these relationships, for which I will apply structural VAR method with imposing restrictions on the parameters of interest. Monetary policy developments are becoming important determinant for decision making of market participants, because they influence economic activity and market performance through different transmission mechanisms. Important aspect is wealth transmission mechanism, where increase in asset prices induce increase in consumption by households. Corporation's credit quality improves, because they can pledge their assets in order to obtain loans for new projects. Funding new projects becomes cheaper due to easier raising of funds. Therefore, when there is high liquidity in the market, risk diminishes and the market is stabilizing. However, too much expansionary monetary policy may create asset bubbles, because the market becomes irrational.

In research, I applied the structural VAR identification method, which allows one to measure exogenous responses of a central bank's interventions to an equity market. In the basic vector autoregressive model, it is hard to measure central bank's interventions, because it does not identify simulatenous responses of the equity market. Therefore, I applied the SVAR model, in order to analyse equity price changes, when there were changes in monetary policy. The main problem of the master thesis is identification of central bank's interventions in the S&P 500 equity index. The aim is to get insight into monetary policy interventions and to understand what effects those interventions had on the equity market. Research will study monetary policy variables, such as Federal Funds rate and money supply (M2), to determine their impact on the equity index. For the correct model specification, I had to include US industrial production index, because it can explain market activity.

Results from the empirical analysis suggest that historical central bank's interventions have influenced the equity market. The analysis indicates the policy of central bank with specific bias toward increase in the money supply (M2) and the constant reduction in Federal Funds rates. The master thesis is structured in the following way. In the first part, I provide a theoretical overview of a central bank's functions and monetary policy. In the second part, monetary policy transmission mechanisms and its relations to equity markets are discussed. In the third section, I decribe theoretical concepts of vector autoregressive methodology used in SVAR analysis for the measurement of monetary policy effects. In the fourth section, I analyse the data and performed empirical analysis using SVAR modelling and specification tests. The last section summarizes and concludes the thesis.

1 MONETARY POLICY AND EQUITY PRICES

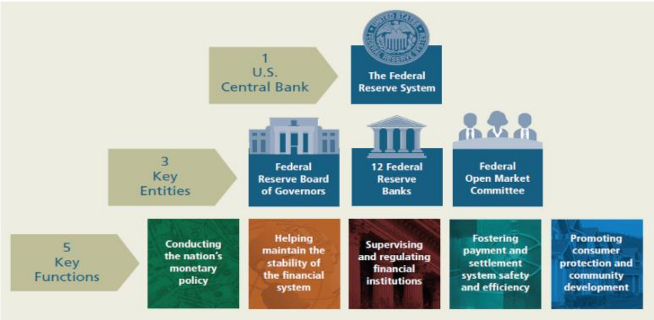
The Federal Reserve has the authority to conduct monetary policy in the USA. However, Congress in the United States of America has the oversight responsibility to elect governing members in the Federal Reserve System. The Federal Reserve (the Fed) has to implement monetary policy according to their objectives. The Central bank's historical objectives were to reach maximum sustainable employment, maintain price stability and to keep moderate Federal Funds rate target. Monetary policy is a mix of regulating discount rates and expanding money to the economy. If a central bank expands its balance sheet, it increases the availability of money and credit to the economy, which is crucial in the time of distress (Carlberg, 2010). Moreover, forward guidance is also part of the monetary policy, because it influences future market expectations. Forward guidance contains statements, directives and governor's statements to inform market participants about future actions. The Price stability objective is met by determining the inflation rate target. The Fed and the central banks around the world normally pursue the inflation target of 2 percent, which may be altered due to a change of circumstances. In practice, markets consist of different interest rates. Interest rates are basically negotiated among financial institutions and are determined as a percentage at which one financial institution is willing to lend to the other institution. Federal Funds effective rates are based on a weighted average for all market interest rates at which the borrowing banks will pay to the lending banks to borrow the funds and these interest rates are negotiated among them. When we talk about the Federal Funds rate target, it is referred to the rate of interest set by the governors at the Federal Open Market Committee. Federal Open Market Committee implements its objective by altering supply and demand of government bonds. Further, I will explain transmission mechanisms through which monetary policy funnel changes in interest rates of different durations, foreign exchange rates, credit availability and other real economic variables. During the Covid-19 crisis, the central bank was forced to cut the Federal Funds rate target by 1.5 percentage points in order to support the economy (Jomo & Chowdhury, 2020). Federal Funds rates were kept at a zero lower boundary, during the entire period of the Covid-19 pandemic. Historical trend of interest rates was downward sloping, and it is interesting to think about what if there will be any trend reversal. However, the central bank started gradually raising interest rates in 2015, when the global market recovered from the past Global Financial crisis. Interest rate mechanism is a powerful monetary policy tool, because a central bank can influence the interest rate sensitive of household and corporate spending. If interest rates widen between Federal Funds rates and interest rates in developing countries, as was the case during the beginning of the Covid-19 pandemic, it triggers capital flows that affect the exchange rates. The change in the foreign exchange rates cause the exports and imports equilibrium to change. Low Federal Funds rates make investments in the US less attractive and therefore investors seek higher interest rates in developing countries such as China or Latin American countries. Transmission mechanism can switch aggregate demand and aggregate spending quite fast, as was the case during the Covid-19 crisis. In the long run, aggressive monetary policy can add inflationary pressure to the economy. However, the central bank should keep the inflation level in line with the monetary policy objective, as it must maintain price stability. Suboptimal inflation may induce adverse effects in the economy, such as the inefficient allocation. If central bank reaches zero lower boundary of interest rate, additional support can be added by quantitative easing (QE). Quantitative easing refers to unsterilized purchases of government bonds and agency asset backed securities. Further, I will describe different stages of quantitative easing, which must be done in a prudent way to avoid adverse effects. Tapering of the Fed's balance sheet is becoming an important topic for the policy-makers and market participants, because it can add substantial market volatility (Clark, 2017).

A central bank might have concerns, when equity prices are going beyond fundamentals. It can in turn cause harmful effects for the equities to stray or as they collapse due to temporarily uncertain economic conditions. Inflated equity prices, relative to fundamentals, may mislead market participants and contribute to asset misallocation in the economy. Households may be spending irrationally; companies be acquiring assets at overvalued prices relative to fundamentals. Households and companies could thus start accumulating credit according to misleading debt ratios. The Fed could have concerns about formation of asset bubbles because if the overvaluation is time dependent, therefore, in principle, the higher they stray beyond the fundamentals, the harder they may collapse. Stock prices matter during steep market decline as there are concerns about the market risk, ripple effect on consumption, market confidence and underestimating of adverse effects (Leahy, Lindsey, Reifschneider & Reinhart, 2001). Recent Fed's interventions proved that they are well developed to repress adverse economic shocks, with supporting markets via the discount window and ability to add credit in difficult periods.

1.1 Central bank's functions

The Covid-19 pandemic increased economic and political instability, therefore supranational bodies had to deploy anti-crisis measures. The Central bank was one of the pivotal institutions to limit the foundations of a deep economic crisis. It is statutory restricted, because it has a monopoly on the issuance of legal tender.

Figure 1: The Federal Reserve System breakdown



Source: Federal Reserve System (2021).

Table 1: The Fed's five key functions

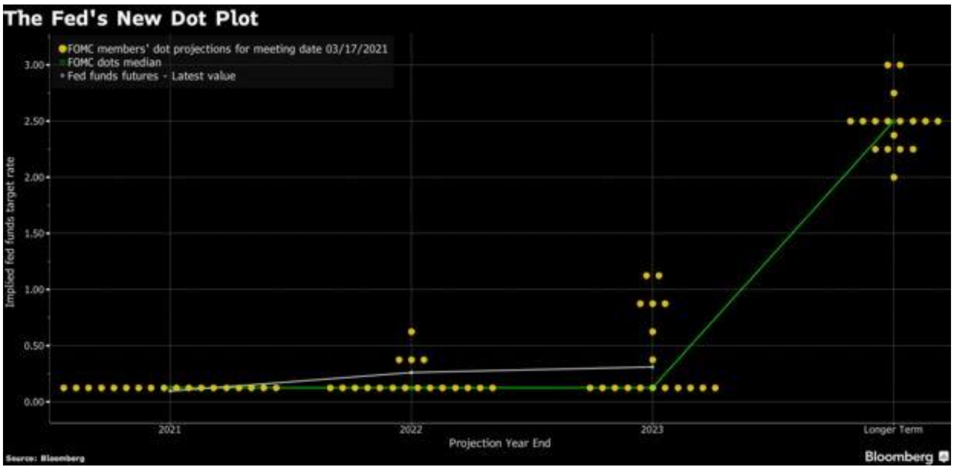
Functions	Objectives	Impacts
Conducting the nation's monetary policy	Maximum sustainable employment (objective is to have the highest level of employment or the lowest level of unemployment, while maintaining stable inflation rate, it can be maintained by assessing labour market conditions, such as changes in types of needed skills in the workforce and trends in the size of population) Stable prices (low and stable inflation helps efficient economic operation, where the money is reliable store of value and where the market participants can make more accurate long-term financial decisions) Moderate long-term interest rates	The Fed's interventions influence discount rates and transmission mechanisms to shift equity prices and foreign exchange rates. Real economic variables, such as investments, production, consumption, inflation and employment are key target variables to conduct monetary policy. Prudent monetary policy is crucial for the well-functioning economy, but it must be supplemented with sound fiscal policy in order to achieve objectives.
Stability of the financial system	Monitor risks of the financial system (critical systemic financial institutions should be run in prudent, safe and sound manner to maintain resilient market structure in extreme market distress) Monitor leverage in banking sector (Dodd-Frank Act stress testing)	Stable financial system enables lower cost of financing and investors can easier grow their money by borrowers and businesses. Highly leveraged financial institutions can amplify the effect of negative shocks in the broad economy.
Supervising and regulating financial institutions	Examine and regulate financial institutions (issuing specific guidelines for formation, operations, activities and acquisitions of financial institutions)	Ensure well-functioning business practice.
Systematic safety and efficiency	Ensure secure, effective and widely available system for financial transactions of the reserve currency. Collaterized Federal Reserve notes by assets	Maintain system's integrity. Sound currency in financial system.
Community development	Ensure community development with investments, economic research to discover issues and supervising financial institutions to function in compliance with regulations.	Implement sound system to prevent illegal actions, ensure accessible lending, well-functioning real estate market and labour market development based on marketplace needs and technology progress.

Source: Federal Reserve System (2021).

1.2 Overview of monetary policy measures during Covid-19 pandemic

Central bank has a set of monetary policy tools that work by altering the overall liquidity in the financial market. Increased liquidity enables financial institutions to borrow at lower cost and increase market confidence. Assets that market participants can acquire are typically in the form of credit, which banks provide to businesses and households. The Fed influences availability of money based on inflation projections and the growth of money itself. A Central bank can employ different types of monetary policy. It can be either expansionary or contractionary. When we talk about expansionary monetary policy, we refer to policy, where central bank takes actions to encourage economic activity (B. S. Bernanke, 2017). During Covid-19 crisis, the Fed reduced Federal Funds rate target and expanded its balance sheet. Further, I will describe monetary policy actions, which were employed during the entire Covid-19 period. However, these actions were obvious because of the switch in the market trend from the steep decline to the strong recovery. On the other hand, it is very important that central bankers recognize desired market recovery to prevent overheating of the economy. Monetary policy can be tightened if the central bank raises the Federal Funds rate target and tamper the money supply by unwinding reserves from depository institutions. Those measures have the opposite effect compared to the expansionary monetary policy measures. Contractionary monetary policy can initially induce slowdown of economic activity. It is desired to have a short-term effect and to smooth business. Policy-makers are striving to achieve sustainable economic growth, because it gives positive long-term effects for society. However, this relationship is far from being complete because the interest rates with longer duration depend on future expectations of central bank's actions and future inflation expectations. Transparent forward-guidance and clear communication with market participants is then crucial for a central bank to anchor future expectations (Blanchard, Dell'Ariccia, & Mauro, 2010). Market participants thus closely monitor public policy announcements. Investors and economists are using Fed's dot plot projections to find trends about upcoming Federal Funds rate target. It helps to determine, whether the monetary policy is expected to be expansionary or contractionary. Dot plot presents the dots, where each dot means the Federal Funds rate projection determined by FOMC member at the specific year of projection (Schumacher, 2020). Figure 2 shows Fed's dot plot as of March 2021.

Figure 2: The Fed's dot plot



Source: Bloomberg (2021).

Dot plot above can be interpreted that the Fed does not plan to rise Federal Funds rate target for the year 2021, but market participants may be aware that Federal Funds rate target will rise in the subsequent years, until it reaches long-run target at around 2.5 percent.

1.2.1 Conventional monetary policy

We can split monetary policy into the conventional monetary policy and the unconventional monetary policy. The first is effective during normal circumstance and the latter is employed during exceptional market distress (B. S. Bernanke & Mihov, 1998). Here, I will describe conventional monetary policy, which can be further divided into three categories, such as open market operations (OMO), reserve requirements and the change in discount rate. In further readings, I will also describe the importance of unconventional monetary policy. Conventional monetary policy was important at the beginning of the Covid-19 crisis, because the global economy contracted by unprecedented speed. First, the reduction of interest rates was important to support aggregate demand and maintain discretionary consumption. Initially we could obtain a large decline in the US industrial production index, due to slowdown in economic activity. Monetary policy was implemented in the right way, so we could see great rebound in economic activity and therefore an increase in the US industrial production index. I will later include the US industrial production index in the SVAR model, because it can help to explain real economic activity and therefore yield a relevant economic model. Additionally, decline in interest rates induce a decline in foreign exchange rate, because of lower currency attractiveness (domestic currency denominated bonds tend to yield lower returns). Currency depreciation makes exports cheaper and imports more expensive, therefore currency depreciation additionally increases domestic economic activity. Historically, we could obtain positive effects on the real economic variables because of temporary expansionary monetary policy. Adding stimulus to the economy increases employment rate and thus quickens recovery in the economic activity. High unemployment, as was the case during the Covid-19 pandemic, decreases inflationary pressure. Therefore, expanding money and credit should not initially increase inflation to suboptimal level, but rather increase employment and economic activity first. However, if we already achieve full employment, the expansionary monetary policy should reflect high inflation. Furthermore, it is crucial that central bankers correctly assess the economic conditions, before intervening with monetary policy. Academics suggested that in the near term it is hard to adjust prices and wages as fast as central bank expanding money and credit. Moreover, market expectations are also rigid to adjustment, what in turn additionally slows adjustment in prices and wages. Increase in money supply has thus great initial effect on increase in GDP and decrease in unemployment, although the monetary policy is laggard. However, the monetary policy should not matter on the long-term, because there will be adjustment in prices, wages, expectations and demand in response to money supply. In some developing countries, where there is present hyperinflation, prices, wages and expectations adjust very quickly (Jawadi & Barnett, 2015).

Open market operations

Open market operations are one of the most common operations through which a central bank conducts monetary policy. A central bank, in this case, buys or sells fixed income securities, depending on whether it conducts expansionary or contractionary monetary policy. It is normally conducted through primary brokers, with trading of high-quality fixed income securities, such as government bonds or agency mortgage-backed securities. It is important to emphasise that in expansionary monetary mode a central bank buys securities on secondary markets, where are bonds actively trading. Central bank finances purchases by printing money or expanding its balance sheet. Central bank has monopoly power over legal tender and therefore can influence the demand and supply equilibrium of highly liquid government bonds. Support to banks is normally conducted by repurchase agreements, which increase banking system liquidity. Repurchase agreement or repo is kind of collaterized loan, where central bank lend money in turn to high quality collateral (normally government bonds). Repo is normally short-term agreement, where at the later date, the borrowing bank has the obligation to buy back pledged collateral. It might be concerning if central bank accumulates too much securities and enters into many repurchase agreements, because unwinding its positions might destabilize the system. In case of unwinding or tapering reserves, a central bank sells the government bonds or enters into reverse repurchase agreement with banks, in order to decrease the money supply in the system (Clark, 2017).

Reserve requirement

Reserve requirement is another monetary policy tool, which commands the percentage of capital that banks have to deposit at central bank. It was implemented to reduce systemic risk of bank runs. Current reserve requirement depends on specification of the bank, and is roughly around 10 percent. Cash in vaults presents opportunity cost for the banks, because they are not able to use these deposits for giving loans. During Covid-19, central bank increased liquidity to the system and thus banks are having excess reserves. This tool was not used in past decades, because altering current reserves requirement would not benefit by reducing the risk of bank runs nor decrease opportunity costs of the banks as they have excess reserves. There is a debate to abolish reserve requirement rules, to rather maintain control over liquidity ratios, in order to increase banks' availability of money, and at the same time keep banks' ability to meet withdrawal requirements in the time of stress. However, financial institutions with the exception of banks are not obligated to deposit reserves at the central bank (Clark, 2017).

Discount rate

Discount rate allows depository banks to borrow from the central bank at a rate slightly above Federal Funds rate. This type of borrowing is normally used in the time of stress and typically used to meet short-term obligations. Banks borrow through discount window for the very short duration, normally overnight and the interest rate is calculated on discount basis. When banks reduce their opportunity costs of reserve requirements, it adds liquidity to the banking system and thus it influences interest rates in interbank lending.

Forward commitment or forward guidance is another central bank's tool to anchor future expectations. Future expectations of market participants are important, because they influence long-term interest rates. It is especially effective at very low interest rates, because it will increase borrowing and therefore market activity, if market participants have the opportunity of low cost funding over a specific period. Therefore, it is important that central banks clearly inform market about their future intentions. In March 2021, when the recovery was underway, the chair of Federal Reserve, Jerome Powell stated that the central bank would support US economy "for as long as it takes", expressing that US recovery was "far from complete". Powell also cited progress, which caused officials to sharply upgrade the forecast for the GDP growth to 6.5 percent for that year. However, it is hard to estimate the effectiveness of forward guidance, because market participants may or may not find credibility in the central bank's expression of future monetary policy. During the period of Covid-19 crisis, the Fed has been expressing monetary policy clearly and making aggressive forward commitments. The Fed committed to keep the interest rates low until the monetary policy objectives are met. This forward commitment might result in long duration, which could pose the risk of inflationary pressure. However, forward commitment is contingent, and if there is change in economic conditions, the Fed may change its forward commitment. In this case, the market may react in a way, which is not in line with forward guidance (Oritani, 2019).

1.2.2 Unconventional monetary policy

Severe economic conditions may cause decrease in interest rates to zero lower boundary, at that time conventional monetary policy reaches its limit for obtaining the monetary policy objective. Therefore, the central bank interferes with unconventional monetary policy to initiate economic growth and stimulate aggregate demand (MacDonald & Popiel, 2020). Unconventional monetary policy measures have different theoretical models and transmission channels compared to the conventional ones. It directly funnels the availability of credit and costs of financing for households and corporations. Expansion of credit could be obtained through purchases of different securities, such as fixed income securities and equities. Central bank directly influences the spreads in various securities. For example, if central bank purchases large quantity of government bonds, it will result in decline of government bond's yields. As the government bonds might be the benchmark for the other corporate bonds, it will result in lower spreads in corporate bonds. Similarly, purchases of equities results in lower cost of funding for corporations. Therefore, expansionary unconventional measures directly affect cost of funding, resulting in increase in asset prices and most importantly increase liquidity in the time of market stress. Long-term interest rates depend on market expectations. As mentioned earlier, forward guidance can influence market expectations. Central bank can also change Federal Funds rate target, which influences long-term interest rates. It thus reduces the long-term interest rates through these channels, with the purpose to reduce the cost of credit. These interventions can in turn lead in higher expectations about price level. Real interest rates are calculated based on inflation expectations. Increase in inflation would result in decline of real interest rate. If central bank's forward commitment is successful, it will result in a flatter yield curve. A flat yield curve, would present low short-term interest rates and also low long-term interest rates, because forward commitment would anchor future expectations and thus keep long-term interest rates on the same level as the short-term interest rate (Miller & Vallée, 2016). However, commitment to keep interest rates low for too long might add inflationary pressures, which reduce real interest rates and cut consumption. Central bank normally uses two types of unconventional monetary policy: quantitative easing and credit easing. They are important to influence the long-term market expectations. In further readings, I will describe both measures in more detail. It is important to understand that quantitative easing is implemented to affect cost of credit for various fixed income securities with different durations and for equities with various risk exposures. Credit easing refers to measures, which influence risk spreads in securities that are adversely affected by exogenous shocks. However, it is good to note that these measures might significantly change the structure of the Fed's balance sheet (Zhang & Du, 2020).

The economy in the United States of America quickly rebounded during Covid-19 pandemic thanks to the central bank's interventions. Quantitative easing added ample liquidity to the system, therefore the equity market remained strong and reached new all-time high levels until the end of 2020. Improved economic activity led to decline in unemployment and thus employment started approaching the sustainable long-term employment objective. However, the inflationary pressures started to emerge. Additionally, the central bank's added liquidity initiated the appreciation of the emerging markets' currencies. Currency appreciation occurred because of the changes in the yield spreads. Emerging markets became more attractive because of the higher yields and thus increased capital inflows led to currency appreciation. Carry traders in this case affected the cross-border inflows to developing countries. It added liquidity to the developing countries and the risk of the asset bubble formation as the asset prices increased. However, it further promoted capital flows and not only promoted the currency appreciation of developing economies, but also worsened debt ratios of developing markets. High capital inflows, might lead to froth of the asset bubbles and that can in turn destabilize the economy. Economy can be quickly destabilized if there occurs extreme capital outflows from the developing country (Cheng, Skidmore, & Wessel, 2020).

1.2.3 Expansionary monetary policy during Covid-19 crisis

Expansionary monetary policy is implemented to stimulate activity in the economy during economic slowdown. A central bank must stabilize the economy with continuous credit flow to companies and households during uncertain period to increase aggregate demand and to repress negative shocks in the economy (Kent, 2017). Another objective is to eliminate long-term damages to the economy. Therefore, when the financial crisis diminishes, the market is set to thrive, and supply and demand approaches equilibrium. Expansionary monetary policy is important to support stagnation in business cycle, but it also includes macroeconomic, microeconomic and political risks (Ndou & Mokoena, 2019). The Covid-19 crisis had initially an adverse effect on the equity market, because of shutting down the economy and presence of unknown risks. Moreover, it had a double-edged effect on different sectors. On one side, we could obtain steep decline in the travel sector and on the other side we could see a highflying technology sector (Nhamo, Dube, & Chikodzi, 2020). However, expansionary monetary policy may have given additional boost to technology growth stocks by higher supply of speculative money and lower interest rates to switch valuations. “We are deploying these lending powers to an unprecedented extent and will continue to use these powers forcefully, proactively and aggressively until we are confident that we are solidly on the road to recovery.” The President of the Fed stated in the beginning of Covid-19 pandemic. Further, I will explain measures, which was deployed by the Federal Reserve (Skidelsky, 2020).

Table 2: The Fed measures during the Covid-19 crisis in the U.S. economy

Measures	**Impacts**
Federal Funds rate target	US central bank has lowered Federal Funds rate target by 1.5 percentage points. As mentioned earlier, it has affected long-term expectations and reduced the cost of credit.
Forward guidance	The Fed has pledged to keep interest rates low until the monetary policy objective is met. It again affects future expectation and lowers long-term interest rates.
Securities purchases (QE)	Quantitative easing, with trillions of dollars added liquidity, has maintained credit flows in the economy, in order to smooth negative effects of Covid-19 crisis.

(table continues)

Table 2: The Fed measures during the Covid-19 crisis in the U.S. economy (cont.)

Supporting securities firms	The Fed has added ample liquidity through primary dealers, with the extension of 90 days loans at the minimum 0.25 percent interest rate.
Backstopping money market mutual funds	The Fed had to intervene with repurchase agreements to support outflows from money market mutual funds. Money market mutual funds could borrow from primary dealers against pledged short-term corporate fixed income securities.
Repurchase agreement operations	Central bank offered over 100 billions of dollars in overnight repurchase agreement to give access of cash to money markets.
Direct bank borrowing	The Fed has lowered discount window to 0.25 percent and increased the loan duration to 90days. All banks agreed to use credit channel. It is important because borrowing through discount window could signal banks' problems.
Temporarily relaxing regulatory requirements	Relaxing regulatory requirements, reduced opportunity costs of maintaining excess reserve requirements at central bank.
Direct lending to major corporate employers	Buying up to 750 billion dollars corporate bonds, with option to postpone interest payments and payment at maturity. It enabled companies to meet short-term liabilities.
Commercial Paper Funding Facility (CPFF)	Corporations could borrow short-term commercial papers at minimum interest rate, 1 percentage point above discount window.
Loans to SME	The Fed supported small and middle size enterprises by 600 billions of dollars in loan with five-year duration. However, they had to obey the covenant of no dividend and buyback policy.
Support to non-profit organizations	Non-profit organizations, which satisfy conditions, such as minimum 10 employees or endowments with less than 3 billion dollars, could take part in lending program.
Term Asset-Backed Securities Loan Facility (TALF)	Lending up to 100 billion dollars in credit, to households, which held asset backed securities.
Extended loans to the municipal governments	The Fed supported municipal governments, as they had difficulty to issue new bonds in the beginning of pandemic.
Supporting municipal bond liquidity	Expanding terms to maturity, accepting municipal bonds as collateral, in order to increase liquidity to municipal governments.
International swap lines	Expanding lending in dollars to other central banks, to increase liquidity in international markets. The Fed had lowered the interest rate charges and extended loans duration.

Source: Cheng et al. (2020). [1]

The Fed seems to have a few more instruments to implement. It could reduce interest rates to negative values, to charge banks for deposits and thus encourage them to expand credit channel to the market. This measure has the impact on the long-term interest rates, as the central bank lowers short-term interest rates further below zero. The Fed did not aim to implement it, but other central banks, such as Bank of Japan did it. The Fed could also monetize government debt, by buying its debt on primary market. This action could pose additional risk as the central bank has monopoly power over legal tender (Joyce, McLaren, & Young, 2013). However, Bank of England implemented this measure. The Fed could also extend primary dealer lending to alternative investment companies, but it could risk an inappropriate action by these profitable organizations. Additionally, to forward guidance, the Fed could implement yield curve control. It would be implemented by buying government bonds of particular duration, in order to keep stable yield curve (Bordo, 2021).

1.2.4 The comparison of Covid-19 pandemic and Global Financial Crisis

Covid-19 pandemic had different effects on the global economy, as well as at the company level, compared to the Global Financial crisis. The Covid-19 crisis has been multifaceted and differently impacted global demand and supply, when many governments were forced to close their economies. Monetary policy tools deployed have been also different from the past crisis. Table 3 compares the complex set of uncertain factors, which interacted in an ambiguous way.

[1] The Fed's tools should be supplemented by fiscal policy to be effective. President of central bank commented, "Monetary policy has a role, but we do think fiscal response is critical."

Table 3: The comparison of crises

Specification	Covid-19 pandemic	Global Financial Crisis
Cause of global crisis	Coronavirus (health crisis, first outbreak on Chinese market)	Subprime mortgage crisis (financial dimensions, US market)
Nature of global crisis	Health, problem with increasing number of Covid-19 infections	Financial, mainly caused by financial institutions
Transmission channels	Numerous lockdowns internationally (sudden close of economic activity) Financial markets (large market correction, due to unknown risks, increase in "safe heaven" assets and liquid assets) Credit market (banks unwilling to extend credit) Unemployment (risk of not meeting loan obligations)	Financial markets (steep decline in commodity prices and high uncertainty of currencies) Credit market and banking sector (problems in financial institutions and liquidity shortage) International trade (weak global demand, foreign direct investment channel, equity market)
Scope of the crisis	Global	Global (mainly developed countries)
Measures for easing the crisis	Monetary and Fiscal policy	Monetary policy
Nature of policy	"Act fast and do whatever it takes" (Powell, 2020)	"Whatever it takes" (Bank of Italy, 2012)
Volatility	Extremely high	Very high
Process	Sudden ripple effect as the Covid-19 virus spread around the world. Immediate disruptions in global supply and demand.	Gradual move from banking sector to overall economy, liquidity problems.

Source: Matysek (2021).

Establishing precise cause-effect relationship among pandemic factors is very hard to measure. The pandemic had unknown trajectory in size and scope, because different countries deployed different measures. Some countries quickly closed their economies, while other remained open and tried not to disturb economic activities. Pandemic also shifted people's habits to the extent that companies would have to adjust their way of operating (Matysek, 2021). Next, I formed some assumptions that are associated with Covid-19 measures:

- Covid-19 crisis was transmitted to global economy through the following channels: a) industrial supply disruptions, b) services with physical interactions, such as leisure activities and transportation, c) commodity prices and decreased demand,
- Liquidity and insolvency problem in the financial market,
- Behavioural changes, which impact businesses in the long-term.

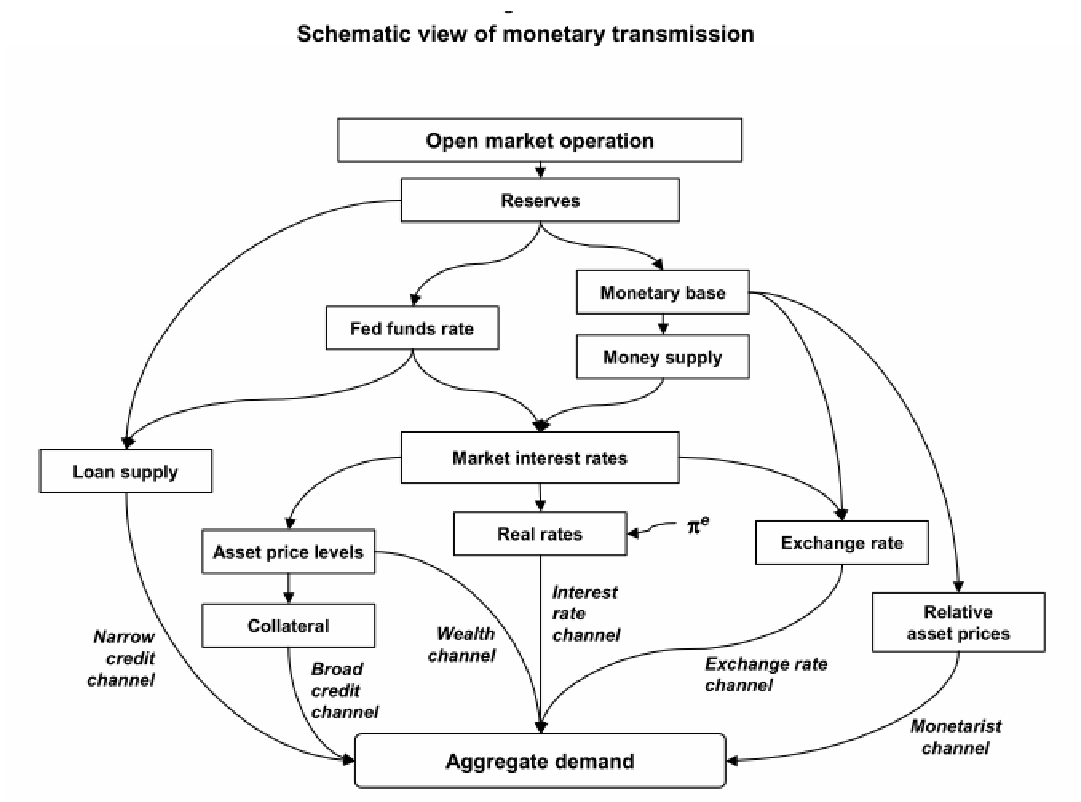
2 THEORETICAL OVERVIEW OF TRANSMISSION MECHANISMS CONNECTING MONETARY POLICY AND EQUITY PRICES

The monetary policy seems to have increasing importance on the real economy. Central bank's measures were extreme in speed, size and scope, in order to limit the long-term consequences of Covid-19 pandemic. If we compare it to the Global Financial Crisis, the Fed deployed as many support measures in almost a week (March 14th to 23rd, 2020) as it deployed during the entire year of Global Financial Crisis (in 2008). Monetary policy targeted problems of the real economy through multiple transmission channels. Transmission mechanisms are intertwined, because they consist of a multitude of channels through which monetary policy operates (Mosser, 2020).

2.1 Interest rate transmission mechanisms

Interest rate transmission mechanism is the first channel through which central bank alters long-term interest rates. The principle of interest rate transmission mechanism is simple. If we assume slow price adjustment (sticky prices). In expansionary monetary policy, central bank lowers nominal interest rate, and triggers a decrease in long-term interest rates (reduction in real interest rate) and thus reduces the cost of capital. Therefore, it boosts new investment expenditure by companies and increases household's consumption. Market quickly responds to policy-induced interest rate change due to conventional elasticities of investment and consumption. The relationships can also be described in financial theory by Philips's curve and assumption of sticky prices and wages. In further readings, I will describe the wealth effect developed by Modigliani & Ando (1963), which is another way of explaining interest rate transmission mechanisms. Asset prices are valued based on interest rates which gives additional importance to the monetary policy. In case of the expansionary monetary policy, decrease in interest rate will increase the valuation of assets. It can be obtained in equation (1), where decrease in WACC will directly increase the present value of future cashflows (Kuttner & Mosser, 2002).

Figure 3: Transmission mechanism



Source: Kuttner & Mosser (2002).

The value of long-lived assets has the importance of expanding availability of credit claimed by Bernanke & Gertler (1989), however not in the same way as in the wealth channel. Credit channel is described as when the prices of assets increase, the company's collateral increases and therefore companies can borrow more. In perfect capital market assumption, a loss of borrowers' collateral value should not change investment decision making. However, in the presence of market frictions, declining prices of collateral would increase the borrower's cost of capital. Higher cost of capital would thus decrease companies' expenditure and investments in new projects. In this channel, banks have pivotal role, because they have to enable credit flows in the economy, in order to minimize credit channel frictions. Alternative exchange rate channel can be described by changes in aggregate demand and supply equilibrium. Expansionary monetary policy reduces interest rate. Lower interest rate thus depreciates the currency, according to interest rate parity. When domestic currency depreciates, it boosts exports, because domestic products become relatively cheap to foreign markets. Higher exports additionally boost aggregate demand in the domestic country. Aggregate supply side is directly connected by inflation, because higher export prices increase domestic price level (Aleem, 2010). Additionally, expensive imported inputs for domestic production are making domestic production less competitive, thus domestic output decreases and adds another inflationary pressure. Further, I will explain transmission mechanism of quantitative easing (Kuttner & Mosser, 2002).

Table 4: Transmission mechanisms in decline of Federal Funds rate

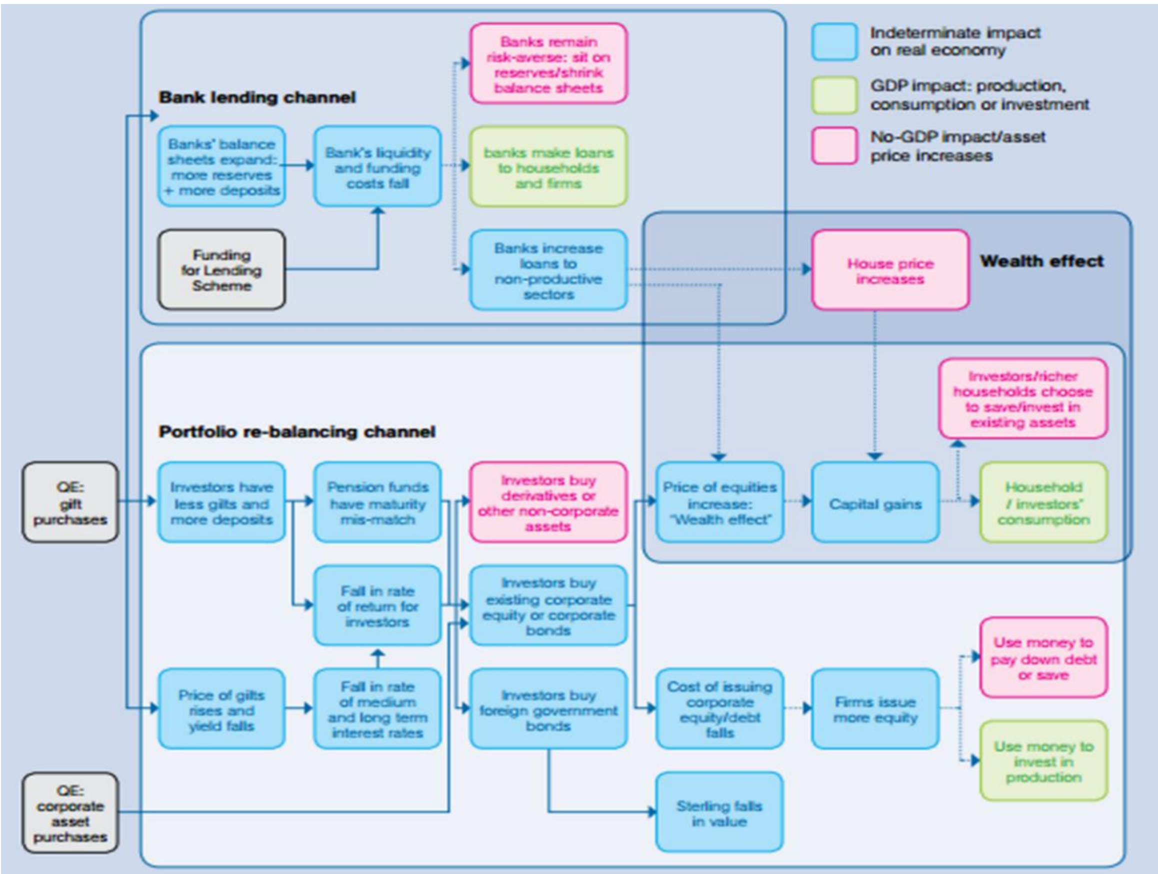
Higher consumption and investment (direct effect), because of lower cost of borrowing
Higher asset prices (see DCF model), what additionally boost consumption and investments due to wealth effect
Higher confidence, which again boosts consumption and investments through expectations channels
Lower exchange rate that raises export demand and reduces import demand
Collateral value offered by firms and individuals for bank loans (credit channel), which in turn increases lending by banks and thus boosts consumption and investment
Upward pressure on inflation

Source: Mosser (2020).

2.2 Quantitative easing transmission mechanism

Quantitative easing impacts the economy through two main channels known as portfolio rebalancing effects (wealth effect) and bank lending channel (Huston & Spencer, 2016).

Figure 4: Quantitative easing transmission mechanism



Source: Aston University (2020).

When implementing quantitative easing, central bank electronically creates money that increases ease of credit and liquidity by expanding size of its balance sheet when acquiring assets (government bonds). First, it induces portfolio-rebalancing effect known as wealth effect. Large bond purchase reduces bond's yield and drives bond's price upward. Investors, who hold bonds, are experiencing wealth effect due to increase in prices. Low yields force investors to seek alternative investment options with higher yield, such as corporate bonds. That improves lending to corporate segment, what boosts investing and economic recovery. Institutional investors, such as pension funds represent big chunk of market. In this case, they have maturity mismatch, due to less long-term government bonds available. Therefore, it is optimal that they buy domestic corporate bonds or domestic equities, because it reduces cost of issuing debt and equity for the corporations. It is desired that corporations use raised capital to invest in production that boosts economic growth. At the same time, equity prices increase lead to capital gains for the investors (wealth effect), which again increases consumption and boost economic growth. Alternatively, negative consequences occur if companies use raised capital for paying old debts or that they increase savings. Quantitative easing is also less effective if institutional investors choose to invest in foreign corporate bonds and foreign equities or other non-corporate assets such as derivates. Those investments do not boost desired economic growth. Secondly, quantitative easing leads to improvements in bank lending channel. Banks' balance sheet expands due to increased reserves and deposits. It increases banks' liquidity and in turn reduces funding costs. Banks are therefore able to make more loans to firms and households, thus additionally boost investments and consumption. Alternatively, bank lending channel can be ineffective if banks remain risk averse and sit on excessive reserves, or if they give loans to non-productive sector. It has no impact on real GDP growth and can induce negative effects such as housing price increase (Loayza & Schmidt-Hebbel, 2014).

2.3 Interest rate changes

Interest rate changes shift the stock market valuations. Primary equity valuation methodologies used on Wall Street are discounted cash flow (DCF), comparable companies, precedent transaction and leverage buyout valuation. Mentioned methodologies determine the intrinsic value for the companies with different types of ownership, for M&A transactions, LBOs, IPOs, restructuring and other investment decisions in equity market, such as valuation of S&P 500 market index.

DCF valuation is an absolute fundamental analysis that determines intrinsic value for the company. The intrinsic value can be thus determined from the present value of the future free cash flows, which are projected for the individual company. Analysts estimate future free cash flows based on current financial ratios and they take into account companies' future growth perspective. Therefore, companies with low or negative current earnings might have high valuations, because of their favourable future earnings. In equation (1), the projected

FCFs and the value at the termination are discounted to the present. Intrinsic value of equity prices can be calculated as:

$$Present\ value\ of\ FCFs = \frac{FCF_1}{(1+WACC)^1} + \frac{FCF_2}{(1+WACC)^2} + \ldots + \frac{Terminal\ value_n}{(1+WACC)^n} \quad (1)$$

WACC discount rate is commensurate with company's business risk, financial risk and importantly with interest rate (risk-free rate). WACC is calculated as proportion (weights) of each source of capital, such as common stock, preferred stock and debt. WACC can be calculated as,

$$\text{WACC} = \omega_e r_e + \omega_p r_p + \omega_d r_d \quad (2)$$

where ω_e represents weights of equity, ω_p represents weights of preferred stock and ω_d represents weights of debt in company's financing structure. Furthermore, the cost of capital for the r_e (equity), r_p (preferred stock) and r_d (debt) have to be further estimated, where monetary policy interest rate can shift the discounting to the present. The equity cost of capital is the rate that needs to be given to investors on an investment in equity. It can be estimated in different ways, but commonly used estimation model is capital asset pricing model (CAPM):

$$r_e = r_f + \beta_e [E(R_M) - r_f] \quad (3)$$

In CAPM equation, we can see that monetary policy interest rate (risk-free rate) substantially influences the cost of equity. Similarly, monetary policy interest rate has an influence on the cost of preferred stock and cost of debt. Those two elements might be even more affected by changes in interest rates, because they have lower risk premiums than equity. Cost of debt is usually estimated with debt-rating approach and it has important debt shield purpose for the company (Flanc, 2014).

$$r_d = (r_f + \text{spread})\,(1 - \text{effective tax rate}) \quad (4)$$

WACC can be viewed as a gravity of valuation, because when interest rates go up, present value of FCFs is discounted more and thus company's intrinsic valuation goes down. In case of expansionary monetary policy, falling interest rates cause rising stock prices. Central bank's forward guidance is therefore very important, because it helps investors to price securities. However, there is uncertainty about forward commitment duration, because the policy is only conditional. Central bank must be clear in its speech, because market participants might adversely interpret the information. The slope of interest yield curve might be another way of projection for the future interest rate and future economic activity (Bianchi, Lettau, & Ludvigson, 2016).

2.4 Quantitative easing

Quantitative easing is most likely successful at very low interest rates, because banks would thus have higher incentive to lend to private sector. In case of high Federal Funds rate, central bank's purchase of private bank's bonds, would give banks profitable opportunity to maintain excess deposits at central bank. Quantitative easing is employed with the purpose to expand the availability of credit in the economy (Gern, Jannsen, Kooths, & Wolters, 2015). Central bank has to use this tool to encourage commercial banks to lend, instead of keeping its liquidity or even cash out in profits. Risk exposure of central bank can be therefore reduced by lowering interest rates to zero lower boundary and by giving dividend or stock repurchase restrictions. As mentioned in section of unconventional monetary policy, quantitative easing objective is to narrow market spreads in order to encourage market activity (Giraud & Pottier, 2016). However, quantitative easing poses the risk for the central bank, because central bank might buy government bonds based on inflated prices. In subsequent period, interest rates might go up and therefore prices go down. Selling government bonds at lower prices would then give losses to the central bank. Interest rates are likely to increase, once the economy fully recovers. Central bank has to be prudent about its decision, because high losses might undermine its financial independence (Farmer & Zabczyk, 2020).

Table 5: The Fed's main balance sheet changes in 2019 and 2020

Extract from Fed's balance sheet (31.12.2019 – 31.12.2020) in $millions		
Assets	**2020**	**2019**
Loans to depository institutions	1,602	42
Other Loans	54,535	-
Securities purchased under agreements to resell (repo)	1,000	255,619
Treasury securities	4,955,871	2,401,604
Federal agency and GSE MBS	2,109,715	1,446,989
Central bank liquidity swaps	17,883	3,728
Consolidated variable interest entities, net	140,335	-
…	…	…
Total assets	**7,358,392**	**4,173,641**

Source: Federal Reserve System (2020).

2.4.1 Credit easing

Credit easing is a type of the unconventional monetary policy, where the central bank acquires securities in the wholesale markets. These securities may vary in their credit risk and duration, and are normally corporate bonds, asset backed securities and short-term commercial papers. Central bank's aim is again to reduce market spreads and increase the ability of meeting short-term obligations, especially in the time of market stress. The central bank in this case directly buys securities in private sector without a bank intermediary. Therefore, it starts adding more risky assets on its balance sheet, because corporate bonds are assumed to be riskier comparing to government bonds (Jarrow & Li, 2014). However, buying corporate bonds is similar to buying government bonds, because both types of fixed income securities equally add money supply to the economy. Even though the end effect is similar, central bank has to be especially cautious about buying private issued bonds, because biased decisions might have double-edged effect on different sectors. Double-edged effect would lead to inefficient allocation in the economy, because some sectors would be positively impacted and the other discriminated. Another issue of the policy is how to target small and medium size firms, because central bank normally buys securities of the large corporations (Ferguson, 2020). Further, I will describe central bank's exit strategy, but here we must note that the authority holds risk of private securities until the maturity or pre-mature sale. Central bank can also control the yield curve by expanding its balance sheet to lend to commercial banks for the long duration and in turn accept pledged collateral. For example, outright purchases of securities with three months duration would directly influence the three-month interbank lending money market. Central bank has thus power to regulate specific horizon on the interest rate yield curve. At the beginning of Covid-19, the Fed intervened by pushing down short-term yields on interest rate yield curve. It also compiled some risky assets on its balance sheet in order to prevent defaults that would cause systemic instability. Next, I will explain how the central bank tapers outright purchases, once the economy is stable (Christensen & Krogstrup, 2016).

2.4.2 Exit strategy

Exit strategy refers to actions where central bank needs to unwind extra monetary stimulus. The central bank ideally implements the exit strategy, once the economy stabilizes and it meets the monetary policy objectives. Unfortunately, that is not always the case, and the central bank might face the tradeoffs. Normally, it has enormous size of assets on its balance sheet, after it implements quantitative and credit easing. Selling high quantity of extra assets disturbs financial market equilibrium and additionally market participants may react to these measures in inappropriate way. Thus, the outright selling may cause another steep decline and market participants can lose confidence in market. However, exit strategy to commercial banks normally occurs automatically in less problematic way. It is because banks decrease demand for central bank's money on their own, due to higher market confidence and the renewal of interbank lending channel. Unconventional monetary policy is basically structured in way to benefit borrowers and penalize lenders in the medium run. This is the case, because central bank wants stimulate investment expenditure and increase demand for risky assets. As mentioned in wealth effect transmission mechanism, the savers have to start buying risky assets in order to get desired yields on their investments. Unconventional monetary stimulus should be unwinding before the central bank raises its interest rate. This is due to various reasons. If central bank increases interest rates, while unconventional monetary policy is still in place, it can induce negative effect for money market. Money market participants may receive mixed signals and therefore start selling their assets and induce unwarranted increase in short-term interest rates. Another issue occurs with the contrary assessment of monetary policy stance. On side, the unconventional monetary policy measures are still in place to increase liquidity, and on the other side, the tight conventional monetary policy could give mixed signals to the market participants. Central bank has also the problem to maintain interest rates at desired level, because banking sector maintains high reserve deposits. Changes in the short-term interest rates might cause the additional volatility in the market, because the central bank gives contradiction in its monetary policy stance. Finally, the central bank might have concerns when is it the appropriate time to taper stimulus, because on the one hand, the economy might not be fully recovered and on the other hand there is inflation with raising commodity prices and short aggregate supply already in place. In this case, the central bank actions are limited and left with trade-off between sluggish recovery or reinforcing inflation. However, if the economy is fully recovered to the level consistent with the monetary policy objectives, there is no sense to delay with unwinding monetary stimulus (Sheedy, 2017).

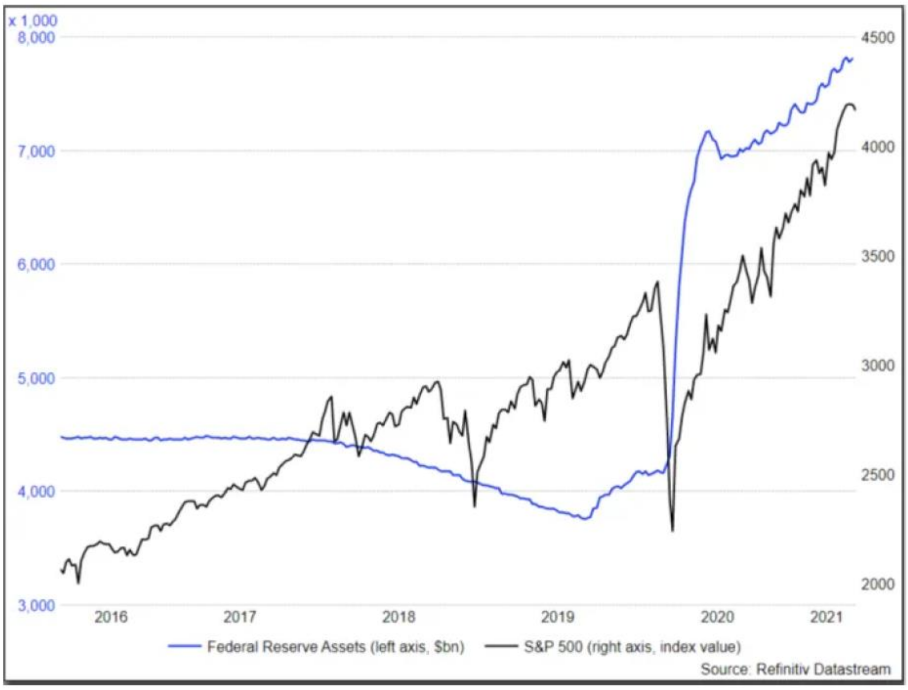
Another question for policy-makers is in timing, when and in which quantities reduce the assets from the balance sheet. Selling assets too quickly might destabilize the entire economy and destroy the recovery. Selling too quickly would substantially increase interest rates and thus penalize lenders. Another issue occurs with selling fixed income securities issued by private entities, because those securities are much less liquid compared to government bonds. Outright selling corporate bonds would thus trigger spreads to widen and drastically decrease liquidity. Furthermore, low interest rates and constantly added money supply induce inflationary pressure. It is more likely the case when expansionary monetary policy measures are present for the long time. Reinforcing inflation destabilizes price level objective and imbalance financial markets, due to higher costs and unexpected disruptions. However, policy-makers have to be prudent with decision when to sell assets, because the sale after the increase in interest rates, would give financial losses to the central bank. As mentioned earlier, the central bank cannot afford to risk its independence (Smaghi, 2009).

2.4.3 Asset bubble

Expansionary monetary policy with increase in money supply might induce asset bubble creation. Asset bubble refers to the movement of asset prices well above its fundamentals. Quantitative easing might be responsible for the asset bubbles formation, because the additional money in the system should find its way to adjust asset prices (Steeley, 2015). The economy can become hooked by constant increase in money supply and if the central bank ceases adding money to the system, market participants may suddenly start selling assets and cause sharp asset price decline. Therefore, some opponents of quantitative easing warn against sudden market crashes that can dramatically allocate wealth in the economy.

Moreover, consequences of unconventional monetary policy are relative unknown, because it is relatively new central bank's innovation. However, He 2021 found that asset bubble creation has positive effects on the innovation. He suggested that asset bubble formation directly induces increase in the value of collateral. The collateral thus enables companies to borrow more and thus increase research and development investments that produce innovations. Another thing that He found is that tighter credit constraints induce bigger effect on the asset bubble formation. It is in line with the history when many innovations in the internet emerged during Dot com burst in 2000, when the NASDAQ index quadrupled. The study suggests that the governments should not induce asset bubble to burst, but rather decrease frictions because it induces growth and innovation. However, He suggested that asset bubble burst decreases investments, because of tighter credit constraint (He, 2021). Figure 5 graphically presents time series of Federal Reserve assets and S&P 500 market index for the past five years horizon.

Figure 5: The movement of Fed's assets and S&P 500 index



Source: Gundlach (2021).

Graph presents the correlation between quantitative easing and market index, during Covid-19 pandemic. However, in normal market conditions decrease in assets of the Federal Reserve did not destabilize market index.

3 METHODOLOGY OF ANALYSIS FOR MONETARY POLICY'S EFFECTS

3.1 Overview of relevant methods from literature

Vector autoregressive (VAR) models are important for the structural analysis. VAR models have been extensively used in the past academic research for identifying the measures of monetary policy. Models have the advantage to capture complete identification. We have to specify the model in a way to distinguish between endogenous and exogenous variables. Endogenous variables are monetary policy interventions, which can be done in response to exogenous variables. Exogenous variables are normally economic shocks, which cannot be controlled by central bankers and that occur exogenously. The dynamic analysis of the SVAR system returns meaningful information of the monetary transmission mechanism if exogenous monetary policy changes are identified. However, model's complete identification can be obtained by correctly specifying model's variables. Appropriate variables explain the economic activity and should be placed in the right order, in order to get correct impulse response relationships. Monetary policy interventions are gaining importance to market participants, as they have direct impact on the economy. Past literature uses SVAR methodology to explain the effect of monetary policy interventions on the economy, most often analysis with the focus on banking sector. Rudebusch (1996) also uses different type of models, which are not the same as VAR model, for explaining similar direct effects to financial markets, due to monetary policy interventions. The empirical analysis in my master thesis concentrates on structural vector autoregressive (SVAR) model, which gives the foundation for the impulse response analysis. This analysis is based on visual presentation of impulse response function, which gives the idea of how the shock's dynamics influences the economic variables of interest. Basic VAR model lacks the explanatory power of technology and other economic variables, because they do not contain deep structural variables. With this in mind, researchers proposed the SVAR model. First academic researchers have been Sims (1980), Bernanke (1989) and Shapiro & Watson (1988). They focused on the methodology, which could explain model's residuals. Model's residuals are pivotal because they are estimated as a linear combination of the economic shocks. Sims (1980) described recursive ordering of variables, where variables are ordered according to their exogeneity status. Further, I will describe the formulation of structural equations for the SVAR, generally in the A, the B and the AB model of Amisano & Giannini (1997). I need to mention the research of Blanchard & Quah (1990), where they confirmed that the nominal shocks do not have any long-term effect to the real parameters. They specified the model based on restriction to long-term structural shocks and inferred that the long-term variables can be affected only by the shift in real variables (i.e., productivity). In further reading, I will give the theoretical overview of the vector autoregressive models (d'Amico & Farka, 2003).

3.2 VAR model

Vector autoregressive models are extensively used in the time series analysis, where we are interested in the dynamic interactions among variables (Bagliano & Favero, 1998). The model has a set of K time series variables; thus, the dependent variable is written as $y_t = (y_{1t},..., y_{Kt})$. The fundamental VAR model with p order, also stated as VAR(p), is defined as:

$$y_t = \nu + A_1 y_{t-1} + \cdots + A_p y_{t-p} + u_t, \quad (5)$$

where $y_t = (y_{1t},..., y_{Kt})'$ is a (K×1) random vector, the A_i are the same coefficient matrices with structure (K×K), $\nu = (\nu_1,..., \nu_K)'$ is a fixed (K×1) vector of intercept terms, which allows the mean $E(y_t)$ to have a nonzero value. Furthermore, $u_t = (u_{1t}, ..., u_{Kt})'$ is a K-dimensional innovation process or white noise, which has important three assumptions: $E(u_t) = 0$, $E(u_t u'_t) = \Sigma_u$ and $E(u_t u'_s) = 0$ for $s \neq t$. We also assume that covariance matrix Σ_u is non-singular. Therefore, if the dependent variable (y_t) is of order p, a corresponding K p-dimensional VAR(1) can be defined as,

$$Y_t = \nu + AY_{t-1} + U_t \quad (6)$$

which can be expressed in matrix form as:

$$Y_t = \begin{bmatrix} y_t \\ y_{t-1} \\ \vdots \\ y_{t-p+1} \end{bmatrix}, \quad \nu = \begin{bmatrix} \nu \\ 0 \\ \vdots \\ 0 \end{bmatrix}, \quad A = \begin{bmatrix} A_1 & A_2 & \dots & A_p \\ I_K & 0 & \cdots & 0 \\ \vdots & I_K & \ddots & \vdots \\ 0 & 0 & I_K & 0 \end{bmatrix}, \quad U_t = \begin{bmatrix} u_t \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (7)$$

Dependent variable (Y_t) is stable if, $\det(I_{Kp} - Az) \neq 0$ for $|z| \leq 1$. The mean vector is therefore $\mu = E(Y_t) = (I_{Kp} - A)^{-1}\nu$ and the autocovariances are $\Gamma_Y(h) = \sum_{i=0}^{\infty} A^{h+i} \Sigma_U (A^i)'$, where $\Sigma_U = E(U_t U'_t)$. In matrix form ($K \times K_p$), where $J = [I_K: 0, ... , 0]$, the VAR process of y_t can be defined as $y_t = JY_t$. Dependent variable (y_t) is specified as random time series, because we have assumed that Y_t is well-defined stochastic process. Mean value is thus $E(y_t) = J\mu$, which has the fixed value in every time t. Similarly, the autocovariances $\Gamma_y(h) = J\Gamma_Y(h)J'$ are assumed to be independent of time. Moreover, we can see that $\det(I_{Kp} - Az) = \det(I_K - A_1 z_1 - ... - A_p z_p)$. Following the definition, the obtained process has the vector autoregressive time series of order p and hence we name it the polynomial of the reverse characteristic. According to this specification and the condition of no unit root in the polynomial of reverse characteristic, the VAR(p) process is stable. As stated in stability condition, the dependent variable (y_t) is stable if $\det(I_K - A_1 z_1 - ... - A_p z_p) \neq 0$ for $|z| \leq 1$. Dependent variable (y_t) is stable VAR(p) process if previous condition holds and $y_t = JYt = J\mu + J \sum_{i=0}^{\infty} A^i U_{t-1}$. VAR process of y_t seems to be determined by innovation process, because the $U_t = (u'_t, 0, ..., 0)'$ involves the innovation process in the residual (u_t) time series. The condition for the residual (u_t) should be assumed, which determines that the VAR process of y_t. We must assume that u_t is Gaussian innovation process, defined as $u_t \sim N(0, \Sigma_u)$ for every time t, u_t and u_s, that satisfy to condition $s \neq t$. Therefore, the dependent variable (y_t) is a Gaussian process of subcollections (y_t,..., y_{t+h}), which contain various normal distributions for every t and h (Lütkepohl, 2005).

Sample (y_1,..., y_T) with preamble values (y_{1-p},..., y_0) can be further estimated by unrestricted VAR. The K equations from (5) could be estimated by OLS regression. The individual estimation method keeps the estimation efficiency. Another way of estimation could be obtained by the GLS approach (Zellner, 1962). Furthermore, estimates are identical for estimation in VAR, OLS and GLS, defined as Y = (y_1,..,y_T) , A = (A_1,...,A_p), U = (u_1,...,u_T) and Z = (Z_0,..., Z_{T-1}) where,

$$Z_{t-1} = \begin{bmatrix} y_{t-1} \\ \vdots \\ y_{t-p} \end{bmatrix} \quad (8)$$

can be modelled as Y = AZ + U. OLS estimator is then $\hat{A} = (\hat{A}_1,\ldots,\hat{A}_p) = YZ'(ZZ')^{-1}$ and OLS estimator is assumed to be consistent and asymptotically normal (Masten, 2020).

We must use a Wald test with null hypotheses stated in sequence as H_0: $A_{pmax} = 0$ and H_0: $A_{pmax-1} = 0$, where we start testing from p_{max} and running tests backwards until the rejection of the null hypothesis. Here we face a problem of choosing p_{max} value. If we take too small p_{max}, it is not that critical, because we will detect the problem in further model checking. However, taking too large p_{max} value can turn out to be spurious. Large p_{max} will thus have different testing size and change the distribution. Hence, we have to be careful before applying p_{max} value and have in mind that the testing procedure is sequential. Alternatively, we can apply the test in sequential procedure, where we state the null hypotheses as H_0: $A_{pmax} = A_{pmax-1} = \ldots = A_{pmax-I} = 0$. In this case, we bound the sequential testing with I stage. In empirical analysis, I will choose lag-length order based on estimated information criteria. Once we find the right lag order, we can estimate VAR(p) p = 0,..., p_{max} models for our sample and minimize specific criteria that give us appropriate p order. Fundamental equation for the criteria is,

$$Cr\ (p) = \log\det(\tilde{\Sigma}_u(p)) + c_T\, \rho\ (p) \quad (9)$$

where $\tilde{\Sigma}_u(p) = T^{-1}\sum_{t=1}^{T}\hat{u}_t\hat{u}_t{}'$ represents error term from the VAR(p) model, c_T term represents constant terms structured by sample size T, and ρ (p) represents a function that helps to determine appropriate order. The latter determines optimal order with the feature that penalizes the large order.

$$\hat{p}\ = \arg\min_p\{\ Cr\ (p)\}_{p\,=\,0}^{p_{max}} \quad (10)$$

Most frequently used criteria are Schwartz information criteria (SC), Hannan-Quinn criteria (HQ) and Akaike information criteria (AIC) (Masten, 2020).

3.3 SVAR model

Structural vector autoregressive (SVAR) models are basically the same as standard vector autoregressive (VAR) models, apart from reduced form and in a way that SVAR models have the option of imposing various restrictions. Imposing structural restrictions enable a model to identify contemporaneous monetary policy interventions and return meaningful impulse response functions (Pham, 2013). Beside the already mentioned SVAR modelling pioneers, additional researches have been done by King, Plosser, Stock, & Watson (1991). The greatest advantage of the SVAR models thus comes with the ability of imposing restrictions with economic meaning. For every imposed restriction, we obtain an impulse response function, which gives an insight of how the one standard deviation shock of impulse variable causes the change in the response variable. From those dynamic responses, we are able to interpret the magnitude, the persistence and the impact of particular shock. We usually start the SVAR modelling by specifying the reduced model. Once the model is correctly specified, we can run the estimation and obtain the structural impulse response functions. Next, I will use K-dimensional stationary time series as starting point, and write it as a VAR(p) process,

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + u_t \tag{11}$$

same as in equation (5), apart from intercept. As already mentioned, dependent variable (y_t) is a (Kx1) vector containing the time series variables, the A_t's (j = 1,..., p) are (KxK) matrices that contain coefficients and u_t is K-dimensional innovation process distributed as $u_t \sim (0, \Sigma_u)$. To make the model more intuitive, we exclude deterministic terms, thus the stochastic part needs to be considered from a data generation process. We need the stochastic part, because it is crucial to obtain the impulse response functions. Furthermore, we have to specify the Wold moving average time series as,

$$y_t = u_t + \Phi_1 u_{t-1} + \Phi_2 u_{t-2} + \cdots \tag{12}$$

$$\Phi_s = \sum_{j=1}^{s} \Phi_{s-j} A_j, \text{ s = 1, 2,… with } \Phi_0 = I_K \tag{13}$$

In the equation (13), Φ_j represents the matrix form of impulse response function, which is derived from the forecast error. However, forecast errors might be instantaneously correlated and thus give spurious impulse response function. In this case, Σ_u matrix does not have a diagonal structure. Additionally, we use a Cholesky decomposition specification, which is based on innovation process in the covariance matrix, $\Sigma_u = PP'$. Cholesky decomposition presents the product between the lower triangular matrix P and the transposed form of the same lower triangular matrix P. This specification is appropriate in the case of process with the recursive structure. Further, I will explain the A, the B and the AB model specified by Amisano & Giannini (1997). This approach gives us the unique impulse response functions, which I use in my empirical analysis (Lütkepohl, 2005).

3.3.1 A-Model

The A-model structural model is built on principle to find the residuals which are not instantaneously correlated. We can obtain those instantaneous relations directly from our observation parameters. First, we specify the following structural model as,

$$Ay_t = A_1^* y_{t-1} + \cdots + A_p^* y_{t-p} + \varepsilon_t, \tag{14}$$

where A_p^* = AA_j (j = 1, ..., p) and $\varepsilon_t = Au_t \sim (0, \Sigma_\varepsilon = A\Sigma_u A')$. For the right choice of matrix, A, error terms (ε_t) should be structured in a diagonal covariance matrix form. Moving average is derived from the error term (ε_t) and can be written as equation,

$$y_t = \Theta_0 \varepsilon_t + \Theta_1 \varepsilon_{t-1} + \Theta_2 \varepsilon_{t-2} + \cdots, \tag{15}$$

where $\Theta_j = \Phi_j A^{-1}$ (where j = 0, 1, 2,...). In the equation, parameters from Θ_j matrices are presenting the responses to the error term (ε_t) changes. We can estimate the unique impulse response function, if we specify the process in the identified structure, same as in the equation (14). This can be done by some restrictions. We can assume the Σ_ε to be a diagonal matrix, in the equation $\Sigma_\varepsilon = A\Sigma_u A'$. Therefore, there is K(K −1)/2 independent equations, where are K(K−1)/2 parameters of $A\Sigma_u A$, which do not lie on the diagonal, equal to zero. However, we need to specify another, in order to get unique results for all K^2 parameter in matrix A. It can be done by setting the K(K+1)/2 set of equations in the restriction form for the parameters in A matrix and to set the diagonal parameters as unity. Additionally, we must apply another K(K −1)/2 restrictions, which are coming from the out of sample source. Here comes the importance of correct causal ordering, as the y_{1t} might have the instantaneous effect on every specified variable, while the y_{2t} might instantaneously affect all variables with the exception of y_{1t} variable. If this principle follows in the same procedure for every following variable, we can specify lower-triangular matrix as,

$$A = \begin{bmatrix} 1 & 0 & \dots & 0 \\ a_{21} & 1 & & 0 \\ \vdots & & \ddots & \vdots \\ a_{K1} & a_{K2} & \cdots & 1 \end{bmatrix} \tag{16}$$

The matrix presents the just identified impulse responses, because there is exact number (K(K − 1)/2) of constraints (0) on the top right part of the matrix. The model has the flexibility of imposing constraints on different variables, which do not lie on the diagonal. Moreover, we can impose more than K(K − 1)/2 number of constraints, if this improves our model. Therefore, the advantage of the SVAR model is that we can get the unique impulse response function, only by the minimum K(K − 1)/2 number constraints, which are necessary to impose. We impose the identification restrictions in the specified A matrix, as $\varepsilon_t = Au_t$, that it has a diagonal covariance matrix. If we assume that we have a specified lower triangular A matrix, with the unit diagonal, the same it should hold for the A^{-1} transformation of this the same matrix. From the Cholesky decomposition of Σ_u, it follows that the Θ_j

impulse responses from the A^{-1}, should be qualitatively the same as the impulse responses from the normalized A matrix. However, we must specify restrictions in the correct form, as $C_A vec(A) = c_A$. The variable C_A stands for the selection matrix, while c_A stands for the fixed vector, which should be specified in a structure that is suitable for the matrix calculation. We must consistently specify the restrictions, in order to get a unique result. The system of equations can be specified as,

$$A^{-1}\Sigma_{\varepsilon}A'^{-1} = \Sigma_u \text{ and } C_A \text{vec(A)} = c_A \quad (17)$$

The system is nonlinear in A, so it cannot assure us to have local uniqueness or identification. Therefore, the locally unique solution of structural variables can be justified by the equation (17). The model is locally identified if the c_A fixed vector has the rank to justify the probability 1. The identification is justified, if the C_A selection matrix has the minimum number of K(K + 1)/2 restrictions (Lütkepohl, 2005).

3.3.2 B-Model

The SVAR analysis is directly focused on the interpretation of the shocks that is done by impulse response function. Thus, we normally identify the structural innovations (ε_t) from the specified residuals (u_t) that are structured in the reduced form. We observe it from the relation $u_t = B\varepsilon_t$, where the residuals (u_t) are written in linear relation with the respect to structural innovation (Σ). Hence, $\Sigma_u = B\Sigma_\varepsilon B'$. Therefore, we obtain $\Sigma_u = BB'$, from the normalization of the structural innovations. We can assume $\varepsilon_t \sim (0, I_K)$, once we normalize them to one. As mentioned in the A-model, we must specify the additional K(K−1)/2 parameters, in order to do the identification for all K^2 parameters in B matrix. Thus, we obtain the appropriate number of restrictions in lower triangular B matrix, to solve the identification problem by Cholesky decomposition. Identification problem can also be referred as uniqueness, because we need to obtain unique impulse response function in order to make a meaningful inference. As mentioned in the A-model, zero restriction can be imposed on the other off-diagonal parameters in the matrix form, which would have then different constraints as the theoretical example of the lower triangular form. The B-model has been first used in the literature by the Christiano, Eichenbaum & Evans (1996). We can write B-model as,

$$u_t = B\varepsilon_t, \text{ where } \varepsilon_t \sim (0, I_K) \quad (18)$$

Additionally, in case of K(K − 1)/2 zero restrictions, we can specify the equation $C_B vec(B) = 0$, where C_B is an ($N \times K^2$) selection matrix. Here we can obtain the identification, if we restrict the sign of the diagonal parameters. The sign restrictions, of the diagonal parameters in the B matrix, exhibit the sign of exogenous shocks. This feature enables us to reverse the signs of a particular column in matrix B, in order to measure the effect of negative shock to specific variable whether the equivalent diagonal element in the B matrix is positive (Lütkepohl, 2005).

3.3.3 AB-Model

The AB-model is based on the combination of the features of the A-model and the B-model. Contemporaneous use of previous specification can be written as,

$$Au_t = B\varepsilon_t, \text{ where } \varepsilon_t \sim (0, I_K) \quad (19)$$

The AB-model presents the system of equations, which is constructed in a way to directly observe the relations for the innovations. The AB-model was applied in the academic research of Gali (1992) and Breitung (2004). The main advantage of this model is that we do not need to specify the direct relations among observable variables. The AB-model from the equation (19), can be rewritten to obtain $u_t = A^{-1}B\varepsilon_t$. Hence, $\Sigma_u = A^{-1}BB'A^{-1\prime}$ with K(K +1)/2 equations needed due to the symmetry, in order to identify K^2 parameters in the A and the B matrices. Additionally, we can use the equation,

$$\text{vech}(\Sigma_u) = \text{vech}(A^{-1}BB'(A^{-1})') \quad (20)$$

where we must specify $2K^2–(1/2)K(K+1)$ new restrictions, in order to locally identify two times K^2 parameters for the A and the B. However, for the unique identification we need to satisfy additional $2K^2-K–(1/2)K(K+1)$ conditions, even though we set the diagonal parameters to one. Furthermore, we have to specify additional conditions as $A = I_K$ (the B-model) or $B = I_K$ (the A-model). This theoretical implication is an important fundamental framework to use the SVAR model in the analysis. Moreover, zero restrictions are normally written in a linear relationship structure. It is presented in the following equations as,

$$\text{vec}(A) = R_A\gamma_A + r_A \text{ and } \text{vec}(B) = R_B\gamma_B + r_B \quad (21)$$

R_A and R_B stand for fixed matrices of restrictions structured from the one and zero values of constraints. γ_A and γ_B variables stand for the vectors of free parameter, while the r_A and r_B represent the vectors with the fixed parameters. This equation helps to normalize the diagonal parameters in the matrices. Furthermore, if we multiple the A and the B set, from the equation (21), with the orthogonalized complements R_A and R_B, $R_{A\perp}$ and $R_{B\perp}$, respectively, we can obtain the following equation,

$$C_A\text{vec}(A) = c_A \text{ and } C_B\text{vec}(B) = c_B \quad (22)$$

where hold the following relations $C_A = R_{A\perp}$, $C_B = R_{B\perp}$, $c_A = R_{A\perp}r_A$ and $c_B = R_{B\perp}r_B$. The matrices C_A and C_B are assumed to be the right selection matrices. As mentioned earlier, we need to impose additional restrictions, because the underlying equations are nonlinear in nature. Nonlinearity thus complicates the identification of the uniqueness for the A and the B matrices. The addition of new restrictions must be carefully monitored, because some restrictions are not appropriate for the specific A and B matrices. However, Blanchard & Quah (1990) pioneered with another type of restrictions. They have analysed the exogenous shocks, of how they affect the economy. Moreover, they specified the following total impact matrix equation,

$$\Xi_\infty = \sum_{i=0}^{\infty} \Theta_i = (I_K - A_1 - \cdot \cdot \cdot - A_p)^{-1}A^{-1}B \tag{23}$$

Equation (23) captures the structural impulse response function, which helps to determine the structural innovation by imposing constraints (0) in the desired place in the total impact matrix. Blanchard & Quah (1990) analysed the long-term effects of GDP growth q_t and an unemployment rate ur_t (specified as $y_t = (q_t, ur_t)'$). Demand and supply shocks were presented by structural innovation in the economic model. Model was based on the assumption that the shift in aggregate demand presents only short-term change to the GDP growth, and that the accumulated long-term effect of the aggregate demand shift is equal to zero (for more information, see Blanchard & Quah (1990)). However, the implication of the AB-model gives the insight of the SVAR model by simply setting the restrictions of the structural innovation on the VAR model, in order to obtain unique impulse response function. The AB-model is thus the fundamental framework for the empirical SVAR analysis (Lütkepohl, 2005).

3.4 Description of SVAR used in analysis

In empirical analysis, I will specify the economy by the structural equation (5). The dependent variable will be a vector of four analysed variables, which will be in the following order: US industrial production index, Money supply (M2), Federal Funds rate and S&P 500 market index. Next, the error term (u_t) will be a vector composed from structural shocks (mutually independent and uncorrelated). The ε will be a vector structured from the fixed values and the A(p) will be an autoregressive polynomial with the p order. The SVAR model will be derived in the same way as the previously described derivation of the AB-model. In the literature, Gali (1992) and Uhlig (1999) have derived similar model based on the complex short and long-run restrictions (Studi, 2002). However, the model used in my empirical analysis relies on the lower triangular matrix, specified in the following way,

$$\begin{bmatrix} \varepsilon_{USIP} \\ \varepsilon_{M2} \\ \varepsilon_{FFR} \\ \varepsilon_{S\&P} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix} \begin{bmatrix} u_{USIP} \\ u_{M2} \\ u_{FFR} \\ u_{S\&P} \end{bmatrix} \tag{24}$$

3.5 Review of Literature: Empirical studies

Review of literature has the purpose to reveal the recent academic researches connected with the structural vector autoregressive model. Goto & Valkanov (2000) were using exclusion restrictions to estimate SVAR models. They were trying to explain monetary policy impacts on the financial markets with simultaneous recursive correlations to separate the impact of monetary policy. Bernanke & Gertler (1989) estimated a model with financial frictions, which amplifies the influence of exogenous shocks. They were using forward-looking models, which required the change of forward-looking parameters with estimated values of these parameters. To solve endogeneity problem, they analysed lagged values of the equity index. Therefore, monetary policy shocks are not correlated with lagged equity index. Goodhart (2000) assumed that monetary policy could be improved if central banks use a wider measure of inflation to include asset prices of real estate market and stock market. Rigobon & Sack (2001) estimated that monetary policy measures negatively impact equity market and that this impact is insignificant, advocating that the Fed does not actively react to stock prices. They estimated a new identification SVAR approach, which allows simultaneous responses of monetary policy to the equity market. Research measured the effects of monetary policy to changes in equity prices. Faust, Rogers, Swanson, & Wright (2003) estimated models with input variables of interest rate derivatives, obtained from the futures market. The models were based on SVAR estimation method and gave the output of impulse response function, where the impulse was monetary policy shock, and the response was change in the interest rate. After the research of Faust, Rogers, Swanson, & Wright (2003), many academics followed their principles. They were trying to measure contemporaneous identification of interest rates with the change in monetary policy and the change in foreign exchange rates. Same as the Rigobon & Sack (2001) estimation method, this method suffers the endogeneity bias, because equity market index and the monetary policy might be endogenous. However, empirical models depart from previous literature in a way to address the issue of exclusion restrictions. Thus, with this achievement, we can measure contemporaneous monetary policy measures to returns of equity index (Vinayagathasan, 2014).

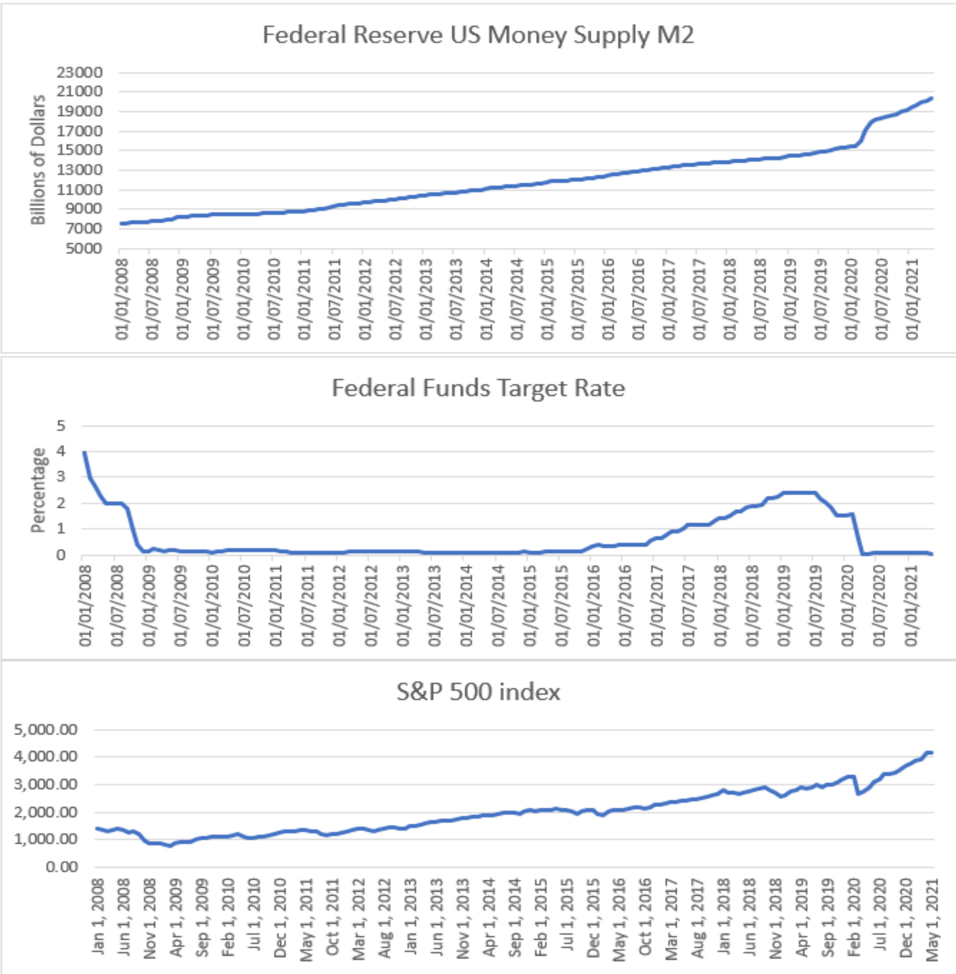
4 EMPIRICAL ANALYSIS

The objective of thesis research is to measure the influence of central bank’s interventions on the US equity market index using the methodology of structural VAR. SVAR model estimates the measures of policy changes through impulse response functions. The expansionary monetary policy has a positive and transitional effect on the equity index. In the period from 2008 to 2021, S&P 500 market index constantly grew to sustainable high levels. A sudden inversion of the trend happened in 2008 during the global financial crisis and in March 2020, because of Covid-19 pandemic. According to these findings, the correlation in the stance of monetary policy and the return in equity prices attracted a lot of attention among market participants and policy-makers. Central bankers and researchers (Bernanke & Gertler, 2000; Rigobon & Sack, 2001) discussed the adequacy of monetary policy interventions in the economy and the importance of equity wealth in the transmission mechanism due to interest rate changes. In the long term, differences in equity prices may increase or decrease the aggregate demand because they account for substantial part of wealth in the economy. Changes in discount rates may alter equity valuation and therefore alter available wealth to households. It may funnel another mechanism, simultaneously with the Federal Funds rate, where the bank's policy transmission mechanisms alter the aggregate output and inflation. Households, in the USA, hold a larger part of equity ownership compared to other countries. Therefore, wealth effect should be more prominent in comparison of historical relationship between financial market prices and aggregate spending. However, findings from research papers suggest that the correlation between returns in equities and the overall consumption is insignificant. Boone, Giorno & Richardson (1998) empirically proved a decline of ten percent in equities lowers US overall consumption by about 0.5 to 0.8 percentage points with a lag of one year. Goto & Valkanov (2000) estimated that the inclusion of equity market index reduces (not fully eliminate) the evidence of initial equity price increase in response to interest rate shock. Furthermore, Rigobon & Sack (2001) suggested that the central bank intervenes to changes in equity market valuations by adjusting their interest rate target. The important conclusion of Rigobon & Sack (2001) suggests that a five percent rise in the S&P 500 increases the likelihood by almost half, that the central bank's interest rate target surges by twenty-five basis points. Thus, the central bank seems to intervene to movements in equity market valuations. However, changes in equity prices should have less significant effects on the aggregate demand and aggregate output, according to estimations. In March 2020, we could observe a large decline in the stock market, therefore it emphasises the importance of exploiting central bank's transmission mechanism in order to affect the equity market. The correlation between monetary policy and equity prices is gaining importance, even though the literature findings suggest that the equity market channel does not contribute to the main transmission mechanism in the economy. Structural VAR models are commonly used by academics to estimate the influence of central bank's interventions in different economies (d'Amico & Farka, 2003b).

4.1 Data description

In my analysis, I use dataset consisting of monthly quotations in the period from January 2008 to May 2021. At the end of this interval (from March 2020 to May 2021) is the period of the Covid-19 pandemic, where we could see substantial changes in equity prices, Federal Funds rate, money supply and in the US the industrial production index. In the SVAR analysis, I have modelled four variables: US equity market index (S&P 500), Money supply (M2), US industrial production index and Federal Funds rate. Bloomberg is the underlying source for all selected time series data. I have estimated variables in logarithmic form and expressed in US dollars, with the only exception of Federal Funds rate. Sample includes data from 161 monthly observations.

Figure 6: Money Supply (M2), Federal Funds Rate, S&P 500 time series during Covid-19

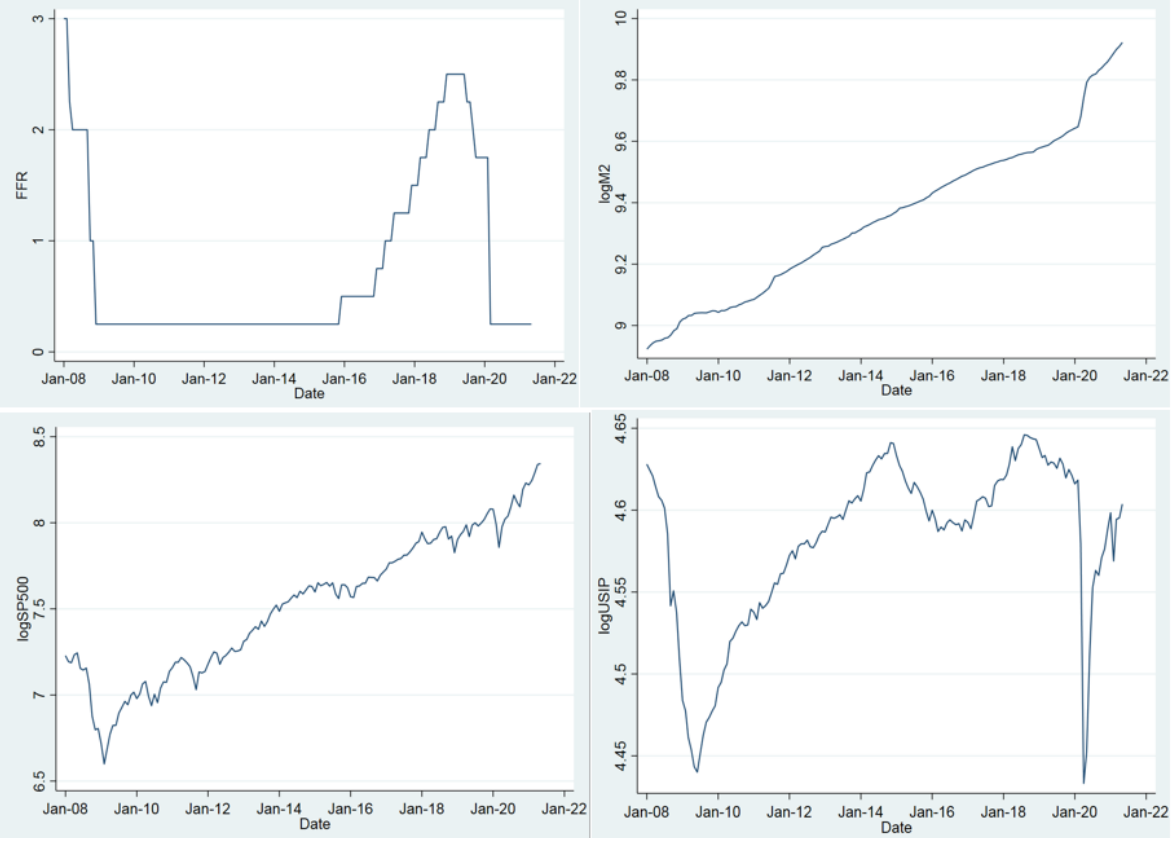


Source: Own work..

4.1.1 Time series of analysed period

Stock market indices are leading (forward-looking) economic indicators, because they include expected earnings of the companies (price adjustment), thus market indices can forecast important direction of the economy if their predictions are unbiased. Great market index performance can indicate upward sloping earnings and economic expansion in the following periods. Weak market performance could forecast a recessionary gap. In the analysed horizon, the Federal Reserve have been using expansionary monetary policy measures to support the market during Global Financial crisis and the Covid-19 downturn, which in turn positively affected S&P 500 index. However, market indices are not good indicators if they are manipulated by traders.

Figure 7: Time series data of analysed variables



Source: Own work.

4.1.2 Pre-estimation specification tests

Stationarity

The fundamental condition of time series modelling is stationarity assumption. To make a valid statistical inference, we must confirm that the data is stationary before estimating a SVAR model.

Strong or strict stationarity implies that the shift in time series is time invariant. Therefore, random variables follow the distribution of finite sequence in stochastic process because of the shift along x-axis. Independent and identically distributed stochastic process is assumed to be stationary for the entire period Cox & Miller (1965). We can write that the time series data, where X = (x_i; i ∈ Z) is strictly stationary if:

$$F_x(x_{t,1+t},..,x_{t,n+t}) = F_x(x_{t,1},..,x_{t,n}) \tag{25}$$

However, strong stationarity has little practical application (for more information, see Diebold (2008)).

Covariance or weak stationarity implies that a time series has time invariant mean and the time invariant covariance. The time series data $\{x_i, i \in \mathbb{Z}\}$ is assumed to be covariance stationary if it satisfies the following three principal requirements:

$$E[y_t] = \mu_t \text{ and } |\mu| < \infty, t = 1, 2, ..., T \quad (26)$$

$$var(y_t) = \sigma^2 < \infty \quad (27)$$

$$cov(y_t, y_{t-s}) = \gamma_s \text{ and } |\gamma_s| < \infty, t = 1, 2, ..., T, s = 1, 2, ..., T \quad (28)$$

where the first equation implies that the expected value of the time series must be constant and finite in all periods. The second equation means that the variance of the time series must be constant and finite in all periods. The third equation requires that the covariance of the time series with itself (for a fixed number of periods in the past or in the future) must be constant and finite in all periods (CFA institute, 2021). Estimation results will have no economic meaning if any of three stationarity conditions is violated. Spurious estimation gives biased coefficients and wrong estimates for effects of shocks, which gives permanent causal relations, even though they are transitory. Time series data must be transformed if stationarity conditions are not satisfied. I transformed the data of equity index, US industrial production index and the money supply using logarithmic values with the first difference transformation. Furthermore, if the data generating process is integrated of order d, it needs transformation to produce stationary time series with I(0). The process has a unit root if it exhibits non-stationarity with I(1). In addition to this transformation, I performed Augmented Dickey-Fuller (ADF) statistical test to infer whether the process has a unit root. The ADF test is usually used because it enables identification in complex models, and it is more flexible compared to a basic Dickey-Fuller test. However, we have to be careful in analysis due to higher probability of Type-I error. Moreover, ADF tests must be performed with satisfactory number of Δy_t lags, that the error term is serially uncorrelated. Statistical package Stata helps to determine how many lags should be included in estimation with DF-GLS test. Methods used in Stata are sequential t method (Ng-Perron), Schwarz criterion (SC) and modified Akaike information criteria (MAIC). Schwartz criterion is normally commonly used method, when sample size is large enough. The hypotheses for the test are:

$$H_0: \rho = 1, \gamma = 0, \quad (29)$$

$$H_a: \rho < 1, \gamma < 0, \quad (30)$$

where the null hypothesis confirms a unit root. Alternatively, the rejection of the null hypothesis confirms that the process is stationary. In the pre-estimation stage, we have to use appropriate data in order to specify correct estimation model. The model with non-zero mean will thus include constant value. Further, I will specify the assumptions of the estimation for the ADF test:

- Model without constant and trend term, $y_t = \rho y_{t-1} + \upsilon_t$ where $\Delta y_t = (\rho-1)y_{t-1} + \upsilon_t$ therefore same as $\Delta y_t = \gamma y_{t-1} + \upsilon_t$, in case of the process that has a pattern around zero, which is the sample average.
- Model with constant term and without trend $\Delta y_t = \alpha + \gamma y_{t-1} + \upsilon_t$ in case of the process that has a pattern around non-zero value, which is the sample average.
- Model with constant and trend term, where $\Delta y_t = \alpha + \gamma y_{t-1} + \theta y_{t-1} + \upsilon_t$, in case of the process that has a pattern around linear trend.

As mentioned earlier, variables in table (with the exception of Federal Funds rate) are in logarithmic values and transformed using first difference ($\Delta = x_t - x_{t-1}$). Table 6 presents the output of performed ADF test for the analysed variables during the entire period and the period excluded Covid-19 pandemic. According to Schwartzman criterion, variables are tested with inclusion of three lags. ADF test gives us Z(t) test statistic and rejection criteria at significance levels of 1, 5 and 10 percent. Hypothesis testing states that we reject the null hypothesis whether the value of Z(t) test statistic is larger than significance level. ADF test results suggest that the Federal Funds rate, Money supply (M2), US industrial production index and S&P 500 market index observations are I(0) stationary (C. A. Sims, 1992).

Table 6: ADF test for analysed variables

ADF test for a unit root	Test statistic	1%	5%	10%
Number of obs = 140, Z(t) dfuller d.logSP500, lags(3)	-4.602	-3.497	-2.887	-2.577
Number of obs = 140, Z(t) dfuller d.logM2, lags(3)	-4.743	-3.497	-2.887	-2.577
Number of obs = 140, Z(t) dfuller d.logUSIP, lags(3)	-4.552	-3.497	-2.887	-2.577
Number of obs = 141, Z(t) dfuller FFR, lags(3)	-5.915	-3.497	-2.887	-2.577
Number of obs = 140, Z(t) dfuller d.FFR, lags(3)	-5.075	-3.497	-2.887	-2.577
Number of obs = 156, Z(t) dfuller d.logSP500, lags(3)	-5.144	-3.491	-2.886	-2.576
Number of obs = 156, Z(t) dfuller d.logUSIP, lags(3)	-4.552	-3.491	-2.886	-2.576
Number of obs = 156, Z(t) dfuller d.logM2, lags(3)	-6.131	-3.491	-2.886	-2.576
Number of obs = 157, Z(t) dfuller FFR, lags(3)	-3.167	-3.490	-2.886	-2.576
Number of obs = 156, Z(t) dfuller d.FFR, lags(3)	-5.691	-3.491	-2.886	-2.576

Source: Own work.

Results are stationary for the entire analysed horizon and for the horizon without the time of Covid-19 pandemic. In every case, transformed data turned out to be good for the estimation and proved to have explanatory power for capturing the dynamics among variables. However, I will not use first difference transformation for the Federal Funds rate, because it is statistically significant in non-transformed version at ADF test. When analysing stock market, it is also more appropriate to use market index returns than the absolute index prices. OLS estimator of the SVAR model should stay consistent, because of justified stationarity condition. In continuation of thesis, I analyse the data of the entire period from January 2008 to May 2021, because results do not differentiate significantly.

SVAR lags selection

SVAR model requires selecting the right number of lags before the estimation. If we include too few lags, the model can have omitted variable bias and serial correlation in residuals. In contrast, model with too many lags restricts the degrees of freedom. However, lag selection specification of the SVAR estimation has to identify optimal number of lags. The model needs enough lags to capture the dependence of the process and simultaneously must be parsimonious about the degrees of freedom remaining. Lag length selection depends on the frequency of sample observations. In the literature, Sims (2011) recommended determining a lag order equivalent to one year's worth lag and the use of Akaike information criteria. Akaike information criteria uses important trade-off because it includes a penalty function that penalizes particular parts that do not explain the model (Félix, 2016).

For the lag length specification of SVAR model, I decided to test the model in accordance with different information criteria. The table 7 shows the appropriate number of lags according to different information criteria.

Table 7: Selection of the lag length for SVAR model

Lag length	Degrees of freedom	prob.	FPE	AIC	HQIC	SBIC
0			2.6e-09	-11.238	-11.214	-11.179
1	9	0.000	1.2e09	-12.037	-11.901	-11.655
2	9	0.006	**1.1e09***	**-12.081***	**-11.941***	**-11.801***
3	9	0.019	1.2e09	-12.065	-11.841	-11.489
4	9	0.210	1.2e09	-12.042	-11.730	-11.273
5	9	0.542	1.3e09	-11.977	-11.592	-11.030
6	9	0.007	1.2e-09	-12.007	-11.552	-10.883

* optimal lag, Endogenous: FFR D.logM2 D.logUSIP D.logSP500, Exogenous: _cons, Number of obs = 154

Source: Own work.

The estimated econometric criterions in the table 7: Final Prediction Error (FPE), Akaike's information criterion (AIC), Hannan-Quinn information criterion (HQIC) and Schwarz information criterion (SBIC), help to select the appropriate lag-length. Optimal lag-length selection is marked with two lags in the table. Therefore, I will use it in my SVAR model.

4.1.3 SVAR model estimation

Vector autoregressive models are relatively easily estimated by OLS estimation method. We can visualize every correctly specified VAR(p) model of K endogenous variable as a model of K seemingly unrelated regression equations. This way we can estimate every equation by OLS (ordinary least squares) estimator. OLS estimator is maximum likelihood estimator, if our model's residuals are normally distributed. If it is not normally distributed, then it is still efficient GMM (generalized method of moments) estimator. OLS estimation should satisfy seven assumptions to forecast correct linear regression. It is crucial that we do not violate the first six assumptions, in order to get meaningful results. Analysts take into account the seventh assumption, when they are restricted with small sample size. First four assumptions must hold in order to get unbiased and asymptotically consistent OLS regression. The standard assumptions for the OLS regression model:

1. Linearity (linear relationship between dependent and independent variable and non-stochastic error term)
2. The expected value of error term is zero (random sample)
3. Independence (independent variable observations are not correlated with the error term)
4. Error term observations are not serially correlated (proving consistency)
5. Homoscedasticity (variance of residuals is the same for all observations, no heteroscedasticity)
6. None of independent variables perfectly fits explanatory variable's function
7. The error term is normally distributed (when restricted with small sample size)

When assumptions 4 (no autocorrelation) and 5 (homoscedasticity) hold, analysts refer that the residual term is independent and identically distributed (i.i.d.). Best linear unbiased estimator (BLUE) for the OLS regression can be theoretically justified by Gauss-Markov theorem (CFA institute, 2021).

As mentioned earlier, if sample $(y_1,..., y_T)$ with preamble values $(y_{1-p},..., y_0)$, with notation: $Y = (y_1,..,y_T)$, $A = (A_1,...,A_p)$, $U = (u_1,...,u_T)$ and $Z = (Z_0,..., Z_{T-1})$ where, $Z_{t-1} = (y_{t-1},..., y_{t-p})$, we can write VAR(p) model as:

$$Y = AZ + U \tag{31}$$

OLS estimator is then:

$$A = (A_1,\ldots,A_p) = YZ'(ZZ')^{-1} \tag{32}$$

Where we assume that the OLS estimator parameters of VAR model is asymptotically normal and consistent with,

$$\text{vec}(A) \sim N(\text{vec}(A), \Sigma_A/T) \tag{33}$$

and variance-covariance matrix is then equal to

$$\Sigma_A = \text{plim}(ZZ'/T)^{-1} \otimes \Sigma_u \tag{34}$$

Asymptotic characteristics of parameters' estimation remains stationary with I(0) time series. In case of a random walk or integrated time series I(1+), variance-covariance matrix is then singular, so the t-test, chi-square-test and F-test are not appropriate for hypotheses testing for the VAR model. However, OLS estimator is consistent, but less efficient (Lütkepohl, 2005).

If the residual is white noise with normal distribution (commonly referred as Gaussian), it grants asymptotic normality and the consistency for the OLS regression. Note that normally distributed residuals confirm the normality of the dependent variable for stable processes. The estimator of variance-covariance matrix residuals is:

$$\tilde{\Sigma}_u = T^{-1} \sum_{t=1}^{T} \widehat{u_t}\widehat{u_t}' \tag{35}$$

We need to adjust for degrees of freedom because it gives covariance matrix with unbiased estimator and the regression with non-stochastic independent variables. Therefore, an estimator is considered as:

$$\hat{\Sigma}_u = \frac{T}{T-Kp-1} \tilde{\Sigma}_u \tag{36}$$

Regression estimators are equivalent, consistent and normally distributed in the calculations (Lütkepohl, 2005). As previously theoretically described methodology of the A, the B and the AB models for SVAR estimation, now I will use A and B matrices with restrictions.

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 \\ . & 1 & 0 & 0 \\ . & . & 1 & 0 \\ . & . & . & 1 \end{bmatrix} \text{ and } B = \begin{bmatrix} . & 0 & 0 & 0 \\ 0 & . & 0 & 0 \\ 0 & 0 & . & 0 \\ 0 & 0 & 0 & . \end{bmatrix} \tag{37}$$

Cholesky identification is here corresponded by restrictions, where A matrix is lower triangular matrix, whereas the B is diagonal matrix. Independent parameters will be in the following order: US industrial production index, Money supply, Federal Funds rate and S&P 500 market index. Thus, I assume that the percentage change in the US industrial production index is not contemporaneously influenced by the percentage increase or decrease in either Money supply, Federal Funds rate or S&P 500 market index. In the same way, the percentage change of Money supply is influenced by contemporaneous increase or decrease in US industrial production index but not with the change in Federal Funds rate and S&P 500 market index. Finally, the percentage increase or decrease in the S&P 500 market index is influenced by contemporaneous changes in US industrial production index, Money supply and Federal Funds rate. Order of estimated variables is in line with the economic hypothesis, as the Fed's interventions affect the real economic variables with a lag. For the SVAR estimation, I use the *svar* command in Stata software package.

Table 8: SVAR model estimation

Sample: Jan-08 thru May-21 — Number of observation = 159
Exactly identified model — Log likelihood = 1520.812

	Coefficient	Standard error	z	P>|z|
/A				
1_1	1	(constr.)		
2_1	-0.0130	0.0189	-6.87	0.000
3_1	-0.00687	0.00126	-5.45	0.000
4_1	0.0616	0.0224	2.75	0.005
1_2	0	(constr.)		
2_2	1	(constr.)		
3_2	1.487	0.181	8.20	0.000
4_2	-0.395	0.157	-2.51	0.006
1_3	0	(constr.)		
2_3	0	(constr.)		
3_3	1	(constr.)		
4_3	0.229	0.0354	6.40	0.000
1_4	0	(constr.)		
2_4	0	(constr.)		
3_4	0	(constr.)		
4_4	1	(constr.)		
/B				
1_1	0.165	0.00928	17.83	0.000
2_1	0	(constr.)		
3_1	0	(constr.)		
4_1	0	(constr.)		
1_2	0	(constr.)		
2_2	0.00393	0.000221	17.83	0.000
3_2	0	(constr.)		
4_2	0	(constr.)		
1_3	0	(constr.)		
2_3	0	(constr.)		
3_3	0.00902	0.000505	17.83	0.000
4_3	0	(constr.)		
1_4	0	(constr.)		
2_4	0	(constr.)		
3_4	0	(constr.)		
4_4	0.0409	0.00231	17.83	0.000

Estimating SVAR short-run parameters in order:
D.logUSIP D.logM2 FFR D.logSP500

Source: Own work.

The SVAR result in Stata software package reports the value of log likelihood on the top of the table. The body of the table presents the estimation results of the estimated variables from the previously specified the A and the B matrices. The results seems to be in line with the expectations (correct variable signs) and the model is just identified (Stata, 2021). In the table 8, we can see that the SVAR model gives desired constraints on the parameters, previously specified in the A and B matrices. We put constraints with fixed values (0, 1) in the specific place in each matrix. The results of coefficients A_{21}, A_{31}, and A_{42} are negative. This is due to actual contemporaneous effects, when the monetary policy effects are positive. Results are statistically significant. In table 9, Cholesky decomposition of variance-covariance matrix of the underlying SVAR shows the impact of responses for the particular variable.

Table 9: Cholesky decomposition

Cholesky decomposition matrix [4,4]				
	D.logUSIP	D.logM2	FFR	D.logSP500
D.logUSIP	0.165	0	0	0
D.logM2	0.00215	0.00393	0	0
FFR	-0.00205	-0.00586	0.00902	0
D.logSP500	-0.00887	0.00291	-0.00206	0.0409

Source: Own work.

4.1.4 Post-estimation specification tests

Granger causality Wald tests

Granger causality is specification test, which tests for causality among independent variables in time series model. Specification test investigates the pattern of correlations in analysed dataset. The Granger causality is confirmed (independent variable Granger-cause dependent one) whether the past values of independent variable can forecast the dependent variables. In order to get the test statistic, we need to regress independent variable on its own lagged values and on the dependent variable's lagged values. Finally, we have to accept or reject the null hypothesis, which determine our conclusion. Granger causality is confirmed if change in one variable cause the change in another variable. The null hypothesis states that lagged values of independent variable cannot explain the variation in independent variable. Generally, the Granger causality test should be estimated to determine whether parameters are simultaneously correlated at the specific moment (Neuhierl & Weber, 2017). In my empirical analysis, I will state the following hypothesis:

1. H_0: money supply and market index lagged values do not cause Federal Funds rates
2. H_0: Federal Funds rate and market index lagged values do not cause money supply
3. H_0: Federal Funds rates and money supply lagged values do not cause market index

We reject the null hypothesis, when chi-squared probability value is less than 0.05. Stata's syntax *vargranger* returns the output in table 10. Output contains the values of Granger causality test for FFR, M2, USIP and S&P500 equation, with various exclusion in SVAR model (Stata, 2021).

Table 10: Granger causality tests for analysed variables

Equation	Excluded	Chi-squared	Df	Prob > Chi-squared
FFR	M2	1.376	2	0.503
FFR	USIP	1.035	2	0.596
FFR	S&P500	9.781	2	0.008
FFR	ALL	18.228	6	0.006
M2	FFR	14.702	2	0.001
M2	USIP	17.979	2	0.000
M2	S&P500	13.041	2	0.002
M2	ALL	44.221	6	0.000
USIP	FFR	18.062	2	0.000
USIP	M2	15.997	2	0.000
USIP	S&P500	15.555	2	0.000
USIP	ALL	54.016	6	0.000
S&P500	FFR	1.039	2	0.595
S&P500	M2	18.527	2	0.000
S&P500	USIP	4.084	2	0.130
S&P500	ALL	28.579	6	0.000

Source: Own work.

Initial result in the column presents a Wald test, which tests the coefficients to the money supply (M2) lags, which are part of the equation in FFR. The specified null hypothesis is not rejected at the 0.05 confidence level; thus, we conclude that M2 does not Granger-cause FFR. Conversely, the null hypothesis is rejected at the 0.05 confidence interval in case of S&P500 in the equation for FFR, so we infer that S&P500 does Granger-cause FFR. The test where is excluded ALL, tests whether all other endogenous parameters are jointly zero. Here, the null hypothesis is rejected for the test that M2, USIP and S&P500 jointly Granger-cause FFR. Finally, we infer that lagged values of S&P500 cause FFR, lagged values of M2 do not cause FFR, lagged values of FFR and S&P500 cause M2, lagged values of M2 and FFR do not cause S&P500. It is consistent with the expectations. Market index changes (decline) encourage policy makers to intervene (expansionary monetary policy) with a lag.

Another way of testing is *varwle* syntax. Results suggest that the first three equations (FFR, M2 and USIP) do not have the same lag structure as the fourth (S&P500).

Lagrange multiplier test for residual autocorrelation after SVAR

The SVAR model's postestimation assumption is that the error terms are not autocorrelated. If model is autocorrelated, it causes an omitted variable bias and violates assumption of BLUE OLS estimator. We can specify the Lagrange multiplier test statistic as,

$$LM_s = (T - d - 0{,}5) \ln \left(\frac{|\tilde{\Sigma}|}{|\tilde{\Sigma}s|}\right) \quad (38)$$

In the equation, the T stands for the number of time series observations, the $\tilde{\Sigma}$ stands for the maximum-likelihood estimate of Σ and the $\tilde{\Sigma}_s$ presents the same element as the $\tilde{\Sigma}$, just in the augmented form. The element Σ has the variance-covariance matrix form, structured from the SVAR model's distrurbances. For the SVAR model with K equations, we specify the residual term (e_t) to have the vectorial structure (Kx1) of residuals. The original SVAR with lags is then augmented with K new variables, which include K residuals from e_t matrix. We can do the regression with each lag s, where the new residual variables generate s lags. As mentioned earlier, the element $\tilde{\Sigma}_s$ represents the MLE of the element Σ from the augmented SVAR. The second element in the equation, the element d, represents the number of estimated parameters in the SVAR in the augmented version. Lagrange multiplier test has the asymptotic distribution of chi-square with K^2 degrees of freedom. Stata's syntax *varlmar* executes the Lagrange multiplier test in the SVAR model. The test is based on the autocorrelation of residuals. For more information, see Johansen (1995). Table 11 presents results of performed test with j = 1,..,5 lags. Command *varlmar* has the input elements from the previously stored SVAR estimation results and returns the active estimation results.

Table 11: Lagrange multiplier test

Lag	Chi-square	Df	Prob > chi-squared
1	16.303	16	0.0708
2	13.869	16	0.127
3	12.945	16	0.149
4	5.210	16	0.815
5	10.062	16	0.345

Source: Own work.

Notes: H_0: no autocorrelation at lag order.

From the results, we cannot reject the null hypothesis (at probability value 0.05). Therefore, we infer for the Lagrange multiplier test that it does not have the residual autocorrelation in any of the above specified lag order. Specification test confirms that the model is correctly specified.

Test for normally distributed disturbances after SVAR

Normally distributed disturbances or normality is one of the properties of the time series that needs to be tested. One of the most frequently used is Jarque-Bera test, which relies on comparison the third and fourth moment to those of the standard normal distribution. Namely, a normal distribution has a skewness of zero (symmetrical around the mean) and a kurtosis of three. This test is one type of the Lagrange Multiplier test. For the Jarque-Bera test, we specify the null hypothesis that the data follows the normal distribution. Conversely, for the alternative hypothesis, we specify that the data does not follow the normal distribution. For more details, see Lutkepohl (2005). Lutkepohl (2005) uses different notation. However, it is important to note that the Jarque-Bera statistic is structured from the two test statistics. We have to test every single equation result to confirm the hypothesis inference. As mentioned earlier, the null hypothesis is that the disturbances in the equation are normally distributed. Model is valid, if we cannot reject the null hypothesis. Conversely, model is incorrectly specified and needs modification (Lütkepohl, 2005). Syntax *varnorm* returns a range of the test statistics tested for the null hypothesis, which indicate whether the disturbances, in a SVAR model, are normally distributed.

Table 12: Normality test

JB test		Chi-squared	Df	Prob > chi-squared
FFR		8.054	2	0.0012
M2		1.281	2	0.527
USIP		0.550	2	0.925
S&P500		0.750	2	0.687
Skewness test	Skewness	Chi-squared	Df	Prob > chi-squared
FFR	0.503	6.668	1	0.00982
M2	0.128	0.832	1	0.212
USIP	-0.091	0.432	1	0.511
S&P500	-0.105	0.560	1	0.454
Kurosis test	Kurtosis	Chi-squared	Df	Prob > chi-squared
FFR	4.315	11.386	1	0.00074
M2	3.359	0.849	1	0.356
USIP	2.518	0.162	1	0.701
S&P500	2.829	0.191	1	0.662

Source: Own work.

In analysis, we do not reject the null hypothesis for the single-equation Jarque–Bera statistics and neither for the joint Jarque–Bera statistic for the money supply, US industrial production index and market index. However, we reject the null hypothesis for the Federal Funds rate, which normally do not follow normal distribution. Violation of the normality for Federal Funds rate is not a problem, because the sample size is large enough. From the above results, we can also reject the null hypothesis for the skewness and kurtosis. As mentioned earlier, Jarque–Bera results do not come from the single test statistic, but they come from the summation of the test statistic for the skewness and kurtosis. The values of the skewness and kurtosis are determined from their coefficients.

Model stability

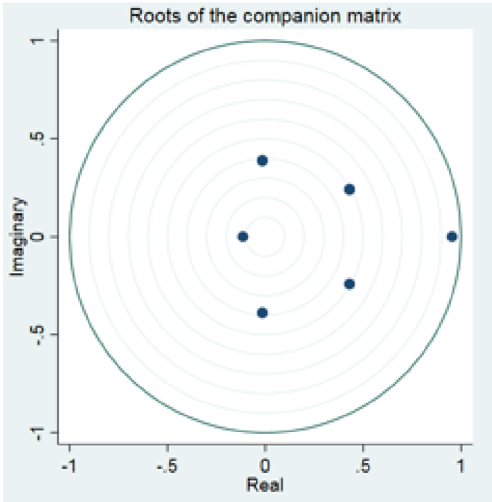
As mentioned earlier, postestimation inference of the SVAR model requires covariance stationarity. The dependent variables (y_t) are covariance stationary if the mean, variance and covariance are finite and time independent. SVAR stability is another important condition to have a valid model. In order to confirm stability, SVAR model has to include infinite order of vector moving-average factors and it has to be invertible. Justified stability condition gives valid interpretation of the impulse-response function (IRF) and the forecast-error variance decomposition (FEVD). Moreover, the stability condition is justified if model's eigenvalues are less than one. Syntax *varstable* returns the results for tested eigenvalue stability condition, following the estimation of SVAR model. It forms the matrix from the equation (6) and obtains own eigenvalues from the eigenvalues of the matrix. The absolute value of the complex eigenvalue (r + ci) is given as $\sqrt{r^2 + c^2}$. Therefore, the SVAR stability condition is satisfied if the absolute value of every eigenvalue in the matrix is strictly less than one. For more information, see Lutkepohl (2005) and Hamilton (1994).

Figure 8: SVAR model stability

Eigenvalue stability condition

Eigenvalue	Modulus
.9542153	.954215
.4301852 + .2416269*i*	.493399
.4301852 - .2416269*i*	.493399
-.01481272 + .3885973*i*	.38888
-.01481272 - .3885973*i*	.38888
-.1143383	.114338

All the eigenvalues lie inside the unit circle.
VAR satisfies stability condition.



Source: Own work.

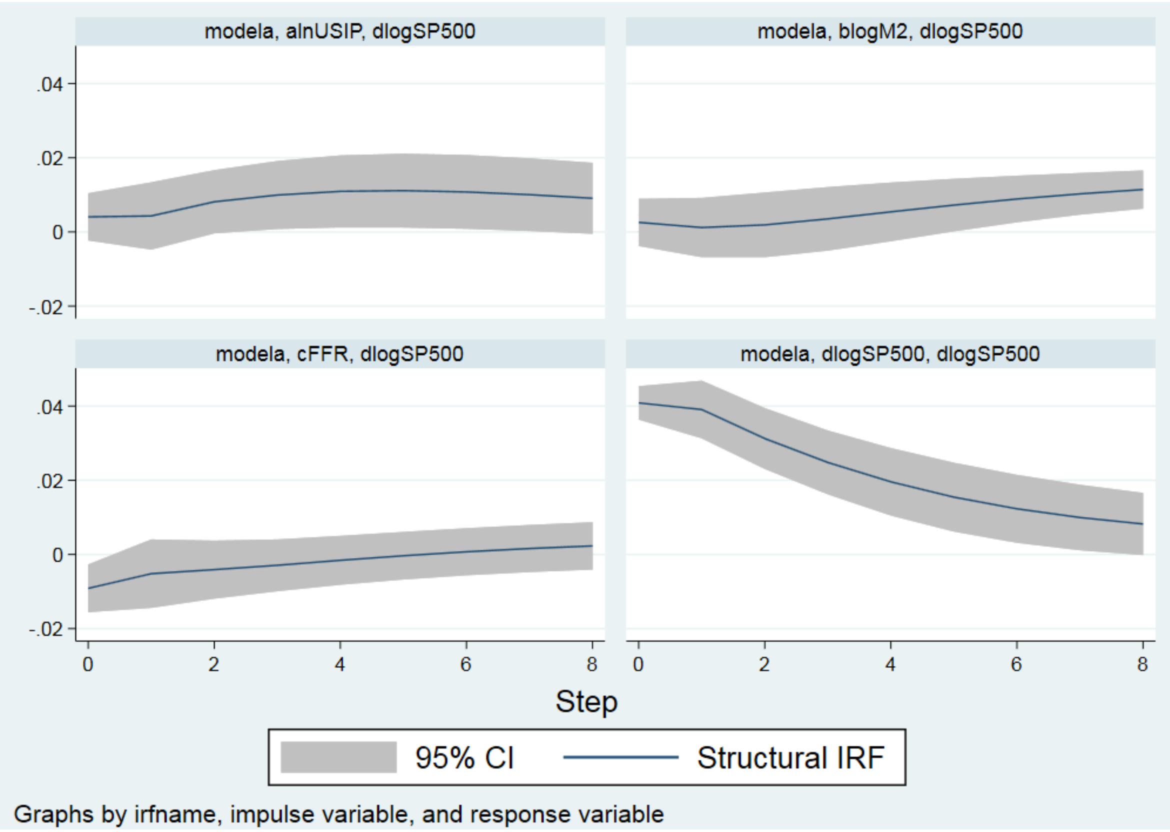
Figure 8 presents the eigenvalues with the real number value on the horizontal axis and the eigenvalues with the complex number value on the vertical axis. From the visual presentation, we can conclude that the eigenvalues are inside the unit circle or in order words less than 1. Additionally, the absolute values of eigenvalues, in the table, are less than one. Therefore, the stability condition for the SVAR estimation is justified.

4.1.5 SVAR model impulse response function

Impulse response functions represent the dynamic response of the response variable to a one standard deviation change of the impulse variable in the SVAR model. Innovation or one standard deviation shock is applied to error term for each variable in particular equation. We interpret impulse response function from visually presented graph, where is plotted impulse response of each variable over specified time horizon. Impulse response functions (IRFs) can be plotted from structural impulse response functions (SIRFs), which are estimated by constraints imposed on the fundamental vector autoregressive model. Another way of estimation can be done through orthogonalized impulse response functions (OIRFs), which are estimated from the Cholesky decomposition (Braun & Brüggemann, 2017).

In my SVAR analysis, variables were subject to expansionary monetary policy, which we obtain from the exogenous decrease in the Federal Funds rate and an exogenous increase in the money supply (M2). Impulse response function can be thus obtained from the one standard deviation shock of market index, to the variable of interest. Figure 9 shows the identified sets of impulse responses surrounded by 95% confidence intervals estimated using the residual-based bootstrap for US industrial production index, Money supply (M2) and Federal Funds rate responses to a one standard deviation shock of S&P 500 market index. It contains four plots, each showing the dynamic SIRF effect of the four variables to innovation of market index. Each graph depicts the impulse of the variable, which is written first after *modela* (above each plot), followed by the response variable. Vertical axis shows the percentage change of response variable. The horizontal axis shows the number of periods.

Figure 9: Structural impulse response functions



Source: Own work.

The bottom-right plot in Figure 9 presents the structural IRF of the one standard deviation shock to logS&P500 on logS&P500. We can see that the identification restrictions in the estimated model suggest that a positive one-unit standard deviation shock to logS&P500 causes an increase in logS&P500 by 4 percentage points and the effect gradually dies out after following periods. The bottom-left plot presents the structural IRF of the one standard deviation shock to FFR on logS&P500. Here, we can see that a positive shock to FFR implies a decrease in logS&P500 by 1 percentage point, which gradually dies out after 7 periods. The top-right plot presents the structural IRF of the one standard deviation shock to money supply (M2) on logS&P500, suggesting that a positive shock to money supply (M2) implies a gradual increase in logS&P500 by 1 percentage point until the last period. Results of the analysis are consistent with the economic theory.

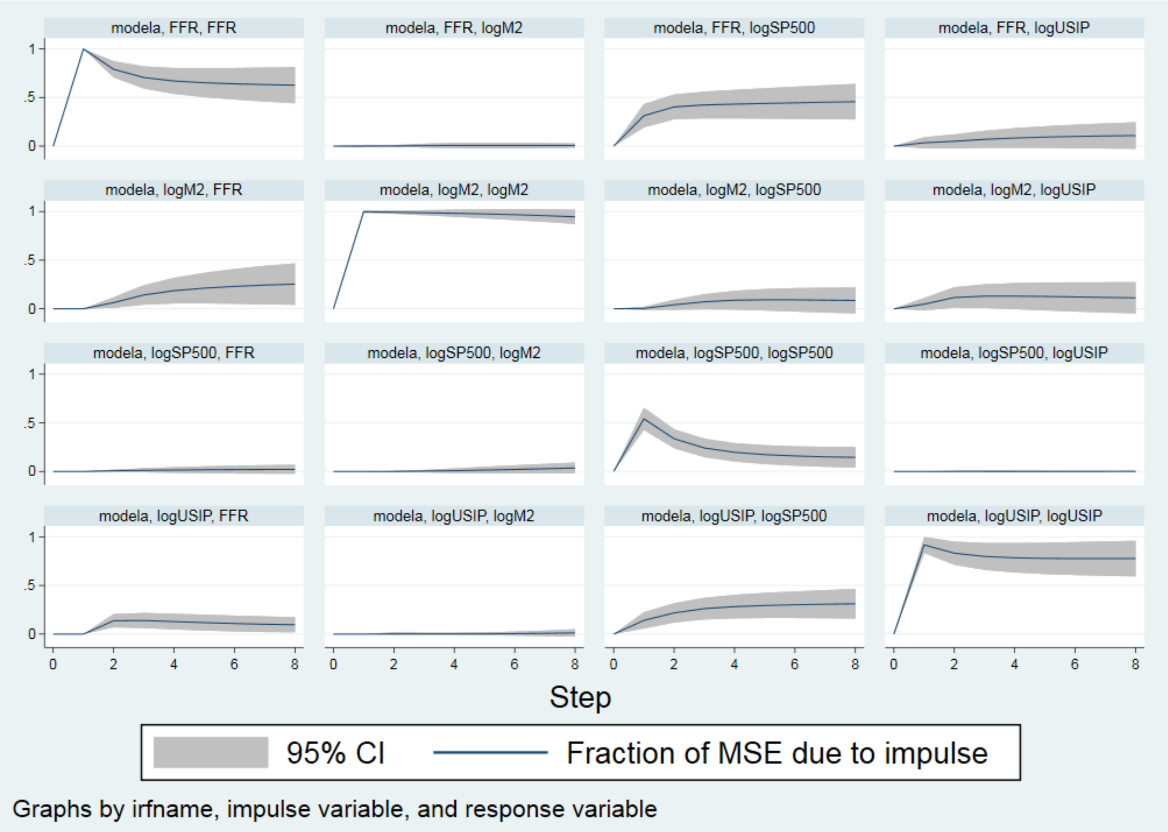
However, market participants have very different views on the monetary policy interventions. Some raises concerns about the scope of the interventions. Aggressive monetary policy interventions might lead to above desired rise in equity prices, which in turn rises inflation expectations. Monetary policy interventions are deemed to be successful if they improve economic fundamentals. Inflation, which comes from the improvement of the fundamentals, such as technological progress, is not concerning. This kind of inflation pose lower stability risk, and therefore policy-makers should not respond with increasing interest rates. Moreover, central bank regularly examines economic conditions and intervenes only when needed. It should react to shocks that contain risk of increases in inflation and ignore shocks that reflect the change in market fundamentals. Findings from the literature advocate in favour of passive monetary policy because the Fed has limited ability to timely recognize the particular type of financial market disturbances (Wolf, 2020).

4.1.6 Forecast error variance decomposition

Forecast error variance decomposition (FEVD) method supplements the SVAR model and splits the total variance of the forecast errors to particular underlying parts of the exogenous shock. Structural analysis helps to give visual intuition about the exogenous shocks in the SVAR model. For instance, some shocks do not exhibit variation initially but might cause gradual fluctuation of the variable. We have available FEVD estimation, if we can identify the one standard deviation shock in the SVAR model. However, the FEVD does not have a unique nature. From the theory, we know that the Θ_i matrices and the P matrix, which we transform, determines the uniqueness of the FEVD. The inference of a FEVD is subject to similar caution as the inference of the IRF. It is important to understand that the FEVDs have the conditional specification on the SVAR model. Therefore, if we change the number of analysed variables in the SVAR model, we must be cautious about the interpretations of the FEVD. Moreover, the FEVD is sensitive to the adjustments of the variable (seasonality, aggregation) and to the measurement errors (Lütkepohl, 2005).

Analysis is also referred to innovation accounting. One standard deviation shock, to exogenous variable, gives the result of the FEVD of the S&P 500 market index (Marczak & Gómez, 2017). The following results are consistent with the economic theory, that innovations of exogenous shocks have gradual effect on the S&P 500 market index. From the literature, we can see that the FEVD methodology is robust and appropriate for the analysis of the monetary policy shocks.

Figure 10: FEVD graphical presentation



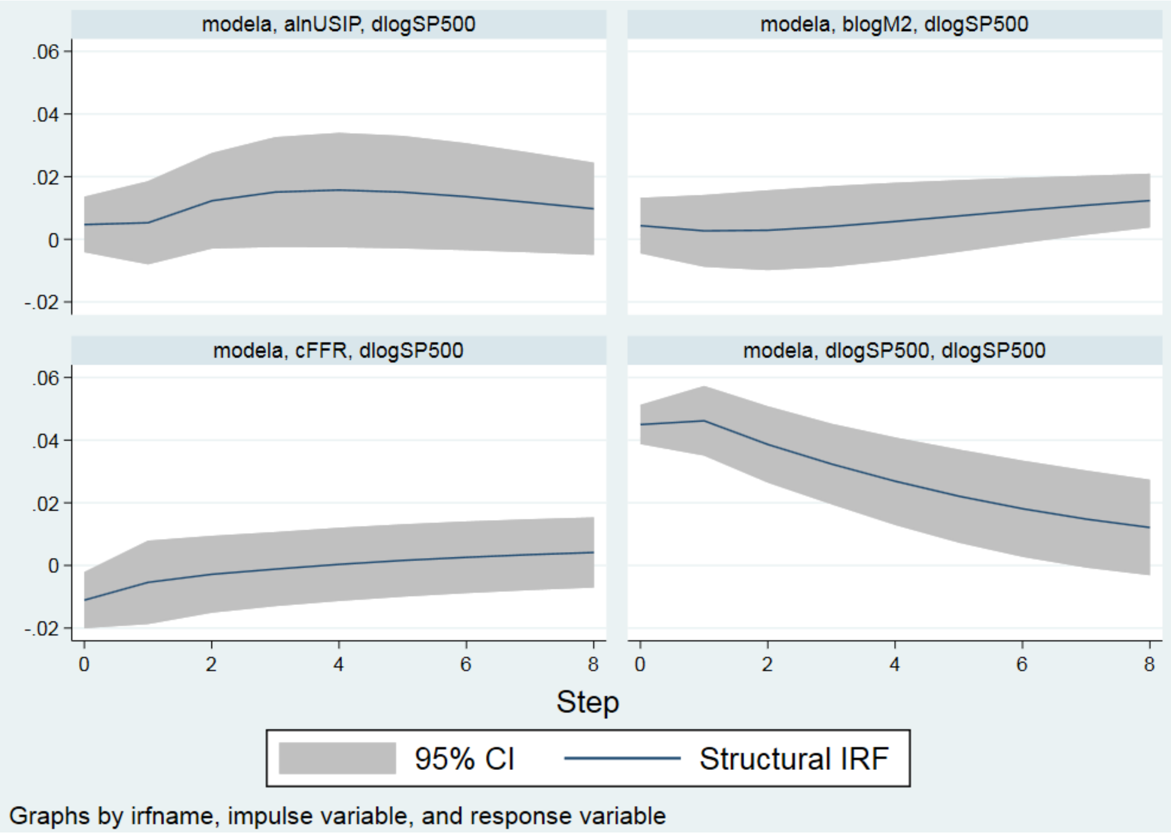
Source: Own work.

The third column of graphs shows that initially approximately 55% of variation in the S&P 500 market index comes from shock in S&P 500 market index itself, about 40% comes from Federal Funds rate and the small remaining percentage comes from the US industrial production index and money supply (M2). The variation contribution of the S&P 500 market index changes quite fast every period till the last period, where the other three variables gradually contribute substantial percentage of the remaining variation. Therefore, we can conclude that monetary policy interventions gradually contribute higher percentage of variation to the equity market index.

4.1.7 Robustness of responses

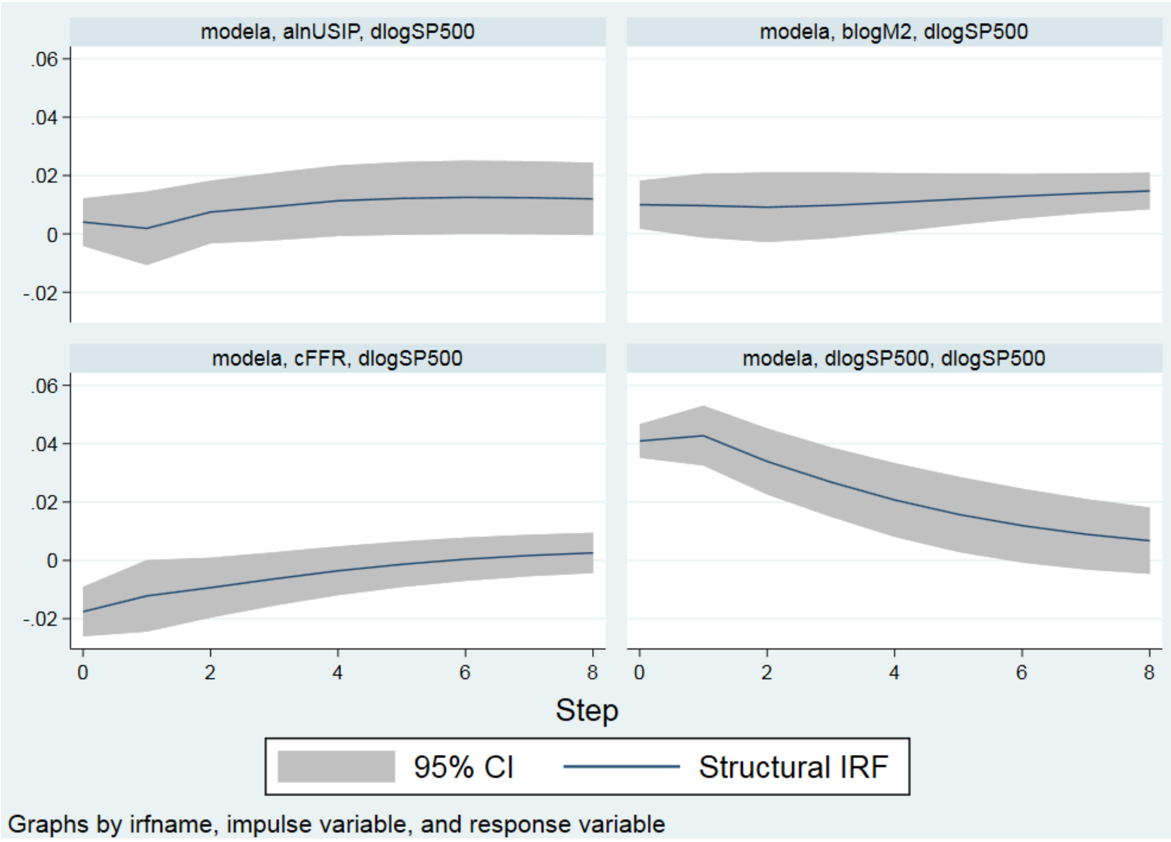
I have divided observation period into two sub-periods to check, whether impulse response functions stay robust to the change. Robustness of impulse responses is confirmed when model's forecasts are consistent, even though the assumptions or input variables change in sample. The first sub-period is between January 2008 and October 2014. The second sub-period is between November 2014 and May 2021. I split observation periods on these two sub-periods because both sub-periods contain financial crisis and expansionary monetary policy interventions. At the final part of second period, it was the time of Covid-19 pandemic, which is the pivotal topic of my thesis. In order to analyse Covid-19 pandemic, I had to take wider time horizon, because I needed larger sample size. In both sub-periods occurred gradual increase in money supply (M2) and S&P 500 market index and decrease to zero lower bond in Federal Funds rate until the end of each period. I have estimated two models for two different sub-periods. In figures 11 and 12 are presented impulse response functions for each SVAR model.

Figure 11: Structural impulse response functions, 2008-2014



Source: Own work.

Figure 12: Structural impulse response functions, 2014-2021



Source: Own work.

In figures 11 and 12, the structural impulse response functions of the one standard deviation shock to logSP500 on logSP500 show that the shock is positive and gradually dies out until the last period. Moreover, we can quantify that the identification restrictions in the estimated model suggest that a positive one-unit standard deviation shock to logSP500 causes an increase in logSP500 by approximately 4 percentage points. The shock in the first sub-period has 0.4 percentage point higher magnitude than the shock in the second period. The structural impulse response function of the one standard deviation shock to FFR on logSP500 exhibits that a positive shock to FFR implies a decrease in logSP500 by 1 percentage point for the first sub-period and by 1.8 percentage point for the second sub-period. We can see that shocks die out in both sub-periods. In the second sub-period, the shock is of the higher magnitude and gradually dies out until the seventh period. Moreover, for the first sub-period the structural impulse response function of the one standard deviation shock to money supply (M2) on logSP500, suggests that a positive shock to money supply (M2) implies an increase in logSP500 by 0.5 percentage point and the function reaches 1.2 percentage point until the last period. For the second sub-period, we obtain the structural impulse response function of the one standard deviation shock to money supply (M2) on logSP500, where a positive shock to money supply (M2) implies an increase in logSP500 by 1 percentage point and the function reaches 1.7 percentage point until the last period. Therefore, the results from the analysis are consistent with the economic theory, as FFR and money supply (M2) are exhibiting different dynamics because an increase in variables have the opposite effect to the equity market. Furthermore, we can see higher impulse responses in the second sub-period, where the monetary policy was more aggressive in the size and scope, compared to the first sub-period. Additionally, in the second sub-period the valuation of the stock market was higher compared to the fundamentals, thus we can see the impulse response function to have a higher magnitude. The test confirms model robustness as the variables in general have similar dynamics and comparable responses to the exogenous shocks.

In 2011, professor Cochrane wrote on his blog how yields predict stock market returns. He advocated that emphasis has shifted in discount part, where risk preference of investors would have principal role. The past paradigm suggests that high equity prices relative to its fundamentals (earnings and dividends), implies that future cash flows are expected to increase. The Cochrane's paradigm suggests that risk appetite in discount rate explains the most of stock market variation. Therefore, if equity prices are high and yields are low, it means that investors are ready to accept lower returns in future. If yields predict equity market returns, investors should sell them when yields are low and buy them when yields are high. In financial markets, signals are too weak to be materialized, but may matter in the long run. In Cochrane's statement, this equity risk premium plays an important role for investors with long-term horizon to use variations to decide on diversification in the mix of risky stocks and safe bonds in portfolio. Academic explanation suggest that memories of the previous financial crisis fade away and that the people are getting more comfortable to hold risky assets until the next market crash, which makes them rethink. Cochrane also suggested that during the market crash, investors are ignoring high equity premiums because the fear of losing a job (Cochrane et al., 2011).

4.2 Summary of empirical analysis

Based on the SVAR analysis, I will conclude the following. First, a decrease in Federal Funds rate and increase in money supply have a stimulative, but temporary effect on the US equity index, which gradually return to baseline values until the end of observation period. Second, the monetary policy effects are relatively small. The results are consistent with the results from the literature. Based on literature, similar findings occurred in measuring the impact of monetary policy to equity market in G-7 countries. Empirical analyses concluded that the increase in interest rates had negative, but also temporary effect on equity index. The proposed model in analysis is also robust to the exogenous response of the equity index to the central bank interventions in terms of policy changes followed by the policy makers (Studi, 2002).

Moreover, other empirical analyses could be used to identify an overall impact of the Fed's measures to the equity market. They are structural vector autoregressive model with long-term restrictions or counterfactual analysis, which compares two different scenarios. In the article of Studi (2002), they also used limited participation DSGE model based on Christiano et al. (1996). It can be specified in a way that considers trading in financial markets. DSGE model has the advantage to further capture liquidity effect, which occurs in expansionary monetary policy, where we have an increase in the money supply and decrease in interest rates. However, these additional steps are open for further research and discussion.

CONCLUSION

Covid-19 pandemic initially caused economic contraction and induced stock market fluctuations. Monetary policy interventions were extremely important to stabilize the financial market. Studies have shown that monetary policy was successful in supporting the economy and reversed the US equity market trend from contraction into strong recovery. Market participants are becoming increasingly worried about inflationary pressures that may follow once Covid-19 restrictions will ease. Inflation could cause rising interest rates, which would in turn change stock market valuations and lead to a contraction in the economy. However, policy makers are still supporting markets with confidence and they believe that the recovery is still underway. Fed announced, that they will allow two percent inflation overshooting over its target, in an attempt to anchor long-term expectations by market participants in order to encourage spending.

In the thesis, I modelled the dynamics of economy with an SVAR model, which could solve the endogeneity problem in analysis. SVAR model included monetary policy variables (money supply and Federal Funds rate), US industrial production index (helps to explain market activity) and the S&P 500 market index. The SVAR, thus enabled to estimate the contemporaneous relations among specified variables. Additionally, tests of specifications supported SVAR analysis and inferred important conclusions. My results indicate that stock market reacted to central bank's interventions. Results confirmed the hypothesis, that the expansionary monetary policy causes increase in equity prices.

I believe that portfolio managers should direct more attention to macroeconomics, because central bank's policies have increasing role in explaining dynamics of the financial markets. Critics of quantitative easing suggest that quantitative easing is inappropriate because it causes asset bubbles. It is important to identify this impact in its early stage. Portfolio managers can enjoy great performance while their assets increase with market trend, but at the same time expose their portfolios to additional risk. Hence, it is also important to establish the right time to exit or rebalance portfolio before the burst of asset bubble.

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APPENDICES

Appendix 1: Povzetek (Summary in Slovene language)

Volatilni delniški trgi spodbudijo centralne banke k posredovanju z monetarno politiko, tako da preprečijo dolgoročne negativne učinke na gospodarstvo. Prvi ukrep centralne banke je sprememba ciljne federalne obrestne mere, ki stabilizira delniški trg, ter vpliva na realne obrestne mere, katere so odvisne od tržnih pričakovanj. V času Covid-19 pandemije, smo bili priča takšnih sprememb monetarne politike. V začetku Covid-19 pandemije so padle cene delnic na delniških trgih, zaradi povečane negotovosti, nato so centralne banke (še posebej ameriška centralna banka) sprejele agresivne ukrepe, ter tako stabilizirale trg. Ameriška centralna banka je tako spodbudila gospodarsko aktivnost in spremenila tržni trend. Namen magistrske naloge je analizirati vplive monetarne politike na ameriški delniški trg, s pomočjo strukturne VAR metode. Spremembe monetarne politike vplivajo na odločitve podjetij, saj z različnimi transmisijskimi mehanizmi vplivajo na gospodarsko aktivnost. Pomemben vidik je mehanizem prenosa bogastva, kjer dvig vrednosti premoženja (delnice, obveznice, nepremičnine, ipd.) povzroči povečano potrošnjo. Prav tako se izboljšuje kreditna sposobnost podjetij, saj lahko podjetja lažje pridobijo posojila za nove projekte, z večjim jamstvom premoženja. Ukrepi izboljšujejo likvidnost trga, kar posledično stabilizira delniški trg. Po drugi strani, se pri ekspanzivni monetarni politiki pojavi tveganje neracionalnih odločitev in nastanek nezaželene inflacije.

Pri empirični analizi sem uporabil strukturno VAR identifikacijsko metodo, ki omogoča merjenje eksogenih odzivov centralne banke na delniški trg. Strukturna VAR metoda prepozna sočasne odzive delniškega trga, ko se spreminjajo različne spremenljivke monetarne politike. Problematika magistrskega dela je identifikacija vplivov centralne banke na ameriški delniški indeks S&P 500. V empirični analizi sem preučeval spremenljivke monetarne politike, kot so ciljne federalne obrestne mere in ponudba denarja na trgu (M2). Poleg spremenljivk monetarne politike sem vključil ameriški indeks industrijske proizvodnje, ker je pokazatelj gospodarske aktivnosti in tako izboljša empirični model. Rezultati empirične analize prikazujejo, da so ukrepi ameriške centralne banke vplivali na ameriški delniški trg, in da ekspanzivna monetarna politika vpliva na dvig cen delnic. Testi specifikacij dodatno podprejo strukturno VAR metodo, ter pripomorejo izpeljati pomembne zaključke.

Po ekspanzivni monetarni politiki, se na trgu pojavljajo skrbi o pojavu inflacije, ki bi lahko sledila po sproščanju omejitev. Inflacija bi lahko povzročila dvig obrestnih mer, kar bi posledično spremenilo gospodarsko aktivnost in povzročilo krčenje gospodarstva. Ameriška centralna banka je napovedala, da bo dovolila dvoodstoten presežek cilja inflacije, saj želi zasidrati dolgoročna pričakovanja, ki vplivajo na potrošnjo.