Possibility of an Asset Bubble Due to the Wide and Extended Use of Unconventional Monetary Policy*

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Abstract

The objective of this paper is to evaluate the possibility of an asset bubble in the US equity markets due to the wide and extended usage of unconventional monetary policy in the post-crisis era. A New Keynesian Model incorporating an entrepreneur, the investment adjustment costs, and a rational bubble component is used. The unconventional monetary policy is introduced into the model through a net worth shock. The findings show that the Dow Jones Industrial Average is not showing any signs of a bubble in terms of mean deviations from the steady state; however, it is in terms of volatility of deviations from the steady state.

Keywords: Stock Market Bubbles, DSGE, Rational Bubble, Net Worth Shock, New Keynesian Model, Unconventional Monetary Policy, Monetary Policy, Quantitative Easing, Forward Guidance

*Word Count: 4,838 + 157 (figures) = 4,995

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Contents

1 Introduction

In the current market environment, the financial framework has witnessed numerous changes, from negative interest rates to central banks purchasing financial assets. After the Global Financial Crisis (GFC), such activities became commonplace as conventional monetary policy became insufficient for a full recovery. Today, the markets are witnessing all-time highs and a large sum of cash is flowing into risky assets. Furthermore, most valuation indicators, such as Shiller's P/E, are signalling overvaluation. Despite these occurrences, market volatility is relatively low and financial condition indicators are hitting new lows resulting in a calm environment.

A number of articles have addressed the possibility of an asset bubble in the current low interest rate environment. The main argument has been focused on the heavy use of unconventional monetary policies (UMP) and the resulting effects: such as ameliorating the borrowing process and pushing investors into purchasing risky assets. One of these articles in The Economist[1] refers to other macroeconomic transformations, such as the divergence of the saving rate from the interest rate. An analysis that considers the aforementioned developments is required to understand whether financial markets are facing an asset bubble due to the adaptation of UMP.

The goal of this paper is to use a dynamic stochastic general equilibrium (DSGE) framework to understand the effects of UMP on the equity markets. For this, Bernanke, Gertler and Gilchrist's model (BGG) is used. This model incorporates the financial accelerator by adding an entrepreneur and investment adjustment costs to a New Keynesian model. With these adjustments, the return to capital becomes a better representation of the equity market returns. The BGG model assumes that the drivers of equity markets are only fundamentals. In order to assess the possibility of an equity market bubble an extension of the BGG model with a rational bubble is used (Bernanke, Gertler, 1999; Lopez, 2014).

The model is run under the zero-lower bound (ZLB) constraint to make the analysis more realistic. This is done by using the OccBin method developed by Guerrieri and Iacoviello (2015). The UMP effects are mimicked in the form of a net worth shock and the reaction of the stock market is analysed. The shock emulates the signalling, portfolio rebalancing, liquidity and credit channels. (Falagiarda, 2012) Later on, a sensitivity analysis is done in four different scenarios, with each scenario bringing the modelled economy closer to reality. The analysis includes impulse response function (IRF) interpretations and moment comparisons of the Dow Jones Industrial Average (DJIA) data.

The remainder of this paper is divided into five. First the related literature is summarised, secondly raw data is analysed, thirdly the modelling procedure is discussed, fourthly the results are analysed, and finally the paper is concluded.

[1]The Economist (2017). "The Bull Market in Everything," October 7th.

2 Related Literature

2.1 Unconventional Monetary Policy

Numerous papers investigated the impacts of UMPs on asset pricing, with an emphasis on the effects of quantitative easing (QE) and forward guidance (FG). QE effects were more apparent due to their nature of signalling future easing with the objective of changing investor expectations and changing risk premium in incentivising portfolio rebalancing (Altavilla, Carboni, Motto, 2015; Valiante 2015). According to Swanson (2016) markets that were impacted the most by UMPs were equity, currency, and debt markets. Even though QE had more impact on longer maturity assets and FG on shorter ones, they impacted the equity markets at an equal rate (Swanson, 2016). As a result, this paper studies the impact of UMPs as a single shock to net worth.

Gal and Gambetti (2014) found that other than a short-term fall, the stock market remained high after the implementation of QE. This could imply that investors priced in the effects instantaneously and the future shocks were not perceived as unconventional anymore, as financial markets are forward-looking agents. Furthermore, Williams (2014) looked at papers focusing on the estimated effects of QE on long-term interest rates. According to his results, the magnitude of the most direct effect ranged from 0 to 400 basis points. Due to such a wide range, Williams (2014) concluded that the magnitudes of these impacts are still uncertain and not fully understood.

Moreover, Greenspan (2007) concluded that economic growth with expansionary monetary policies can result in overvalued asset markets. If the impact of UMPs is mispriced and the positive expectations on economic growth resulted in overvaluation, then this could explain the current market highs.

2.2 Asset Bubbles

Barlevy (2007) defined a bubble as the price of an asset exceeding its fundamental value. Using this definition, Tirole (1982) studied speculative bubbles and concluded that they do not occur when there are fixed number of traders and common set of beliefs. In this set-up, relaxing the first assumption requires economic activity to increase at least as fast as the bubble in order to accommodate for trading the asset. Abel (1989) has shown that this has never been seen in data, concluding that the there will always be a finite number of traders. Relaxing the common set of beliefs assumption, De Long (1990) proposed that rational traders will take advantage of arbitrage opportunities, but due to their risk averse and myopic natures they will not bring down the price back to the fundamental value. As a result, it can be argued that risk aversion and short sightedness of traders may potentially result in a bubble even in the presence of a finite number of market participants.

Furthermore, the rational bubble hypothesis states that the price of any asset should have a fundamental component and a bubble component (Blanchard and Watson,1982). By conducting a Hausman-specification test on US stock market data, West (1987) concluded that there is always a bubble component. Assuming the efficient market hypothesis does not hold, it stands to reason that bubbles are naturally a part of the market in the form of deviations from the fundamental component, and if market participants are not careful such bubbles can lead to disastrous crises.

2.3 Modelling Bubbles

There is a growing literature on Agent Based Models (ABM) in analysing financial markets, as they can give insights on bubbles due to their decentralised nature (Fagiolo, Roventini, 2012). ABMs are good at forecasting and understanding complex behavioural networks, such as financial markets, but they implement a relatively new approach. Furthermore, there is more DSGE model based literature that can be used to compare relative performances of models. On the other hand, DSGEs are criticised for being poor predictors of financial markets due to their centralised frameworks (Iori, Porter, 2012). Yet, DSGE models that implement bubble components to overcome such shortcomings can be as insightful as ABMs, especially since ABMs use similar methods to the ones used by DSGEs in assessing monetary policy shocks (Fagiolo, Roventini, 2012). Therefore, a DSGE model that includes a bubble component is sufficient for the purpose of this paper.

In a DSGE framework, return on capital is equivalent to equity returns; however, in application these models do not incorporate the volatility of the equity markets well (Gomme, Ravikumar, and Rupert, 2017). However, complex DSGE models with financial markets can produce better representative results. In fact, including only the investment adjustment costs improves DSGE models' explanatory power (Jermann, 1998). As the relevant literature suggests, a DSGE model with a bubble component and an equity market serves the objective of this paper.

3 Data Analysis

This paper uses a log-linearized version of the BGG, which means the simulated variables are deviations from the steady-state rather than actual deviations. Consequently, to assess the predictive power and the results of the model, the macroeconomic and financial data used for comparison are log-linearized.

3.1 Financial Data

The main question of the presence of an equity market bubble is answered through a comparison of the DJIA data moments to those of the model simulated bubble and fundamental variables. This is done by seeing if DJIA data is closer to the bubble or fundamental variable in terms of mean, standard deviation, kurtosis and skewness.

In order to conduct this analysis, the DJIA[2] price levels from 2000 to 2018 are turned into deviations from steady-state. This transformation is done by taking the natural logarithm of the price data and de-trending it in reference to the linear trend of 2000-2007, which is the steady-state growth path of the markets. For the sake of the argument this paper assumes that during the pre-crisis period (2000-2007) the economy functioned normally and at full capacity.

The two trend lines for 2000-2007 and 2007-2018 can be seen on Figure 9. The reason for not using the general trend or the 2007-2018 trend is that the main driver for these time periods is the recovery from the GFC, and using them as the steady-state growth path will give biased results.

[2] Data stream. (2018) Thomson Reuters Data stream. [Online]. Available at: Subscription Service (Accessed: January 2018)

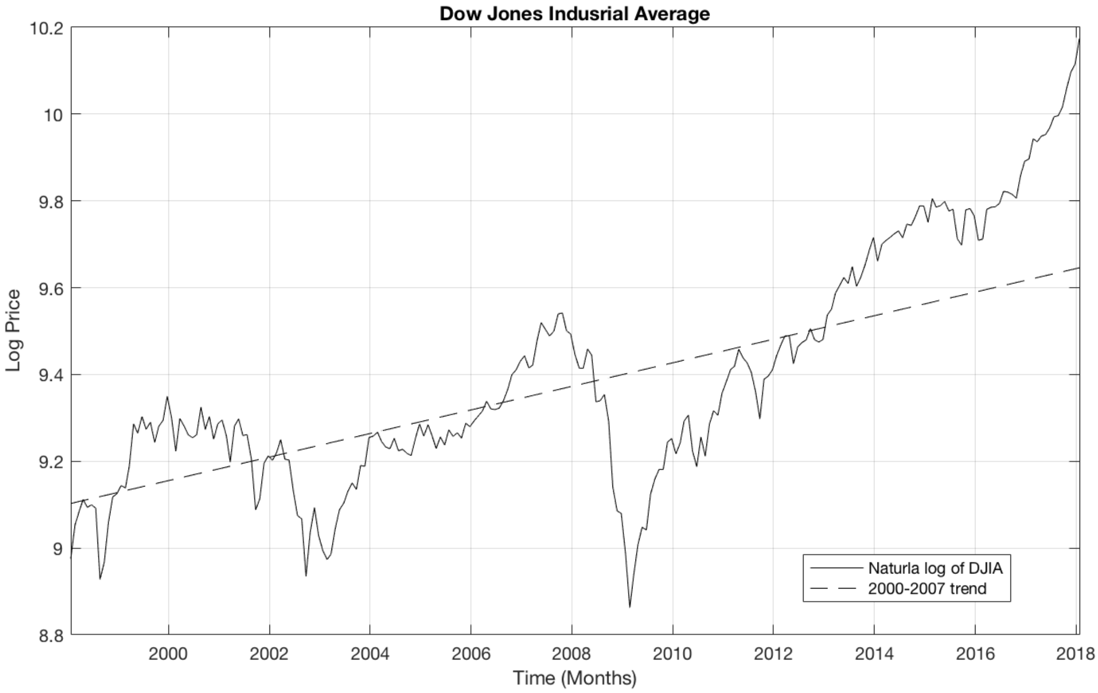

Figure 1: Steady-State Trend

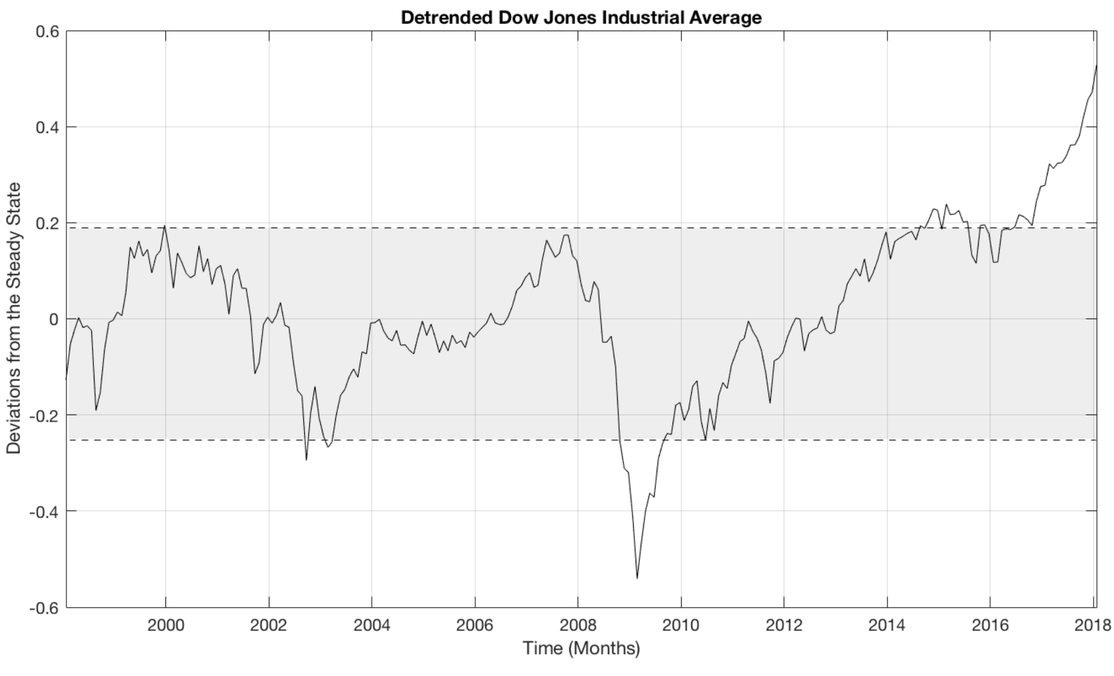

Figure 2: Deviations from the Steady-State

Figure 2 is the log-linearized DJIA data. As it can be seen from the graph, the deviations from the steady-state are bounded by the highlighted area. Two exceptions to this rule are the GFC, during which the data went below the boundaries, and from 2016 to today. The last time data went across the boundaries, the world witnessed a financial crisis. Since it is happening again, it is a point of concern and this paper investigates the reason behind it.

3.2 Macroeconomic Data

In order to assess the model's explanatory power, the real economy variables are compared to the model simulated variables. Traditionally, this is done by comparing the relative standard deviations of the macroeconomic variables to those generated by the model. For this reason, log-linearized U.S. macroeconomic data is required. Fortunately, Gomme, Ravikumar, and Rupert's (2017) paper has the relative standard deviation values for the log-linearized U.S. output, consumption, investment, hours worked, productivity, capital, and return to capital. This data is on a quarterly basis and the time-span is 1954-2015. Since these values calculated cover 51 years, they are suitable as a benchmark for the BGG model. The data is presented on Figure 10.

4 Methodology

4.1 Model

4.1.1 BGG Model

This paper uses an extension of the BGG model which includes the bubble component. The framework of the BGG model is laid out on Figure 11. There are three markets and three agents. Households have infinitely lived lives and they can consume, save, and provide labour. Firms are owned by entrepreneurs, have finite lives and produce goods by using labour and capital. In order to finance capital purchases, they either use internal financing, which is using profits and capital gains, or external financing, which is borrowing from the financial markets. The output is then sold to Retailers, who sell them back to Households at a mark-up. All the agents are optimising and forward-looking.

There are a number important factors that make the BGG model a suitable one. The main modification of the BGG model is the implementation of the financial accelerator. Financial accelerator is introduced by assuming financial-market frictions, such as the lack of a common set of beliefs amongst investors or the cost of evaluating the soundness of a business. As a result, external finance costs go up. The idea of an external finance premium is similar to an equity premium an investor receives from investing in a company (risky asset) rather than a risk-free asset.

This external finance premium has an effect on the cost of funds for firms. The premium depends inversely on the financial conditions of the borrower. In other words, a firm with a strong balance sheet will have a low external finance premium as it is less risky to invest in it. In a scenario where the economy experiences a shock that improves all firms' balance sheets, the overall external finance premium will fall, and the firms will be able to use the improved internal and external finance sources to invest further and purchase more capital, which will result in more output.

Another source of the financial accelerator is the asset price effect. When a shock that boosts the balance sheets of firms occurs, asset prices go up. Such an increase in the asset prices, improves the financial conditions of the firms, lowers the external finance premium even more and leads to an indirect amplification effect on output. Since portfolio rebalancing channel is aimed at incentivising risky investments to improve the balance sheets of companies so that they can use the invested capital to boost production, the asset price effect is handy in implementing various channels of UMP.

The entrepreneurs have a net worth which they use to fund their ongoing businesses. A positive shock to net worth improves their internal equity and have impacts to the economy similar to those caused by shocks improving firms' balance sheets. However, in the long-run the effects of the shock on the external finance premium wither away, but the firms enjoy a larger sum of capital. The effects of such a net worth shock can be seen on Figure 13. The move from point A to point B shows the fall in external finance premium; however, in the long-run the firm will move from point B to point C as it is incentivised to optimise its profits. In the current markets, equity premiums are still relatively low, implying that the long-run has not been reached. This fall in the external finance premium is one of the many aims of UMPs.

All the aforementioned features of the BGG model make it suitable to investigate the effects of UMP on the financial markets. However, it still lacks the means of understanding the formation of a bubble in the external finance markets.

4.1.2 The Addition of the Bubble Component

The BGG model assumes that the asset price is dependent only on fundamentals. In other words, the value of any asset is the sum of the discounted values of the future cash-flows it will generate.

However, in reality the market does not value the financial assets correctly all the time. As a result, the model requires a bubble component. Bernanke and Gertler have included one in their paper 'Monetary Policy and Asset Price Volatility.' Their approach was to introduce an additional variable called the Market Asset Price and assume that the difference between that and the price of capital would grow each period and persist with probability p,

$$S_{t+1} - Q_{t+1} = \frac{a}{p}(S_t - Q_t)R^q_{t+1}$$

and crash with probability 1-p.

$$S_{t+1} - Q_{t+1} = 0$$

As a result, taking the expectation of the discounted value of the difference between S_t and Q_t gives the bubble component.

$$E_t(\frac{S_{t+1} - Q_{t+1}}{R^q_{t+1}}) = a(S_t - Q_t)$$

However, the bubble component is implemented through the rate of return variables:[3]

$$R^s_{t+1} = R^q_{t+1}[b + (1-b)\frac{Q_t}{S_t}]$$

where $b = a(1 - \delta)$.

Such an implementation is enough to make the model sufficient to analyse the possibility of a bubble, as the bubble component is in line with Barlevy's (2007) definition and the rational bubble hypothesis (Blanchard and Watson,1982). The paper assumes a bubble to be any speculative deviations from the fundamental value due to market optimism or pessimism.

4.2 UMP Shock

Since the objective of this paper is to give a single shock to the economy, which emulates the entirety of the effects of UMPs summarised on Figure 12, an inclusive net worth shock is given. The idea behind the introduction of a single shock comes from the fact that FG and QE have an equal impact on the equity markets as mentioned in Swanson's (2016) paper.

The idea of introducing a shock to the net worth variable comes from the dynamics of the model. As stated above, the net worth variable of the entrepreneur is the main source of financing for production and consequently running the business cycle. In theory, UMPs are aimed at providing a means of cheap financing for firms, so that they can continue to produce at prices affordable by consumers. However, other indirect effects take form as well. Portfolio rebalancing channel and liquidity channels are both helpful in terms of providing economic stimulus. In reference to Figure 12, all the intermediate effects can be emulated using a positive shock to the net worth, which is a direct boost to the firms' balance sheets. The rest of effects occur indirectly as a result of the model's structure.

[3] S_t = Market Asset Price, Q_t = Fundamental Asset Price, R^q_{t+1} = Return on Capital, R^s_{t+1} = Return on Stock Market, a = Constant

Once the shock is given to the economy and IRFs are produced, the applicability of the shock is tested by comparing the IRFs to the ones produced by a more complex model with the banking system that explicitly implements a QE shock. Furthermore, the functional form of the net worth shock is an autoregressive process. This functional form is used in reference to Hohberger, Priftis, Vogel's (2017) paper, in which they point out that the AR(1) functional form for a QE shock is fitting for two main reasons:

1. The financial markets are responsive to the initial announcement of UMP. Even if further implementations are announced the market will price in the effect of the policy at the beginning and will not react to further implementations as they lose their unconventionality.
2. UMPs are highly persistent policies as they take time to work through the economy. This point is further backed by the fact that only after 10 years of QE, has the central banks decided to start normalising their balance sheets. (Financial Times, 2017)

The first point results in the shock to take the following form:

$$nw_t = \rho_{nw} nw_{t-1} + \epsilon_t^{nw}$$

The second point on the persistence of the policy results in using $\rho_{nw} = 0.987$ from Hohberger, Priftis, Vogel's (2017) paper.

The shock variable is added to the net worth equation:

$$n_t = R^q[\frac{K}{N}(r_t^s - E_{t-1}r_t^s) + \frac{(1-\tau R^q)}{\tau}y_t + n_{t-1}] + nw_t{}^4$$

As discussed above, the implementation of such a shock primarily effects the equity markets through the external finance premium, and have indirect effects throughout the framework of the model.

5 Results and Analysis

The results of the model are analysed in two parts: IRF and Moment. However, before the analysis stage, the IRFs from the net worth shock are compared to those produced by Hohberger, Priftis, Vogel's (2017) paper. The ZLB is implemented in both models and the IRFs of the net worth shock given to the BGG model are observed to see if they are similar to the ones captured by the QE shock given to Hohberger, Priftis, and Vogel's model.

In reference to Figure 14, the IRFs highlighted in grey are the ones produced by the BGG model and the other ones are produced by the more complex model. The responses of output, investment, nominal interest rate, and inflation to the net worth shock are similar to the QE shock implemented in the other model. The amplitudes of the responses are not the same; however, this is due to the difference in the model frameworks. This comparison shows the effectiveness of implementing UMPs in a single net worth shock on the BGG model.

In assessing the model's predictive power, Figure 3 compares the model simulated standard deviations of consumption, investment, hours worked, productivity, capital, and return to capital relative to output to those of U.S. data.

[4] τ = Firm Survival Rate, n_t = Net Worth, R^q = Long-run Return on Capital. r_t^s = Return on Equity, y_t = Output, $\frac{K}{Y}$ = Capital as a Fraction of Output, nw_t = Net Worth Shock.

In retrieving the relative standard deviations, the model is run for 245 quarters in order to achieve the same number of U.S. data points (1954:Q1-2015:Q1). According to these results, the model is good at predicting relative standard deviations in general, other than overestimating it for Investment and underestimating it for Capital. In conclusion, the model functions well at explaining macroeconomic deviations and the net worth shock is good at emulating the effects of UMP.

	U.S. 1954:Q1-2015:Q1	Model Simulated Data
	Relative Standard Deviation	Relative Standard Deviation
Output	1.00	1.00
Consumption	0.55	0.54
Investment	2.85	4.69
Hours	1.06	1.02
Productivity	0.60	0.51
Capital	0.81	0.10
Return to Capital	6.27	5.21

Figure 3: Model and US Data Comparison

5.1 Sensitivity Analysis

In order to get a better sense of the macroeconomic environment, some of the parameters are altered from the ones that have been estimated by Bernanke and Gertler.[5] The parameters to be altered are the interest rate responsiveness and the survival rate of firms. As stated before, firms do not have infinitely lived lives; the survival rate is the probability of a firm surviving to the next period. The model initially assumes that this probability is 95%. The interest responsiveness of consumers is initially assumed to be one-to-one, meaning a percentage increase in the real interest rate is translated into a unit less of consumption.

Figure 15 shows that the financial conditions index has been hitting new lows lately, and it has been below zero since 2012. This implies easier financial conditions for firms to borrow and keep away from financial distress. In reference to easier conditions, the survival rate of firms is increased to 99%. The reason it is increased 4% to 99% is because a 100% survival is impossible and it is aimed at emphasising the fact that financial conditions have been low for a long time.

Figure 16 shows how the savings rate and the effective federal funds rate have been diverging from each other, implying that consumers are becoming less responsive to the changes in the federal funds rate. As a result, the interest rate responsiveness is dropped to 0.5, implying that a percentage increase in the real interest rate will result in a 0.5 unit drop in consumption. The interest rate responsiveness is halved because the savings rate has not fully diverged away from the effective federal funds rate, it has converged back from time-to-time.

Using the following alterations, four different scenarios are laid out.

1. Scenario: firm survival = 95%, interest rate responsiveness = 1.0.
2. Scenario: firm survival = 95%, interest rate responsiveness = 0.5.
3. Scenario: firm survival = 99%, interest rate responsiveness = 1.0.
4. Scenario: firm survival = 99%, interest rate responsiveness = 0.5.

The least realistic scenario is the first one, and the most realistic is the fourth one. By analysing the IRFs and moments of these four scenarios, this paper tries to answer the question of a bubble in the equity markets.

[5] This paper uses the parameters estimated by Bernanke and Gertler in their paper "Monetary Policy and Asset Price Volatility."

5.2 Impulse Response Functions

Figure 4 shows that in the presence of a bubble, being constrained by the ZLB amplifies the market's pricing of the assets and the amplification effect persists for a long time. However, in the absence of a bubble the amplification dies out pretty fast. In fact, after 10 periods, the fundamental price goes back to the benchmark of no ZLB.

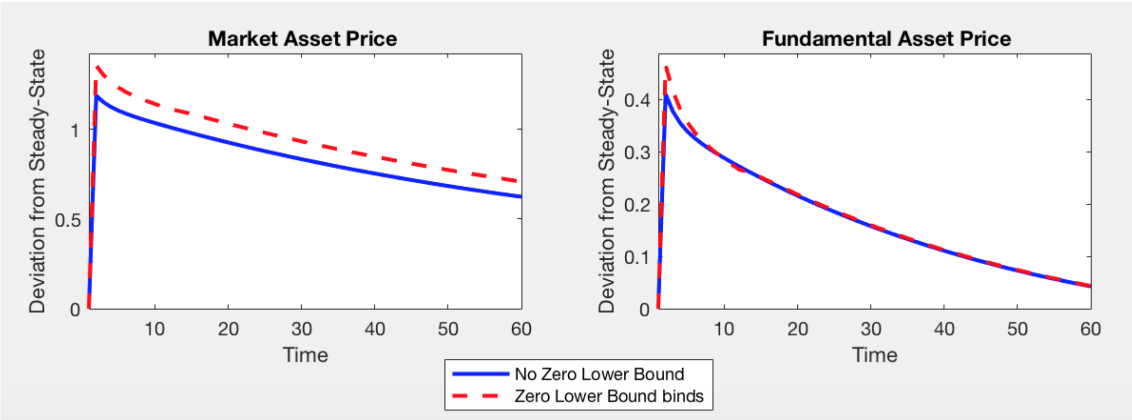

Figure 4: Market and Fundamental Asset Prices

The economic implication behind the initial amplification of the prices in both cases is that when ZLB holds, the arbitrage opportunities improve for potential investors/firms. For the BGG model, the main difference between the return on equity variable r_t^s and the real interest rate r_t is the arbitrage equation:

$$E_t r_{t+1}^s = r_t - \Psi(n_t - s_t - k_{t+1})$$

This equation shows the spread between a risk-free rate and the stock market return. In the presence of ZLB, the r_t, which is the difference between the nominal interest rate and inflation, equals inflation only. As a result, arbitrage opportunities incentivise investments into equity markets, as the excess return from investing in the equity markets only depends on inflation and not on a positive risk-free interest rate.

The model is run, on a monthly basis, for all the scenarios. The resulting IRFs are shown on Figure 5. All the scenarios assume that the ZLB holds. Output, investment, nominal interest rate, and inflation rate all act in a similar manner in all the scenarios, as a result they are omitted from the figure. On the other hand, the effects of UMP on the Fundamental Asset Price disappear almost to a full extent after 60 periods, regardless of the scenario.

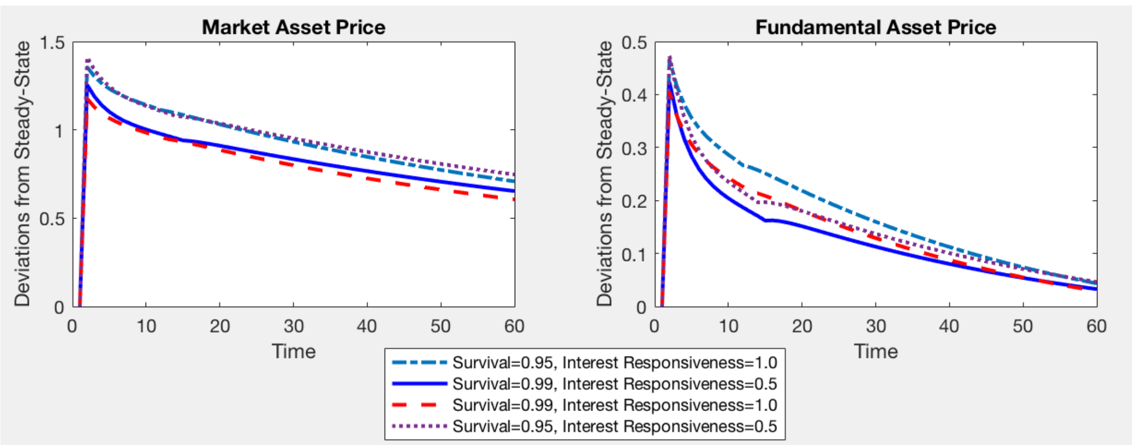

Figure 5: IRFs for the scenarios.

However, this is not the case for the Market Asset Price variable. Changing the survival rate from 95% to 99% and keeping the interest responsiveness at one-to-one has the greatest impact on the Market Asset Price. In fact, it reduces the amplification caused by the ZLB. Altering the model furthermore, by decreasing the interest responsiveness to 0.5, results in a slower recovery of the Market Asset Price to the steady-state without the greater initial impact due to ZLB. This scenario, which is the blue-line, seems to be a better representation of what the US equity markets are experiencing today. The effects of UMPs have been felt for a long time, which can be interpreted from the fact that even after 60 periods the Market Asset Price still has not recovered back to the steady-state on Figure 5.

Qualitatively speaking, the Market Asset Price IRF seems to be a better representation of the current markets, compared to the Fundamental Asset Price.

5.3 Moment Analysis

Unlike the IRF analysis, moment analysis involves comparing actual data to the model simulated variables. In order to conduct moment analysis, the model is run for a period of 109 months, which represents the time-span of the UMP.[6] Later on the first four moments of the representative period for the log-linearized DJIA deviations from the steady-state is calculated and compared to the model simulated variable moments. The results for mean and standard deviation can be seen on Figure 6.

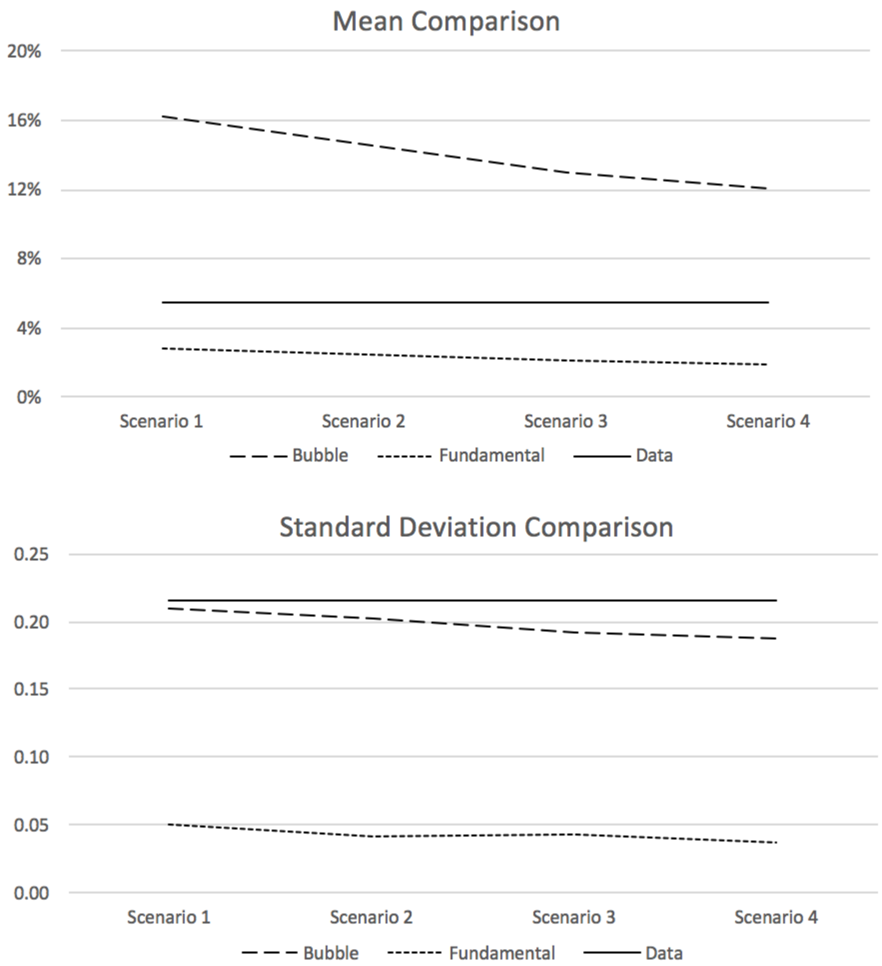

Figure 6: Mean and Standard Deviation

[6]Start of UMP is the initial announcement of QE1 by the Fed, which is 25 November, 2008. (Federal Reserve, 2008)

In terms of mean deviations from the steady-state DJIA seems to be closer to the fundamental values but still above it, implying the presence of a bubble component. This is in line with West's (1987) conclusion that there is always a bubble component in the markets. Unlike the mean comparison, the standard deviation of deviations from the steady-state comparison implies that DJIA is showing signs of a bubble as the data values are almost identical to bubble values. In the mean comparison, as the scenario becomes more realistic, the bubble variable gets closer to DJIA and the fundamental variable moves further away from it.

	KURTOSIS			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Data	-0.13	-0.13	-0.13	-0.13
Bubble	-0.68	-0.80	-0.79	-0.89
Fundamental	-0.11	-0.19	-0.18	-0.26

	SKEWNESS			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Data	-0.40	-0.40	-0.40	-0.40
Bubble	-0.42	-0.39	-0.40	-0.37
Fundamental	-0.24	-0.17	-0.20	-0.12

Figure 7: Kurtosis and Skewness

Looking into higher moments, it seems that the bubble variable is closer to DJIA in terms of skewness. Negative skewness implies a higher chance of a negative deviation from steady-state. In both bubble and fundamental variables, the negative skewness is captured. In the third scenario, bubble skewness is exactly the same as DJIA skewness. As the scenarios get more realistic, bubble skewness is still closer to DJIA, implying a volatility bubble.

In terms of kurtosis, the DJIA data has a negative kurtosis, meaning that the distribution is flatter than a normal distribution and that the probability of having large fluctuations is smaller. The negativity is once again captured in both bubble and fundamental variables, with the fundamental variable being closer to the DJIA in the first scenario. However, as the scenarios get more realistic both variables move further away from DJIA, meaning kurtosis values are inconclusive.

In conclusion, the results of the second and third moment comparisons dictate that there is a volatility bubble in the US equity market.[7] The term volatility bubble implies that the market is showing signs of a speculative bubble in terms of volatile deviations from the steady-state.

[7] The word volatility is referring to the volatility of deviations from the steady-state, which is not the same as market volatility.

6 Conclusion

The main goal of this paper is to emphasise the importance of the financial market innovations which preceded the GFC and to consider these in financial market research. This paper tries to achieve this by investigating the potential formation of an asset bubble in the US equity markets due to the intensive usage of UMP.

The BGG model with a market bubble component is used and the UMP is introduced in the form of a shock to the net worth. The analysis of the model is done in two parts: a qualitative assessment of the IRFs and a quantitative assessment of the first four moments. The final results show that the US equity markets are showing signs of a bubble in terms of volatile deviations from the steady-state, but not in terms of mean deviations. The current market movements can be used to support the argument for a volatility bubble: the recent rise in the VIX — market volatility indicator — and the rise in long-term bond yields, which resulted in a potential correction of the DJIA.

It is important to keep in mind that this paper is using a simple DSGE model and using multiple assumptions — such as assuming the steady-state for DJIA is the trend from 2000 to 2007. As a result, no positive statements can be made in terms of answering the question of a bubble in the markets due to UMPs and further analysis is required.

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8 Appendix

8.1 Preliminary Data Analysis

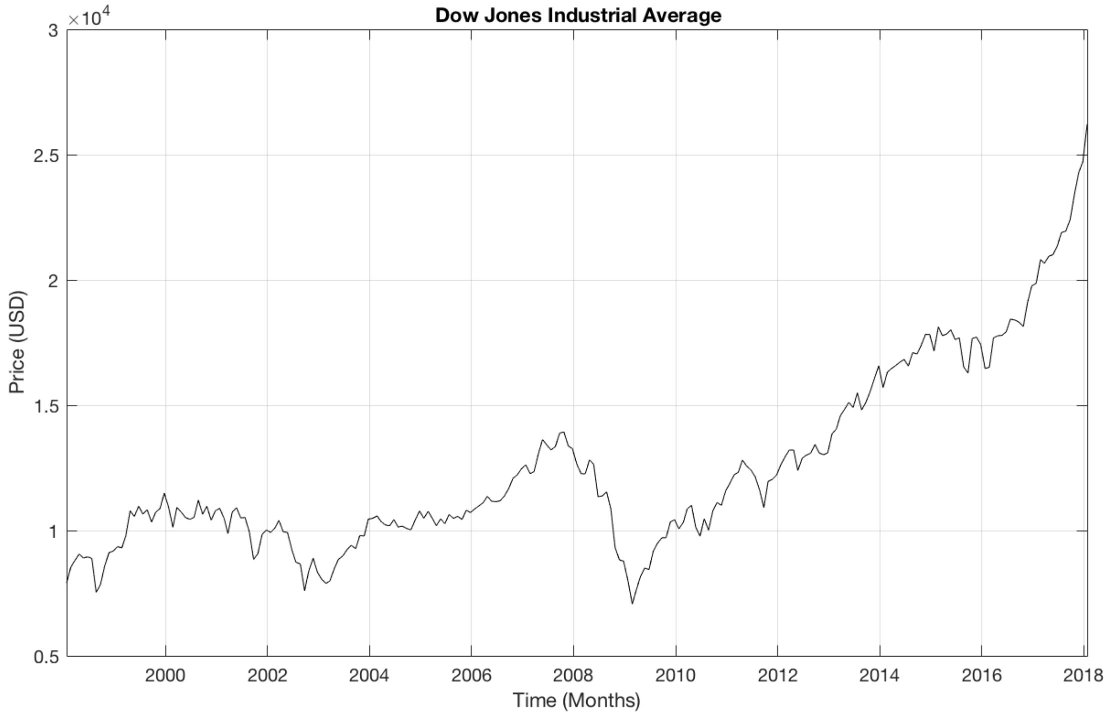

Figure 8: Dow Jones Industrial Average

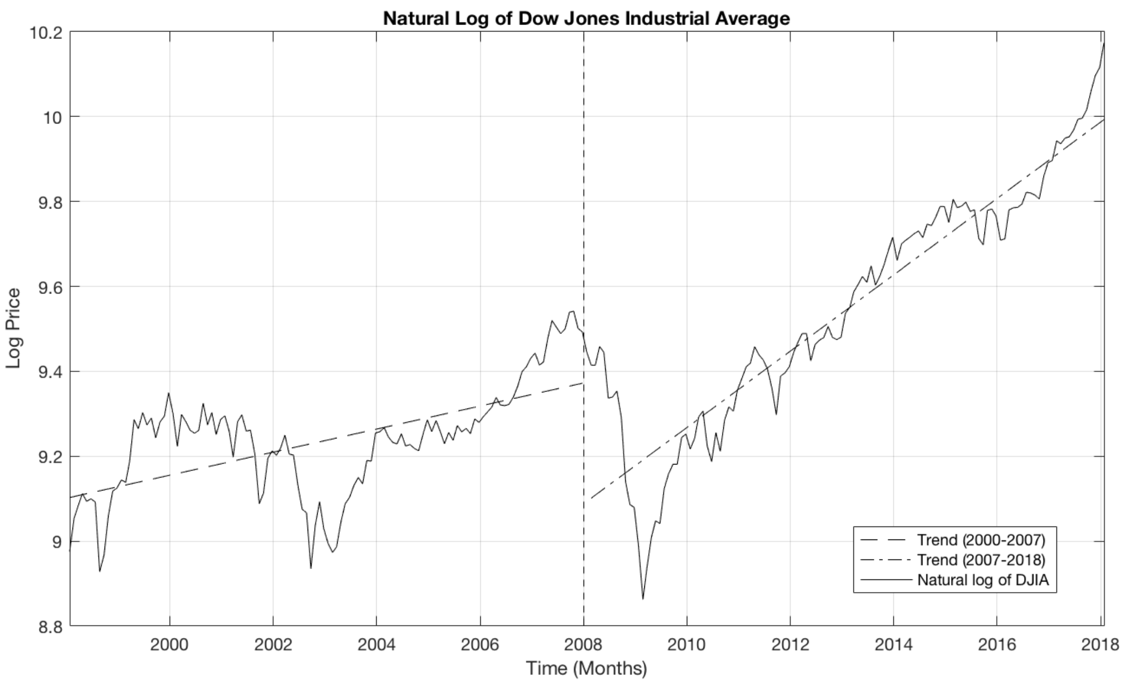

Figure 9: Log DJIA with Trend Lines

8.2 Relative Standard Deviations of US Macro Data

	U.S. 1954:Q1–2015:Q1		
	Percent standard deviation	Relative standard deviation	Correlation with output
Output	1.72	1.00	1.00
Consumption	0.94	0.55	0.82
Investment	4.90	2.85	0.90
Hours	1.83	1.06	0.83
Productivity	1.04	0.60	0.19
Capital	1.40	0.81	0.26
Return to capital	10.79	6.27	0.36

Figure 10: US Macroeconomic Data

8.3 The Framework of the BGG Model

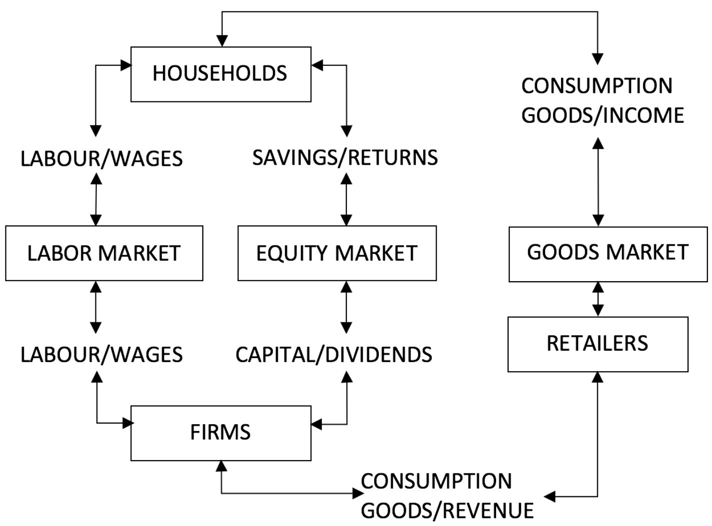

Figure 11: A simple framework of the BGG Model

8.4 The Effects of Unconventional Monetary Policy[8]

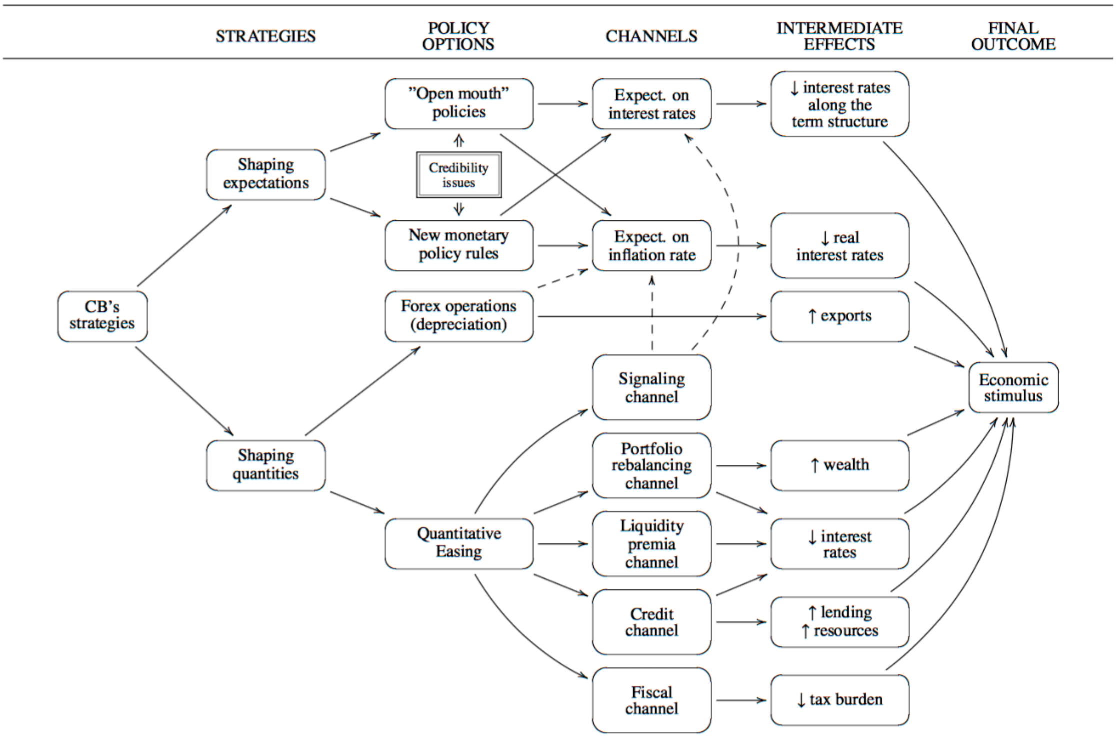

Figure 12: Intermediate effects of UMP

[8]Falagiarda, M. (2013): "Evaluating Quantitative Easing: A DSGE Approach."

8.5 Stock Market Return in DSGE Models

Gomme, Ravikumar, and Rupert's (2017) paper shows how the return on capital in a DSGE model can be interpreted as the return on a financial asset in theory.
The capital accumulation equation:

$$k_{t+1} = (1-\delta)k_t + i_t$$

In theory the dividend payed by a firm to the investor is:

$$d_t = F(k_t, z_t n_t) - w_t n_t - i_t$$

Combining these equations:

$$d_{t+1} = F(k_{t+1}, z_{t+1} n_{t+1}) - w_{t+1} n_{t+1} - k_{t+2} + (1-\delta)k_{t+1}$$

In order to get the rate of return on capital,

$$\frac{d_{t+1} + k_{t+2}}{k_{t+1}} = \frac{F(k_{t+1}, z_{t+1} n_{t+1}) - w_{t+1} n_{t+1}}{k_{t+1}} + 1 - \delta$$

As Euler's Theorem suggests

$$F(k_t, z_t n_t) = F_1(k_t, z_t n_t)k_t + F_2(k_t, z_t n_t) z_t n_t$$

From the first order condition of the firm's optimisation problem

$$z_t F_2(k_t, z_t n_t) = w_t$$

Using the above two equations:

$$\frac{d_{t+1} + k_{t+2}}{k_{t+1}} = F_1(k_{t+1}, z_{t+1} n_{t+1}) + 1 - \delta$$

Gomme, Ravikumar, and Rupert (2017) show mathematically using the first order conditions of the households and firms that

$$p_t = k_t$$

Combining this identity with the previous equation

$$\frac{d_{t+1} + p_{t+2}}{p_{t+1}} = F_1(k_{t+1}, z_{t+1} n_{t+1}) + 1 - \delta$$

The following equation proves theoretically that the return of a financial asset, such as a stock, is equal to the return of capital under the DSGE framework.

Variables: z_t = productivity, k_t = capital, n_t = labour, w_t = wages, i_t = investment, δ = depreciation, p_t = asset price, d_t = dividend

8.6 Effects of an Increase in Net Worth[9]

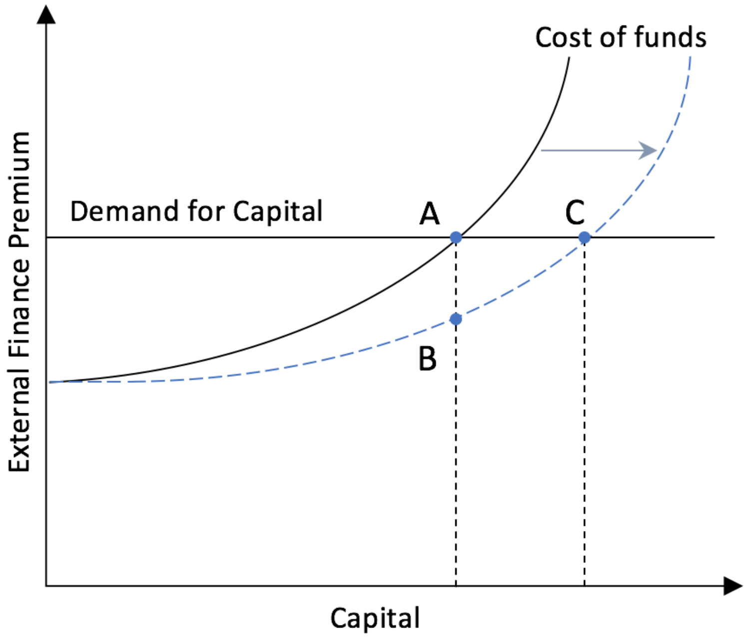

Figure 13: Effects of a net worth shock

[9]Bernanke, B., Gertler, M., and Gilchrist, S. (1999). "The Financial Accelerator in a Quantitative Business Cycle Framework,"

8.7 Log-linearized BGG Model and Variables[10]

Aggregate Demand:

$$y_t = \frac{C}{Y}c_t + \frac{C^e}{Y}c_t^e + \frac{I}{Y}i_t + \frac{G}{Y}g_t$$
$$c_t = -\sigma r_t + E_t c_{t+1}$$
$$c_t^e = s_t + k_{t+1}$$
$$E_t q_{t+1} = \varphi(i_{t+1} - k_{t+1})$$

Financial Markets:

$$r_t^q = (1-\zeta)(mc_t + y_t - k_t) + \zeta q_t - q_{t-1}$$
$$r_t^s = (1-\zeta)(mc_t + y_t - k_t) + \zeta s_t - s_{t-1}$$
$$E_t r_{t+1}^s = E_t r_{t+1}^q - (1-b)(s_t - q_t)$$
$$E_t r_{t+1}^s = r_t - \Psi(n_t - s_t - k_{t+1})$$
$$\zeta = (1-\delta)/(\frac{\alpha Y}{K} + 1 - \delta)$$

Aggregate Supply:

$$y_t = z_t + \alpha k_t + (1-\alpha)l_t$$
$$y_t - l_t + mc_t - c_t = (\chi - 1)l_t$$
$$E_{t-1}\pi_t = \kappa mc_t + \theta_f E_t \pi_{t+1} + \theta_b \pi_{t-1}$$

Evolution of State Variables:

$$k_{t+1} = \delta i_t + (1-\delta)k_t$$
$$n_t = R^q[\frac{K}{N}(r_t^s - E_{t-1}r_t^s) + \frac{(1-\tau R^q)}{\tau}y_t + n_{t-1}]$$

Shocks:

$$g_t = \rho_g g_{t-1} + \epsilon_t^g$$
$$z_t = \rho_z z_{t-1} + \epsilon_t^z$$
$$nw_t = \rho_{nw} nw_{t-1} + \epsilon_t^{nw}$$

Monetary Policy Rules:

$$r_t^n = \bar{r}^n + \beta E_t \pi_{t+1}$$
$$r_t = r_t^n - E_t \pi_{t+1}$$

Variables:

y_t	=	Output	q_t	=	Fundamental Asset Value
c_t	=	Consumption	r_t^q	=	Rate of Return on Capital
c_t^e	=	Entrepreneur Consumption	r_t^s	=	Rate of Return on Equity
r_t	=	Real Interest Rate	n_t	=	Net Worth
r_t^n	=	Nominal Interest Rate	z_t	=	Productivity
i_t	=	Investment	l_t	=	Labour
g_t	=	Government Spending	mc_t	=	Marginal Cost
s_t	=	Market Asset Value	π_t	=	Inflation
k_t	=	Capital			

[10] Bernanke, B. and Gertler, M. (1999). "Monetary policy and asset price volatility."

8.8 DSGE Model IRF Comparisons

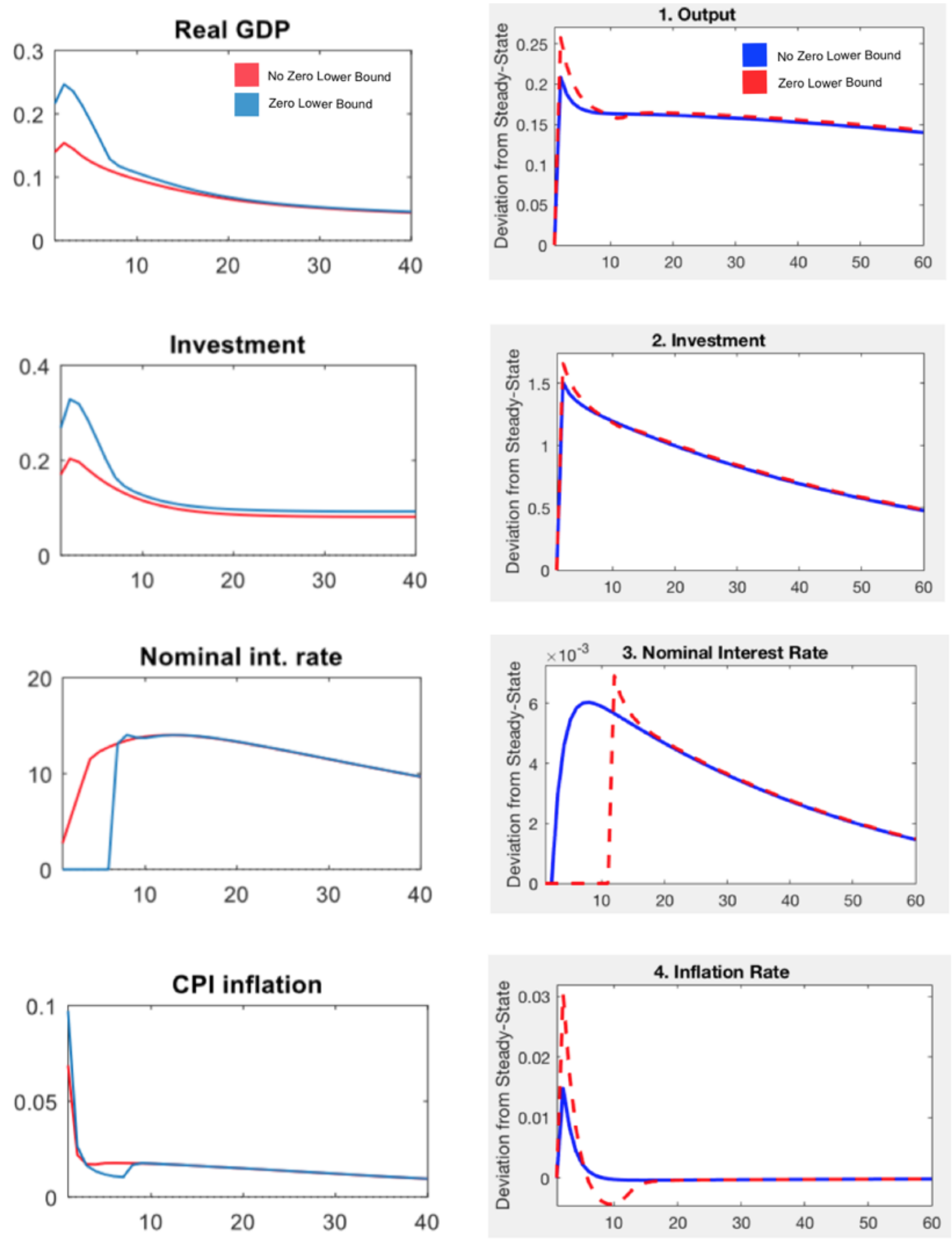

Figure 14: IRF comparisons of net worth shock and QE shock

8.9 Economic Indices for Sensitivity Analysis[11]

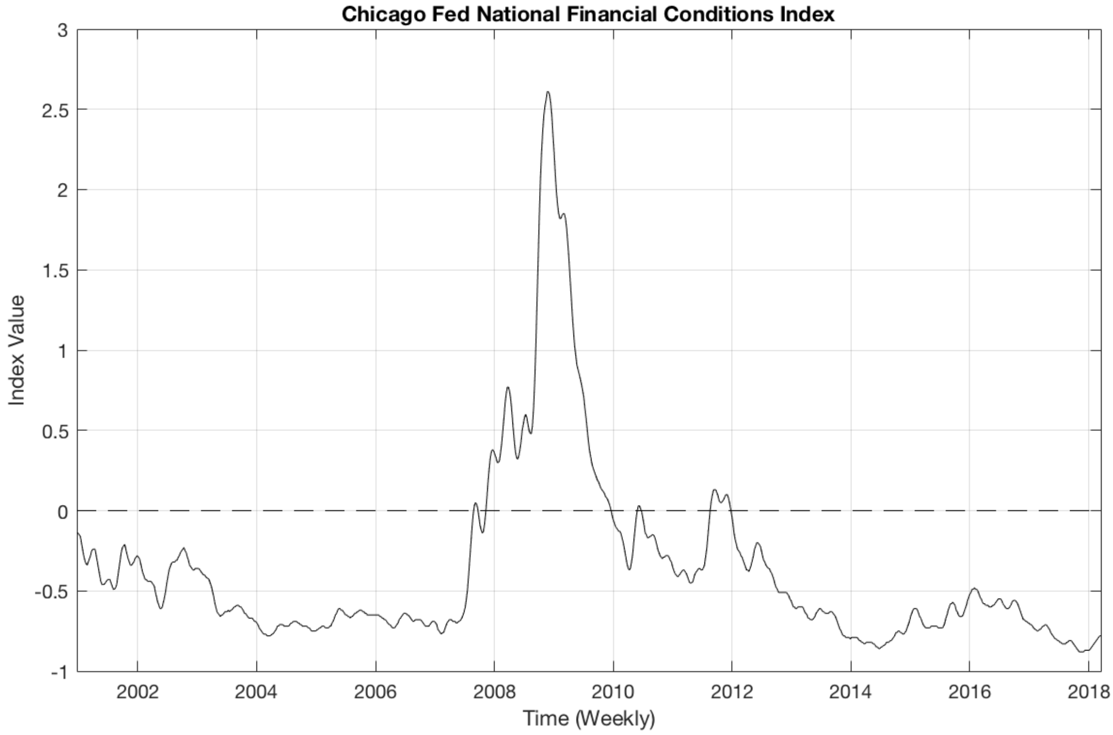

Figure 15: Financial Conditions Index

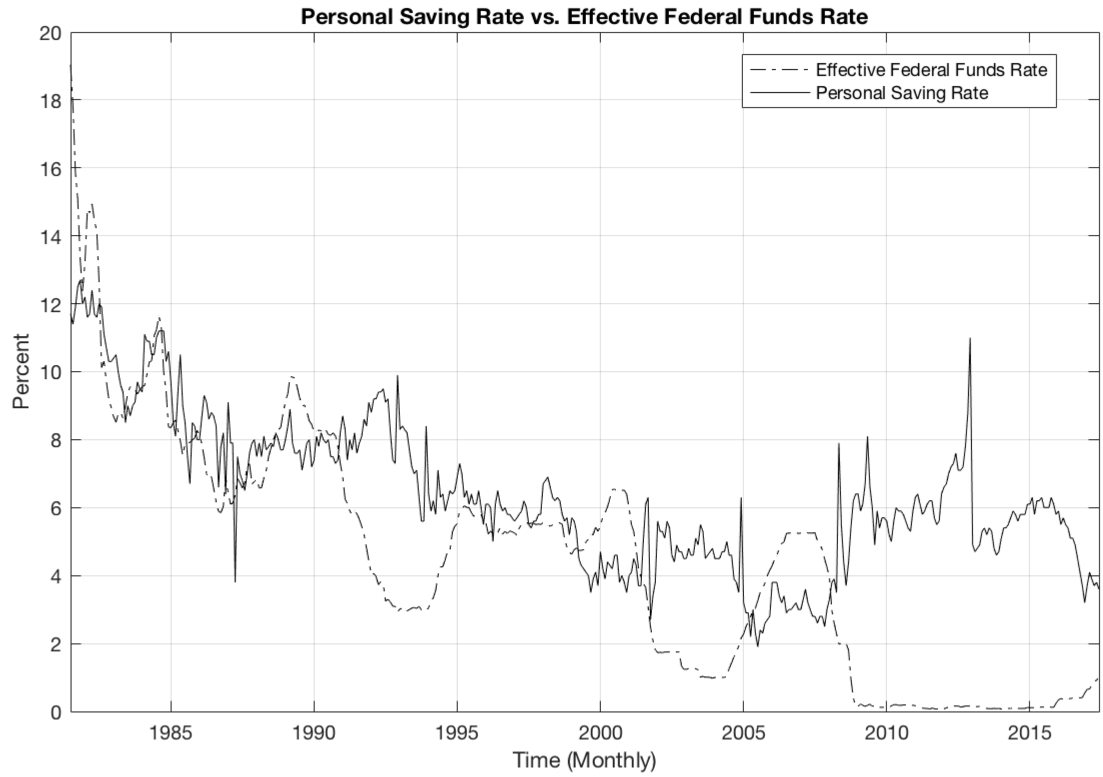

Figure 16: Interest rate and Savings rate

[11]U.S. Bureau of Economic Analysis, retrieved from FRED, Federal Reserve Bank of St. Louis, March 7, 2018.