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Three Essays on Monetary Policy

A dissertation submitted in partial satisfaction of the
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by

Xu Zhang

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The Dissertation of Xu Zhang is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California San Diego

2019

DEDICATION

I dedicate my dissertation work to my family and many friends, whose support and encouragement have enriched my soul and inspired me to pursue and complete this research.

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I would like to acknowledge Professor James Hamilton for his support as the chair of my committee. Through multiple drafts, his guidance has proved to be invaluable.

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ABSTRACT OF THE DISSERTATION

Three Essays on Monetary Policy

by

Xu Zhang

Doctor of Philosophy in Economics

University of California San Diego, 2019

Professor James Hamilton, Chair

This dissertation studies the identification of monetary policy and the effects of monetary policy on the macroeconomy.

Chapter 1 provides a new methodology to identify monetary policy shock. Federal Reserve announcements contain information about both economic fundamentals and monetary policy. My paper proposes to disentangle the information effects using Federal Reserve's forecasts about the macroeconomy and constructs a new measure of monetary policy shocks. The new shock series is consistent with the traditional view.

Chapter 2 investigates the effects of unconventional monetary policy when the nominal interest rate reaches the zero lower bound. There are two types of monetary policy, i.e. forward

guidance and large-scale asset purchases. I identify the separate contributions of each monetary policy shock to the effects on yield curve and macroeconomy.

Chapter 3 studies the effects of monetary policy on the household behavior. I look at how households with heterogeneous balance sheet composition would make their decisions in response to monetary policy interventions, and to what extent and this could affect the aggregate economy. I provide empirical analysis using household-level data, and document empirical stylized facts that can be used to evaluate different theoretical transmission channels of monetary policy.

Chapter 1

Disentangling the Information Effects in the Federal Reserve's Monetary Policy Announcements

Abstract

Federal Reserve announcements affect private sector beliefs in two different ways, revealing information about both economic fundamentals and monetary policy. This paper separates the information revelation from the effect of policy by combining the high-frequency multidimensional approach of Gürkaynak et al. (2005) with Greenbook measures of the Fed's information as in Romer and Romer (2004). The new shock series is consistent with the traditional view. In contrast to existing measures, a contractionary shock causes an upward revision in private forecasts of unemployment, a downward revision in private forecasts of inflation, and a decline in stock price.

1.1 Introduction

A number of approaches have been suggested for measuring a monetary policy shock. Kuttner (2001) use the daily change in the current month federal funds futures contract on the day of a Federal Open Market Committee (FOMC) meeting. Gertler and Karadi (2015) use the change in the 3-month-ahead federal funds futures contract. Gürkaynak et al. (2005) calculated principal components of the current and 3-month-ahead federal funds future along with 6-month, 9-month, and 1-year ahead Eurodollar futures. Romer and Romer (2004) use the change in the Fed's intended target that could not be predicted on the basis of the Fed's Greenbook forecasts of inflation, GDP, and unemployment. Miranda-Agrippino and Ricco (2018) use the component of the change in the 3-month-ahead fed funds futures in a 30-minute window around FOMC announcements that could not be predicted using Greenbook forecasts.

In this paper I present evidence that none of these measures completely corrects for the Fed information effect. The first four measures are all statistically significantly negative on average during NBER recessions. The Fed was surprising the market by lowering rates at these times in response to weak economic fundamentals that the Fed recognized but the market did not. This means that existing measures are conflating the effects of monetary policy, the effects of information revelation, and the effects of the recession itself. I extend the analysis of Campbell et al. (2012) and Nakamura and Steinsson (2018) to find that revisions to the Blue Chip consensus forecasts of unemployment typically fall after a contractionary monetary policy shock according to all of the measures except for Romer and Romer, the opposite response from that predicted for a true contractionary monetary shock, and a response suggesting that revelation of the Fed's information about economic fundamentals is likely an important component of what is treated as a shock to monetary policy. I extend the analysis of Cieslak and Schrimpf (2018) and Jarociński and Karadi (2018), finding that about half the time, stock prices rise at the time of a contractionary monetary policy shock according to the Kutter, Gertler-Karadi, or Romer-Romer measures. Finally, the federal funds rate, current month feral funds futures rate and the 3-month-ahead fed funds futures rate exhibited essentially no variation over 2009 to 2014, meaning that the Kuttner, Gertler-Karadi, Romer-Romer, and Miranda-Agrippino-Ricco measures do not exist for this important subsample. It will create bias when calculating the principal components in the extended sample.

I develop a new measure that solves all of these problems, combining the multidimensional aspect of monetary policy information noted by Gürkaynak et al. (2005) with the use of Greenbook forecasts by Romer and Romer (2004) and Miranda-Agrippino and Ricco (2018) and exploiting the basic insight of using high-frequency observations for identification that is common to all of the above measures. I use separate regressions to isolate the component of the change on the day of an FOMC announcement of each of the five different fed funds and Eurodollar futures that could not have been predicted on the basis of Greenbook forecasts. I next calculate the principal component of this vector using an unbalanced panel approach that takes into account the lack of variability of the shorter horizon contracts during 2009-2014. In contrast to the other five measures, this measure is actually slightly positive on average (though far from statistically significant) during NBER recessions. It is the only measure for which revisions to the Blue Chip forecasts of both inflation and unemployment tend to change in the direction predicted for a monetary expansion or contraction. And about 2/3 of the time, stock and bond prices move together in the way predicted by theory. I use the new measure to revisit the structural vector autoregression of Gertler and Karadi (2015) and find that the new measure eliminates both the "price puzzle" and the "output puzzle" (responses to a monetary shock of the opposite sign predicted by theory) that is sometimes found using other measures. Given the 5-year delay in releasing Greenbook forecasts, the most recent value for the new measure is 2013:m12, though this still extends the usable sample by at least 4 years beyond that available for the Kuttner, Gertler-Karadi, Romer-Romer, or Miranda-Agrippino-Ricco measures.

This paper contributes to several important literatures. First, it adds to the monetary policy identification literature. This includes the VAR studies such as Christiano et al. (1999) and also the work of Romer and Romer (2004). More recent studies provide lots of evidence that monetary policy news is multi-dimensional. For example, Gürkaynak et al. (2005) construct a "current federal funds rate target" factor and a "future path of policy" factor. Campbell et al. (2012) distinguish between Delphic and Odyssean monetary policy, where the Delphic type publicly states central banks' macroeconomic performance forecast whereas the Odyssean type publicly commits the policymaker's future action. To separate the non-information movement, Campbell et al. (2012) estimate a monetary policy rule with anticipated shocks. Nakamura and Steinsson (2018) model Fed's information as beliefs about the path of the "natural rate of interest" and estimate the structural model using real rates. To disentangle the two components, I provide a method that combines the high-frequency approach of Gürkaynak et al. (2005) and Romer and Romer (2004)'s narrative approach. It is easy to implement and survives the prevailing tests in the literature.

My paper also contributes to the literature regarding the assessment of the effects of the unconventional monetary policies. Many of the world's largest economies have experienced the zero short-term nominal interest rate over the last decade. It's hard to find a measure for monetary policy surprises during this period. In addition, as Hamilton (2018) documents, like conventional monetary policy announcement, the Fed's unconventional monetary policy announcements also contain Fed's assessment of economic fundamentals. Since I use longer term federal funds futures to construct the measure, it survives the zero lower bound period.

The remainder of the paper proceeds as follows. I review the literature on the monetary policy identification in Section 1.2. In section 1.3, I describe the procedure to construct the monetary policy shock. Section 1.4 describes the effects of monetary policy using the new measure and applies the new measure to previous studies. Section 3.4 concludes.

1.2 Existing approaches and the problem

A number of studies have proposed alternative methods to measure a monetary policy shock. In this section I will review the five existing approaches and evaluate their performance.

Surprise in the federal funds rate target (MP1). The high-frequency identification approach was pioneered by Kuttner (2001). Under the identifying assumption that no other shocks affect the expectation for federal funds rate around the 30-minute window of FOMC announcement, the surprise in the target rate is measured as the daily change in the spot-month federal funds future rate (FF1), scaled up to reflect the number of days affected by the change. This monetary policy shock is called MP1 in the literature.

To compare the size among different measure of monetary policy shocks, I rescale MP1 (and will do the same for all the other measures presented below) such that its effect on the daily two-year nominal Treasury yield is equal to 100 basis points.[1]

To convert the shock series into monthly frequency, I assign each shock to the month in which the corresponding FOMC announcements are made. If there are two meetings in a month, I sum the shocks. If there are no meetings in a month, I record the shock as zero for that month.

Monetary surprises are supposed to capture only unanticipated movements in interest rates. However, the mean of the MP1 series is nonzero, and it is serially correlated. After 2008, the MP1 didn't vary much and was almost zero between 2009 and 2014. For this reason, I restrict the sample period of MP1 to be between 1990:1m and 2008:12m.

In the upper left panel of Figure 1.1, I plot the cumulative change in MP1 over a 12-month period using just the days of FOMC announcements. The shaded areas represent NBER-defined recessions for the U.S. economy. The Fed was surprising the market with lower interest rates during the recessions, and it was doing this because it saw the economy as weaker than many private analysts recognized at the time. To quantify this observation, I regress the monetary policy surprises on the NBER recession indicator and look at the regression coefficient. The regression equation is

$$\text{MPS}_t = \beta \text{Recession}_t + \varepsilon_t \tag{1.1}$$

where MPS_t is the monetary policy surprise in month t. In the case of Kuttner (2001), it is represented by the MP1_t. Recession_t is a binary variable equal to 1 if the the month t is a NBER recession month and equal to zero otherwise.

As shown in Table 1.1, the estimated β is -2.66 and is statistically significant at the 1% level. If one uses the MP1 to study the correlation between monetary shock and economic variables of interest, it will in part reflect the effect of the recession, not the effect of actions by

[1] The daily zero-coupon nominal Treasury yields are obtained from Gürkaynak et al. (2007) dataset. Swanson and Williams (2014) provide evidence that the zero lower bound was not a constraint on the Federal Reserve's ability to manipulate the two-year Treasury yield.

the Fed.

Next I look at whether the measure of MP1 includes an information effect. I follow Campbell et al. (2012) and estimate the responses of revisions of inflation and unemployment rate forecasts to the proposed monetary policy measure. The regression equation is

$$\triangle y_{t+1}^{h} = \beta_h \text{MPS}_t + \varepsilon_{t+1} \tag{1.2}$$

where $\triangle y_{t+1}^{h}$ is the revision of the h-quarter-ahead Blue Chip consensus forecast of inflation and unemployment rate at the beginning of month $t+1$, and $h = 0, 1, 2, 3, 4$.

Table 1.2 presents the regression result.[2] In theory, a true contractionary monetary policy shock should increase unemployment rate expectation and decrease the inflation expectation. However, most coefficients in column 1 show the opposite direction. The interpretation is that part of what happens is the Fed raises the interest rate because it sees fundamentals as stronger, and the private forecasts respond to the signal by being more optimistic about the the fundamentals.

Cieslak and Schrimpf (2018) and Jarociński and Karadi (2018) look at the problem from the perspective of the comovement of S&P 500 with bond yields. Again, a true contractionary monetary policy shock should raise interest rates and depress output, both of which should lower stock prices. A contractionary monetary policy shock again seems to be interpreted by private forecasters as expansionary. However, as Table 3 shows, on 51% of all the announcement days do MP1 and the intraday change in S&P 500 co-move in the "correct" direction. This number decreases to 45% if we use the daily change in S&P 500.

Change in 3-month ahead Federal funds futures ($\triangle$FF4). Gertler and Karadi (2015) use the three month ahead funds rate future surprise ($\triangle$FF4) around the 30-minute of Fed's

[2] Blue Chip Economic Indicator survey is conducted between the 2nd and the 7th day of each month. The monetary surprise data I use for this regression is restricted to include only the announcements made after the first week of the calendar month. The result is robust if I use the observations where the entire month's announcements are made after the first week of the calendar month.

announcement to identify monetary policy shock.

I plot the 12-month backward-rolling window cumulative change in the first row second column of Figure 1.1. $\triangle$FF4 didn't vary considerably and was almost zero between 2009 and 2013, which will make it impossible to use as an instrument during the Great Recession period. The sample period is 1990:1m-2008:12m.

From the figure as well as Table 1.1, we see that $\triangle$FF4 is more likely to be negative during the NEBR recession months. Column 2 of Table 1.2 presents the regression result of equation 1.2 with the monetary policy surprise MPS measured by $\triangle$FF4. Still, the contractionary monetary policy looks like expansionary one. Table 1.3 shows that MP1 and the intraday change in S&P 500 move together as predicted on only 52% of announcement days. This number falls to 48% if we use the daily change in S&P 500.

Instrument set of futures (MP1, MP2, $\triangle$ED2, $\triangle$ED3, $\triangle$ED4). Gürkaynak et al. (2005) find that the FOMC statements affect the financial market through current policy action along with influence on the market expectations of future policy actions. They suggest to use mixed horizons of futures data to measure the response of market expectations. I follow the literature and use the following instrument set: the surprises in the current month's fed funds futures with a scale factor to account for the timing of FOMC meetings within the month (MP1), in the three-month ahead monthly fed funds futures (also scaled, known as MP2), and in the six-month, nine-month and year ahead futures on three month Eurodollar deposits (ED2, ED3, ED4) on the days of FOMC announcement.

The sample period in Gürkaynak et al. (2005) is from 1990:1m to 2004:12m, and Nakamura and Steinsson (2018) use the sample period 1995:1m - 2014:3m. I use the extended sample period 1990:1m -2018:12m, take the first principal component of the balanced panel, and rescale it such that the effect on the two-year nominal Treasury yield is equal to 100 basis points. This shock is called PC1.

One problem of applying Gürkaynak et al. (2005)'s principal components idea to longer samples is that short term federal funds futures, and thus the MP1 and MP2 were unresponsive during the Great Recession. Taking the principal component of the balanced sample will generate bias, especially for the recession period. In middle panel of Figure 1.1, I compare the PC1 with a modified PC1 which is calculated using the expectation maximum (EM) algorithm developed in Stock and Watson (2002) where MP1 and MP2 are treated as missing during the recession.

Let's take look at the performance of the PC1. Again, the coefficient in Table 1.1 indicates the PC1 is more likely to be negative during the recession. And if I use the modified PC1, the result still holds. The coefficients in Column 3 of Table 1.2 are usually the opposite of what they should be. Table 1.3 shows PC1 and the intraday change in S&P 500 move together as predicted on 71% of announcement days. The results won't change much if using the modified PC1 because these analysis is conducted for the sample period 1990:m1 - 2007:m12.

The Romer-Romer (RR) shock. The seminal empirical paper on Fed information is Romer and Romer (2004). They construct their monetary policy shocks by combining the narrative approach with the Greenbook forecasts.[3] They derive the intended federal funds rate changes during FOMC meetings using narrative methods. In order to separate the endogenous response of policy to information about the economy from the exogenous policy deviation, they then regress the intended funds rate change on the current rate and on the Greenbook forecasts of output growth and inflation over the next two quarters. The specific equation they estimate in the second step is as follows.[4]

$$\begin{aligned}\triangle \mathrm{fft}_m = {} & \beta_0 \mathrm{fft\_level}_{m^-} + \sum_{j=-1}^{2} \beta_j^{\triangle \mathrm{INFL}} \triangle \mathrm{INFL}^{\mathrm{GB}}_{m,q+j} + \sum_{j=-1}^{2} \beta_j^{\triangle \mathrm{RealGDP}} \triangle \mathrm{RealGDP}^{\mathrm{GB}}_{m,q+j} \\ & + \sum_{j=-1}^{2} \beta_j^{\mathrm{INFL}} \mathrm{INFL}^{\mathrm{GB}}_{m,q+j} + \sum_{j=-1}^{2} \beta_j^{RealGDP} \mathrm{RealGDP}^{\mathrm{GB}}_{m,q+j} + \beta^{\mathrm{UNEMP}} \mathrm{UNEMP}_{m,q} \\ & + \mathrm{constant} + \varepsilon_m\end{aligned}$$

[3]Wieland and Yang (2016) extend their shock series to the end of 2007.

[4]This is the equation 1 in Romer and Romer (2004).

where $\triangle \text{fft}_m$ denotes the change in the federal funds target on the FOMC meeting m, and fft_level_{m^-} is the level of the federal funds rate before any changes associated with the meeting, which is included to capture any tendency toward mean reversion in FOMC behavior. Let q be the quarter where the meeting m takes place. $\text{INFL}^{GB}_{m,q+j}$, $\text{RealGDP}^{GB}_{m,q+j}$ and $\text{RealGDP}^{GB}_{m,q+j}$ denote the Greenbook forecasts for inflation, real GDP and unemployment rate for quarter $q+j$ made at meeting m, j=-1,0,1, 2, respectively. $\triangle\text{INFL}^{GB}_{m,q+j}$ and $\triangle\text{RealGDP}^{GB}_{m,q+j}$ is the revised forecast for inflation and real GDP growth between two consecutive meetings. In computing the forecast innovations, the forecast horizons for meetings m and m-1 are adjusted so that the forecasts refer to the same quarter.

The Romer-Romer shock starts from 1969 and ends on 2007 due to the zero lower bound. Their meeting dates are very different from Gürkaynak et al. (2005), especially for the pre-1994 period. The FOMC did not explicitly announce changes in its target for the federal funds rate, but such changes were implicitly communicated to financial markets through the size and type of the following open market operation, which is used as announcement dates in Gürkaynak et al. (2005).

Table 1.2 column 4 shows the responses of Blue Chip forecast revisions for inflation and unemployment rate to Romer-Romer shock. In some cases, contractionary monetary policy seems to increase the inflation expectation, which is not true according to theory. The stock price co-movements analysis in Table 1.3 shows Romer-Romer shock and the intraday change in S&P 500 move together as predicted on only 46% of announcement days.

The MAR shock. Miranda-Agrippino and Ricco (2018) regress the 30-minute window surprise in FF4 onto the Greenbook forecasts and uses the residual to construct the monetary policy shock. First they estimate the following regression.

$$\triangle \mathrm{FF4}_d = \sum_{j=-1}^{2} \beta_j^{\triangle \mathrm{INFL}} \triangle \mathrm{INFLINFL}_{d,q+j}^{\mathrm{GB}} + \sum_{j=-1}^{2} \beta_j^{\triangle \mathrm{RealGDP}} \triangle \mathrm{RealGDP}_{d,q+j}^{\mathrm{GB}}$$
$$+ \sum_{j=-1}^{3} \beta_j^{\mathrm{INFL}} \mathrm{INFL}_{d,q+j}^{\mathrm{GB}} + \sum_{j=-1}^{3} \beta_j^{\mathrm{RealGDP}} \mathrm{RealGDP}_{d,q+j}^{\mathrm{GB}} + \beta^{\mathrm{UNEMP}} \mathrm{UNEMP}_{d,q}^{\mathrm{GB}}$$
$$+ \mathrm{constant} + \varepsilon_d$$

Next they construct a monthly instrument by summing the regression residuals within each month. Then they regress the non-zero monthly aggregation onto its 12 lags, and the residual is the MAR monetary policy shock.

The three-month ahed federal funds futures is only available after 1990 and is not responsive during the zero lower bound. Therefore the MAR series is begins 1991:m1 and ends 2009:m12.

The coefficient in Table 1.1 indicates the MAR shock is more likely to be negative during the recession, though insignificant. Table 1.2 column 5 presents the responses of Blue chip expectation revisions for unemployment rate and inflation to contractionary MAR monetary policy shock.[5] Almost all the coefficients are insignificant from zero, and all the unemployment rate revision responses go into the opposite direction as predicted by theory. Table 1.3 shows MAR shock and the intraday change in S&P 500 move together as predicted on 64% of announcement days.

In summary, all the measures of monetary policy shocks mentioned above still seem to have an important signaling component. They tend on average to be pro-cyclical, as if the fed was lowering rates during recessions for some reason other than a response to perceived economic conditions.

[5]The meeting frequency measure is used.

1.3 Construction of the new measure

There are two components of the responses of interest rates to the FOMC announcement. One relates to the FOMC's monetary policy actions based on the policymaker's potentially superior information about economic fundamentals. Another one is the policymaker's commitment to the current and future monetary policy.[6] In the rest of this section, I lay out a new procedure to construct monetary policy shocks that isolates the second component from the information effects. I proceed in the following five steps.

Step 1, following Kuttner (2001) and Gürkaynak et al. (2005), I build the unanticipated change over the 30-minute windows in the following five interest rates[7]: the current month's fed funds target rate (MP1)[8], the three month ahead monthly fed funds futures (FF4), and the six month, nine month and year ahead futures on three month Eurodollar deposits (ED2, ED3, ED4).

Since there's little variation for the shorter horizon interest rate futures in the zero lower bound period, the sample length for these data is reduced. For MP1 and FF4, the sample period is 1990:m1- 2008:m12. However, the longer horizon futures, like ED2, ED3 and ED4, still respond to the monetary announcement. The sample periods are 1988:m1- 2012:m12, 1988:m1- 2012:m12, 1988:m1- 2013:m12, respectively.

Step 2, I regress these surprises, MP1, $\triangle FF4$, $\triangle ED2$, $\triangle ED3$, $\triangle ED4$ onto (i) the level of the futures's interest rate one day before to capture mean reversion in FOMC behavior, (ii) two lags in previous meetings, to control for the autocorrelation, (iii) Greenbook forecasts and

[6] Campbell et al. (2012) defines the former one as Delphic monetary policy and the latter one as Odyssean monetary policy.

[7] The intraday data for the futures and the meeting dates is obtained from the Federal Reserve Board.

[8] Different from the original construction method in Kuttner (2001), when the FOMC meeting occurs on a day when there are 7 days or less remaining in a month, I instead use the change in the price of next month's fed funds futures contract. This avoids multiplying the change by a very large factor. Let FF1 be the interest rate of the current month fed funds futures and FF2 be the interest rate of the next month fed funds futures. The announcement is made on day d, which is the t^{th} of the month, and the calendar month has T days in total. The surprise in the federal funds rate target MP1 is defined as

$$MP1_d = \begin{cases} FF2_d - FF1_{d-1} & \text{if} \quad \mathrm{t} = 1 \\ (FF1_d - FF1_{d-1})\frac{T}{T-t} & \text{if} \quad 1 < \mathrm{t} < \mathrm{T} - 7 \\ FF2_d - FF2_{d-1} & \text{if} \quad \mathrm{t} >= \mathrm{T} - 7 \end{cases}$$

forecast revisions for real output growth, inflation and the unemployment rate, as in Romer and Romer (2004), to control for the central bank's private information. The specific equation I estimate is:

$$
\begin{aligned}
\text{MPS}_d = {} & \beta_0 \text{MPS\_level}_{d^-} + \beta_1 \text{MPS}_{d-1} + \beta_2 \text{MPS}_{d-2} \\
& + \sum_{j=-1}^{s} \beta_j^{\triangle\text{INFL}} \triangle\text{INFL}_{d,q+j}^{GB} + \sum_{j=-1}^{s} \beta_j^{\triangle\text{RealGDP}} \triangle\text{RealGDP}_{d,q+j}^{GB} \\
& + \sum_{j=-1}^{s} \beta_j^{\text{INFL}} \text{INFL}_{d,q+j}^{GB} + \sum_{j=-1}^{s} \beta_j^{\text{RealGDP}} \text{RealGDP}_{d,q+j}^{GB} + \sum_{l=0}^{m} \beta_j^{\text{UNEMP}} \text{UNEMP}_{d,q+j}^{GB} \\
& + \text{constant} + \varepsilon_d
\end{aligned}
\tag{1.3}
$$

where MPS_d denotes the market-based monetary policy surprise that on the FOMC announcements day d. q is the quarter where the announcement takes place. The j subscripts refer to the horizon of the real GDP and inflation forecast: -1 is the previous quarter; 0 is the current quarter; and 1, 2, 3, ..., s are one, two, three, ..., s quarters ahead, respectively. Because these interest rate futures represent expectation of future federal funds rate for different horizon, I use different forecast horizon s as well. In particular, up to 2 quarters ahead, i.e. s=2, for MP1, $\triangle FF4$ and $\triangle ED2$, up to 3 quarters ahead for $\triangle ED3$, up to 4 quarters ahead for $\triangle ED4$. Following Romer and Romer (2004), because of the strong Okun's Law relationship between output growth and unemployment only the contemporaneous unemployment forecast is controlled for MP1, $\triangle FF4$ and $\triangle ED2$, up to 1 quarter ahead for $\triangle ED3$, and up to 2 quarters ahead for $\triangle ED4$.

Step 3, I normalize the residuals of each regression to have zero mean and unit variance, similar to the procedure in Gürkaynak et al. (2005).

The different sample periods for the interest rate futures result in different sample periods for the different residuals. I therefore use the expectation maximum (EM) algorithm developed in Stock and Watson (2002) to calculate the principal components of the unbalanced panel of residuals. The first principal component which explains 77.5% of the variation.

Step 4, I rescale the first principal component such that the effect on the daily two-year nominal Treasury yield is equal to 100 basis points. This is the the new monetary policy shock series at the announcement frequency.

Step 5, to obtain monthly frequency, I assign each shock to the month in which the corresponding FOMC announcement occurred. If there are two announcement days in a month, I sum the shocks. If there are no meetings in a month, I record the shock as zero for that month.

The last figure in Figure 1.1 plots the 12-month cumulative new measure. The use of the longer horizon eurodollar futures allows the new measure to spans from 1988:m1 to 2013:12m. The NBER recession regression coefficient is 0.15 and insignificant shown in Table 1.1.

1.4 Effects of the monetary policy surprise

In this section, I use the new measure to estimate the effects of the monetary policy on the macroeconomic variables and their forecasts.

1.4.1 Response of private sector forecast

Table 1.2 columns 6 and 7 show the estimated private forecast responses to the new measure. Following a contractionary monetary policy news shock, the current and expected unemployment rate tend to increase, and the current and expected inflation rate tend to fall. Thus, the contractionary monetary policy shock behaves as predicted.

1.4.2 Comovement of stock price and monetary policy surprise

As shown in Table 1.3, 69% of all the announcement days the new measure and the intraday change in S&P 500 co-moves in the opposite direction, and this number becomes 60% if we use the daily change in S&P 500.

1.4.3 Application in a proxy SVAR framework

In this section, I apply the new measure of monetary policy surprises to the proxy structural VAR specification of Gertler and Karadi (2015). It is a 12-lag monthly VAR using the monetary policy surprises as external instrument. Miranda-Agrippino and Ricco (2018) extend the framework to six variables: the log of industrial production, the unemployment rate, the log of the CPI, the log of a commodity price index, excess bond premium, and one-year government bond yield. The sample period starts from 1979:m1 and ends on 2016:m8 due to the availability of excess bond premium data.

Before the estimation, I test the relevance condition required for identification using the F-statistic provided by Montiel Olea et al. (2018). It provides an indication of possible weak-instrument concerns for inference, with the 5% critical value of 3.84. The F-statistics are 3.93, 5.49, 4.08, 1.54, 3.68 and 2.89 when we instrument the monetary policy shock using the new measure, PC1, Romer-Romer, MP1, $\triangle$FF4 and MAR, respectively. Thus we conclude that the new measure, PC1, and Romer-Romer are relevant instruments, but do not reject the null hypothesis of instrument irrelevance for MP1, $\triangle$FF4 and MAR.

Figure 1.2 plots the impulse responses a monetary policy shock that on impact raises the one-year government bond yield by 25 basis points using the new measure, PC1 and Romer-Romer(RR) shock. The 90% confidence interval is constructed using the inference approach in Montiel Olea et al. (2018) for weak instrument.

Using the new measure, the estimates imply that a shock that raises the bond yield is contractionary: price level, commodity price level, industrial production drop immediately, excess bond premium and the unemployment rate increase. However, if we use the PC1, the effects on industrial production and unemployment rate never become significant, and the initial response of unemployment rate goes in the wrong direction; if we use Romer-Romer shock, the initial responses of both industrial production and the unemployment rate are inconsistent with the theory.

1.5 Conclusion

Evaluating the effects of monetary policy is important for both policy makers and researchers. In this paper, I provide a new method of constructing monetary policy shocks that can be used for monetary policy evaluation and compare it with the existing approaches. The new measure successfully isolates the non-information movement of the Federal Reserve's announcement, whereas the previous methods are incapable to achieve. The new measure is consistent with the standard theory's prediction: monetary policy shock is independent of recession period; a pure monetary policy tightening lowers private investors' expectations about inflation and output growth; the majority of the comovement between S&P 500 futures and monetary policy shocks is negative. Furthermore, the new measure can be used as a relevant instrument for IV-SVAR analysis. "Price puzzle" and "Output puzzle" disappear in the analysis.

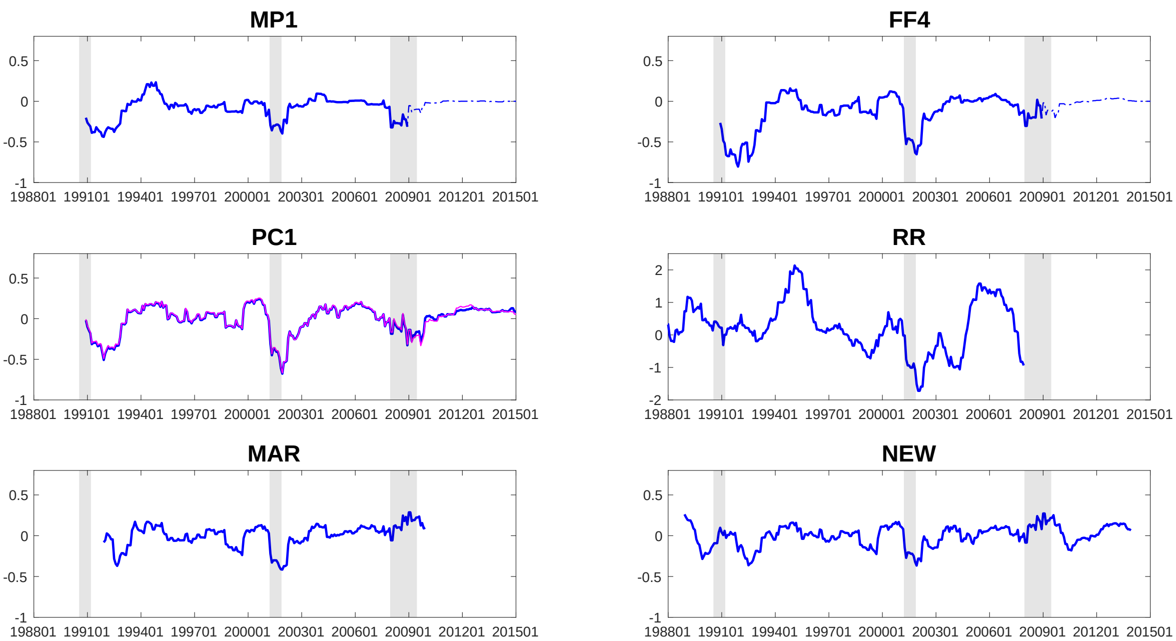

Figure 1.1. 12-month Backward Rolling Window of Cumulative Monetary Shocks

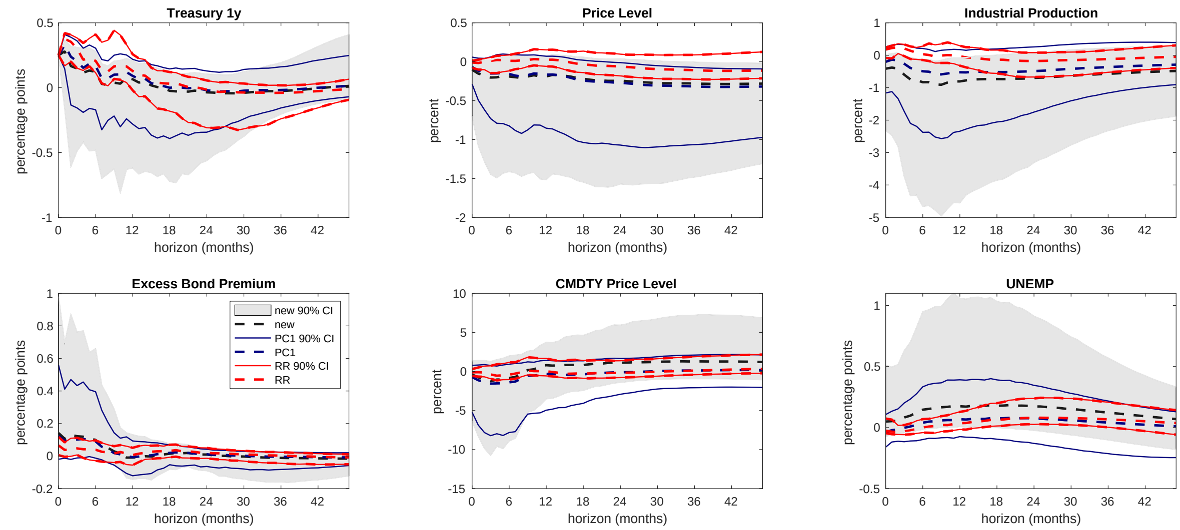

Figure 1.2. Impulse Responses Using the New Measure, PC1 and Romer-Romer

Table 1.1. Regression on NBER Recession Indicator

	MP1	FF4	PC1	RR	MAR	NEW
β	-2.66***	-2.18***	-1.63**	-0.18**	-0.41	0.15
	(0.85)	(0.75)	(0.67)	(0.09)	(1.02)	(0.90)
	1990:m1-2008:m12	1990:m1-2008:m12	1990:m1-2018:m12	1969:m3-2007:m12	1991:m1-2009:m12	1988:m1-2013:m12

NOTES: Robust standard errors are in parentheses, *, ** and *** denote statistical significance at 10 percent, 5 percent and 1 percent levels, respectively.

Table 1.2. Regressions Estimating Private Forecast Responses to Various Measures of Contractionary Monetary Policy Shocks

	MP1	$\triangle$FF4	PC1	RR	MAR	NEW	NEW (full sample)
Inflation							
Current quarter	0.17	0.17	0.14	0.07	0.08	**-0.03**	0.06
	(0.41)	(0.32)	(0.29)	(0.07)	(0.31)	(0.32)	(0.28)
Next quarter	0.10	0.11	**-0.00**	0.01	**-0.09**	**-0.14**	**-0.06**
	(0.30)	(0.22)	(0.20)	(0.05)	(0.19)	(0.18)	(0.19)
2-quarter ahead	**-0.16**	**-0.15**	**-0.23**	0.00	**-0.37****	**-0.41****	**-0.21**
	(0.20)	(0.15)	(0.16)	(0.05)	(0.17)	(0.19)	(0.17)
3-quarter ahead	0.10	0.05	**-0.06**	**-0.03**	**-0.18**	**-0.18**	**-0.13**
	(0.25)	(0.18)	(0.16)	(0.04)	(0.17)	(0.17)	(0.15)
4-quarter ahead	**-0.12**	**-0.09**	**-0.17**	**-0.00**	**-0.17**	**-0.24**	**-0.10**
	(0.22)	(0.15)	(0.15)	(0.04)	(0.16)	(0.17)	(0.15)
Unemployment rate							
Current quarter	-0.19	-0.15	-0.24**	**0.02**	-0.16	-0.08	**0.04**
	(0.18)	(0.13)	(0.12)	(0.04)	(0.14)	(0.13)	(0.15)
Next quarter	-0.18	-0.23	-0.21	**0.02**	-0.07	**0.02**	**0.12**
	(0.23)	(0.16)	(0.14)	(0.06)	(0.16)	(0.17)	(0.20)
2-quarter ahead	-0.31	-0.38**	-0.29**	**0.05**	-0.16	-0.02	**0.02**
	(0.28)	(0.17)	(0.14)	(0.06)	(0.17)	(0.18)	(0.23)
3-quarter ahead	-0.31	-0.30*	-0.24*	**0.06**	-0.06	**0.05**	**0.14**
	(0.24)	(0.16)	(0.14)	(0.05)	(0.15)	(0.16)	(0.24)
4-quarter ahead	-0.10	-0.16	-0.10	**0.02**	-0.01	**0.05**	**0.36**
	(0.19)	(0.14)	(0.11)	(0.06)	(0.14)	(0.15)	(0.25)

Table 1.3. % of Days Where S&P 500 Moves in the Opposite Direction with Monetary Policy Shocks

Stock Market Index	MP1	$\triangle$FF4	PC1	RR	MAR	New	New (full sample)
S&P 500 30-minute	51%	52%	71%	46%	64%	69%	68%
S&P 500 daily	45%	48%	57%	51%	56%	60%	58%

NOTES: This table displays % of days where S&P 500 moves in the opposite direction with non-zero monetary policy shocks. The sample period for the first six columns is from 1990:m1 to 2007:m12. The last column is from 1988:m1 to 2013:m12.

Chapter 2

Evaluating the Effects of Forward Guidance and Large-scale Asset Purchases

Abstract

This paper evaluates the effects of forward guidance and large-scale asset purchases (LSAP) when the nominal interest rate reaches the zero lower bound. I investigate the effects of the two policies in a dynamic new Keynesian model with financial frictions adapted from Gertler and Karadi (2011, 2013), with changes implemented so that the framework delivers realistic predictions for the effects of each policy on the entire yield curve. I then match the change that the model predicts would arise from a linear combination of the two shocks with the observed change in the yield curve in a high-frequency window around Federal Reserve announcements, allowing me to identify the separate contributions of each shock to the effects of the announcement. My estimates correspond closely to narrative elements of the FOMC announcements. My estimates imply that forward guidance was more important in influencing inflation, while LSAP was more important in influencing output.

2.1 Introduction

Between December 2008 and December 2015, the federal funds rate - that is, the conventional monetary policy instrument of the Federal Reserve, or the Fed - consistently hovered near the zero lower bound (ZLB). To provide a much-needed stimulus to the economy, the Federal Open Market Committee (FOMC) resorted to two unconventional monetary policies at once: forward guidance and large-scale asset purchases (LSAP).[1] In this paper, I propose a new method of separating the components of forward guidance and LSAP for each FOMC announcement, reconciling the various interest rates' responses predicted from a structural model with observed high frequency yield curve data. In a follow-up step, I aggregate the effects from each type of monetary policy and provide quantitative estimates of the influence of each FOMC announcement on the financial market and the real economy.

The top reason for separating forward guidance from LSAP is that they affect the financial market and macroeconomy via different channels. When the Fed provides forward guidance - that is, communicating to the public about the likely future course of monetary policy - individuals and businesses will use this information in making decisions about spending and investments.[2] When the Fed purchases longer-term securities issued by the U.S. government and longer-term securities issued or guaranteed by government-sponsored agencies, long-term interest rates decline as risk premiums drop, which ultimately reduces the cost of borrowing for the private sector.[3] To better understand the efficacy of the policies and accurately estimate their effects, however, we first need to quantify the importance of each type of monetary policy.

In this paper, I contribute to monetary policy evaluation literature in three ways: (i) by providing a micro-foundation of how various interest rates respond to different unconventional monetary policies, (ii) by quantifying the responses of financial markets and the real economy,

[1]For example, on December 16, 2008, the FOMC lowered the target for the federal funds rate to a range from 0 to 1/4 percent and indicated that it expected the target to remain there "*for some time*". In the same announcement, the Fed announced that it would continue to consider ways of using its balance sheet to further support credit markets and economic activity.

[2]Eggertsson et al. (2003) show that lowering the expected path of policy rates can be highly effective in increasing economic activity and inflation for an economy at the zero lower bound. There is a rapidly growing literature on assessing the effect of forward guidance that has been used during the Great Recession. Important contributions include Campbell et al. (2012), Swanson and Williams (2014), Gertler and Karadi (2015), Del Negro et al. (2015), Keen et al. (2016) and Swanson (2017).

[3]Chen et al. (2012) augment a standard DSGE model with segmented bond markets, and Gertler and Karadi (2011, 2013) provide a framework where limits to arbitrage exist. Most empirical research has focused on analyzing the effects of LSAP on interest rates, output, inflation, term and risk in financial markets, and spillover effects in other countries. For example, Gagnon et al. (2011), Krishnamurthy et al. (2011), Gilchrist and Zakrajšek (2013), Bauer and Rudebusch (2014). Studies using a variety of methodologies generally agree that LSAP has been effective at lowering long-term interest rates and stimulating economic growth.

and (iii) by examining which type of unconventional monetary policy can more thoroughly explain those responses. To those ends, I develop a model that accounts for different channels of transmitting unconventional monetary policies and perform an empirical analysis using high-frequency interest rate data.

I begin by building a New Keynesian dynamic stochastic general equilibrium (DSGE) model based on the work of Gertler and Karadi (2011, 2013). I introduce a nominal short-term shadow interest rate that I assume follows a Taylor rule, as well as a forward guidance shock is the form of an announcement of future shocks to the interest rate rule, following the modeling device for generating innovations in expected future interest rates proposed by Laséen and Svensson (2011). I allow a ZLB where a one-period nominal interest rate endogenously remains when the economy enters a recession. Also following Gertler and Karadi (2011, 2013), I model LSAP as the central bank's purchase of a perpetuity, which affects the economy to the extent that limits to arbitrage in private intermediation exist.

Next, I perform some model simulations in which the economy endogenously remains at the ZLB for a few periods as a result of a negative shock. I also suppose that either a forward guidance policy or an LSAP program involving the purchase of long-term securities is initiated in the wake of the shock. I obtain the different impulse responses of short-term shadow and perpetuity interest rates to each type of monetary policy.

The mechanisms by which the forward guidance and LSAP affect the shadow rate and the perpetuity rate differently are as follows. I assume that the central bank has limited commitment power and influences people's expectations up to a finite horizon. That assumption is realistic insofar as the central bank wants to be flexible and adjust its monetary policy as economic conditions change. Instead of setting up an infinite horizon interest rate path now and changing it later, which will hurt its credibility, the central bank provides guidance for a short period. As a result, when the Fed exercises the forward guidance policy, the shadow interest drops below the perpetuity interest rate. When the Fed makes asset purchases, on the one hand it will increase the demand for the perpetuity interest rate and lower the long-term interest rate; on the other, it will increase people's expectations for short-term output and inflation, which will increase the shadow interest rate by way of the interest rate rule.

However, the daily change in the shadow rate cannot be observed in the data. To compare the model's prediction with interest rate data, I thus interpolate the entire yield curve by using a two-factor yield curve interpolation method adapted from Wu and Xia (2016). As a result, forward guidance affects Treasury yields at all maturities, with a peak effect at a maturity of about 20 months. By contrast, the effects of LSAP increase along with maturity, meaning that LSAP exerts its peak effect on the longest-term maturities but increases short-term maturities.

One of the implications of using a formal model of LSAP such as the one developed here is that expansionary LSAP, by lowering long-term rates, stimulates the economy and helps achieve higher inflation and output at the intermediate run horizon. If the Fed in the future were to respond to the higher inflation and output with its usual Taylor rule, the result would be sooner lift-off from the zero lower bound and a higher path for short-term interest rates. The model predicts that LSAP would lower long-term interest rates but raise intermediate-term interest rates. If the Fed does not want to have this effect, it should always use expansionary forward guidance as a complementary tool in conjunction with LSAP. Our empirical estimates imply that this is typically what the Fed in fact did.

Next I combine the theoretical result with data to identify the sizes of forward guidance and LSAP for each Fed's announcement. The data I use is the movements of Treasury yields at various horizons in a daily window that brackets the Fed's announcement. Three forces drive those movements: the Fed's superior information about economic conditions, the unexpected forward guidance policy, and the unexpected asset purchases policy. To isolate the latter two from the Fed's information, I use Zhang (2018)'s method and regress the observed changes of yields at each maturity on the Green Book forecasts. The residuals are orthogonal to the Fed's information and represent the monetary policy component of the Fed's announcements. Then I match the change that the structural model predicts from a linear combination of the two types of shocks with this monetary policy component. Figure 2.1 shows the estimated size of each type of monetary policy on each of the Fed's announcement days.

With the size of the policy shock at each date identified, I use the structural model to make inferences about the other variables of interest. Overall, my estimates indicate that the QE I program (i.e., from November 2008 to March 2010) increased two quarters ahead of real GDP by 1.11% and two quarters ahead of expected inflation by 0.81 annualized percentage points. Forward guidance thus exerts a greater influence on inflation expectations (0.60 vs. 0.21 annualized percentage points), whereas LSAP is more important in influencing output (0.39 vs. 0.72 percent).

This paper contributes to four major strands of literature on monetary policy evaluation. First, among economists who have increasingly emphasized the multidimensionality of monetary policy, Campbell et al. (2012) and Nakamura and Steinsson (2018) have found that the Fed's announcements contain information about economic conditions. However, to the best of my knowledge, only Swanson (2017), who mobilized principal component representations of various interest rates, has separated the effects of forward guidance and LSAP for each of the Fed's announcements. My paper differs from Swanson's (2017) work in three aspects. (i) I decompose the movement in various interest rates into information effects and monetary policy effects, the latter of which I decompose into forward guidance and LSAP. Crucially, that separation directs my estimates to show that much of the movement in interest rates results from the Fed's information; without that distinction, by contrast, the overall effects on real GDP are three times larger. (ii) My paper provides a micro-foundation of the different effects of forward guidance and LSAP on the yield curve. (iii) My method can allow practitioners and researchers to forecast the long-term effects on real activity by using a structural model; otherwise, by using time series approach, such forecasting is quite difficult to achieve, because the sample period for ZLB only lasted for 7 years.

The second strand of literature to which my paper contributes is the use of event studies such as Gagnon et al. (2011), Krishnamurthy et al. (2011), for instance - to assess the effects of four unconventional monetary policies on interest rates.[4] Instead of using text analysis to discern changes in words and sentences in current FOMC statements compared to previous statements or whether the event date belongs to a certain period of policy implementation, I allow the data indicate the direction and size of monetary policy. Using this approach can capture anything the Fed does or fails to do that affects the market. For example, if the Fed chose not to take some action or not to make a change in wording that the market anticipated[5], that absence of action can also be interpreted as revealing new information about monetary policy to the market.

Third, my paper provides a micro-foundation for identifying assumptions made in empirical studies. Gertler and Karadi (2015), for instance, have used external instruments in a vector autoregression (VAR) to identify monetary policy shocks and 1- and 2-year Treasury bond yields as conceptually preferred policy indicators to study the mechanism of the transmission of forward guidance. Earlier, Chung et al. (2012) estimated a structural model that assumes that the term premium of long-term Treasury bonds is inversely proportional to the Fed's holdings of long-term securities. The following year, Baumeister and Benati (2013) employed a time-varying parameter structural VAR model under the assumption that LSAP lowers the long-term yield spread while short-term interest rates remain unchanged.

Fourth and last, my paper draws from empirical studies on channels used to signal the Fed's bond purchases. Previously, scholars such as Bauer and Rudebusch (2014) found that such purchases have important signaling effects that lower expected future short-term interest rates by using an event study. My paper provides a theoretical explanation for their finding[6]: a LSAP announcement that causes output and inflation to rise today implies higher interest rates today,

[4]Wright (2012) uses a structural VAR to identify the effects of monetary policy shocks on various long-term interest rates. The VAR is identified using the assumption that monetary policy shocks are heteroskedastic: monetary policy shocks have higher variance on days of FOMC meetings and certain speeches than the other days.

[5]For example, on January 28, 2009, the FOMC statement was interpreted by some market participants as disappointing because of its lack of concrete language regarding the possibility and timing of purchases of longer-term Treasuries in the secondary market contrary to the other announcements Gilchrist and Zakrajšek (2013); Bauer and Rudebusch (2014). As another example, on September 18, 2013, the FOMC was widely expected to begin tapering its asset purchase while it turned out not to do so.

[6]Bhattarai et al. (2015) build a signaling theory where QE is effective because it generates a credible signal of low future real interest rates in a time consistent equilibrium.

particularly via the endogenous component in the central bank's policy rule. Therefore, to keep short-term rates at a low level, an additional expansionary policy should be implemented.

The remainder of the paper proceeds as follows. In Section 2.2, I begin by describing the model, which I calibrate in Section 2.3 to match the key features of the data, as well as calculate the state-dependent impulse responses in different scenarios. In Section 2.4, I describe the shadow interest rate framework used, after which I describe the regression methodology and results in Section 2.5. In Section 2.6, I discusses the key announcement days, and I explain the robustness of my methodology in Section 2.7. Last, I close the paper in Section 3.4 by summarizing the findings.

2.2 A Structural Model

My framework is based on the model of Gertler and Karadi (2011, 2013). They modify a reasonably standard New Keynesian model to explicitly include financial market structure and financial balance sheets. The model makes three primary assumptions. Banks finance risky, long-term assets with riskless, short-term debt. The existence of an agency problem between households and banks constrains the borrowing ability of the latter and generates excess return between long- and short-term debts. The central bank provides mediation for long-term asset purchases during economic crises and boosts the economy by reducing the credit costs of the banking sector.

I add the following features to their model. First, I introduce a nominal short-term shadow interest rate that I assume follows a Taylor rule subject to the ZLB. The shadow interest rate is the short-term rate when the ZLB is not binding. The shadow rate is negative when the ZLB is binding. A larger negative value implies a longer period of time before the shadow rate becomes positive and there is a lift-off from the ZLB. Downward shocks to the shadow rate can thus be used as a way to represent forward guidance in the ZLB. Instead of assuming that the one-period nominal interest rate is pegged for a certain length of time as in Gertler and Karadi, in my model the length of time that the economy stays at the ZLB is an endogenous response to the interaction between forward guidance and other shocks.

In the following part of this section, I characterize the distinctive elements of the model, including the behavior of households, banks, producers, and the central bank. See Online Appendix[7] for thorough expositions of the model.

2.2.1 Households

The economy is populated by a continuum of households of measure unity. Within each household there are two types of members: workers and bankers. A fraction $1-f$ of the household members are workers, and a fraction f are bankers. Workers provide labor and earn wages. Each banker manages a financial intermediary and returns the profit back to the household. Within the family there is perfect consumption insurance.

A banker this period remains a banker next period with probability θ, implying the average survival time for a banker in any given period is $1/(1-\theta)$. After the bankers exit, their retained earnings return to their respective household in the form of dividends. The bankers who exit become workers and are replaced by a similar number of workers randomly; thus the relative proportion of each type is fixed. New bankers will get startup funds equal to X_t provided by the household.

Let c_t be consumption and l_t labor supply. Then the household's discounted utility u_t is given by:

$$u_t = \mathrm{E}_t \sum_{j=0}^{\infty} \beta^j [\ln(c_{t+j} - hc_{t+j-1}) - \frac{\chi}{1+\phi} l_{t+j}^{1+\phi}] \tag{2.1}$$

where $\beta \in (0,1)$ denotes the household's subjective discount factor, $h \in (0,1)$ governs the strength of habits, and $\chi, \phi > 0$. The household's inter-temporal elasticity of substitution is unity, and its Frisch elasticity of labor supply is $1/\phi$.

[7]The Online Appendix can be found at http://acsweb.ucsd.edu/~xuz039/pdfs/JobMarketPaperAppendix_XuZhang_UCSD.pdf

There are three types of assets that the household can hold. Households can borrow and lend in a default-free one-period nominal bond market at the nominal interest rate i_t. Subject to some transaction costs, they can also make private loans to non-financial firms to finance capital to earn the real rate of return R_{kt} and hold a nominal long-term government bond to earn the real rate of return R_{bt}.

Let S_{ht} be the amount of private securities that households have. The transaction cost is equal to the percentage $\frac{1}{2}\kappa_s(S_{ht}-S_h)^2/S_{ht}$ of the value of the securities in its respective portfolio for $S_{ht} > S_h$. Similarly, for government bonds there is a holding cost equal to the percentage $\frac{1}{2}\kappa_b(B_{ht}-B_h)^2/B_{ht}$ of the total value of government bonds held for $B_{ht} > B_h$, where B_{ht} is the amount of long-term government bond that households have.

I define P_t as the price level of the consumption good. Q_t is the real price of the private securities at time t, and q_t be the real price of the government bond at time t.

Accordingly, at time t the household faces a flow budget constraint in nominal term:

$$\begin{aligned} & P_t c_t + P_t D_{ht} + P_t Q_t [S_{ht} + \frac{1}{2}\kappa_s (S_{ht}-S_h)^2] + P_t q_t [B_{ht} + \frac{1}{2}\kappa_b (B_{ht}-B_h)^2] + P_t T_t + P_t X_t \\ & = P_t W_t l_t + P_t \Pi_t + (1+i_{t-1}) P_{t-1} D_{ht-1} + P_{t-1} R_{kt} Q_{t-1} S_{ht-1} + P_{t-1} R_{bt} q_{t-1} B_{ht-1}. \end{aligned} \tag{2.2}$$

where D_{ht} is the quantity of one-period nominal bond held by household at time t, T_t is the lump-sum taxes in real term, X_t is the total transfer the household gives to its members that enter banking at t, W_t is the real wage, and Π_t are the payouts to the household from ownership of both non-financial and financial firms in real term.

The household's objective is to choose c_t, l_t, D_{ht}, S_{ht} and $B_{h,t}$ to maximize (2.1) subject to (2.2). The first-order conditions are:

$$\begin{aligned}
\frac{\partial u_t}{\partial c_t} W_t &= \chi l_t^{\phi} \\
\mathrm{E}_t \Lambda_{t,t+1} R_t &= 1 \\
S_{ht} - S_h &= \frac{1}{\kappa_s} \mathrm{E}_t \Lambda_{t,t+1} (R_{kt+1} - R_t) \\
B_{ht} - B_h &= \frac{1}{\kappa_b} \mathrm{E}_t \Lambda_{t,t+1} (R_{bt+1} - R_t)
\end{aligned}$$

where the household's stochastic discount factor is $\Lambda_{t,t+1} \equiv \beta \frac{\partial u_t / \partial c_t}{\partial u_t / \partial c_{t+1}}$.

Let $\pi_t \equiv \frac{P_t}{P_{t-1}} - 1$ be the inflation rate, then the link between nominal interest rate i_t and real interest rate R_t is given by the Fisher equation:

$$1 + i_t = R_t (1 + \mathrm{E}_t \pi_{t+1})$$

Following Woodford (2001) and other authors (e.g Arellano and Ramanarayanan (2012), Chen et al. (2012)), I model the nominal long-term government bond as a depreciating nominal perpetuity that pays a geometrically declining coupon of ϑ^n dollars in each period $n = 1, 2, \ldots$ after issuance. Let $q_t^n \equiv P_t q_t$ be the nominal price of the nominal bond. Then the ex-coupon real rate of return on the nominal bond R_{bt} is given by

$$R_{bt} = \frac{1/P_t + \vartheta q_t}{q_{t-1}} = \frac{1 + \vartheta q_t^n}{q_{t-1}^n (1 + \pi_t)}$$

where the size of the next coupon payment is normalized to one dollar. The very simple recursive structure above makes this type of long-term bond extremely convenient to work with. By choosing ϑ appropriately, we match the perpetuity's Macauley duration with the corresponding 10-year zero-coupon Treasury bond.

2.2.2 Banks

Banks lend funds obtained from households to non-financial firms and to the government. In addition to acting as specialists that assist in channeling funds from savers to investors, they engage in maturity transformation. They hold long-term assets and fund these assets with short-term liabilities (beyond their own equity capital). Financial intermediaries in this model are meant to capture the entire banking sector, i.e., investment banks as well as commercial banks.

Let n_t be the amount of net worth that a banker/intermediary has at the end of period t, d_t the deposits the intermediary obtains from households, s_{pt} the quantity of financial claims on non-financial firms that the intermediary holds, and b_t the quantity of long-term government bonds. The intermediary balance sheet is then given by:

$$Q_t s_{pt} + q_t^n b_{pt} = n_t + d_t \tag{2.3}$$

Net worth is accumulated through retained earnings. It is thus the difference between the gross return on assets and the cost of liabilities:

$$n_t = R_{kt} Q_{t-1} s_{pt-1} + R_{bt} q_{t-1}^n b_{pt-1} - R_{t-1} d_t \tag{2.4}$$

The banker's objective is to maximize the discounted stream of payouts back to the household, where the relevant discount rate is the household's inter-temporal marginal rate of substitution. The terminal wealth is given by:

$$\mathrm{V}_t = \mathrm{E}_t \sum_{i=1}^{\infty} (1-\theta)\theta^{i-1} \Lambda_{t,t+i} n_{t+i} \tag{2.5}$$

To motivate a limit on the bank's ability to obtain deposits, Gertler and Karadi (2011) introduce a moral hazard/costly enforcement problem. At the beginning of the period, the banker can choose to divert funds from the assets he holds and transfer the proceeds to the household of which he is a member. The cost to the banker is that the depositors can force the intermediary into bankruptcy and recover the remaining fraction of assets. However, it is too costly for the depositors to recover the funds that the banker diverted. It is assumed that it is easier for the bank to divert funds from its holdings of private loans than from its holding of government bonds: it can divert the fraction λ of its private loan portfolio and the fraction $\lambda\triangle$ with $0 < \triangle < 1$ from its government bond portfolio. Therefore, for depositors to be willing to supply funds to the banker, the following incentive constraint must be satisfied:

$$V_t \geq \lambda Q_t s_{pt} + \lambda \triangle q_t^n b_{pt} \tag{2.6}$$

The left side is what the banker would lose by diverting a fraction of assets. The right side is the gain from doing so. The banker's maximization problem is to choose s_t, b_t, and d_t to maximize (2.5) subject to (2.3), (2.4), and (2.6). Let Γ_t be the Lagrange multiplier associated with the incentive constraint. The first order conditions are:

$$\mathrm{E}_t\widetilde{\Lambda}_{t,t+1}(R_{kt+1} - R_t) = \frac{\Gamma_t}{1+\Gamma_t}\lambda$$
$$\mathrm{E}_t\widetilde{\Lambda}_{t,t+1}(R_{bt+1} - R_t) = \triangle\frac{\Gamma_t}{1+\Gamma_t}\lambda$$

with

$$\begin{aligned}
\widetilde{\Lambda}_{t,t+1} &\equiv \Lambda_{t,t+1}\Omega_{t+1} \\
\Omega_t &= 1-\theta+\theta\frac{\partial V_t}{\partial n_t} \\
\frac{\partial V_t}{\partial n_t} &= \widetilde{\Lambda}_{t-1,t}[(R_{kt} - R_{t-1})\phi_t + R_{t-1}]
\end{aligned}$$

The constraints are:

$$
\begin{aligned}
Q_t s_{pt} + \triangle q_t^n b_t &= \phi_t n_t \quad \text{if} \quad \Gamma_t > 0 \\
&< \phi_t n_t \quad \text{if} \quad \Gamma_t = 0
\end{aligned}
$$

where

$$
\phi_t = \frac{\mathrm{E}_t \widetilde{\Lambda}_{t,t+1} R_t}{\lambda - \mathrm{E}_t \widetilde{\Lambda}_{t,t+1} (R_{kt+1} - R_t)}
$$

2.2.3 Central bank's asset purchases

The central bank is allowed to purchase quantities of private loans S_{gt} and long-term government bonds B_{gt}. To finance these purchases, it issues risk-free short-term debt D_{gt} that pays the safe market interest rate i_t. In particular, the central bank's balance sheet is given by

$$
Q_t S_{gt} + q_t B_{gt} = D_{gt}.
$$

When limits to arbitrage in the private market are operative, the central bank's acquisition of securities will have the effect of bidding up the prices on each of these instruments and down the excess returns.

2.2.4 Aggregation

Let S_{pt} be the total quantity of loans that banks intermediate, B_{pt} the total number of government bonds they hold, and N_t their total net worth. Since neither component of the maximum adjusted leverage ratio depends on bank-specific factors, we can simply sum across the portfolio restriction on each individual bank to obtain

$$
Q_t S_{pt} \leq \phi_t N_t - \triangle q_t^n B_{pt}
$$

Total net worth evolves as the sum of the retained earnings by the fraction θ of surviving bankers and the transfers that new bankers receive, X, as follows:

$$N_t = \theta[(R_{kt} - R_{t-1})\frac{Q_{t-1}S_{pt-1}}{N_{t-1}} + (R_{bt} - R_{t-1})\frac{q^n_{t-1}B_{pt-1}}{N_{t-1}} + R_{t-1}]N_{t-1} + X_t$$

Let S_t and B_t be the total supplies of private loans and long-term government bonds, respectively. Then by definition,

$$\begin{aligned} S_t &= S_{pt} + S_{ht} + S_{gt} \\ B_t &= B_{pt} + B_{ht} + B_{gt} \end{aligned}$$

We combine these identities with the balance constraint on the banks to obtain the following relation for the total value of private securities intermediated:

$$Q_t(S_t - S_{ht} - S_{gt}) \leq \phi_t N_t - \triangle q^n_t[B_t - (B_{gt} + B_{ht})] \tag{2.7}$$

2.2.5 The Production Sector

Intermediate goods firms

The economy also contains a continuum of infintely-lived monopolistically competitive firms, each producing a single differentiated good. Each operates a constant returns to scale technology with capital and labor inputs and have identical Cobb-Douglas production functions:

$$Y_t = A_t(\xi_t K_{t-1})^{\alpha} l_t^{1-\alpha}$$

where ξ_t is a random disturbance that we refer to as a “capital quality” shock. The capital quality shock as a simple way to introduce an exogenous source of variation in the return to capital. It is best thought of as capturing some form of economic obsolescence, as opposed to physical depreciation.

To finance the new capital, the firm must obtain funding from a bank. Then by arbitrage, the value of the security is equal to the market price of the capital underlying security: $Q_t K_t = Q_t S_t$.

Let P_{mt} be the real marginal cost. Then the firm's demand for labor and capital is given by

$$\begin{aligned} W_t &= P_{mt}(s)(1-\alpha)\frac{Y_t}{l_t} \\ Z_t &= P_{mt}(s)\alpha\frac{Y_t}{\xi_t K_{t-1}} \end{aligned}$$

Then the real rate of return to the bank on the loan R_{kt} is given by

$$R_{kt} = \frac{Z_t + (1-\delta)Q_t}{Q_{t-1}}\xi_t$$

The capital accumulation equation is:

$$K_t = \xi_t K_{t-1}(1-\delta) + I_t$$

Capital goods producers

Capital producers make new capital using input of final output and subject to adjustment costs. They sell the new capital to firms at the price Q_t. Given that households own capital producers, the objective function of a capital producer is

$$\mathrm{E}_t \sum_{j=0}^{\infty} \Lambda_{t,t+j}\{Q_{t+j}I_{t+j} - [1+f(\frac{I_{t+j}}{I_{t+j-1}})]I_{t+j}\}$$

Final goods firms

The output of each firm s is purchased by a perfectly competitive final goods sector, which aggregates the differentiated goods into a single final good using a CES production technology:

$$Y_t = [\int_0^1 Y_t(s)^{\frac{\varepsilon-1}{\varepsilon}} ds]^{\frac{\varepsilon}{\varepsilon-1}}$$

where Y_t denotes the quantity of the final good. Each intermediate firm s thus faces a downward-sloping demand curve for its product with elasticity $1/(\varepsilon-1)$. Then

$$Y_t(s) = (\frac{p_t(s)}{P_t})^{-\varepsilon/(\varepsilon-1)} Y_t$$

where P_t is the CES aggregate price of the final good:

$$P_t = [\int_0^1 p_t(s)^{1/1-\varepsilon} ds]^{1-\varepsilon}$$

Firms set prices optimally subject to nominal rigidities in the form of Calvo (1983) price contracts, which expire with probability $1-\gamma$ each period. Each time a Calvo contract expires, the firm sets a new contract price freely, which then remains in effect for the life of the new contract. When a firm's price contract expires, the firm s chooses the new contract price $p_t^*(s)$ to maximize the value to shareholders of the firm's cash flows over the lifetime of the contract. In between these periods, the firm is able to partially index its price to the steady state rate of inflation. The objective function is:

$$\mathrm{E}_t \sum_{j=0}^{\infty} (1-\gamma)\gamma^j \Lambda_{t,t+j} [\frac{p_t^*(s)}{P_{t+j}} (1+\bar{\pi})^{j\gamma_p} - \frac{\varepsilon}{\varepsilon-1} P_{mt+j}(s)] Y_{t+j}(s)$$

The evolution of the price level is:

$$P_t = [(1-\gamma)(P_t^*)^{1-\varepsilon} + \gamma(\bar{\pi}^{\gamma_p} P_{t-1})^{1-\varepsilon}]^{1/(1-\varepsilon)}$$

2.2.6 Monetary Policy

This section describes the monetary policy by the central bank. There are two types of policies: the forward guidance and the asset purchases.

The central bank sets the one-period nominal interest rate i_t according to the following policy rule,

$$
\begin{aligned}
i_t^* &= r + \bar{\pi} + \kappa_\pi(\pi_t - \bar{\pi}) + \kappa_y(\log Y_t - \log Y_t^*) + z_t \\
i_t &= \max\{\underline{\imath}, i_t^*\}
\end{aligned}
$$

where $\underline{\imath}$ is the lower bound on the one-period nominal interest rate, i_t^* is the rate the central bank would set if it was unconstrained, $r = -\log\beta$ denotes the steady-state one-period real interest rate, Y_t^* is the natural (flexible-price equilibrium) level of output. For simplicity, minus the price markup is used as a proxy for the output gap. Based on the previous work of Laséen and Svensson (2011), Del Negro et al. (2015) and Keen et al. (2016), which use a combination of current and anticipated monetary policy shocks to model forward guidance shocks[8], I model z_t, the monetary policy deviation at time t as

$$
z_t = \varepsilon_{t,t}^m + \sum_{j=1}^{T} a_j \varepsilon_{t,t-j}^m \tag{2.8}
$$

for a give $T \geq 0$, where $\varepsilon^{m,t} \equiv (\varepsilon_{t,t}^m, \varepsilon_{t+1,t}^m, \ldots, \varepsilon_{t+T,t}^m)'$ is a zero-mean i.i.d. random $(T+1)$-vector realized in the beginning of period t and called the innovation in period t. $\varepsilon^{m,t}$ can be interpreted as the new information the central bank announces in the beginning of period t about current and future periods.[9] a_j governs the size of each shock.

In order to determine the magnitude of a_j, where $j > 0$, I follow the specification in

[8]Best and Kapinos (2016) studies how monetary policy should be conducted in the presence of anticipated shocks.

[9] It follows that the dynamics of the deviation and the projection $z^t = (z_t, z_{t+1,t}, \ldots, z_{t+T,t})'$ can be written

$$
z^{t+1} = A_z z^t + \varepsilon^{m,t+1}
$$

Bundick and Smith (2016). They assume that the series of the size is an exponential decay process. In this case equation (2.8) could be rewritten as,

$$z_{t,t} = \varepsilon^{m}_{t,t} + \sum_{j=1}^{T} \rho_z^j \varepsilon^{m}_{t,t-j}.$$

In addition to the interest rate monetary policy, the central bank could conduct monetary policy through direct purchases of government bonds. During the crisis, the central bank purchases a fraction φ_{bt} of the outstanding stock of long-term government bonds:

$$B_{gt} = \varphi_{bt} B_t$$

Following Gertler and Karadi (2013), φ_{bt} obeys second-order stationary stochastic processes to capture the cumulative buildup of asset purchases program.

$$\varphi_{bt} = \rho_{0b} + \rho_{1b}\varphi_{bt-1} + \rho_{2b}\varphi_{bt-2} + \varepsilon_t^b \tag{2.9}$$

The reason why the central bank's credit policy works is as follows. When the bank faces balance constraint shown in equation (2.7), given the total quantity of bank equity, an increase in the central bank's holding of long-term government bonds will increase the total demand for private securities. Since asset supplies are relatively inelastic in the short run, the enhanced asset demand pushes up the real price of capital Q_t and pushes down the excess return on capital. Furthermore, the presence of inelastic household security demands will strengthen the effects.

---

where the $(T+1)\times(T+1)$ matrix A_z is defined as

$$A_z \equiv \begin{bmatrix} 0_{T\times 1} & I_T \\ 0 & 0_{1\times T} \end{bmatrix}.$$

2.2.7 Government, Resource Constraint and Equilibrium

Let G_t be the government spending at time t, and G_{ss} be the steady state level of government spending. The government budget constraint is

$$G_t + (R_{bt} - 1)B_t = T_t + (R_{kt} - R_{t-1})Q_{t-1}S_{gt-1} + (R_{bt} - R_{t-1})q^n_{t-1}B_{gt-1}$$

Equilibrium in the final goods market requires

$$Y_t = C_t + [1 + f(\frac{I_t}{I_{t-1}})]I_t + G_t$$

Market clearing in markets for private securities, long-term government bonds and labor. The supply of private securities at the end of period t is given by the sum of newly acquired capital I_t and leftover capital from last period:

$$S_t = I_t + (1-\delta)K_{t-1}$$

The supply of long-term government bonds is fixed by the government: $B_t = \bar{B}$. This completes the description of the model.

2.3 Calibration and Simulation of the Structural Model

2.3.1 Calibration

Table 2.1 lists the choice of parameter values for the model.

I begin with the parameters that have the same value as in Gertler and Karadi (2013). These are shown in Panel (A). I assign a quarterly value of 0.995, which implies short-term real interest rate of 2%.The depreciation rate of capital δ is set to be 0.025, and the capital share α is 0.33. The price rigidity parameter γ is 0.779, which implies firms resetting prices approximately every 13.6 months on average. The degree of price indexation γ_p is assumed to be zero. The steady-state leverage ratio is 4 as in their 2011 paper (6 in their 2013 paper). The steady state government expenditure share G_{ss}/Y is 0.2, and the steady state labor is 1/3. $\phi_y = -0.125$ for the Taylor rule coefficient on output gap. I set $\bar{K}_h$ so that in steady state, households hold half the quantity of private securities, and $\bar{B}_h$ so that households hold three-quarters of the outstanding stock of long-term government debt. $\bar{B}$ is set such as the ratio of the stock of long-term government bond to output in steady state is equal to its pre-crisis value of approximately 0.45. The AR(2) coefficients for the LSAP shock are 1.5 and -0.55.

However, some of the other parameters used by GK imply properties of the yield curve and the relation between bond and stock yields that are inconsistent with the observed data. Since interpreting the response of the yield curve to shocks is the focus of the present exercise, I have made a number of changes so that the predictions of the model better match the properties observed in financial data.

Panel (B) shows the parameters that are closely related to yield curve properties. GK assume an inflation target $\bar{\pi} = 0$. To match the average values of the nominal interest rate in the pre-ZLB data from Gürkaynak et al. (2007) dataset, I set $\bar{\pi} = 0.006$, corresponding to an annual inflation target of 2.4%. Thus the steady state value of nominal interest rate is 4.4%. GK assume a lower bound of 0 in their original calibration. But the short end of the yield curve was never literally zero, with excess reserves earning 0.25% interest from the Fed throughout this period. For this reason, I set $\underline{\iota} = 0.25\%$.

The other parameters in Panel (B) matter for the steady state bond excess return and equity excess return. GK set the steady state real excess return on long-term government bonds to be 50 basis points and real excess return on private securities 100 basis points. Since there is no observed series for the real interest rate on an overnight government bond, I use the 2-year inflation-indexed Treasuries (TIPS) yield instead. Taken from the updated Gürkaynak et al. (2010) online dataset, from 2004 to 2007 the average difference between a 10-year TIPS and a 2-year TIPS is 69 basis points[10], which is much larger than GK's implied spread of 33 basis

[10] I use the 2004-2007 period to avoid both the low liquidity of TIPS in its first few years and the financial crisis

points. By contrast, my parameters imply a predicted spread that is exactly equal to 69 basis points. For the private securities, I follow GK to use the information on pre-2008 spreads between mortgage rates and 10-year Treasury yield and between BAA corporate and 10-year Treasury yield. Using data from the St. Louis Federal Reserve Economic Database (FRED), I find that on average the former is 163 basis points and the latter is 353 basis points from January 1990 to November 2008.[11] Therefore, I set the steady state excess return on private securities to be 172 basis points, higher than the 100 basis points in GK.

The expected horizon for bankers, the steady-state leverage ratio, together with the two excess return values mentioned above, pin down the θ, λ, Δ, and X, where the parameter λ is the percent of funds that a bank can divert to his household. Since I have adjusted the excess return values, I need to adjust the other targets to make the implied λ still realistic. Therefore, I choose an expected horizon of 5.7 years instead of 8.77 years for bankers. As a result, the implied value for λ becomes 38.4%, close to the 38.1% in their 2011 paper and 34.5% in their 2013 paper.

The remaining part of Panel (B) is the household portfolio adjustment cost parameters κ_s and κ_b. These parameters are chosen to make the predicted effects of LSAP on medium-term bond yields more consistent with the data in the crisis. Since I have made the above changes, I also have to make adjustment for those parameters.

Panel (C) presents other parameters used by GK that differ substantially from previous studies and turn out to raise the possibility of some odd dynamics of the model. I have found that the model is much more realistic when more conventional values are used for these parameters. I set the habit parameter $h = 0.615$, close to the estimated value in Christiano et al. (2005), instead of 0.815 in Gertler and Karadi (2013). GK assume a value for $1/\phi$, the Frisch labor supply elasticity, equal to 3.6. I instead set $1/\phi = 2$. GK assume an elasticity of substitution ε between goods of 4.167, implying a steady-state markup of 31.58%. My exercise sets $\varepsilon = 6$, implying a

and recession. Over this sample, real yields average between about 1.4% and 2.1%.

[11]Another way is look at the relative size of the two excess returns. The average ratio of the spread between 10-year Treasury yield and federal funds rate over the spread between BAA and federal funds rate is 0.29 while over the spread between 30-year mortgage rate and federal funds rate is 0.87. My calibration implies 0.6.

more realistic markup of 20%. GK assume an inverse elasticity of investment with respect to the price of capital, η_i, of 1.728. I instead use $\eta_i = 4.5$, close to the prior mean of the DSGE model estimated by Del Negro and Schorfheide (2008). The coefficient for the Taylor rule ϕ_π is taken from Coibion et al. (2012).

Finally, there is one parameter that is new to our model, ρ_z, which governs the decaying behavior of the forward guidance shock. In the crisis experiment below, we've chosen ρ_z equal to 0.65 to match the evidence on the impact of forward guidance on the term structure. In Section 2.7, I discuss the effects of forward guidance persistence.

2.3.2 Solution Method

I solve the model using the OccBin toolkit developed by Guerrieri and Iacoviello (2015). The solution method constructs a piecewise linear approximation to the original nonlinear model. It allows us to model the occasionally-binding zero lower bound and solve for the short-term and long-term yields.

2.3.3 Crisis Experiment

I now explore how the unconventional monetary policy works in the context of a financial crisis as described in Gertler and Karadi (2011, 2013). The initiating shock for the crisis is a decline in capital quality. It forces the asset prices to decline and the excess return of capital to rise, which depresses real activity and in turn amplifies the downturn. Further, the drops of output and inflation are sufficiently sharp to push the economy to the point where the nominal interest rate hits the zero lower bound.

I suppose that the shock obeys a first-order autoregressive process with coefficient 0.88. I consider three scenarios:

(i) capital quality shock without central bank response,

(ii) capital quality shock with forward guidance,

(iii) capital quality shock with LSAP.

As discussed in Keen et al. (2016) and Bundick and Smith (2016), initial state of the economy matters for the performance of unconventional monetary policy. Swanson and Williams (2014) have examined the number of quarters until the private sector expected the funds rate to be 25 bp or higher using the the median "consensus" response to the monthly Blue Chip survey of professional forecasters. Their findings show that Blue Chip consensus expectation of the length of time fluctuated between two and five quarters before August 2011, and private-sector expectations of the time until lift-off jumped to seven or more quarters after that. In addition, most of the literature has specified the length of the zero lower bound period to be between 1 and 7 quarters. In the baseline result presented here, the initial shock will have the nominal shadow rate will fall to negative 121 basis points with the a total zero lower bound episode of 4 quarters. In Section 2.7, I show the identification is robust to shallower (60 basis points) and deeper (180 basis points) initial shadow rates.

Figure 2.2 plots the the responses of capital quality, short-term nominal interest rate, output, inflation, the excess return of capital as well as the 10-year Treasury yield in the model to a negative capital quality shock. The solid red lines are the impulse responses not considering the zero lower bound; in contrast, the blue-dash lines with the zero lower bound constraint. The initial decrease of capital quality drives up the real excess return of capital. The process is amplified as the asset fire sale and decline in real activity further weaken bank's balance sheets. As Figure 2.2 shows, the existence of zero lower bound will make the recession more severe. The real output drops about 3 percent at the peak, and the annual inflation rate drops 2 percentage points in the initial.

The forward guidance horizon T is set to last 7 quarters. On one hand, the horizon must be larger than the ZLB episode to allow the monetary policy to provide stimulus. On the other hand, a promise to hold the interest rate down for at a date T arbitrarily distant in the future has a surprisingly large effect in models like this one. Among other practical issues, it's not clear how the FOMC can commit future Fed chairs to a particular policy.[12] In the Section 2.7, I show the final results are robust whether we have shorter (6 quarters) or longer (8 quarters) forward guidance horizon.

I define that one unit of forward guidance shock will lower the nominal shadow rate by 25 basis points on impact. With parameter calibration in Section 2.3, this requires to set each element of $\varepsilon^{m,t} \equiv (\varepsilon^m_{t,t}, \varepsilon^m_{t+1,t}, \ldots, \varepsilon^m_{t+T,t})'$ to be -0.11%. I define that one unit of LSAP shock will lower the 10-year yield by 5 basis points. It requires to set ε^b_t in equation 2.9 to be 7%.

Figure 2.3 plots how much difference the unconventional monetary policy made to the response of the yield curve in addition to the negative capital quality shock. One unit easing forward guidance shock will decrease the annualized shadow short-term nominal interest rate by 25 basis points, the current output by 0.02 percent, and the current annualized inflation rate by 0.08 percentage points. One unit easing LSAP shock will raise the shadow short-term nominal interest rate by 44 basis points, the current output by 0.1 percent, and the current annualized inflation rate by 0.18 percentage points.

2.4 Yield Curve Interpolation

Because we cannot directly observe the daily change in ex-ante shadow rate in the data, we use a flexible approximation to the shape of the model implied yield curve and compare it with the data. One can think this is the bridge linking the model in Section 2.3 and the empirical analysis in Section 2.5.

2.4.1 Yield curve interpolation when away from the ZLB

First I consider the case when the economy is far away from the ZLB, so that $i^*_t = i_t$ (the shadow rate equals the observed one-period rate). Suppose there are two possibly unobserved factors, (ξ_{1t}, ξ_{2t}) that summarize everything that matters for determining interest rates. Their

[12] McKay et al. (2015) suggest refinements to make models of long-term forward guidance more realistic. Here I simply limit the potential reach of forward guidance to 7 quarters.

Q-measure dynamics are characterized by

$$\xi_{1t} = \phi_1 \xi_{1t-1} + \varepsilon_{1t}$$
$$\xi_{2t} = \phi_2 \xi_{2t-1} + \varepsilon_{2t}$$

The one-period nominal interest rate i_t is given by

$$i_t = \xi_{1t} + \xi_{2t} \tag{2.10}$$

Then the nominal forward rate at date t at horizon n is

$$f_{nt} = E_t^Q(i_{t+n}) = \phi_1^n \xi_{1t} + \phi_2^n \xi_{2t} \tag{2.11}$$

The yield at date t with maturity n is

$$i_{nt} = n^{-1} \sum_{j=0}^{n-1} f_{jt}$$

When $\phi_1 = 1$ and $|\phi_2| < 1$, this framework implies the Dynamic Nelson-Siegel model:

$$i_{nt} = \xi_{1t} + n^{-1} \frac{1-\phi_2^n}{1-\phi_2} \xi_{2t} \tag{2.12}$$

Equations (2.10) and (2.12) allow us to recover the two factors directly off the level of one-period rate i_t and the long-term rate, i_{Nt}:

$$\xi_{2t} = (N^{-1} \frac{1-\phi_2^N}{1-\phi_2} - 1)^{-1} (i_{Nt} - i_t)$$
$$\xi_{1t} = i_t - \xi_{2t}$$

Moreover, once ξ_{1t} and ξ_{2t} are known, I can interpolate the entire yield curve using equation 2.12.

2.4.2 Yield curve interpolation at the lower bound

Next we consider the case $i_t^* = \xi_{1t} + \xi_{2t} < \underline{\imath}$, $i_t = \underline{\imath}$. Wu and Xia (2016) demonstrate that in equilibrium, the forward rates f_{nt} can be approximated as

$$f_{nt}^* = \xi_{1t} + \phi_2^n \xi_{2t}$$
$$f_{nt} = \underline{\imath} + \sigma_n g\left(\frac{f_{nt}^* - \underline{\imath}}{\sigma_n}\right)$$

where $g(z) = z\Phi(z) + \phi(z)$ for $\Phi(z)$ the cumulative distribution function for a standard Normal variable and $\phi(z)$ the density, and σ_n is a parameter.

I have

$$i_{nt} = n^{-1} \sum_{j=0}^{n-1} f_{jt},$$

which along with $i_t^* = \xi_{1t} + \xi_{2t}$ give two equations in two unknowns to determine (ξ_{1t}, ξ_{2t}) from the model-implied interest rates (i_t^*, i_{Nt}).

2.4.3 Calibration for the yield curve interpolation

I need to choose the parameter values for ϕ_2, $\imath$ and σ_n. I calculate ϕ_2 using average yield curve shape in the pre-ZLB period. The yield data is from Gürkaynak et al. (2007)'s online dataset. The first row of Table 2.2 reports average yields from January 1990 to November 2007, a span that excludes the Great Inflation as well as the Great Recession periods which I refer as pre-ZLB period. Over this sample, the average nominal 1-year Treasury yields is about 4.57 percent, and the average nominal 10-year Treasury yields is about 6 percent. I choose (ξ_1, ξ_2, ϕ_2) such as the fitted yield curve best matched the average yield curve. It turns out that $\xi_1 = 7$, $\xi_2 = -2.77$, $\phi_2 = 0.979$.

I use the same ϕ_2 along with the model steady state values of the one-period and long term rates, i_{ss} and i_{Nss}, to construct the yield curve implied by the model steady state. It turns out that $\xi_1 = 6.23$, $\xi_2 = -1.62$ give the best fit. The second row of Table 2.2 reports the nominal yield curves implied by the model. The model is able to reproduce these features of the data quite well: the average level of nominal yields in the model between about 5.4 and 6.4 percent, with an upward slope of 109 bp.

I calibrate σ_n by following Krippner (2016),

$$\sigma_n = \sqrt{\rho_1^2 n + \rho_2^2 G(2\phi_3, n) + 2\rho_{12}\rho_1\rho_2 G(\phi_3, n)}$$

where ρ_1, ρ_2, ρ_{12} and ϕ_3 are parameters estimated from an arbitrage-free Nelson and Siegel (1987) model with two state-variables (level and slope), and $G(\phi_3, n) = \frac{1}{\phi_3}[1 - \exp(-\phi_3 n)]$. ρ_1, ρ_2, ρ_{12} and ϕ_3 are estimated to be equal to 0.0111, 0.0142, -0.7390 and 0.2498 using 6 months, 1, 2, 5, 7, and 10 years monthly Treasury yield data from January 2009 to November 2015.

Next, I compute the implied yield curve during the ZLB period using the impulse responses of interest rates derived from the structural model. Panel B of Table 2.2 compares the yield data during the ZLB period with the interpolated data. Between November 2008 and November 2015, the average nominal 1-year Treasury yields was about 0.27 percentage points, and the average nominal 10-year Treasury yields was about 2.80 percentage points. Although the simulated model cannot capture the dramatic drop of the 10-year Treasury bond yield, it improves upon GK's specification.

Figure 2.4 shows the paper's key identification. It illustrates the difference between the yield curves in scenarios (i) and (ii) and the difference between (i) and (iii). As shown in the figure, one unit of easing forward guidance lowers Treasury yields at all maturities, with a peak effect at a maturity of about 20 months. In contrast, one unit easing LSAP will increase the shortest-maturity Treasury yields because of the feedback of the interest rate rule but will lower medium-term and long-term yields, with the peak effect on the longest maturities. I use $\triangle i_n^{fg}$, where n =2,3,...,10 to represent the effects of one unit of forward guidance on the various interest rates, and $\triangle i_n^{fg}$, where n =2,3,...,10 to represent the effects of one unit of asset purchases on the various interest rates.

2.5 Decomposition of the Federal Reserve's announcement

In this section, I decompose the responses of various interest rates according to the driven forces and look at the sizes and effects of forward guidance and LSAP over time.

2.5.1 Information and monetary policy components of the announcement

Following studies on high-frequency identification, I assume that the movements of Treasury yields on various horizons in a daily window that brackets the Fed's announcement days are responses to the Fed's announcements only. That assumption exploits the fact that a lumpy amount of monetary policy news is released during a short period. The Fed could surprise the markets (i) by announcing a monetary policy path deviating from the private sector's previous expectations, (ii) by announcing an asset purchase program that also deviates from the private sector's previous expectations, or (iii) by shaping the private sector's beliefs about economic conditions. I refer to (i) as forward guidance and (ii) as LSAP, both of which are exogenous monetary policy deviations, whereas I refer to (iii) as the effects of information. In recent literature on the topic, Campbell et al. (2012) and Nakamura and Steinsson (2018) have provided extensive evidence of the information effects.

The focus of this paper is on the first two effects. In the rest of this section, I provide estimates of how the effects of information influence financial markets but leave the analysis of those effects on the macroeconomy to future studies[13].

To disentangle the Federal Reserve's information effect, I follow Zhang (2018) and perform a regression of the observed changes of yields at each maturity on Green Book forecasts

[13]To study the information effects on the macro variables, one may need a model with the following features, (i) the central bank has superior information about the fundamentals, (ii) private sectors update their belief after the banks' announcement, and (iii) there are various interest rates or stock prices in the model thus they respond to the Fed's information differently from other policy shocks.

and use the residuals to represent the monetary policy component of the Fed's announcement. In particular, I estimate the following equation for each yield at maturity n:

$$\begin{aligned}\triangle i_{nt} = \beta_{n0}\triangle i_{nt-1} + \beta_{ni} i_{nt\text{-}} + \sum_{j=-1}^{s} \beta_{nj}^{\triangle INFL} \triangle INFL_{t,q+j}^{GB} + \sum_{j=-1}^{s} \beta_{nj}^{\triangle RealGDP} \triangle RealGDP_{t,q+j}^{GB} \\ + \sum_{j=-1}^{s} \beta_{nj}^{INFL} INFL_{d,q+j}^{GB} + \sum_{j=-1}^{s} \beta_{nj}^{RealGDP} RealGDP_{t,q+j}^{GB} + \sum_{j=-1}^{s} \beta_{nj}^{UNEMP} UNEMP_{t,q+j}^{GB} \\ + constant + \varepsilon_{nt}, \quad \text{for all t} \qquad (2.13)\end{aligned}$$

where t indexes the event day, $\triangle i_{nt}$ is the observed daily change of interest rate of maturity n at event date t; and i_{nt-} is the level of the interest rate before any changes associated with the announcement, which is included to capture any tendency toward mean reversion in Fed's behavior. Let q be the quarter when the announcement day t takes place. $INFL_{t,q+j}^{GB}$ denotes Greenbook forecasts for inflation for quarter $q+j$ made at event day t, j=-1,0,1, 2. $RealGDP_{t,q+j}^{GB}$ denotes Greenbook forecasts for real GDP for quarter $q+j$ made at event date m. $\triangle INFL_{t,q+j}^{GB}$ and $\triangle RealGDP_{m,q+j}^{GB}$ is the revised forecast for inflation and real GDP growth rate between two consecutive events, respectively. In computing the forecast innovations, the forecast horizons for event t and $t-1$ are adjusted so that the forecasts refer to the same quarter. The data period for the regression is from 1990:2m to 2013:12m.

I use the fitted value of the each regression, $\triangle i_{nt}^{info}$, to approximate the change caused by the Fed's superior information and use the residuals of each regression, $\triangle i_{nt}^{mp}$, as the monetary policy component.

2.5.2 Decomposition of monetary policy component into forward guidance and LSAP

Next I will decompose the monetary policy component, $\triangle i_{nt}^{mp}$, into forward guidance component and LSAP component. Figure 2.4 is used for identification. In the figure, the blue dashed line plots how one unit of easing forward guidance shock will immediately change the yields at various maturities. And the red solid line plots the effects of one unit of easing LSAP shock. I collect the values of $\triangle i_n^{fg}$ and $\triangle i_n^{lsap}$, where n =2,3,...,10 and use them as the explanatory variables in a regression of the following form to estimate how many units of forward guidance and LSAP for each event date t:

$$\triangle i_{nt}^{mp} = \beta_t^{fg} \times \triangle i_n^{fg} + \beta_t^{lsap} \times \triangle i_n^{lsap} + \varepsilon_{nt}, \text{for } n = 2, 3, \cdots, 10 \tag{2.14}$$

There are 9 observations in the regression. There is a separate regression for each of the event day t from 2008:11m to 2013:12m. The parameters of interests in the regression equation are β_t^{fg} and β_t^{lsap}, which represent the size of forward guidance and LSAP on event date t, respectively.

2.5.3 Data

For the event days, I obtain FOMC meeting dates between February 1990 and December 2004 from the appendix in Gürkaynak et al. (2005)[14] and all remaining scheduled FOMC meetings from the Federal Reserve Board's website. By following the literature, I also add some days during the ZLB period when the chairperson of the Fed's delivered important speeches. In particular, there were 63 event days from November 2008 to December 2015.

For the Green Book data, I download them on the Philadelphia Fed website[15]. The original Green Book can also be accessed on the website of the Board of Governors. Because Green Book data are released approximately five years later than the meeting day, the latest data that I can access represent December 2013.

[14]As stated in their paper, prior to 1994, the FOMC did not explicitly announce changes in its target for the federal funds rate, but such changes were implicitly communicated to financial markets through the size and type of open market operation. Therefore, they define a monetary policy announcement date to be the one of the next open market operation following the FOMC decision.

[15]https://www.philadelphiafed.org/research-and-data/real-time-center/greenbook-data/philadelphia-data-set. This data set will be updated annually, usually in April.

2.5.4 Estimated size of forward guidance and LSAP

Figure 2.1 plots the estimates for β_t^{fg} and β_t^{lsap} between November 2008 and December 2013. The vertical axis charts the size of shocks. As described in section 2.3.3, I have defined a one-unit forward guidance shock to lower the nominal shadow rate by 25 basis points on impact. I define a one-unit LSAP shock to lower the 10-year yield by 5 basis points on impact. Several notable announcements, which I discuss in Section 2.6, are labeled in the figure for reference. Unsurprisingly, forward guidance and LSAP policies announced on the same day always work in the same direction - that is, by either tightening or easing the market. Among all event dates, the QE I announcements have the greatest effects.

2.5.5 Estimated contribution of forward guidance and LSAP to the interest rates

Column 1 in Table 2.3 lists the announcement dates, whereas Columns 2 to 6 list results of interest rate decomposition.

Figure 2.5 plots the observed interest rate change $\triangle i_{nt}$, information part $\triangle i_{nt}^{info}$ and the monetary policy part $\triangle i_{nt}^{mp}$ from 1990:2m to 2013:12m.

Figure 2.6 plots $\beta_t^{fg} \times \triangle i_n^{fg}$ and $\beta_t^{lsap} \times \triangle i_n^{lsap}$, contribution by forward guidance and asset purchases respectively.

2.5.6 Estimated contribution of forward guidance and LSAP to the real activities

Assessing the financial market effects of asset purchases is the first step in gauging the effectiveness of unconventional monetary policy actions. The next goal of this paper is to look at to what extent monetary policy has fostered economic growth and inflation stability.

Given β_t^{fg} and β_t^{lsap}, I simulate the model described in Section 2.2 and obtain the impulse responses of macroeconomic variables to β_t^{fg} units of forward guidance shock and β_{2t}^{lsap} units of LSAP shock, separately. The high-frequency yield data is used to figure out the sizes of each type of shocks while the structural model is to show the persistence of the monetary policy shocks on aggregate economy.

The last 4 columns of Table 2.3 give the effects on GDP and inflation that the model predicts would occur two quarters after each shock. The change in GDP is measured by percent, and change in inflation is measured by annualized percentage points.

2.6 Unconventional Monetary Policy on Several Key FOMC Announcement Days

I follow the literature and group the announcement dates into the following six phases: QE I phase (November 2008 to March 2010), QE II phase (November 2010 to June 2011), "Operation Twist" phase (September 2011 to August 2012), QE III phase (September 2012 to May 2013), "Tapering" phase (June 2013 to October 2014), and Post QE phase (December 2014 to December 2015), respectively.[16] Although some of the phases' names are associated with QE, there is forward guidance policy component in those periods as well. Among all the event days, there are several key announcements widely discussed in the literature. The dates are grouped into different sections, and the cumulative effects over the certain phase are shown at the end of each section of Table 2.3 .

2.6.1 QE I phase (November 2008 to March 2010)

The "QE I" program began on November 25, 2008, when the Federal Reserve Board announced it would purchase \$600 billion of mortgage-backed securities and \$100 billion of debt issued by the mortgage-related government-sponsored enterprises. In Figure 2.7, I plot the decomposition of yield curve changes into information and monetary policy components in the upper left panel. The upper right panel compares the non-info component with the fitted value from regression equation 2.14. We notice that the major movement of the interest rates, especially the median and the long-term ones, were driven by the information effects. Even

[16] The categorization of QE I, QE II, "Operation Twist" and QE III comes from Wu (2014).

though there's no explicit words about the forward guidance policy, I argue, as in Bauer and Rudebusch (2014), LSAP announcements may signal to market participants that the central bank has changed its views on current or future economic conditions, which leads investors to alter their expectations of the future path of the policy rate. According to the structural model, a LSAP policy will drive up the output and inflation in the near term, to which the interest rate rule would respond with higher short-term rates in the near future. Therefore, the Fed needs to communicate to the public that this is not its intention to raise the short-term rate in response to the higher inflation and output that LSAP is expected to generate. This argument justifies why we see the LSAP is always used together with forward guidance as shown in Figure 2.1. In particular, based on the way yield curve responded, I have identified that there are easing forward guidance as well as LSAP on November 25, 2008. The overall effect of the two types of policies is lowering the whole yield curve. The middle panels show the effects of forward guidance shock and LSAP on the yield curve. 90% confidence intervals are shown in both cases. The lower panels show the impulse responses of output and inflation for the current and next 8 quarters. As for GDP, LSAP plays an important role in lifting output growth path. Forward guidance has similar effect on current inflation compared to LASP, but LSAP is more effective afterwards.

On December 16, 2008, the FOMC decreased the target for the policy rate to a range from 0 to 1/4 percent and indicated that it expected the target to remain there "for some time". In addition, it also stated that the Fed will continue to consider ways of using its balance sheet to further support credit markets and economic activity. My identification of forward guidance and LSAP effects shown in Figure 2.8 lowers both short-term and long-term interest rate as a whole with long-term rate decreasing by more.

On January 28, 2009, the FOMC restated that the Fed will continue to consider ways of using its balance sheet to further support credit markets and economic activity. However, the FOMC statement was interpreted by some market participants as disappointing because of its lack of concrete language regarding the possibility and timing of purchases of longer-term Treasuries in the secondary market. There my identification procedure finds contractionary forward guidance and LSAP shocks as in Figure 2.9.

As shown in Table 2.3, the cumulative drop in 10-year Treasury yield in the seven key announcement dates in QE I phase was 80 basis points, 42 basis points contributed by information effects while 38 basis points by monetary policy component. Forward guidance explained 5 basis points and the LSAP 35 basis points. My estimates indicate that the QE I program increased the two-quarter hence real GDP by 1.11 percent, 0.39 percent from forward guidance and 0.72 percent from LSAP. Forward guidance raised the two-quarter hence inflation rate by 0.60 annualized percentage points, and LSAP has an effect of 0.21 annualized percentage points. Thus the total effects on inflation is 0.81 percentage points. I conclude that LSAP are more effective on output, while forward guidance is more effective on inflation in the short run.

2.6.2 QE II phase (November 2010 to June 2011)

It's also interesting that the FOMC's subsequent QE II program, launched on November 3, 2010, has very small easing forward guidance and LSAP components, which are not significant at 10% level. A possible reason in the literature (e.g. Krishnamurthy et al. (2011), Bauer and Rudebusch (2014)) is that expectations of QE II were incrementally formed before official confirmation. The event study on the single QE II official announcement day may underestimate the full effect of the program. Therefore, I also include some important pre-announcement QE II news. For example, on September 21, 2010, the FOMC was "prepared to provide additional accommodation if needed", which was viewed as a setup statement to another round of asset purchases. As shown in Figure 2.1, I estimate a forward guidance factor and a LSAP factor in easing direction on this day.

2.6.3 Mid-2013 phase (November 2010 to June 2011)

August 9, 2011 is another interesting date. This is the first announcement in which the FOMC gave explicit forward guidance about the likely path of the federal funds rate over the next several quarters. In that announcement, the FOMC stated that it expected the current level of the federal funds rate would be appropriate "at least through mid-2013". In Figure 2.10 I estimate that the forward guidance raises the two-quarter ahead output by 0.18 percent and the inflation by 0.54 annualized percentage points, and the LSAP raises the two-quarter ahead output by 0.27 percent and the inflation by 0.36 annualized percentage points.

2.6.4 "Operation Twist" (September 2011 to August 2012)

September 21, 2011 is one of the dates when our results are different from Swanson (2017). It corresponds to "Operation Twist". The FOMC announced to purchase $400 billion of Treasury securities of median-and long maturities and to sell an equal amount of short-term Treasury securities. This program "should put downward pressure on longer-term interest rates and help make broader financial conditions more accommodative." Swanson (2017)'s identification procedure for forward guidance vs. LSAP announcements attributes the effects of this announcement to a tightening forward guidance and an easing LSAP factor. It is surprising for the two types of unconventional monetary polices implied from the same announcement to have different directions. However, as can be seen in Figure 2.11, my identification estimates this announcement to have both LSAP and forward guidance components in the easing direction. The forward guidance on that day decreased the l0-year Treasury yield by 1 basis points, while the LSAP had an effect of 9 basis points.

2.6.5 QE III phase (September 2012 to May 2013)

The economy continued to disappoint policymakers and the Fed issued the statement on September 13, 2012 meeting promising to maintain a zero federal funds rate "at least through mid-2015". In addition, the Fed said it would continue to extend the average maturity of its holdings of securities and announced an open ended program purchasing additional agency mortgage-backed securities at a pace of $40 billion per month. This announcement put downward pressure on longer-term interest rates. The two-quarter hence real GDP was predicted to increase by 0.25 percent and the inflation by 0.22 annualized percentage points

On December 12, 2012, the FOMC again adjusted its forward guidance from the calendar-based language "at least through mid-2015" to forward guidance based on unemployment and expected inflation. The policy statement read: "...this exceptionally low range for the federal funds rate will be appropriate at least as long as the unemployment rate remains above 6-1/2 percent, inflation between one and two years ahead is projected to be no more than a half percentage point above the Committee's 2 percent longer-run goal". This resulted in some concerns of the investors that the central bank would have to start tightening policy earlier than the time they anticipated before.[17] Therefore, the medium-term and long-term yields increase.

2.6.6 Tapering (June 2013 to October 2014)

On June 19, 2013, there is little change in the FOMC statement on that date, but the FOMC released economic projections along with the statement that showed a substantial increase in the FOMC's economic outlook. Given earlier remarks by Chairman Ben Bernanke that the FOMC could begin tapering its asset purchases soon, markets interpreted this as a signal that a tapering was imminent. In addition, the FOMC statement says, "...14 of 19 FOMC participants indicated that they expect the first increase in the target for the federal funds rate to occur in 2015, and one expected the first increase to incur in 2016". Thus, this episode fits into the "taper tantrum" period, and I have identified a large tightening forward guidance factor and a medium size tightening LSAP factor. In Figure 2.12, I have estimated that the forward guidance would decrease the two-quarter ahead output by 0.26 percent and the inflation by 0.37 annualized percentage points, and the LSAP would decrease the two-quarter ahead output by 1.51 percent and the inflation by 1.53 annualized percentage points.

On September 18, 2013, the FOMC was widely expected to begin tapering its asset purchase while it turned out not to do so. As shown in Table 2.3, the surprise decision by the FOMC not to taper its asset purchases is correctly identified in my estimates: the easing LSAP shock together with easing forward guidance shock had a result of 17 basis points drop of the

[17] https://www.wsj.com/articles/SB10001424127887324481204578175112571119362

10-year yield. This in turn would raise the two-quarter ahead real GDP by 0.84 percent and the inflation by 0.73 annualized percentage points.

On December 18, 2013, the policy statement said that "... it likely will be appropriate to maintain the current target range for the federal funds rate well past the time that the unemployment rate declines below 6-1/2 percent, especially if projected inflation continues to run below the Committee's 2 percent longer-run goal." Evidence shows the labor market had improved and as a result, the FOMC decided to begin tapering their monthly asset purchases. The new language on unemployment was probably added to prevent the market from moving up the date in which they expect the federal funds rate to rise. Figure 2.13 show that the overall effect is contractionary.

2.7 Discussion

In this section, I first show that the information and monetary policy decomposition is crucial for the monetary policy evaluation. I then conduct several robustness checks and show that my specification is robust to alternative assumptions.

2.7.1 The importance of isolating the monetary policy component

I redo all the above analysis except that I use the total change in yield curve instead of the monetary policy component. The estimated effects are that the QE I program (November 2008 to March 2010) increased real GDP by 2.94 percent and inflation by 2.8 percentage points, which is three times as large as the one I estimated in the previous section.

2.7.2 Robustness check

The initial state

In the baseline model, the initial capital quality shock decreases the shadow rate to negative 121 bps to match the average shadow rate in the ZLB period. Keeping everything else the same, Figure 2.14 plots the variation of the difference in yield curves when the initial shock changes from negative 60 bps to negative 180 bps. A weaker economy skews the LSAP more effective.

The definition of one unit shock

In the baseline model, I define that one unit of forward guidance shock will lower the nominal shadow rate by 25 basis points and one unit of LSAP shock will lower the 10-year yield by 5 basis points. Now I illustrate how our estimate of the initial aggregate demand shock affects our main results. Figure 2.15 shows how the difference in yield curve varies when we define one unit LSAP shock to change 10-year yield by 3 bps or by 7 bps. Figure 2.16 plots the separate contribution of forward guidance and LSAP shocks. The main results change barely when we use different definition of one unit of shock.

The forward guidance persistence

The persistence of forward guidance shock is set to be 0.65 in the baseline model. Figure 2.17 shows how the difference in yield curve varies when the persistence of forward guidance shock increases from 0.6 to 0.7. Intuitively, a more persistent forward guidance shock is more effective on the 10-year interest rate.

The forward guidance horizon

The baseline model assumes forward guidance is effective for 7 quarters. Figure 2.18 shows how the difference in yield curve varies when the horizon is 6 quarters or 8 quarters.

2.8 Conclusion

In this paper, I show how to identify and estimate the forward guidance and large-scale asset purchase component of every FOMC announcement between 2008 and 2015. Building on earlier work by Gertler and Karadi (2013), the theoretical model shows that easing forward guidance announcement lowers Treasury yields at all maturities, with a peak effect at a maturity of about 20 months; in contrast, easing LSAP will increase the shortest-maturity Treasury yields because of the feedback of the interest rate rule and will lower medium-term and long-term yields, with the peak effect on the longest maturities.

I match the responses of the yield curve to a linear combination of the two shocks predicted by the model with the observed change in the yield curve in a high-frequency window around each Federal Reserve announcement. In this way, I estimate a time series for each type of unconventional monetary policy announcement and show that these series correspond closely to narrative elements of the FOMC announcements.

With the estimates of the shock series, I study the persistence of the monetary policy shocks on aggregate economy using the structural model. My approach circumvents the limitations of the standard event-study methodology. Among the key announcement dates in QE I program I find that forward guidance was more effective at inflation, while LSAP was more important in influencing output.

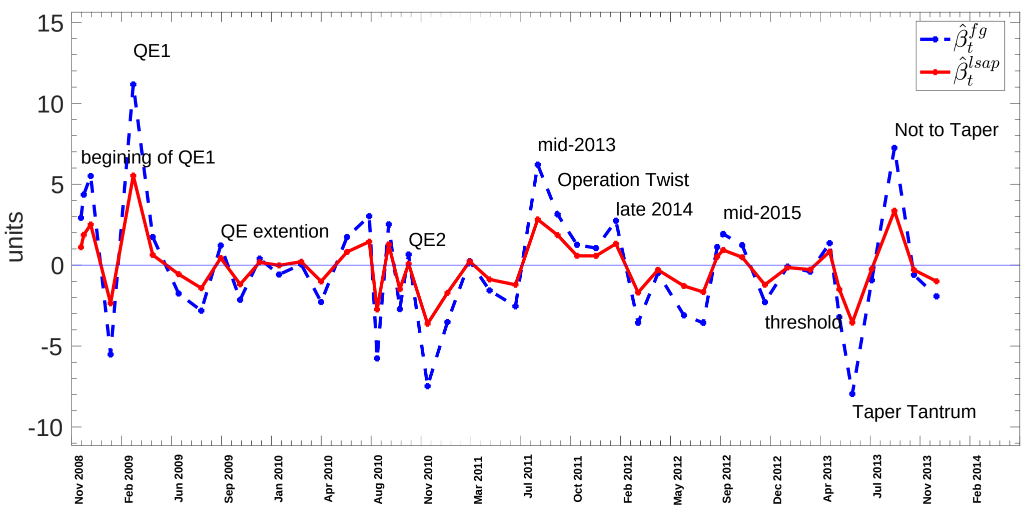

Figure 2.1. Estimated Size of Each Shock Type

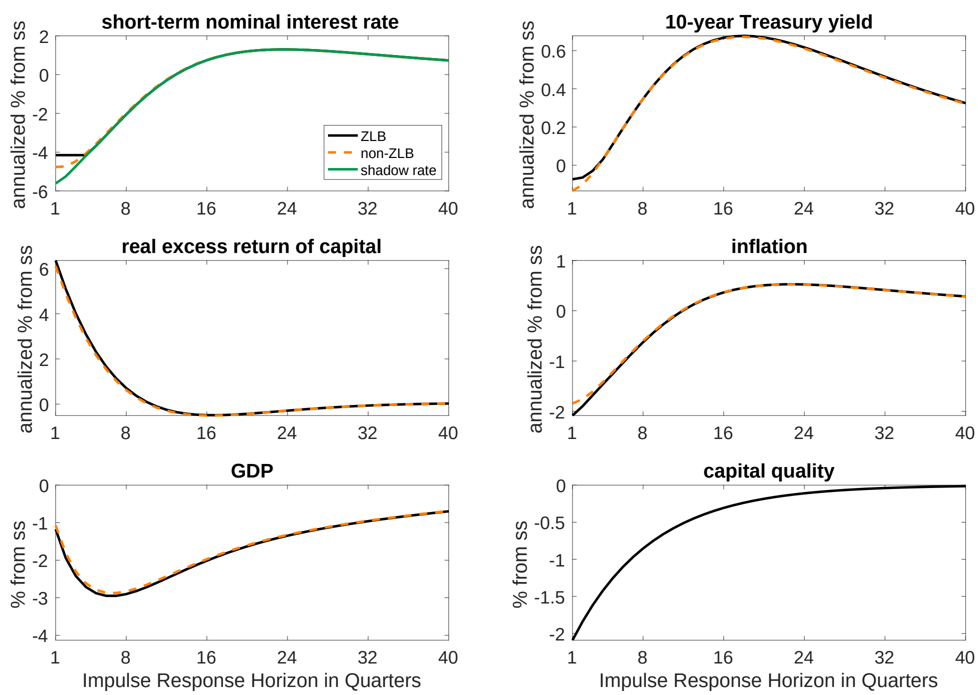

Figure 2.2. Crisis Experiment

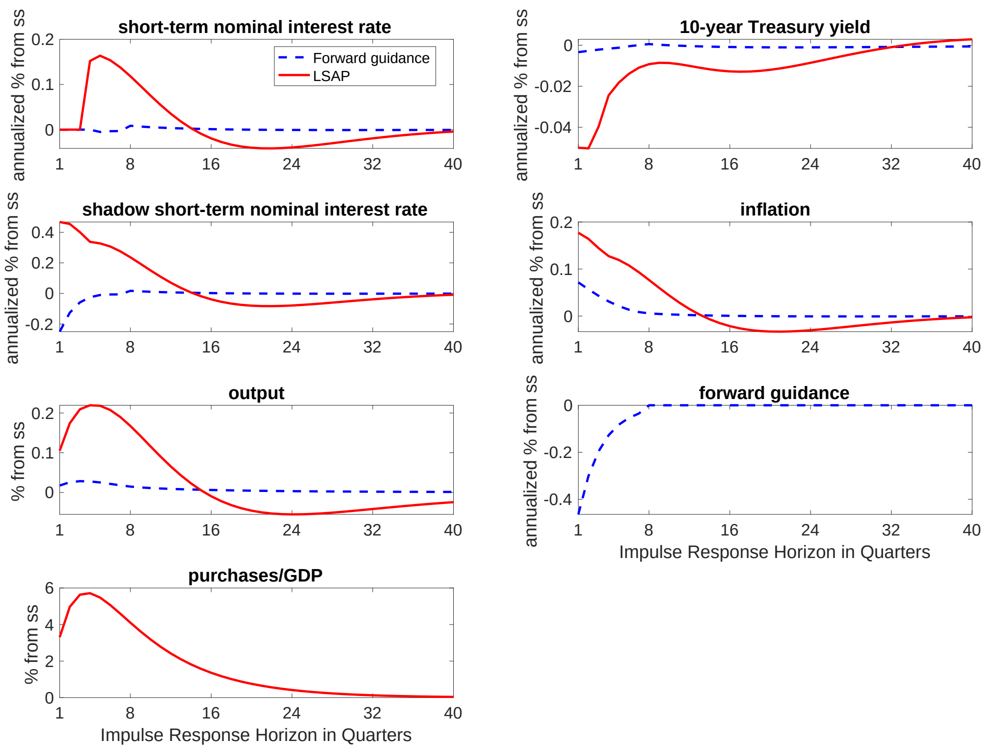

Figure 2.3. Effects of Forward Guidance and LSAP Shocks

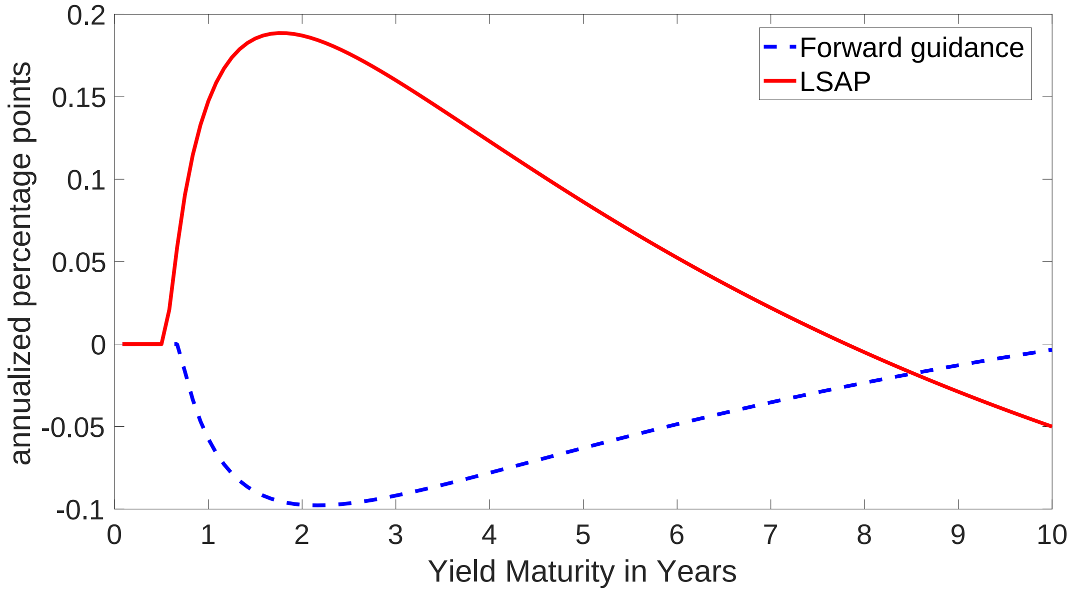

Figure 2.4. Difference Between Fitted Yield Curves

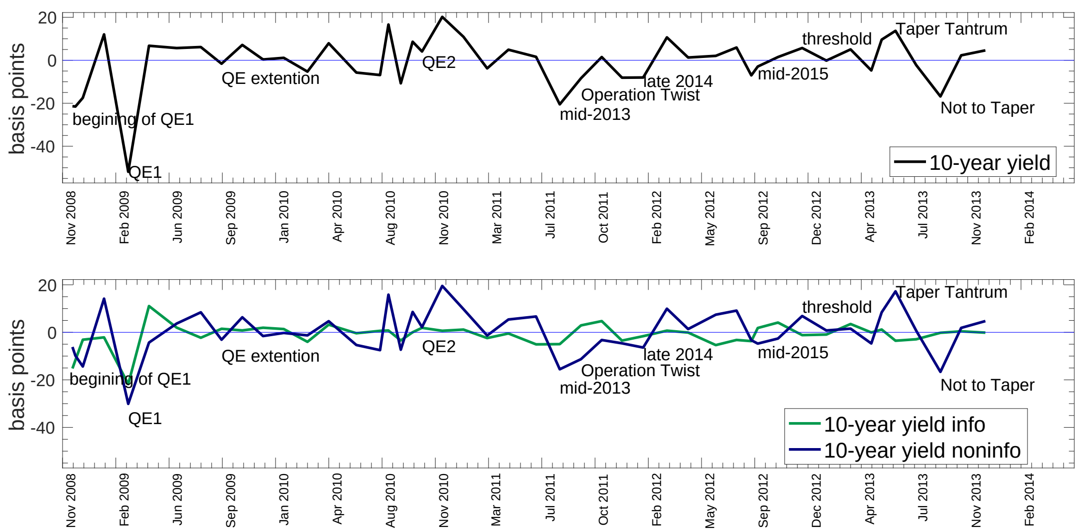

Figure 2.5. Estimated Effects on 10-year Treasury Yield

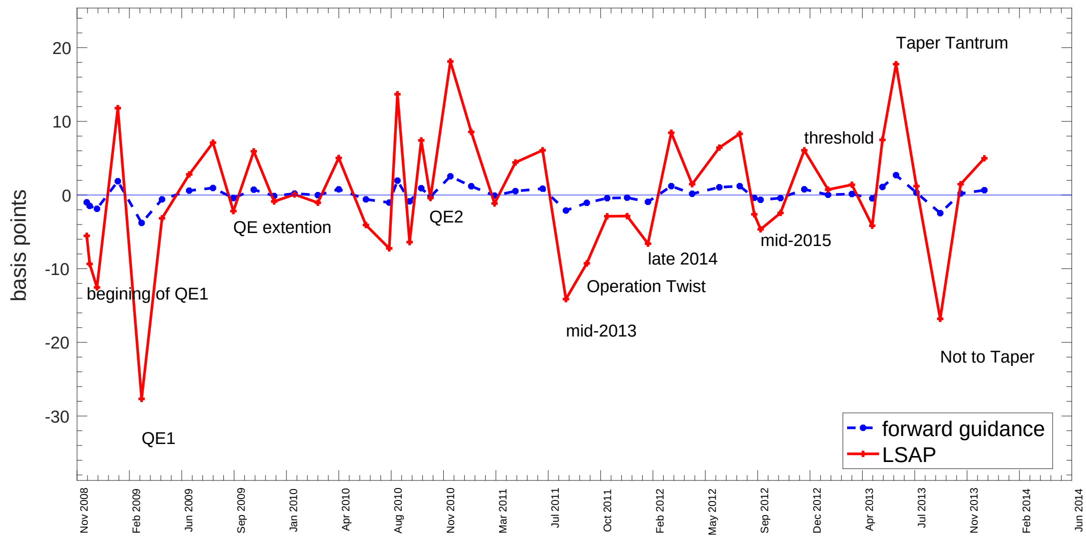

Figure 2.6. Estimated Effects on 10-year Treasury Yield

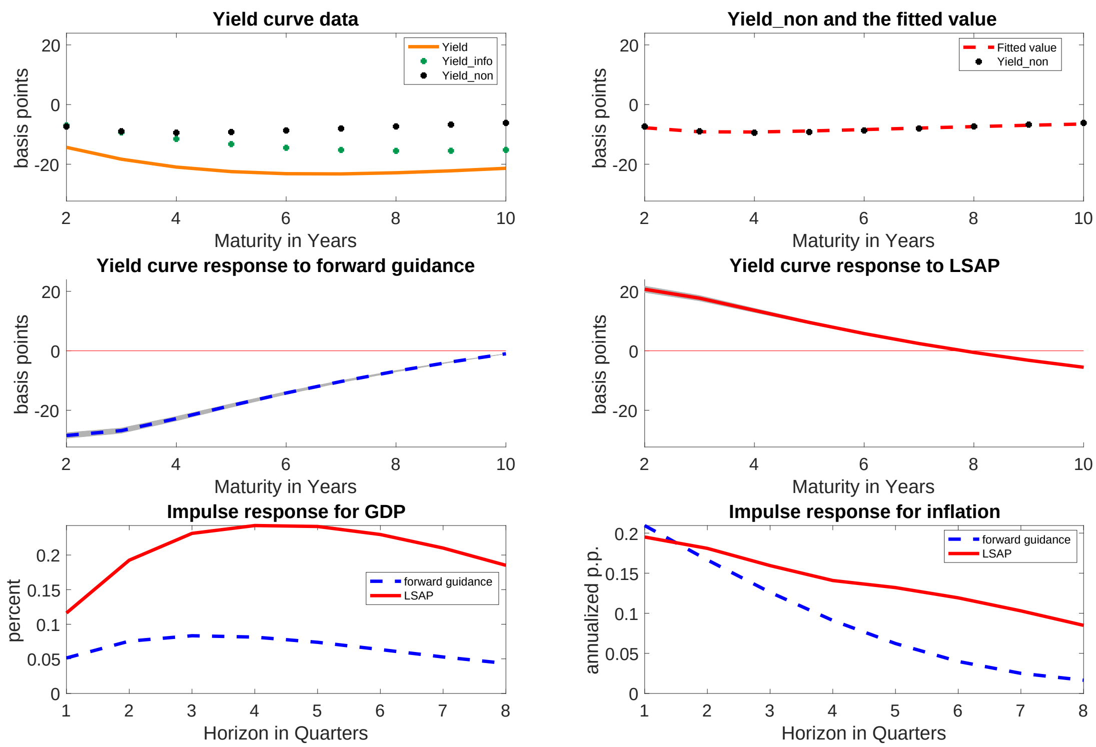

Figure 2.7. Estimated Effects on 11/25/2008

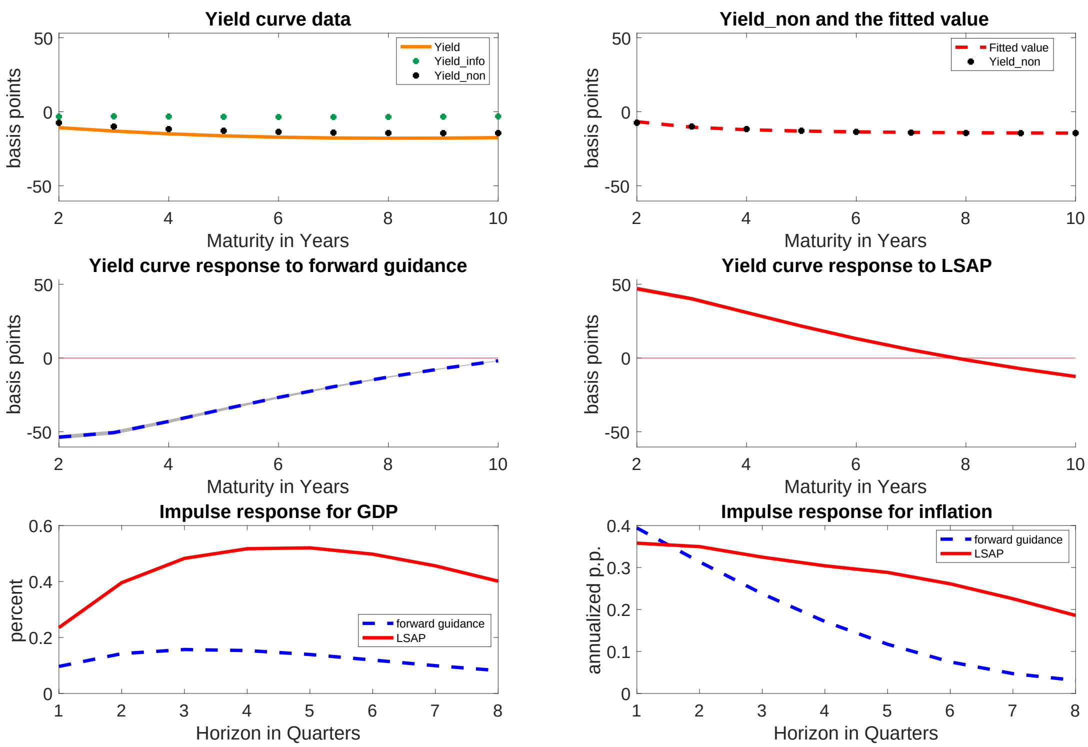

Figure 2.8. Estimated Effects on 12/16/2008

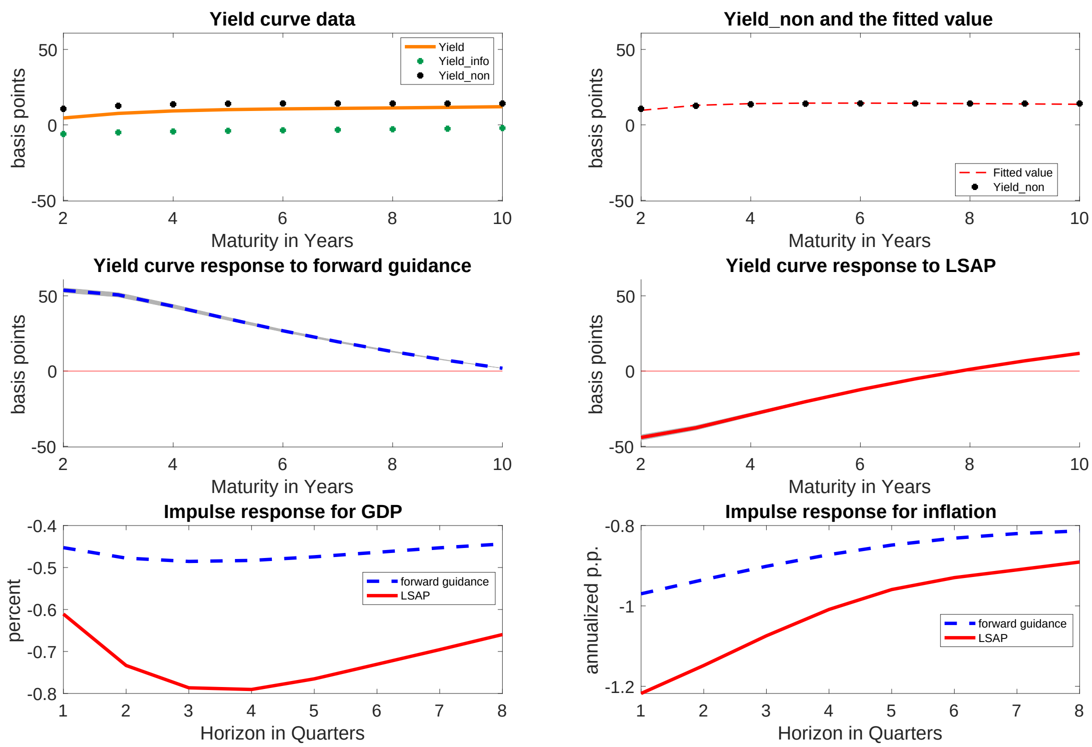

Figure 2.9. Estimated Effects on 01/28/2009

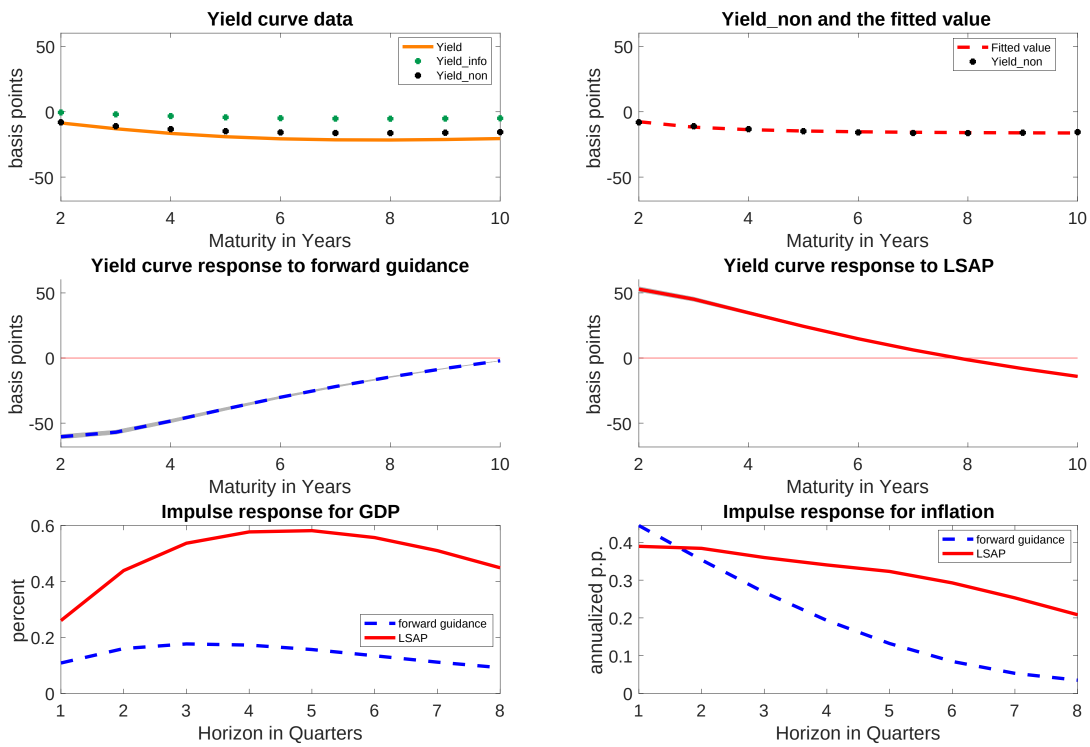

Figure 2.10. Estimated Effects on 08/09/2011

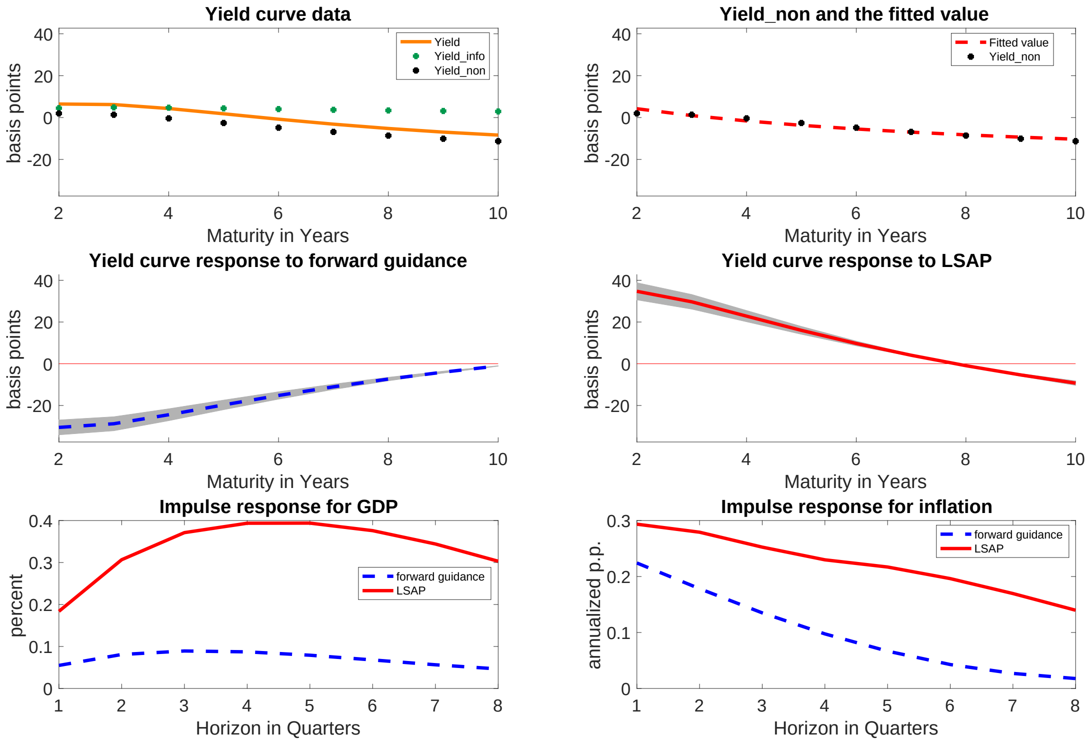

Figure 2.11. Estimated Effects on 09/21/2011

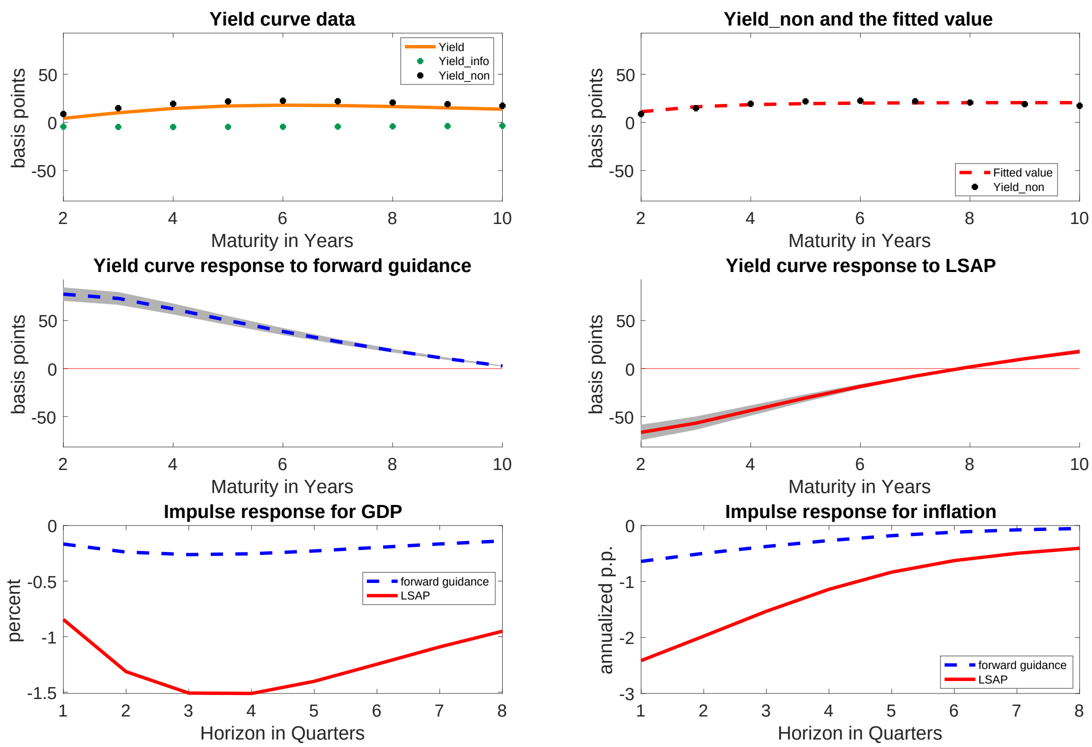

Figure 2.12. Estimated Effects on 06/19/2013

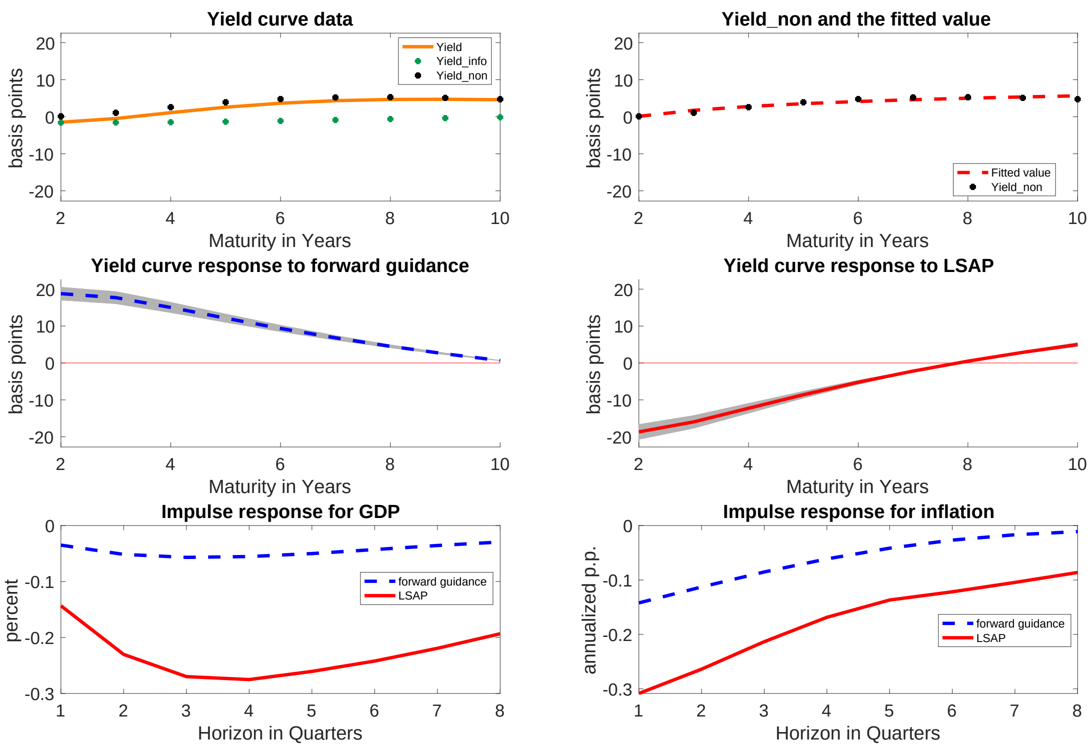

Figure 2.13. Estimated Effects on 12/18/2013

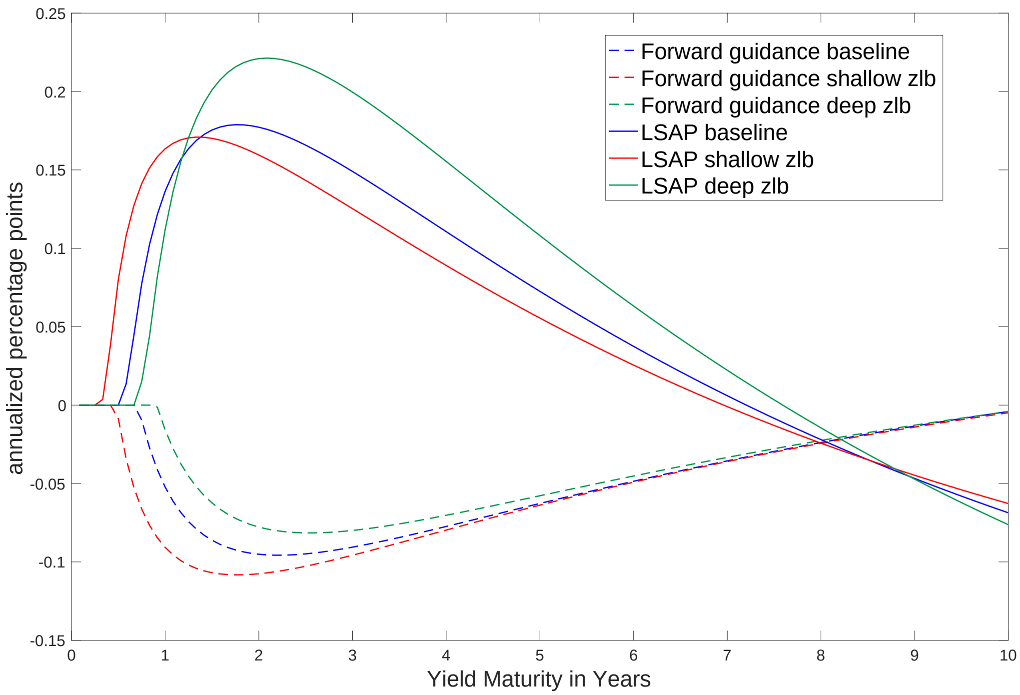

Figure 2.14. Difference Between Fitted Yield Curves When Initial Condition Varies

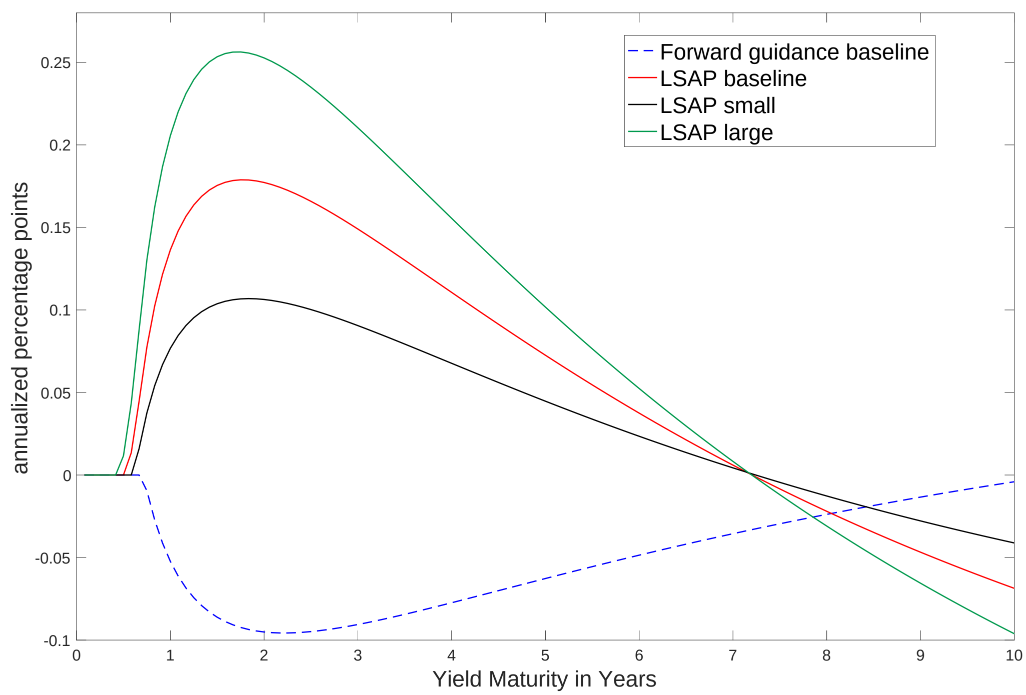

Figure 2.15. Difference Between Fitted Yield Curves When the Definition of One Unit Shock Varies

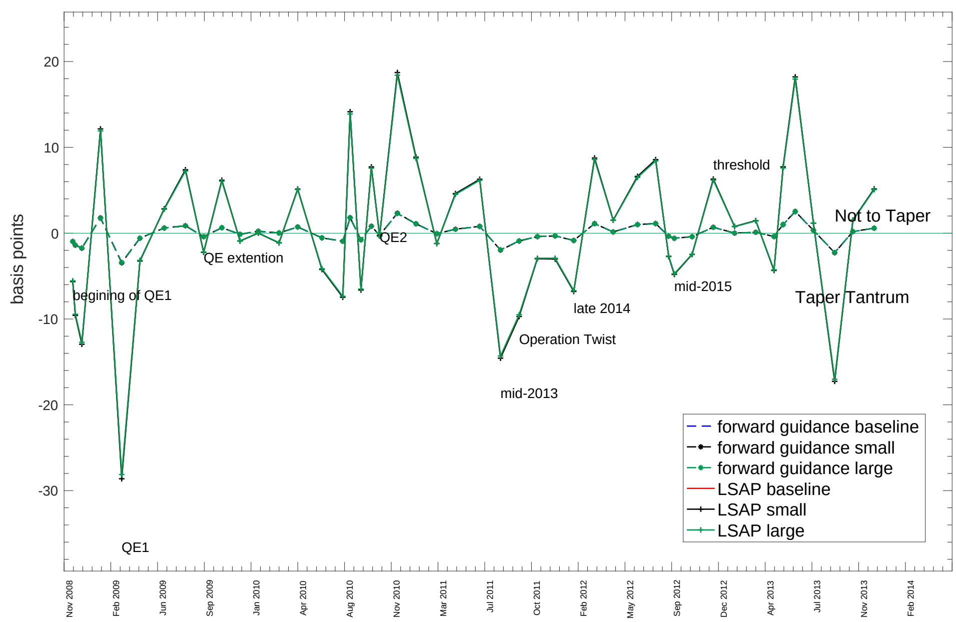

Figure 2.16. Estimated Effects on 10-year Treasury Yield When the Definition of One Unit Shock Varies

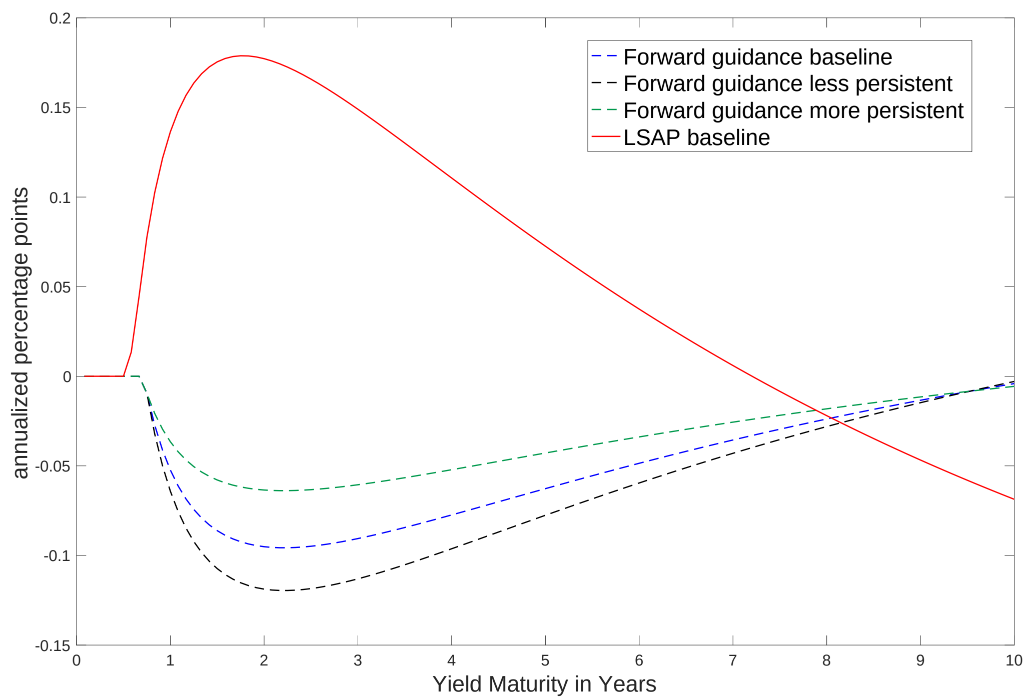

Figure 2.17. Difference Between Fitted Yield Curves When Forward Guidance Persistence Varies

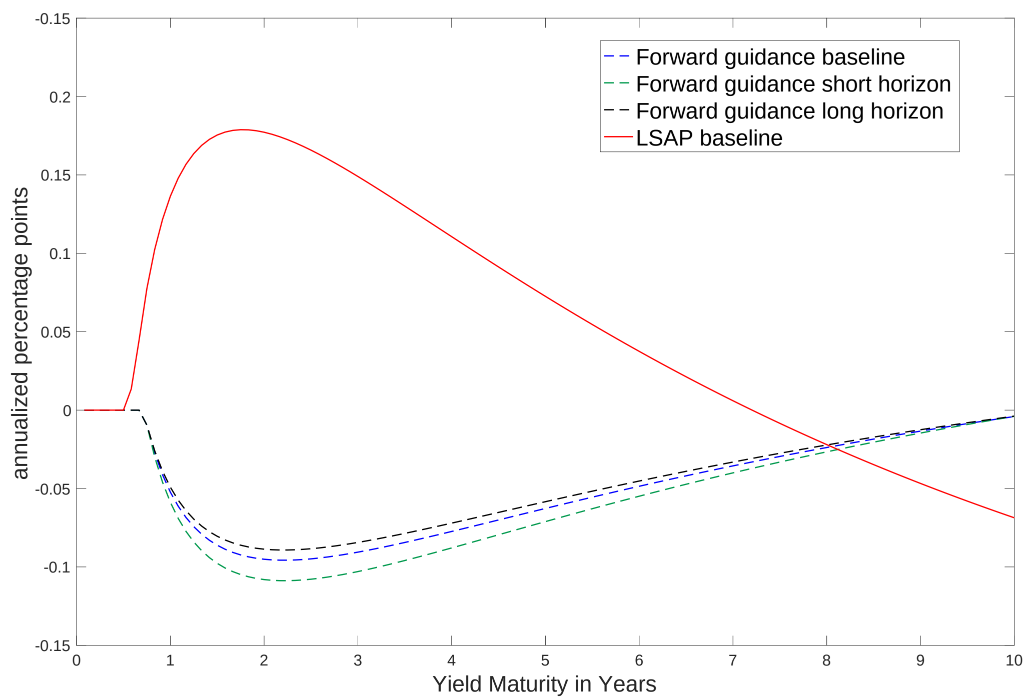

Figure 2.18. Difference Between Fitted Yield Curves When Forward Guidance Horizon Varies

Table 2.1. Parameter Values

	symbol	value	meaning	value in GK	meaning
(A)	Parameters in common with GK(2011, 2013)				
	β	0.995	ss. annual real interest rate = 2 percent		
	δ	0.025	depreciation rate		
	α	0.33	capital share in production function		
	γ	0.779	Calvo price-setting, resets every 13.6 months		
	γ^P	0	inflation indexation		
	ϕ_{ss}	4	steady state leverage ratio	4, 6	
	G_{ss}/Y	0.2	steady state government spending-GDP ratio		
	$Ł_{ss}$	1/3	steady state labor supply		
	ϕ_y	0.125	response of monetary policy to output gap		
	$\bar{K}^h/K$	0.5	prop. of ss. direct capital holdings of the hh.		
	$\bar{B}^h/B$	0.75	prop. of ss. direct Treasury holdings of the hh.		
	B/Y	0.45	ss. Treasury supply		
	ρ_{1b}	1.5	AR(2) process governing LSAP		
	ρ_{2b}	-.55	AR(2) process governing LSAP		

Table 2.1. Parameter Values, continued

	symbol	value	meaning	value in GK	meaning
(B)	Parameters changed from GK in order to more accurately math the yield curve				
	$\bar{\pi}$	0.006	annual inflation target = 2.4 percent	0	
	$\underline{\iota}$	0.25	lower-bound of interest rate, annu. pp	0	
	$R_{k,ss} - R_{ss}$	172	steady state excess return on capital, annu. bp.	100	
	$R_{b,ss} - R_{ss}$	103	steady state excess return on bond, annu. bp.	50	
	θ	0.956	survival rate of the bankers, 5.7 years	0.9715	8.77 years
	Δ	0.6	prop. advantage of gov. debt over divertible capital	0.5	
	λ	0.384	fraction of capital that can be diverted	0.381, 0.345	
	X	0.0017	transfer to the entering bankers	0.002, 0.0062	
	κ_s	4	elasticity for hh. holdings of capital	1	
	κ_b	1.5	elasticity for hh. holdings of bonds	1	

Table 2.1. Parameter Values, continued

	symbol	value	meaning	value in GK	meaning
(C)	Parameters changed from GK in order to be more consistent with the consensus from other studies				
	h	0.615	habit persistent	0.815	
	φ	1/2	Frisch elasticity of labor supply =1/φ=2	0.276	3.6
	ε	6	price mark-up 20%	4.167	31.58%
	η_i	4.5	quadratic investment cost parameter	1.728	
	ϕ_π	2.5	response of monetary policy to inflation	1.5	
(D)	Parameters not in GK				
	ρ_z	0.65	AR(1) process governing forward guidance		
	ϑ	0.98	Macauley duration of the 10-year bond is 30 quarters		

Table 2.2. Data and Model mplied yield curve, in annualized percentage points

	3-month	1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year
(A) Normal time											
Jan. 1990-Nov. 2008	4.13	4.45	4.72	4.94	5.13	5.30	5.45	5.58	5.70	5.80	5.90
model steady state	4.42	4.58	4.74	4.88	5.00	5.10	5.19	5.26	5.33	5.38	5.43
(B) Crisis											
Nov. 2008-Nov. 2015	0.27	0.28	0.54	0.89	1.24	1.58	1.89	2.16	2.40	2.62	2.80
Nov. 2008-Jan. 2010	0.31	0.54	0.91	1.34	1.79	2.22	2.61	2.96	3.27	3.52	3.73
scenario (i)	0.25	0.39	1.18	1.97	2.68	3.30	3.83	4.30	4.70	5.05	5.36
scenario (ii)	0.25	0.33	1.08	1.88	2.60	3.23	3.78	4.26	4.68	5.04	5.36
scenario (iii)	0.25	0.54	1.37	2.13	2.80	3.38	3.88	4.32	4.69	5.02	5.31

Table 2.3. Unconventional Monetary Policy on Several Key FOMC Announcement Days

Date	$\triangle i_{10,t}$	$\triangle i_{10,t}^{Info}$	$\triangle i_{10,t}^{mp}$	$\beta_t^{fg} \times \triangle i_{10}^{fg}$	$\beta_t^{lsap} \times \triangle i_{10}^{lsap}$	$\triangle \text{GDP}_t^{fg}$	$\triangle \text{GDP}_t^{lsap}$	$\triangle \text{inflation}_t^{fg}$	$\triangle \text{inflation}_t^{lsap}$
QE I phase (November 2008 to March 2010)									
25-Nov-08	-21.38	-15.21	-6.17	-0.99	-5.53	0.08	0.23	0.13	0.16
1-Dec-08	-21.54	-11.71	-9.83	-1.48	-9.35	0.12	0.37	0.19	0.25
16-Dec-08	-17.48	-3.10	-14.38	-1.87	-12.54	0.16	0.48	0.24	0.32
28-Jan-09	12.04	-2.13	14.17	1.87	11.79	-0.17	-0.77	-0.25	-0.69
18-Mar-09	-51.89	-21.79	-30.10	-3.79	-27.67	0.32	0.97	0.48	0.65
29-Apr-09	6.75	11.06	-4.31	-0.59	-3.16	0.05	0.13	0.08	0.09
24-Jun-09	5.68	1.99	3.69	0.60	2.79	-0.05	-0.15	-0.08	-0.12
12-Aug-09	6.15	-2.28	8.43	0.96	7.11	-0.09	-0.41	-0.13	-0.33
23-Sep-09	-1.61	1.50	-3.11	-0.41	-2.19	0.03	0.09	0.05	0.07
4-Nov-09	7.14	0.80	6.34	0.73	5.93	-0.06	-0.32	-0.10	-0.25
16-Dec-09	0.37	1.94	-1.57	-0.14	-0.87	0.01	0.04	0.02	0.03
27-Jan-10	1.13	1.38	-0.25	0.20	0.07	-0.02	0.00	-0.03	0.00
16-Mar-10	-5.28	-4.00	-1.28	-0.02	-1.05	0.00	0.05	0.00	0.03
Sum	-79.92	-41.54	-38.38	-4.93	-34.66	0.39	0.72	0.60	0.21

Table 2.3. Unconventional Monetary Policy on Several Key FOMC Announcement Days, continued

Date	$\triangle i_{10,t}$	$\triangle i_{10,t}^{Info}$	$\triangle i_{10,t}^{mp}$	$\beta_t^{fg} \times \triangle i_{10}^{fg}$	$\beta_t^{lsap} \times \triangle i_{10}^{lsap}$	$\triangle \text{GDP}_t^{fg}$	$\triangle \text{GDP}_t^{lsap}$	$\triangle \text{inflation}_t^{fg}$	$\triangle \text{inflation}_t^{lsap}$
Pre-QE II phase (April 2010 to October 2010)									
28-Apr-10	7.91	3.22	4.69	0.77	5.03	-0.07	-0.27	-0.10	-0.22
23-Jun-10	-5.72	-0.39	-5.33	-0.59	-4.07	0.05	0.17	0.07	0.12
10-Aug-10	-6.87	0.63	-7.50	-1.03	-7.24	0.09	0.30	0.13	0.21
27-Aug-10	16.63	0.77	15.86	1.95	13.68	-0.18	-0.97	-0.26	-0.90
21-Sep-10	-10.73	-3.42	-7.31	-0.85	-6.40	0.07	0.27	0.11	0.18
15-Oct-10	8.62	0.03	8.59	0.92	7.42	-0.08	-0.43	-0.12	-0.36
Sum	9.84	0.85	8.99	1.18	8.42	-0.12	-0.93	-0.17	-0.96
QE II phase (November 2010 to June 2011)									
3-Nov-10	4.08	1.90	2.18	-0.22	-0.41	0.02	0.02	0.03	0.02
14-Dec-10	20.19	0.65	19.54	2.54	18.13	-0.24	-1.56	-0.35	-1.59
26-Jan-11	10.91	1.16	9.75	1.19	8.57	-0.11	-0.52	-0.16	-0.44
15-Mar-11	-3.77	-2.42	-1.35	-0.08	-1.15	0.01	0.05	0.01	0.04
27-Apr-11	4.92	-0.48	5.40	0.53	4.42	-0.05	-0.24	-0.07	-0.19
22-Jun-11	1.60	-5.06	6.66	0.86	6.07	-0.08	-0.33	-0.11	-0.26
Sum	37.93	-4.25	42.18	4.81	35.64	-0.45	-2.57	-0.65	-2.43

Table 2.3. Unconventional Monetary Policy on Several Key FOMC Announcement Days, continued

Date	$\triangle i_{10,t}$	$\triangle i_{10,t}^{Info}$	$\triangle i_{10,t}^{mp}$	$\beta_t^{fg} \times \triangle i_{10}^{fg}$	$\beta_t^{lsap} \times \triangle i_{10}^{lsap}$	$\triangle \text{GDP}_t^{fg}$	$\triangle \text{GDP}_t^{lsap}$	$\triangle \text{inflation}_t^{fg}$	$\triangle \text{inflation}_t^{lsap}$
Mid-2013 phase (August 2011)									
9-Aug-11	-20.51	-4.96	-15.55	-2.11	-14.13	0.18	0.54	0.27	0.36
"Operation Twist" (September 2011 to August 2012)									
21-Sep-11	-8.37	2.92	-11.29	-1.06	-9.28	0.09	0.37	0.14	0.25
2-Nov-11	1.50	4.73	-3.23	-0.43	-2.88	0.04	0.12	0.05	0.09
13-Dec-11	-8.10	-3.48	-4.62	-0.36	-2.86	0.03	0.12	0.05	0.08
25-Jan-12	-8.02	-1.61	-6.41	-0.93	-6.60	0.08	0.27	0.12	0.19
13-Mar-12	10.65	0.71	9.94	1.21	8.46	-0.11	-0.51	-0.16	-0.43
25-Apr-12	1.28	-0.10	1.38	0.17	1.47	-0.01	-0.08	-0.02	-0.06
30-Jun-12	2.05	-5.37	7.42	1.05	6.44	-0.09	-0.35	-0.14	-0.28
1-Aug-12	5.93	-3.21	9.14	1.21	8.31	-0.11	-0.50	-0.16	-0.42
31-Aug-12	-7.02	-3.70	-3.32	-0.38	-2.62	0.03	0.11	0.05	0.08
Sum	-10.10	-9.11	-0.99	0.48	0.43	-0.06	-0.44	-0.08	-0.51

Table 2.3. Unconventional Monetary Policy on Several Key FOMC Announcement Days, continued

Date	$\triangle i_{10,t}$	$\triangle i_{10,t}^{Info}$	$\triangle i_{10,t}^{mp}$	$\beta_t^{fg} \times \triangle i_{10}^{fg}$	$\beta_t^{lsap} \times \triangle i_{10}^{lsap}$	$\triangle \text{GDP}_t^{fg}$	$\triangle \text{GDP}_t^{lsap}$	$\triangle \text{inflation}_t^{fg}$	$\triangle \text{inflation}_t^{lsap}$
QE III phase (September 2012 to May 2013)									
13-Sep-12	-2.92	1.82	-4.74	-0.65	-4.66	0.05	0.20	0.08	0.14
14-Oct-12	1.50	4.11	-2.61	-0.42	-2.43	0.04	0.10	0.05	0.07
12-Dec-12	5.70	-1.17	6.87	0.78	6.07	-0.07	-0.33	-0.10	-0.26
30-Jan-13	-0.15	-0.93	0.78	0.03	0.73	0.00	-0.04	0.00	-0.03
20-Mar-13	5.06	3.51	1.56	0.14	1.40	-0.01	-0.08	-0.02	-0.06
1-May-13	-4.74	-0.05	-4.69	-0.46	-4.17	0.04	0.18	0.06	0.12
22-May-13	9.60	1.18	8.42	1.09	7.49	-0.10	-0.43	-0.15	-0.36
Sum	14.05	8.46	5.59	0.50	4.42	-0.05	-0.40	-0.07	-0.38
Tapering (June 2013 to October 2014)									
19-Jun-13	13.70	-3.53	17.23	2.70	17.76	-0.26	-1.51	-0.37	-1.53
31-Jul-13	-2.25	-2.92	0.67	0.32	1.20	-0.03	-0.07	-0.04	-0.05
18-Sep-13	-16.83	-0.19	-16.64	-2.46	-16.81	0.21	0.63	0.31	0.42
30-Oct-13	2.29	0.42	1.87	0.20	1.46	-0.02	-0.08	-0.03	-0.06
18-Dec-13	4.60	-0.14	4.74	0.65	4.99	-0.06	-0.27	-0.09	-0.21
Sum	1.51	-6.36	7.87	1.42	8.61	-0.16	-1.30	-0.21	-1.44

Chapter 3

Monetary Policy and Household Balance Sheet Heterogeneity

Abstract

Monetary policy interventions have distributional effects across the population depending on the composition of the assets and liabilities of households. I provide empirical analysis using household-level panel data and document the responses of households' expenditure, saving and labor market outcome to monetary policy by their balance sheet heterogeneity. When there is an expansionary monetary policy shock, households with mortgage debt spend more, save less and supply less labor intensively and extensively compared to the renters, while responses of home-owners without mortgage are not significantly different. Within the homeowners, liquidity, leverage ratio or household wealth alone cannot generate any heterogeneity in expenditure, saving or labor. To explain the results, one needs consider the wealth level as well as the borrowing constraint at the same time.

3.1 Introduction

Understanding the transmission channels of monetary policy is an important topic for both policymakers and researchers. In this paper, I investigate how households with heterogeneous balance sheet composition would make their decisions in response to monetary policy interventions, and to what extent and this affects the aggregate economy.

I contribute towards existing literature in two ways: (i) by quantifying the response of expenditure, asset allocation and labor market outcome to monetary policy shocks by heterogeneity in the composition of households balances sheet, and (ii) by examining which channels can explain the heterogeneous responses. To do so, I provide empirical analysis using household-level micro data, and document empirical stylized facts that can be used to evaluate different theoretical channels of monetary policy transmission.

In theory, changes in interest rates can have both direct and indirect effects. In response to interest rate cut, households save less or borrow more and increase their expenditure. This is the direct effect. Indirect effects could come from the expansion in labor demand and thus in labor income and also come from wealth effects.

This paper estimates the response of household's decision to monetary policy shocks. I identify monetary policy shocks using high-frequency data on Federal funds futures and Eurodollar futures. I obtain longitudinal household level asset allocation and employment data from Survey of Income and Program Participation (hereafter SIPP). I find that monetary policy will affects the choice of asset allocation, while the homeowners with mortgages respond more than renters and outright owners. Among homeowners with the same level of home equity, households with the median Loan-to-Value ratio are more responsive than other groups. I also find that expansionary and contractionary monetary policy have asymmetric effects, probably through the refinancing channel.

There are four reasons why the household's balance sheet composition is important for monetary policy transmission. First, home equity, the largest asset in the homeowner's balance sheet(details are in section 3.2), can serve as the dual role of durable good and collateral for borrowers along the lines of Kiyotaki and Moore (1997). Therefore, homeowners will respond differently to monetary policy shocks compared to renters, who don't have collaterals (Cloyne et al. (2016)). Figures 3.1, 3.2 and 3.3 plot the home ownership over time and the percentage of mortgage holders within homeowners over time. We can see from the figures that the composition changed over time and so would the aggregate effects of monetary policy.

Second, monetary policy could also affect through the refinancing and new borrowing decisions. Iacoviello (2005), Kaplan and Violante (2014) and Kaplan et al. (2018) have highlighted that the redistribution channel between borrowers and savers monetary policies. Wong (2018) finds that young people's consumption is more responsive to monetary policy, and this is driven by homeowners who refinance or enter new loans, which is concentrated among younger people. In my analysis I confirmed the life-cycle component and also found that the asset position still plays a role after controlling the demographics.

Furthermore, as outlined in the literature, both housing net worth and the leverage ratio have a sizable effect on consumption and employment. Mian and Sufi (2014) show that counties with a larger decline in housing net worth experience a larger decline in non-tradable employment. Mian et al. (2013) find poorer and more levered households have a significantly higher marginal propensity to consume(MPC) out of housing wealth.

Finally, the short-term nominal interest rates were at zero between 2009 and 2015, and long term nominal Treasury yields remained low in this period. This has affected U.S. households and their financial portfolios, as they traditionally hold a certain portion of their financial assets in the form of deposits and government bonds. The heterogeneity comes from the fact that richer households tend to have a higher propensity to save than households at the lower end of the income distribution (e.g. Dynan et al. (2004)).

My first contribution is to provide a novel set of empirical stylized evidence and to use these to evaluate different theoretical channels of monetary transmission. Different from studies using pesudo panels, e.g. Luetticke (2015) and Cloyne et al. (2016), my paper is the first to empirically document heterogeneity in the portfolio response to monetary shocks and analyze its implications for monetary policy in a household level panel data setting. I focus on a far broader set of household-level variables, including mortgage payments, labor income, saving and labor market status.

My second contribution is presenting another channel of heterogeneity. In their seminal papers, Kaplan and Violante (2014) and Kaplan et al. (2018) treat home equity as one kind of illiquid asset and don't distinguish the property value from the mortgage. However, I find that among the households who have the same level of home equity, the ones associated with median level of Loan-to-Value responds the most to the monetary policy. One possible reason is that there exists a fixed rate of refinance cost as well as there exists a Loan-to-Value threshold for refinancing. Therefore, only the households with the median Loan-to-Value will take advantage on refinancing opportunity.

The remainder of the paper proceeds as follows. I begin by describing the data sets in Section 3.2. In Section 3.3, I describe the regression methodology and results. Section 3.4 concludes.

3.2 Data

The main data source of this paper is the Survey of Income and Program Participation. The SIPP is a nationally representative sample of non-institutionalized individuals and the households in which they reside. It is a longitudinal survey designed specifically to provide accurate and comprehensive information about the income and program participation of individuals and households in the United States, and about the principal determinants of income and program participation. The survey follows the same individuals for periods up to four years. Each individual in the survey is assigned to one of four rotation groups and is interviewed once every four months, in a staggered fashion, collecting information on income, assets, and demographics for the duration of the panel.

The SIPP 1990, 1992, 1996, 2001, 2004, and 2008 panels are used in the paper's empirical analysis. A panel starts in every 2 years or more and tracks thousands of households over a period of two or three years, collecting information on income, assets, and demographics. The sample is divided into four groups equally. Each group is interviewed in a different month over four consecutive months about activities and characteristics over the previous four-month period. Each group is then re-interviewed at four-month intervals.1 Besides the core questionnaire, extra questions about assets and liabilities are added once per year. For example, among the total 16 interviews, the 2008 panel has collected asset data three times.

I restrict attention to the households of either owning or renting a residence. Households living in a mobile home or living in a government subsidized living quarters are excluded.

There are three main advantages of using SIPP data instead of other commonly used datasets. The first advantage of the SIPP is its large sample size and detailed information about household portfolio allocation. Second, not like other annually collected data, or even the Panel Study of Income Dynamics (PSID) data which collects almost every two years, the SIPP data is collected within certain periods of a year, for example, between May and August. This allows the paper to look at the monetary policy in a short window. Finally, main advantage of SIPP over the Survey of Consumer Finances (SCF), another principal sources of wealth data for the U.S. population, is that SIPP is a panel data, which allows us to study household's decision problem while controlling the initial balance sheet position.

3.2.1 Household balance sheet

Table 3.1 is the balance sheet of a typical household. The assets of the households have several sources: the real estate property, vehicle, financial asset, retirement account, private business, and other assets. The debts is divided into secured debt and unsecured debt[1], where the secured debt is home mortgages, car loans, business debt, stock debt and debt on rental properties, while the unsecured debt is store bills/credit cards debt, loans and other debt. The SIPP survey defines total wealth as total asset minus total secured debt. Therefore, the total wealth is equal to the sum of home equity, net equity in vehicles, interest earning assets, equity in stocks and mutual funds, in retirement account, in private business, in other real estate and in other assets, where, for example, home equity is equal to real estate property value subtracted by home mortgages, net equity in vehicles is equal to car value minus car loans, etc. Figures 3.7,

[1]Property can serve as collateral for a loan, in which case the loan is called a secured debt. If the loan is based on future income, it is an unsecured debt.

3.8, 3.9 and 3.10 plot the time varying asset composition for the three different types of home ownership.

Tables 3.2, 3.3 and 3.4 reports summary statistics for the cross-sectional sample. The SIPP 2008 panel contains information on 37,755 unique households, of which 21,644 are homeowners, whom we define as individuals with positive property value and positive home equity. Of these households, 13,038 have positive mortgage. We exclude an additional 1,608 households whose reported total wealth is top 5% in the sample. An additional 1,503 households whose interest earning bank account is top 5% in the sample, and 787 household whose stock and mutual funds account is top 5% in them sample. These exclusions leave us with 33,858 households in our longitudinal analysis sample. Home tenure is defined as the number of years living in the current house. All monetary values are in real 2000 dollars.[2] Safe assets contains bonds, checking accounts, and savings accounts. Liquid wealth is defined as the sum of safe assets and stockholdings.

3.2.2 Household labor market outcome

Labor market related data and income data is observed monthly for each individual. An employment status is assigned as follows. I classify the individual as employed if one reports having a job and being either present or absent without salary, either on layoff or not. I classify the individual as unemployed if one reports having no job, but looking for job actively or being on layoff. Individual will be assigned out of the labor force if he reports having no job, not actively looking and not being on layoff. Further, I assign to each employed worker the total working hours, based on the first and second jobs. Figures 3.4 and 3.5 plot the unemployment rate and labor market participation rate. The numbers are very similar to those released by Bureau of Labor Statistics. For each household, I then calculate the average hours worked, the percentage of employed workers and labor market participants.

[2] The CPI data we use to adjust nominal values is downloaded from FRED.

3.2.3 Household expenditure

Unfortunately, the survey doesn't ask the respondent's consumption directly. However, I can recover the annual expenditure flow using the net worth in two continuous years and the income flows in between. To be specific, I can observe the household's net worth at month $t-12$ and month t; at the same time I also know the monthly income for each of the months between $t-12$ and t. Using simple accounting, the outflow between $t-12$ and t, which I define as the expenditure of the household, is thus equal to the sum of old net worth in month $t-12$ and the 12-month income flow minus the new net worth.

3.2.4 Monetary policy surprises

The monetary policy instrument set consists of futures rates surprises on FOMC dates, including the surprises in the current month's fed funds futures (MP1), in the three month ahead monthly fed funds futures (FF4), and in the six month, nine month and year ahead futures on three month Eurodollar deposits (ED2, ED3, ED4). I turn the futures surprises on FOMC days into daily surprises that are orthogonal to fundamentals according to Zhang (2018), and I cumulate the shocks into an annual surprise. Figure 3.6 plots the monetary policy shock over time.

3.3 Empirical methodology

The goal of the empirical analysis is to estimate the effect of a change in interest rate on the household's decision and test the importance of different heterogeneity.

3.3.1 Baseline specification

I first present the baseline specification where the effects of monetary policy is explored.

$$y_{i,t} = \sum_j \eta_j y_{i,t-j} + \beta_1 MP_t$$
$$+ \sigma X_{i,t-12} + \tau\alpha_i + \gamma\lambda_{i,t} + \sigma WlthDistr_{t-12} + constant + \varepsilon_{i,t} \tag{3.1}$$

In the regression equation, $y_{i,t-j}$ denotes the variables of interest for household i at month $t-j$, such as the log of expenditure, the log of the holdings of safe assets, the average hours worked per week, the percentage of the household that is employed or in the labor market force; MP_t is the cumulative monetary surprise happened between period $t-12$ and t; $X_{i,t-12}$ denotes a vector of controls, including the log of residential property value and total wealth in month $t-12$; α_i is the time-invariant variables, such as gender of the household head, and $\lambda_{i,t}$ is some other control variables in month t, such as household income; $WlthDistr_{t-12}$ represents the 10 quantiles from the population wealth distribution from $t-12$ to capture the effects of total wealth distribution; the error term $\varepsilon_{i,t}$ captures other sources of heterogeneity. [3]

β_1 describes the effects of monetary policy on the outcome variables. Table 3.5 shows the regression result. Each column represents dependent variable being the log of the expenditure, the log of the amount held as safe asset, the hours per week, employment rate and labor market participation rate.[4] Contractionary and expansionary monetary policies do have opposite effects on the expenditure and labor market outcomes.

[3] To distinguish between the responses to expansionary shocks from the responses to contractionary shocks, I test the following specificaiton:

$$y_{i,t} = \sum_j \eta_j y_{i,t-j} + \beta_1 MP_t^+ + \beta_2 MP_t^-$$
$$+ \sigma X_{i,t-12} + \tau\alpha_i + \gamma\lambda_{i,t} + \sigma WlthDistr_{t-12} + constant + \varepsilon_{i,t}$$

where MP_t^+ and MP_t^- are the cumulative contractionary and expansionary monetary surprise happened between period $t-12$ and t, defined as $MP_t^+ = max\{\sum_{j=0}^{11} mps_{t-j}, 0\}$ and $MP_t^- = min\{\sum_{j=0}^{11} mps_{t-j}, 0\}$($mps_t$ is the monetary policy shock in month t) respectively.

[4] I used the survey regression function (svy) in Stata to account for the clustering within the samples and respondents and to generate population estimates using sample weights.

3.3.2 Specification I: age

First, I revisit the age heterogeneity, which has been widely discussed in the previous literature. One of the reasons that age plays an important role in the transmission channel is because of the young people is more likely to be the borrowers.

$$
\begin{aligned}
y_{i,t} = & \sum_j \eta_j y_{i,t-j} + \beta_1 MP_t \\
& + \beta_2 \text{Young}_{i,t} + \beta_3 \text{MiddleAge}_{i,t} \\
& + \beta_4 MP_t * \text{Young}_{i,t} + \beta_5 MP_t * \text{MiddleAge}_{i,t} \\
& + \sigma X_{i,t-12} + \tau \alpha_i + \gamma \lambda_{i,t} + constant + \varepsilon_{i,t} \qquad (3.2)
\end{aligned}
$$

$\text{Young}_{i,t}$ is a dummy variable indicating whether the household head of household i is between age 25 and 35, and MiddleAge a dummy variable for household head between 35 and 64 years old; the omitted group is for 64 and above. As in the baseline, I have controlled the household type (single, married, etc), race, education, number of total household members and number of children and population wealth distribution.

The parameters of interest are β_4 and β_5. Table 3.6 shows the regression result. When there's contractionary monetary policy, the household on average will increase their safe asset. However, compared to the old household, middle age household save 1.3 percent less, and young household save 1.8 percent less than the old household. There's no significant different among the age groups for labor market outcome.

3.3.3 Specification II: homeownership

The second heterogeneity I look at is the homeownership. Homeowner differs from renters by having their residence as collaterals for borrowing, while they face a higher cost to liquid their housing asset. Another channel is that the mortgage holding homeowners could be more sensitive to interest rate. I use the following specification:

$$
\begin{aligned}
y_{i,t} = & \sum_j \eta_j y_{i,t-j} + \beta_1 MP_t \\
& + \beta_2 HOwD_{i,t-12} + \beta_3 HOnD_{i,t-12} \\
& + \beta_4 MP_t * HOwD_{i,t-12} + \beta_5 MP_t * HOnD_{i,t-12} \\
& + \sigma X_{i,t-12} + \tau\alpha_i + \gamma\lambda_{i,t} + constant + \varepsilon_{i,t}
\end{aligned} \tag{3.3}
$$

$HOwD_{i,t-12}$ is a dummy variable indicating whether the household i is homeowner with debt in month $t-12$, and $HOnD_{i,t-12}$ a dummy variable for the homeowner without mortgages. The omitted group is the renter. I also controlled the age heterogeneity by including the interaction term between age dummies variables and the monetary policy shocks.

Table 3.7 shows that compared to renters, the household with mortgages expend more, save less and supply less labor intensively and extensively to expansionary monetary policy.

3.3.4 Specification III: "wealthy" hand-to-mouth

In this section, I'm investigating the household liquidity constraint. I follow Kaplan and Violante (2014) and define a household as hand-to-mouth if at any given point in time their net liquid wealth is less than half of their total monthly labor income. I first investigate whether being hand-to-mouth will respond different to monetary policies. The regression equation is:

$$
\begin{aligned}
y_{i,t} = & \sum_j \eta_j y_{i,t-j} + \beta_1 MP_t + \beta_2 HtM_{i,t-12} + \beta_4 MP_t * HtM_{i,t-12} \\
& + \sigma X_{i,t-12} + \tau\alpha_i + \gamma\lambda_{i,t} + constant + \varepsilon_{i,t}
\end{aligned} \tag{3.4}
$$

where $HtM_{i,t-12}$ is a dummy variable to indicate whether household i in month $t-12$ is hand-to-mouth or not. However, as shown in Table 3.8, whether the household facing liquidity constraint or not doesn't result in heterogeneous response.

Kaplan and Violante (2014) define the hand-to-mouth households are 'wealthy' if they have positive illiquid asset. Here I investigate the "wealthy" hand-to-mouth household and furthermore distinguish them by renter, homeowner with debt, and homeowner without debt, where the latter two groups both have positive asset.

$$\begin{aligned} y_{i,t} =& \sum_j \eta_j y_{i,t-j} + \beta_1 MP_t * HtM_{i,t-12} * HOwD_{i,t-12} + \beta_2 MP_t * HtM_{i,t-12} * HOnD_{i,t-12} \\ &+ \beta_3 HtM_{i,t-12} * HOwD_{i,t-12} + \beta_4 HtM_{i,t-12} * HOnD_{i,t-12} \\ &+ \beta_5 MP_t * HOwD_{i,t-12} + \beta_6 MP_t * HOnD_{i,t-12} \\ &+ \sigma X_{i,t-12} + \tau\alpha_i + \gamma\lambda_{i,t} + constant + \varepsilon_{i,t} \end{aligned} \tag{3.5}$$

Table 3.9 shows homeowner with debt spend less than the homeowner without debt in response to expansionary montary policy shock.

3.3.5 Specification IV: home equity

In this section, I investigate the household indebtedness. I focus on homeowners and use home equity as a measure of indebtedness. The specification is as follows:

$$\begin{aligned} y_{i,t} =& \sum_j \eta_j y_{i,t-j} + \beta_1 MP_t + \beta_2 ln(\text{HEQ}_{i,t-12}) + \beta_3 MP_t * ln(\text{HEQ}_{i,t-12}) \\ &+ \sigma X_{i,t-12} + \tau\alpha_i + \gamma\lambda_{i,t} + constant + \text{other controll variables} + \varepsilon_{i,t} \end{aligned} \tag{3.6}$$

where $ln(\text{HEQ}_{i,t-12})_{i,t-12}$ is log of the$i$ in month $t-12$, which could be either the log of home equity or net worth. β_3 describes how the heterogeneous balance sheet position of the household could affect the portfolio/labor allocation decision when there is monetary policy announcement. Most of the coefficients are insignificant from zero as shown in Table 3.10.

3.3.6 Specification V: Loan to Value ratio

In this section, I restrict the sample to be homeowners with mortgages and investigat the household's housing leverage ratio. I measure the loan to value (LTV) of the house as the total mortgage divided by the property value. I group the mortgage holders into 4 quantile groups based on their LTV ratios. The specification I'm using is as follows:

$$
\begin{aligned}
y_{i,t} =& \beta 1 MP_t * LTVq2_{i,t-12} + \beta 2 MP_t * LTVq3_{i,t-12} + \beta 3 MP_t * LTVq4_{i,t-12} \\
&+ \sigma X_{i,t-12} + \tau \alpha_i + \gamma \lambda_{i,t} + constant + \text{other controll variables} + \varepsilon_{i,t}
\end{aligned}
\tag{3.7}
$$

However, most of the coefficients are insignificant from zero as shown in Table 3.11.

3.3.7 Specification VI: home equity and Loan to Value ratio

Chetty et al. (2017) show that characterizing the effects of housing on portfolios requires distinguishing between the effects of home equity and mortgage debt. In this section, I separate home equity and the leverage ratio. The specification I'm using is as follows:

$$
\begin{aligned}
y_{i,t} =& \sum_j \eta_j y_{i,t-j} + \beta_1 MP * \ln(\text{HEQ}_{i,t-12}) * LTV_{i,t-12} \\
&+ \sigma X_{i,t-12} + \tau \alpha_i + \gamma \lambda_{i,t} + constant + \text{other controll variables} + \varepsilon_{i,t}
\end{aligned}
\tag{3.8}
$$

Table 3.12 shows the regression result. The difference in leverage ratio can explain the heterogenous response of labor market outcome.

3.4 Conclusion

Assessing the empirical effects of changes in monetary policy is very important for distinguishing between different macro models and frictions in the economy. In this paper, I provide empirical analysis using household-level micro data and document the responses of households’ expenditure, saving and labor market outcome to monetary policy by their balance sheet heterogeneity.

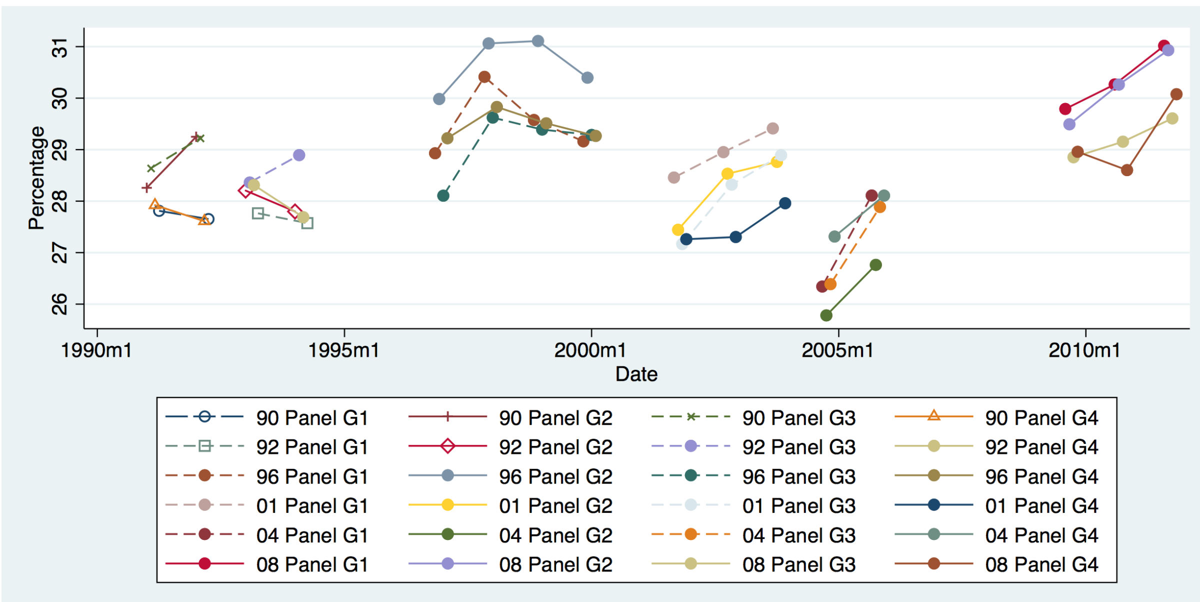

Figure 3.1. Ratio of Homeowner without Debt in the Population

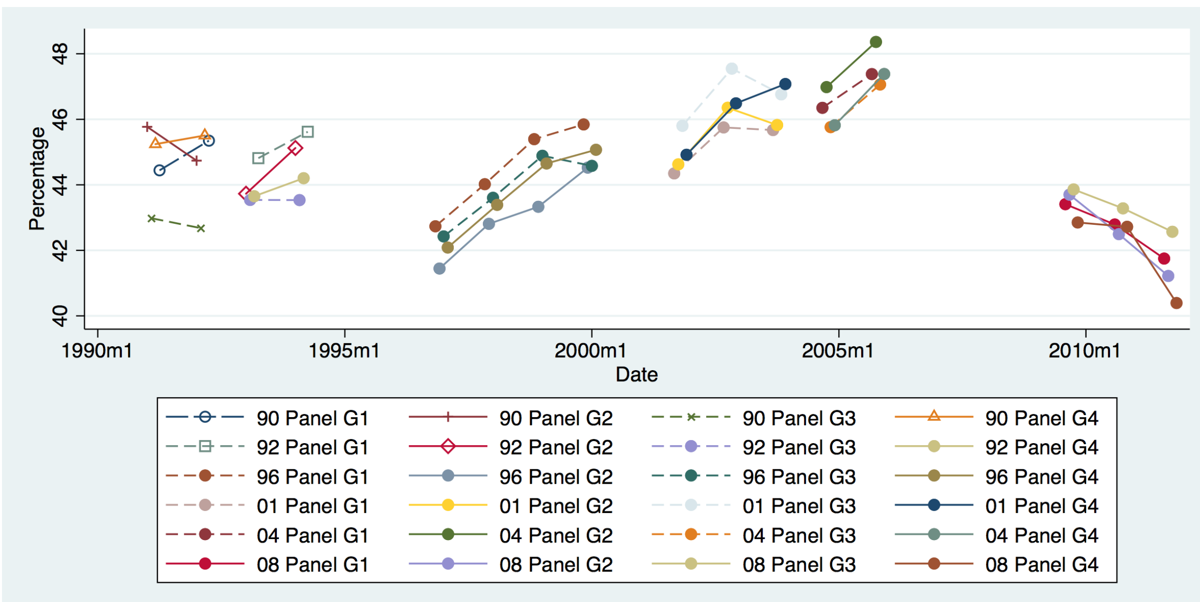

Figure 3.2. Ratio of Mortgage Holder in the Population

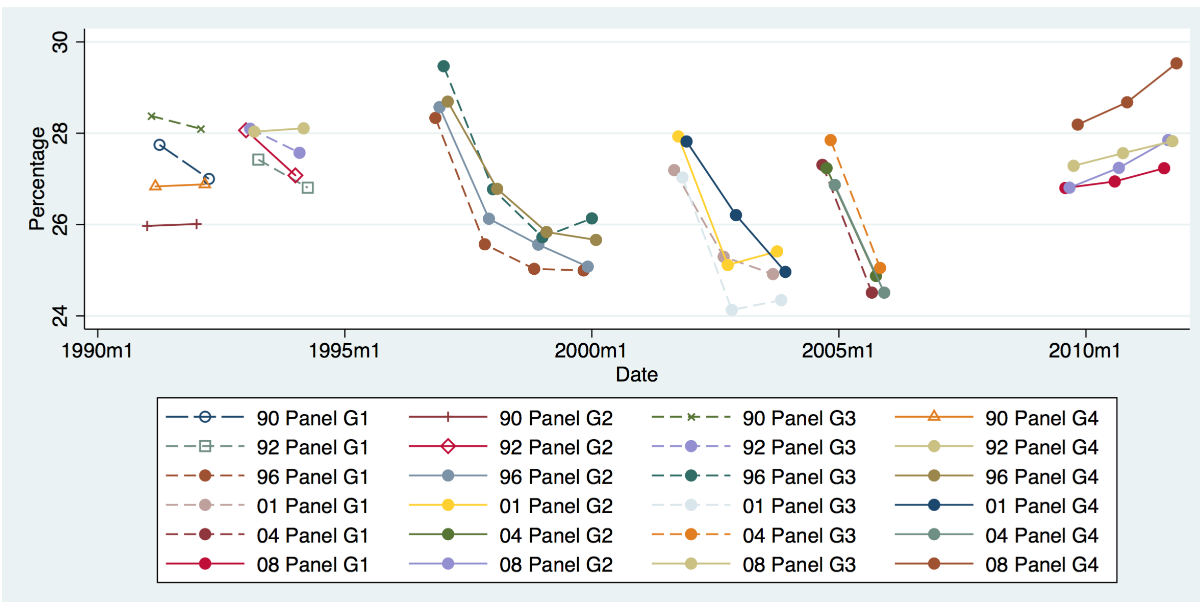

Figure 3.3. Ratio of Renter in the Population

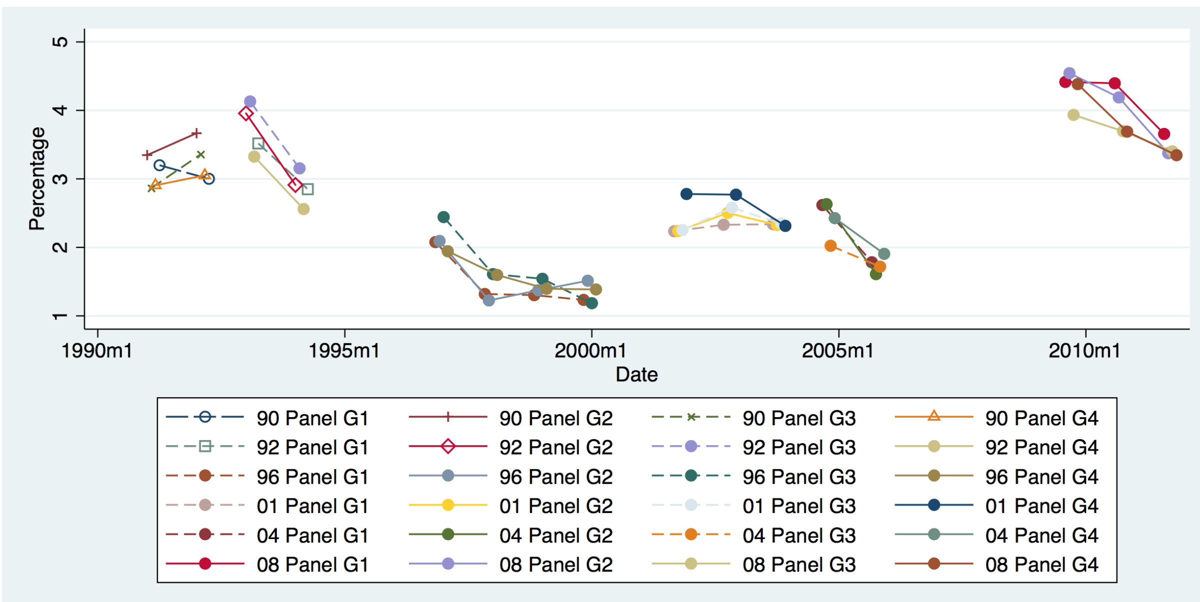

Figure 3.4. Unemployment Ratio in the Population

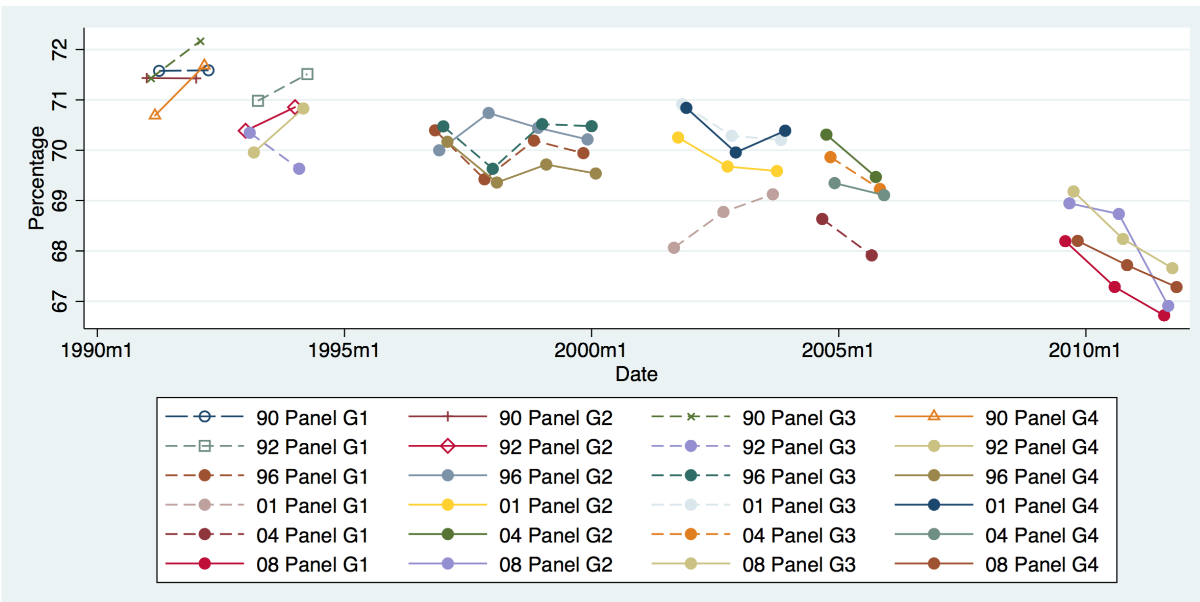

Figure 3.5. Labor Force Participation Ratio in the Population

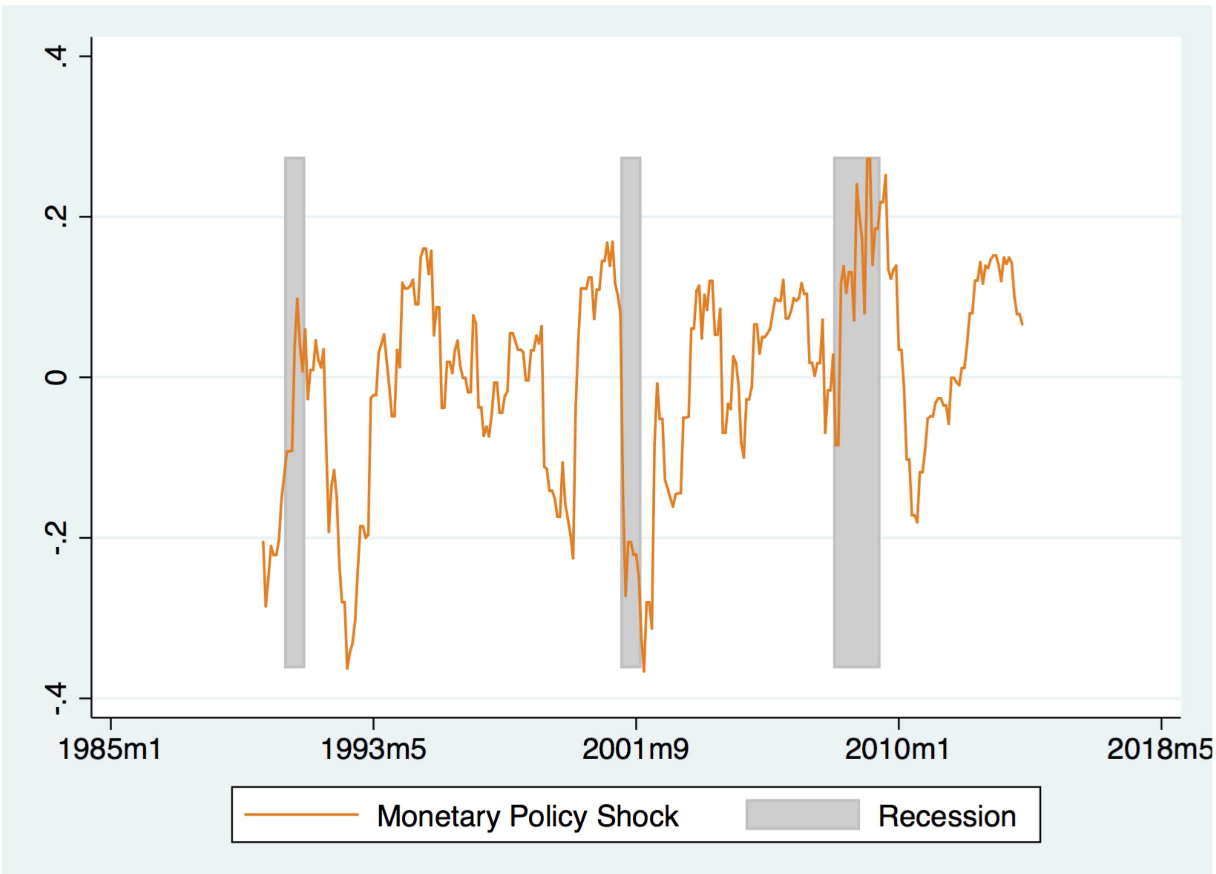

Figure 3.6. Cumulative Monetary Policy Shock

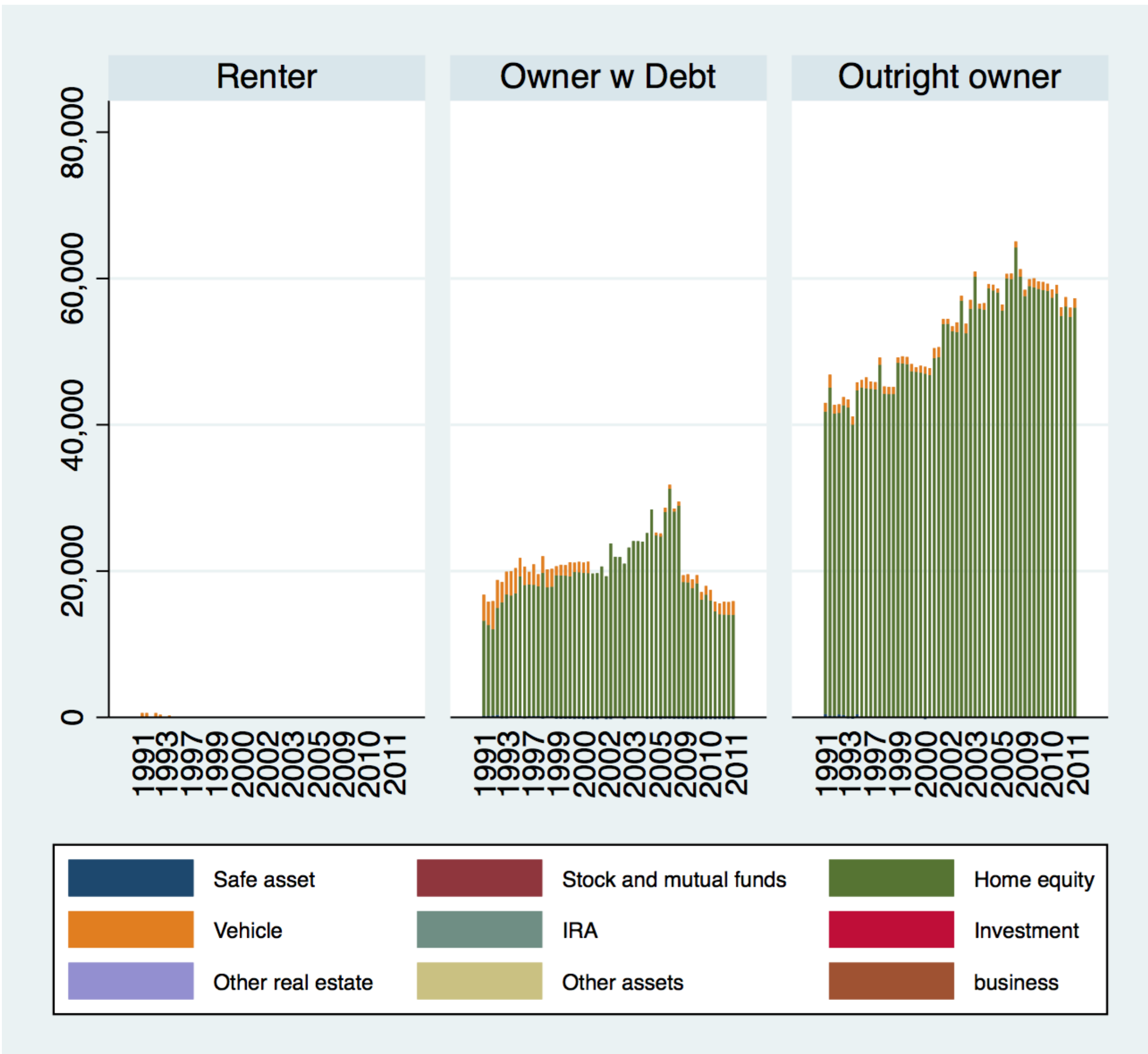

Figure 3.7. 25th Quantile Asset Composition Over Time by Housing Status

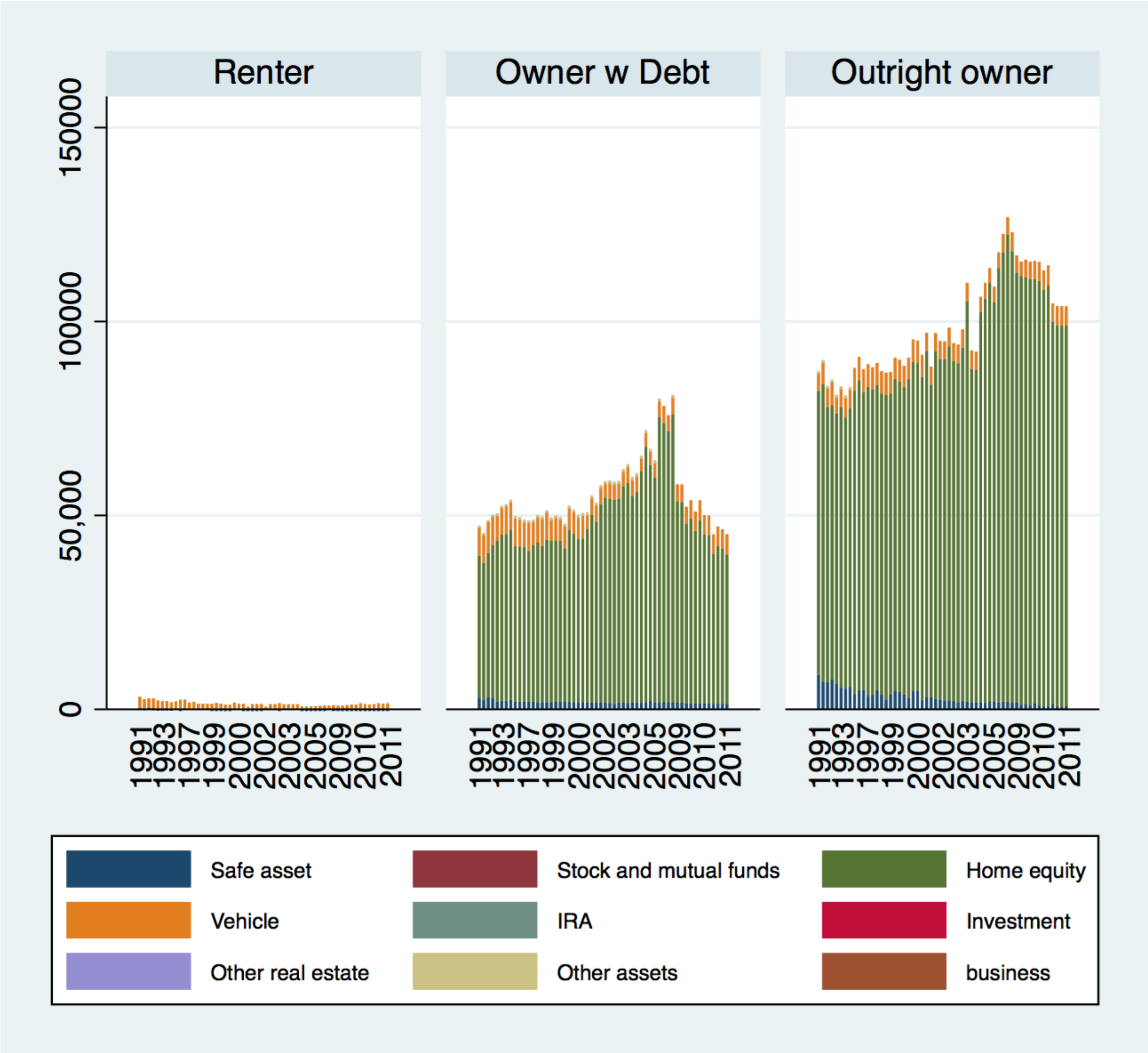

Figure 3.8. Median Quantile Asset Composition Over Time by Housing Status

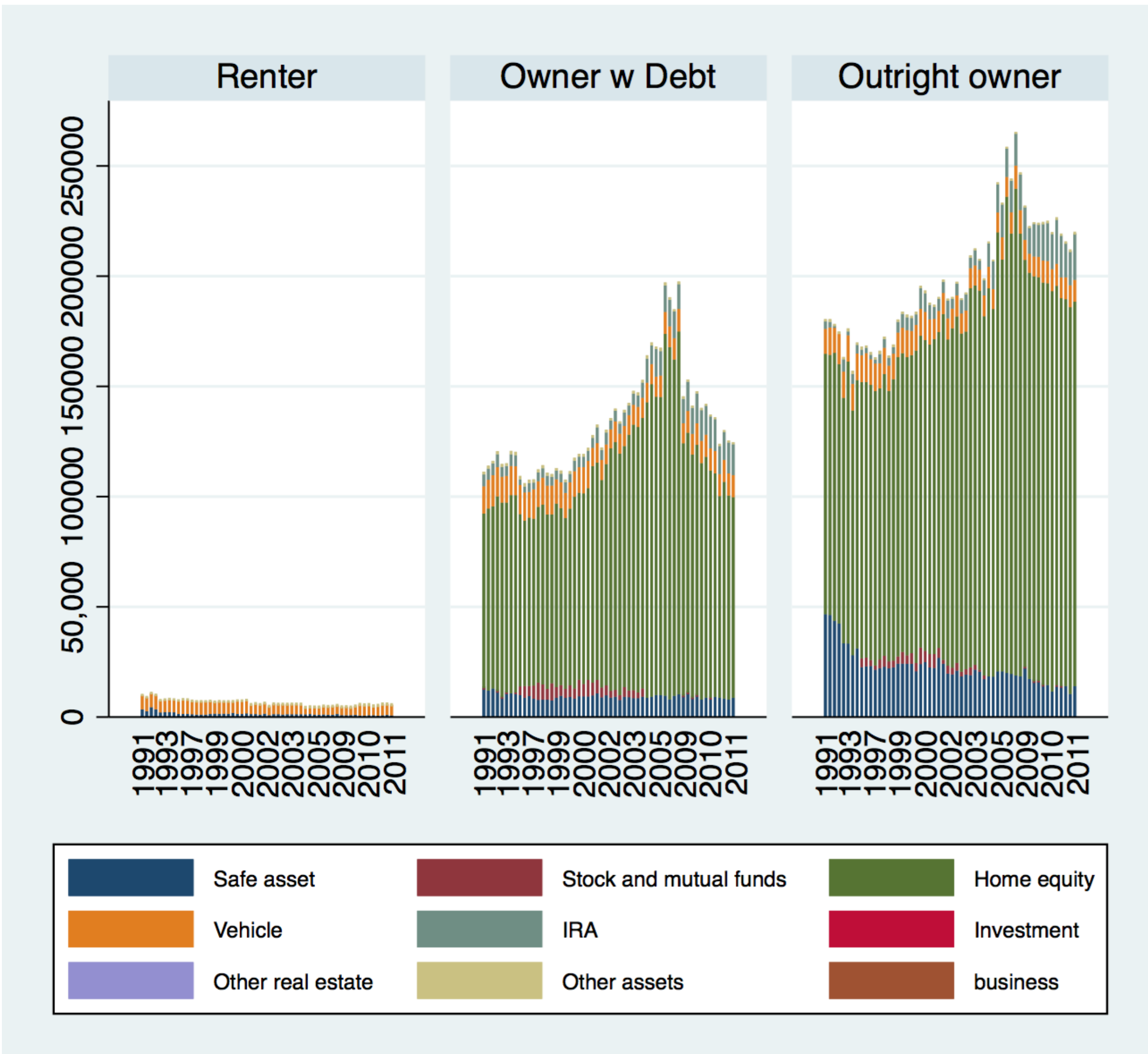

Figure 3.9. 75th Quantile Asset Composition Over Time by Housing Status

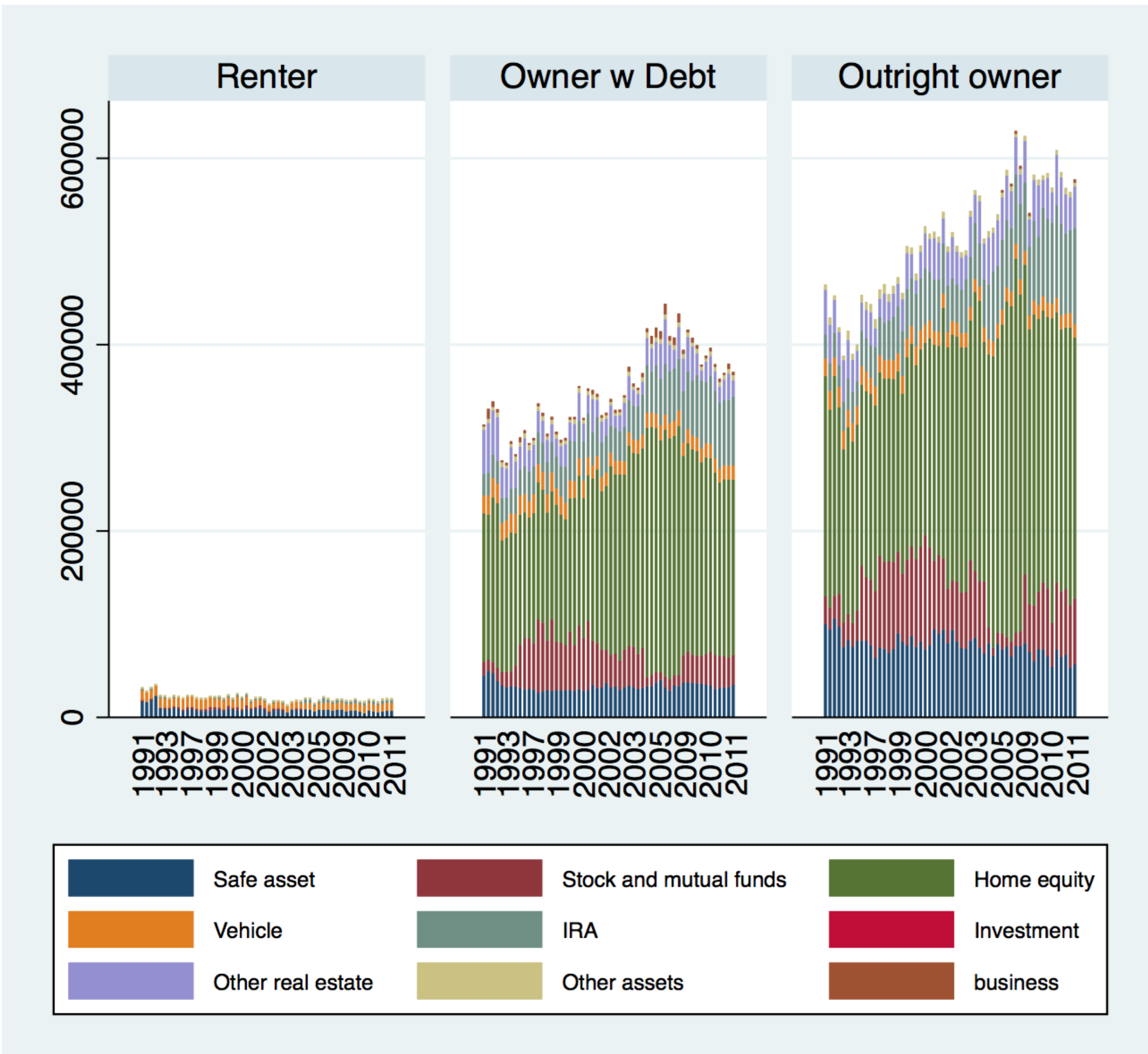

Figure 3.10. 90th Quantile Asset Composition Over Time by Housing Status

Table 3.1. Household Balance Sheet

Total Wealth	Debts
Home equity	Amount owed for loans
Net equity in vehicles	Amount owed for store bills or credit cards
Equity in stocks and mutual fund shares	Amount owed for other debt
Interest earning assets held in banking	**Net Worth**
Interest earning assets held in other	
Equity in other assets	
Equity in IRA and KEOGH accounts	
Equity in 401K and Thrift savings accounts	
Business equity	
Equity on other real estate	

Table 3.2. Summary Statistics for SIPP Cross-sectional Homeowner with Debt

	(1)				
	mean	sd	p25	p50	p75
age	46	12	37	45	54
education	14	3	12	13	16
number of kids	0.74	1.05	0.00	0.00	1.00
totoal income	5,342	4,348	2,791	4,408	6,605
property value	145,893	123,408	66,395	116,044	193,552
mortgage	76,838	66,629	26,875	62,790	108,587
home tenure	9.74	8.97	3.00	7.00	14.00
total wealth	179,525	874,821	31,367	83,394	205,208
liquid asset	42,150	884,784	106	3,002	19,317
home equity	69,055	86,363	11,819	39,681	92,105
equity in other real estate	15,511	77,342	0	0	0
equity in vehicle	6,886	8,795	1,500	5,489	10,825
business equity	13,157	98,362	0	0	0
retirement account	30,159	67,411	0	132	26,254
percent of households holding stock	0.21	0.36	0.00	0.00	0.33
stock share (% of liquid wealth)	0.22	0.36	0.00	0.00	0.40
safe assets share	0.78	0.36	0.60	1.00	1.00

Table 3.3. Summary Statistics for SIPP Cross-sectional Homeowner without Debt

	(1)				
	mean	sd	p25	p50	p75
age	64	15	54	66	75
education	12	3	12	12	13
number of kids	0.21	0.65	0.00	0.00	0.00
totoal income	3,086	3,297	1,233	2,237	3,862
property value	109,524	112,330	36,091	79,198	144,900
mortgage	0	0	0	0	0
home tenure	24.61	16.13	11.00	24.00	36.00
total wealth	244,562	1,107,576	59,057	130,422	280,098
liquid asset	69,465	1,126,262	0	4,446	41,299
home equity	109,524	112,330	36,091	79,198	144,900
equity in other real estate	18,189	85,755	0	0	0
equity in vehicle	7,092	8,564	1,116	4,926	10,571
business equity	10,114	88,040	0	0	0
retirement account	25,873	66,407	0	0	15,752
percent of households holding stock	0.20	0.38	0.00	0.00	0.00
stock share (% of liquid wealth)	0.21	0.34	0.00	0.00	0.33
safe assets share	0.79	0.34	0.67	1.00	1.00

Table 3.4. Summary Statistics for SIPP Cross-sectional Private Renter

	(1)				
	mean	sd	p25	p50	p75
age	42	16	29	38	50
education	13	3	12	12	14
number of kids	0.60	1.02	0.00	0.00	1.00
totoal income	2,777	2,606	1,217	2,200	3,590
property value	0	0	0	0	0
mortgage	0	0	0	0	0
home tenure	.	.	.	.	.
total wealth	28,781	397,316	651	4,453	14,429
liquid asset	11,803	407,277	0	20	1,826
home equity	176	4,835	0	0	0
equity in other real estate	2,612	26,428	0	0	0
equity in vehicle	2,857	5,184	0	1,500	4,848
business equity	3,880	49,164	0	0	0
retirement account	5,894	26,214	0	0	0
percent of households holding stock	0.08	0.25	0.00	0.00	0.00
stock share (% of liquid wealth)	0.12	0.29	0.00	0.00	0.00
safe assets share	0.88	0.29	1.00	1.00	1.00

Table 3.5. Baseline Specification

	(1) ln(expenditure)	(2) ln(safe asset)	(3) labor hours	(4) labor employment	(5) labor participation
MP	0.109**	0.278***	0.004	0.003	-0.001
	(2.55)	(2.92)	(0.01)	(0.50)	(-0.25)
Observations	103864	81716	88004	126050	126050

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.6. Specification I, Age

	(1) ln(expenditure)	(2) ln(safe asset)	(3) labor hours	(4) labor employment	(5) labor participation
main					
MP	-0.063	0.216	-0.324	0.003	0.001
	(-0.79)	(1.22)	(-0.28)	(0.34)	(0.15)
Young	-0.143***	-0.817***	3.368***	0.065***	0.054***
	(-10.34)	(-30.11)	(18.71)	(26.77)	(25.65)
MiddleAge	-0.085***	-0.570***	3.072***	0.053***	0.045***
	(-7.13)	(-32.09)	(21.52)	(28.42)	(25.71)
MP*Young	0.247***	0.426	-0.089	-0.024	-0.024*
	(2.72)	(1.64)	(-0.06)	(-1.38)	(-1.71)
MP*MiddleAge	0.217**	0.010	0.482	0.007	0.002
	(2.58)	(0.06)	(0.41)	(0.68)	(0.21)
Observations	103864	81716	88004	126050	126050

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.7. Specification II, Homeownership

	(1) ln(expenditure)	(2) ln(safe asset)	(3) labor hours	(4) labor employment	(5) labor participation
main					
MP * HO w/debt_t-12	0.151**	-0.407*	-0.672	-0.028**	-0.029**
	(2.15)	(-1.91)	(-0.69)	(-2.03)	(-2.10)
MP* HO w/o debt_t-12	0.025	-0.015	-0.424	-0.005	-0.003
	(0.28)	(-0.06)	(-0.32)	(-0.32)	(-0.16)
Observations	103864	81716	88004	126050	126050

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.8. Specification III(i), Hand to Mouth Household

	(1) ln(expenditure)	(2) ln(safe asset)	(3) labor hours	(4) labor employment	(5) labor participation
MP	-0.068	0.210	-0.488	-0.001	-0.001
	(-0.79)	(1.19)	(-0.42)	(-0.06)	(-0.14)
HtM_t-12	-0.155***	-0.208***	0.113	0.001	0.001
	(-19.15)	(-9.62)	(1.56)	(0.70)	(1.26)
MP*HtM_t-12	-0.007	0.013	0.505	0.011	0.007
	(-0.10)	(0.08)	(0.66)	(0.98)	(0.76)
Observations	103864	81716	88004	126050	126050

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.9. Specification III(ii), "Wealthy" Hand to Mouth Household

	(1) ln(expenditure)	(2) ln(safe asset)	(3) labor hours	(4) labor employment	(5) labor participation
MP*HO w/debt _t-12	-2.800***	1.096	13.377	-0.274**	-0.222*
	(-3.45)	(0.55)	(1.18)	(-2.22)	(-1.69)
MP*ln(HomeEquity)_t-12	-0.128*	0.136	1.204	-0.021**	-0.012
	(-1.92)	(0.94)	(1.37)	(-2.31)	(-1.30)
MP*ln(HomeEquity)*HO w/debt _t-12	0.270***	-0.123	-1.219	0.023**	0.018
	(3.60)	(-0.71)	(-1.19)	(2.08)	(1.54)
Observations	76949	68634	66601	97122	97122

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.10. Specification IV, Home Equity

	(1) expenditure	(2) safe asset	(3) labor hours	(4) labor employment	(5) labor participation
MP	-0.551	-0.388	-5.728	0.063	0.001
	(-1.34)	(-0.44)	(-1.12)	(1.03)	(0.02)
ln(HEQ)_t-12	-0.078***	0.019	-0.177***	-0.001	-0.001
	(-10.43)	(1.41)	(-2.94)	(-1.39)	(-1.04)
MP*ln(HomeEquity)_t-12	0.045	0.051	0.389	-0.005	0.000
	(1.20)	(0.71)	(0.92)	(-1.01)	(0.02)
Observations	76557	68442	66226	96723	96723

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.11. Specification V, Loan to Value Ratio

	(1) expenditure	(2) safe asset	(3) labor hours	(4) labor employment	(5) labor participation
MP*LTVq25_t-12	-0.005	-0.021	1.301	-0.041**	-0.034*
	(-0.03)	(-0.08)	(0.93)	(-2.22)	(-1.86)
MP*LTVq50_t-12	-0.013	0.057	1.894	-0.030*	-0.048***
	(-0.08)	(0.20)	(1.28)	(-1.71)	(-2.76)
MP*LTVq75_t-12	-0.164	0.189	-0.378	-0.029	-0.032*
	(-1.07)	(0.68)	(-0.23)	(-1.43)	(-1.73)
Observations	49081	42529	51945	57777	57777

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.12. Specification VI, Home Equity and LTV

	(1) expenditure	(2) safe asset	(3) labor hours	(4) labor employment	(5) labor participation
MP*ln(HomeEquity)*LTVq25_t-12	0.078	-0.613	-1.319	0.003	0.008
	(0.34)	(-1.51)	(-0.61)	(0.08)	(0.28)
MP*ln(HomeEquity)*LTVq50_t-12	-0.008	0.131	-0.440	0.076**	0.068**
	(-0.03)	(0.27)	(-0.18)	(2.48)	(2.28)
MP*ln(HomeEquity)*LTVq75_t-12	-0.297	-0.017	-0.756	0.026	0.024
	(-1.36)	(-0.04)	(-0.39)	(0.77)	(0.78)
Observations	38152	33615	40575	45157	45157

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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