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Essays on Monetary Policy

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Essays on Monetary Policy

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Economics

by

Vishuddhi Sajeewa Jayawickrema

Dissertation Committee:
Professor Eric Swanson, Chair
Professor William Branch
Professor Fabio Milani

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ABSTRACT OF THE DISSERTATION

Essays on Monetary Policy

By

Vishuddhi Sajeewa Jayawickrema

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Professor Eric Swanson, Chair

This dissertation consists of three chapters focusing on the transmission of monetary policy surprises and the challenges faced in modeling unconventional monetary policy. Of that, two chapters analyze the effects of both conventional and unconventional monetary policies on the financial markets and the overall economy. The empirical findings support the argument that the unconventional monetary policies followed by the U.S. Federal Reserve are effective and the Federal Reserve is not very constrained by the lower bound on nominal interest rates. The chapter focusing on modeling of unconventional policy surprises highlights that extensions to standard macroeconomic models are required to realistically reflect the future effects of such policy.

In the first chapter, I estimate the effects of the Federal Reserve's forward guidance and large-scale asset purchase announcements, along with the effects of interest rate changes under conventional policy, on the U.S. stock market, and assess their transmission channels. Although the overall stock market responds meaningfully to a surprise change in the federal funds rate with a high level of statistical significance, a heterogeneity in responses is observed among different sectors in the stock market. In contrast, forward guidance is found to have relatively homogeneous effects on sector-wise stock market performance. Such

effects are large in magnitude and highly statistically significant. However, large-scale asset purchases exhibit minimal effects on equity price movements. The present value of future excess returns emerged as the most important channel through which the surprise changes in the federal funds rate as well as forward guidance and large-scale asset purchases affect current equity prices. The present value of future dividends and the real interest rates are found to make smaller contributions to the propagation of policy shocks. However, the relative contribution of future dividends, real interest rates and excess returns vary across different types of policy shocks. The contribution from future dividends is found to be relatively high for a forward guidance shock than a current federal funds rate shock. Large-scale asset purchases shocks are found to have transmission channels making both positive and negative contributions supporting the arguments on information effects associated with such announcements. Meanwhile, the sector-wise analysis highlights that for a federal funds rate shock, the sectors which are more interest rate sensitive tend to report large excess equity return responses. Further, the sectoral equity premium responses derived for a forward guidance shock reaffirmed the relatively homogeneous effects of forward guidance on equity prices.

The second chapter proposes a potential solution to the open economy version of the *forward guidance puzzle*. Standard models for monetary policy analysis show that far future forward guidance has implausibly large effects on current output and inflation, and these effects grow with the forward guidance horizon, a phenomenon known as the forward guidance puzzle. I attempt to analyze the effectiveness of forward guidance policies in a small open economy model, focusing on an open economy version of the forward guidance puzzle, in order to assess its impact on the exchange rates, in addition to output and inflation. In a standard small open economy model with complete international financial markets, not only the output gap and inflation, but also the exchange rates tend to overreact in a forward guidance experiment. In order to find a possible resolution to this phenomenon, a perpetual youth structure is incorporated into the benchmark small open economy model under consideration. I then show that the presence of agents with finite lives tends to weaken the excessive response of key macroeconomic variables to a forward guidance announcement, including the exchange rate.

In the third chapter, I estimate the high-frequency changes in interest rate expectations and term premia across the yield curve due to monetary policy surprises on the Federal Open Market Committee (FOMC) announcement days, and analyze its effects on the financial markets and the overall economy. Disaggregation of yield curve responses shows that a current federal funds rate shock has a bigger impact on expectations than on term premium for short-term yields. For long-term yields, a forward guidance shock has a bigger impact on expectations than on term premium. A large-scale asset purchase shock is mainly transmitted through expectations supporting the signaling channel of balance sheet policies. It is shown that instruments for the changes in expectations could be identified along the lines of conventional short-term rate shocks as well as forward guidance and asset purchase shocks. In the financial markets, a shock to expectations for the short end of the yield curve is associated with substantial and statistically significant effects on short-term debt instruments, while shocks to expectations about the future interest rate path and asset purchases are associated with substantial and statistically significant effects on long-term debt instruments. Term premium effects, although orthogonalized against expectations, relate to meaningful responses in both short- and long-term instruments. Regarding the macroeconomic impact, a shock to expectations for the short end of the yield curve brings about the usual contractionary effects. A shock to expectations about the future rate path results in an increase in long-term yields and a drop in consumer prices, although with an expansion in economic activity suggesting the presence of either the “Fed response to news” channel or the “Fed information effect” channel. A surprise to asset purchase expectations leads to an increase in economic activity and employment, supporting the arguments for the balance

sheet policies of the Federal Reserve. Meanwhile, orthogonalized term premium effects on the economy are found to be similar to those of a policy uncertainty shock.

Chapter 1

The Impact of Federal Reserve's Conventional and Unconventional Monetary Policies on Equity Prices

1.1 Introduction

The ability of monetary policy to achieve its long-term objective of stabilizing macroeconomic variables such as inflation, output and employment largely depends on the effectiveness of the policy transmission channels. Given the importance of the asset price channel in the overall monetary transmission mechanism, it is critical to understand the link between monetary policy actions and asset prices. In the meantime, turbulent economic and financial conditions in recent years warranted central banks to use a broad spectrum of monetary policy instruments rather than resorting to conventional monetary policy tools. In such a context, this research attempts to analyze the impact of the U.S. Federal Reserve's monetary policy actions, both conventional and unconventional, on one of the most important financial markets, the equities market.

Under conventional monetary policy, I consider the surprise changes in the federal funds rate on FOMC announcement days, while under unconventional monetary policy I consider the two most extensively used policies: forward guidance and large-scale asset purchases (LSAPs). Under forward guidance, a central bank attempts to influence expectations about the future path of the policy interest rate. Under LSAPs, a central bank purchases large quantities of longer-term Treasury securities and mortgage-backed securities to influence long-term interest rates. For this study, monetary policy surprises are taken from Swanson (2021), which separately identifies surprise changes in the federal funds rate, forward guidance, and LSAPs on FOMC announcement days by extending the high-frequency approach of Gurkaynak et al. (2005). Equity price changes are measured by the movements in the S&P 500 Index, where prices at the aggregate level as well as at economic sector levels are considered.

The first part of the study focuses on assessing the impact of monetary policy surprises on different sectors of the stock market. Swanson (2021) analyses the effects of interest rate, forward guidance and LSAP shocks on the overall stock price index. I widen the scope of this analysis by assessing the effects on sector-wise stock price indexes. By doing so, it is possible to gauge how various sectors in the economy perceive different policy actions of the Federal Reserve. The estimates show that although the overall stock market respond strongly to a surprise change in the federal funds rate with a high level of statistical significance, a heterogeneity in responses is present among different sectors in the stock market with some sectors displaying an increased interest rate response, whereas certain other sectors report small coefficients with are not statistically significant. Sectors that either undertake long-term investments which are sensitive to the cost of capital or produce goods that require large consumer loans are found to be more sensitive to the current federal funds rate surprises.

Forward guidance is also estimated to have meaningful and highly statistically significant effects on overall stock prices. More importantly, forward guidance is reported to have a relatively homogeneous effect on sector-wise stock market performance. Almost all sectors exhibit statistically significant coefficients for forward guidance shocks, while the variation in the magnitude of coefficient values across sectors is not as large as that for the federal funds rate. Accordingly, the empirical evidence suggests that although the investors in the stock market weigh the industry-specific effects of short-term interest rate changes, when it comes to changes to the future path of interest rates, investors focus more on the overall macroeconomic effects of such policy actions. Meanwhile, the effects of LSAPs on overall equity prices as well as on sectoral equity prices are not statistically significant, indicating that the argument that LSAPs during the ZLB period were an effective substitute for conventional monetary policy needs to be accompanied with some caveats.

The second part of the study performs a variance decomposition of excess equity returns (i.e., the equity premiums) following the vector autoregression (VAR) based methodology used in Campbell (1991), and Campbell and Ammer (1993). This analysis helps determine the relative contributions of news about the real interest rates, dividends and expected future excess returns to fluctuations in the current period's excess return. The studies by Campbell and Ammer (1993) and Bernanke and Kuttner (2005) focus only on the excess equity returns calculated based on the overall price index. However, I expand on this by focusing on sector-wise equity returns, in addition to overall equity returns, thereby analyzing the variance decompositions for different sectors of the economy. The results show that the variance in future excess returns emerge as the dominant factor determining the current period's equity premium both for the overall stock price index and most of the sector indexes. Dividends and the future real interest rates record smaller contributions to the equity premium, with dividends reporting a slightly larger contribution than the real rates. However, the relative contribution of future dividends, real interest rates and excess returns vary across sectors.

The last part of the study focuses on analyzing the impact of different monetary policy surprises using the methodology in Bernanke and Kuttner (2005). This approach works within the VAR based framework introduced in Campbell and Ammer (1993). This part of the study is an extension to Bernanke and Kuttner (2005), since the authors focus only on interest rate surprises, whereas I consider forward guidance and LSAP surprises in addition to the federal funds rate surprises. Furthermore, I analyze the sector-wise effects of policy shocks as well. Accordingly, the dynamic responses to the three types of monetary policy surprises are estimated. Overall, the resultant impulse responses exhibit intuitive and meaningful changes in macroeconomic variables to monetary tightening/loosening scenarios under both conventional and unconventional tools. Moreover, since the current period's excess equity return can be specified in terms of the discounted sums of future excess equity returns, current and future real interest rates and dividends, these factors can be considered as the channels through which the monetary policy actions get transmitted to the equity prices. Therefore, in order to assess the relative importance of each of these channels, the present value estimates for one standard deviation surprises in the federal funds rate, forward guidance and LSAPs are estimated. The results indicate that the future excess returns account for a major share of the current period's response in equity premium, while dividends and the real interest rates account for a minor share. This result holds true for each type of monetary policy shock considered. For surprises in the federal funds rate, the real interest rates make a marginally higher contribution than dividends. For forward guidance, dividends record the second largest relative contribution, while the real interest rates record a significantly small contribution. With regard to LSAP shocks, the contribution of dividends is surprisingly negative, although the real interest rates make a positive contribution as one would expect. The presence of both negative and positive contributors suggests that there could be information effects associated with LSAP announcements as highlighted in Joyce et al. (2011).

The sector-wise decomposition broadly follows the patterns observed for the overall stock market, with some notable highlights. For the federal funds rate shocks, the sectors which are more interest rate sensitive than others are found to report large excess equity return responses. The relatively homogeneous nature of the effects of forward guidance observed in the first part of the study is reaffirmed by the excess return responses derived for different economic sectors. Meanwhile, a considerable heterogeneity in the contribution of transmission channels is evident across sectors for LSAP surprises, where the response of the current period's excess returns is a mix of both positive and negative contributions from different transmission channels under consideration.

The remainder of the chapter is structured as follows. Section 1.2 briefly summarizes some selected literature, which are closely related to my study. In Section 1.3, I elaborate on the data used for the study including the monetary policy surprises. Section 1.4 presents regression estimates for the impact of policy surprises on equity prices. In Section 1.5, I provide a variance decomposition analysis of excess equity returns, while in Section 1.6 the effects of monetary policy surprises are analyzed within the framework developed under Section 1.5. Section 1.7 summarizes the results and concludes.

1.2 Related Literature

There are several studies assessing the impact of surprises in the federal funds rate, the Federal Reserve's forward guidance announcements, and LSAPs or quantitative easing on the U.S. asset markets. Such studies include Bernanke and Kuttner (2005), Gurkaynak et al. (2005), Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011), D'Amico et al. (2012), Joyce et al. (2012) and Swanson (2021) among others. However, only a selected set of papers are summarized in this section since those studies have some methodological similarities to the approach I follow.

In an early study, Gurkaynak et al. (2005) investigate the effects of the Federal Reserve's policy actions on asset prices using a high-frequency event study approach. The study finds that the effects of monetary policy on asset prices are best characterized by two factors, which are identified as the "current federal funds rate target" factor and "future path of policy" factor. In today's terminology, the seconds factor corresponds to forward guidance. According to their findings, the two factors are found to have important but differing effects on asset prices. Swanson (2021) extends this analysis by separately identifying surprise changes in the federal funds rate, forward guidance, and LSAPs. Overall, the paper shows that forward guidance and LSAPs had substantial and statistically significant effects on asset prices. In particular, forward guidance is estimated to have a highly statistically significant effect on equity prices, with the magnitude of the effect amplifying during the zero lower bound (ZLB) period. In contrast, the effects of LSAP surprises on stock prices are not found to be significant. The analysis in Swanson (2021) however is limited to the overall stock price index, whereas I assess the effects on sector-wise stock price indexes and the transmission channels.

Bernanke and Kuttner (2005) is another early study which analyzes the impact of surprise changes in policy interest rates on equity prices. A technique proposed by Kuttner (2001) is used to construct a measure of the surprise changes in policy interest rates, and the results show that the stock market reacts reasonably strongly to interest rate surprises. The analysis is carried out both at the aggregate level and at industry portfolio levels as measured by the CRSP value-weighted index. The paper then adapts the methodology introduced by Campbell (1991) and Campbell and Ammer (1993) to explore as to what explains the equity price response. Under this, the paper assesses how the policy surprises affect future interest rates, dividends, and excess returns of equities, and finds out that the impact on equity prices comes mainly through the policy's effect on expected future excess equity returns. Nonetheless, the studies by Campbell and Ammer (1993) and Bernanke and Kuttner (2005) focus only on excess equity returns calculated based on the overall price index. However, I expand on this by decomposing the excess equity returns for different sectors of the economy. Furthermore, Bernanke and Kuttner (2005)'s analysis is limited to conventional monetary policy, where the dynamic responses are evaluated only for interest rate surprises. In contrast, I assess the dynamic responses to forward guidance and LSAP shocks in addition to the conventional interest rate surprises.

1.3 Data on Policy Surprises and Equity Prices

Separately identifying the effects of forward guidance and LSAPs could be challenging due to several reasons: some of the announcements by FOMC provide information about both types of policies simultaneously; only the unanticipated component of monetary policy should be determined as financial markets are forward-looking; and FOMC can even surprise markets through inaction Swanson (2021). In order to address these problems, Swanson (2021) extends the high-frequency approach of Gurkaynak et al. (2005) to separately identify forward guidance and LSAP surprises, in addition to interest rate shocks. Monetary policy surprises for this study are taken from Swanson (2021), where the full sample includes estimates of policy surprises on FOMC announcement days from July 1991 to June 2019. The techniques presented in Swanson (2021) and its estimated policy surprises are used in several studies related to monetary policy. For example, the methodology developed in Swanson (2021) is adopted in Altavilla et al. (2019) and Leombroni et al. (2021) to identify the key dimensions of policy shocks of the European Central Bank (ECB). Further, Cieslak (2018) consider monetary policy shocks estimated in Swanson (2021) to assess the ex-post predictability of policy surprises.

The methodology followed by Swanson (2021) starts with calculating the high-frequency (30-minute) responses of the prices of the federal funds futures, Eurodollar futures, Treasury securities, equities and foreign exchange, bracketing each FOMC announcement. These responses are then arranged as a factor model. Following Cragg and Donald (1997a) and Gurkaynak et al. (2005), the rank of the unobserved factors is found to be three, suggesting that the observed data are well explained by a model with three factors. Since the principal components by themselves do not have a structural interpretation, identifying assumptions are imposed to choose an appropriate rotation matrix such that the rotated factors have a structural interpretation. The key identification restrictions considered are: the changes in forward guidance and LSAPs have no effect on the current federal funds rate, and the LSAP factor is as small as possible in the pre-ZLB period. With these identification assumptions, Swanson (2021) argues that the resulting factors closely correspond to changes in the federal funds rate, forward guidance and LSAPs, respectively.[1] Finally, these rotated factors are normalized to have a unit standard deviation. The signs of the estimated factors are such that positive values in the federal funds rate and forward guidance factors correspond to a contractionary policy shock, whereas positive values in the LSAP factor correspond to an expansionary shock.

Equity price changes are measured using the S&P 500 stock market index. Daily data from July 1991 to June 2019 of the overall price index as well as its sector-wise indexes are used for the analysis. The sector-wise indexes of S&P 500 are based on the Global Industry Classification Standard (GICS) industry taxonomy developed by the S&P Dow Jones Indices and MSCI Inc. The GICS structure comprises 11 sectors, 24 industry groups and 69 industries, where all public companies in the S&P 500 index are categorized under. A list of GICS sectors and their respective weights in the S&P 500 index as of end September 2020 are summarized in Table 1.1.

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[1] Please refer Swanson (2021) for mathematical details of the factor model, identification restrictions, robustness checks, and details on the correspondence of estimated factors to notable FOMC announcements.

Table 1.1: Sector indexes of S&P 500

Sector Index	Weight*
Energy	2.1 %
Materials	2.6 %
Industrials	8.3 %
Consumer Discretionary	11.6 %
Consumer Staples	7.0 %
Health Care	14.2 %
Financials	9.7 %
Information Technology	28.2 %
Communication Services†	10.8 %
Utilities	3.0 %
Real Estate‡	2.6 %

* Weight in the overall S&P 500 index as of September 30, 2020

† Formerly Telecommunication Services

‡ Spun off from the Financial sector in 2016

1.4 Estimation of Equity Price Responses

This section estimates the effects of the surprise changes in monetary policy on FOMC announcement days on stock market performance. I calculate the daily changes in different stock price indexes around FOMC announcements from July 1991 to June 2019. The relationships between the calculated changes in the S&P 500 Index and the corresponding monetary policy surprises identified in Swanson (2021) are first presented in a series of scatter plots as depicted in Figure 1.1. The top panel of Figure 1.1 shows the respective data for the pre-ZLB period (i.e., from July 1991 to December 2008). The three scatter plots in the top panel suggest that it is likely for the three monetary policy factors to have a negative regression coefficient for the corresponding period. Furthermore, it can be noted that both forward guidance and LSAP factor estimates are distributed equally around zero to a greater extent. Nonetheless, extreme negative values can be observed for the federal funds rate factor.

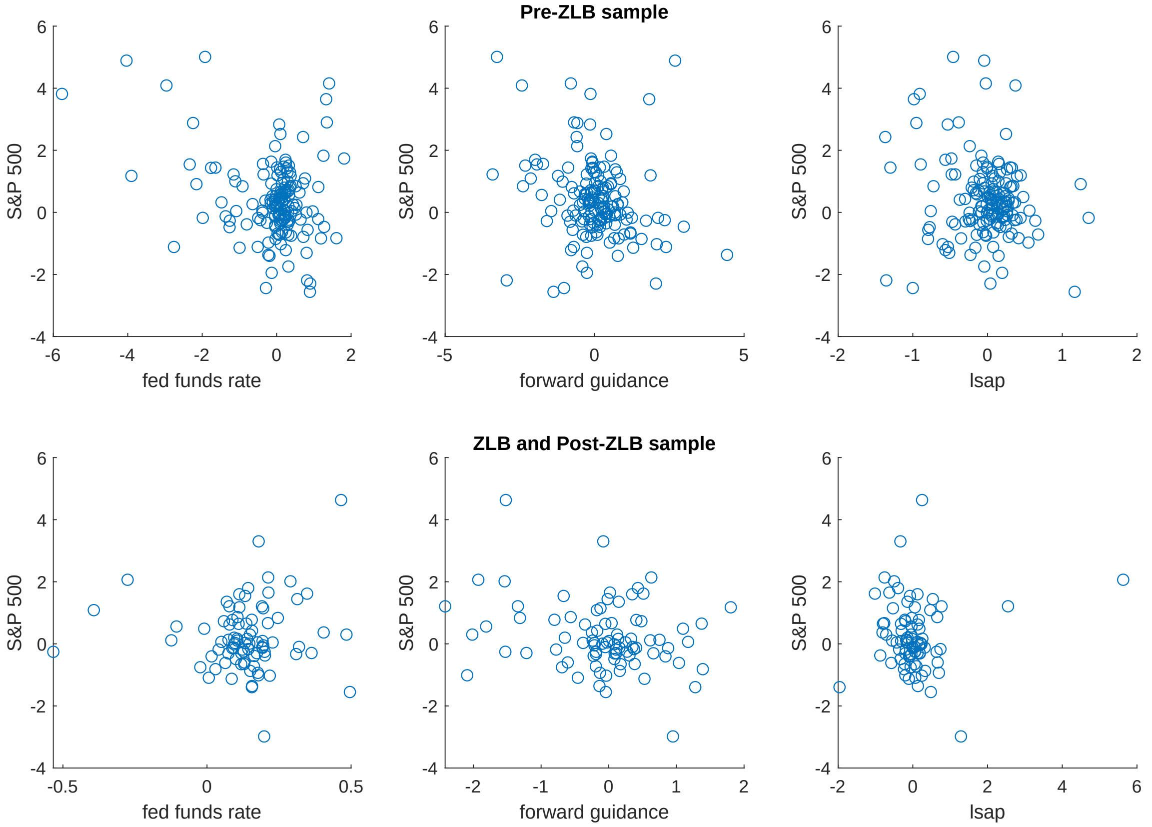

Figure 1.1: Daily change in the S&P 500 index versus estimated policy surprises

The bottom panel of Figure 1.1 depicts the estimated policy surprises against the respective daily changes in the S&P 500 index for the ZLB and post-ZLB period (i.e., from January 2009 to June 2019). Some degree of negative correlation is visible between the estimated forward guidance factors and stock prices. However, such a clear relationship is not visible for the federal funds rate as well as LSAP surprises. Meanwhile, a clear outlier is visible in the scatter plot for LSAPs, which corresponds to the "QE1" LSAP announcement on March 18, 2009. This announcement is considered to be very influential since that was the first time the FOMC announced an LSAP program as an expansionary monetary policy tool when its traditional policy instrument was constrained at the ZLB. Moreover, this seems to have been a major surprise to financial markets, given the large size of the LSAP factor estimated in March 2009.

1.4.1 Effects on Overall Equity Prices

I begin the analysis by estimating the effects of the surprise changes in the federal funds rate, forward guidance and LSAPs on overall stock prices. Accordingly, following Swanson (2021), OLS regressions of the following form are carried out:

$$\Delta y_t = \alpha + \beta \tilde{F}_t + \varepsilon_t, \tag{1.1}$$

where Δy denotes the daily change in the (log) equity price index multiplied by 100, $\tilde{F}$ denotes the monetary policy factors, and ε is the residual. Furthermore, t indexes the FOMC announcement dates. The regressions are similar to those of Swanson (2021) except for the fact that I consider daily changes in equity prices in contrast to a 30-minute response. Furthermore, I repeat the estimates for the Dow Jones Industrial Average and the NASDAQ Composite Index in addition to S&P 500, which is the primary index of analysis. Table 1.2 presents estimated effects of policy surprises for the overall equity price indexes for the full sample from July 1991 to June 2019 as well as its sub samples.

In the pre-ZLB period (panel B of Table 1.2), the coefficient on the federal funds rate surprise is negative and highly statistically significant, indicating that a one-standard-deviation surprise increase in the federal funds rate causes the S&P 500 Index to fall by 0.38 percent. With regard to forward guidance, the estimated coefficient is again negative and highly statistically significant. As such, the S&P 500 Index is estimated to fall by 0.25 percent during this period for a one-standard-deviation tightening of forward guidance. However, the R^2 value of the regression takes a low value of 0.14 as there could be many idiosyncratic factors affecting stock prices in any given period.

Table 1.2: Estimated effects on overall equity prices

	S&P 500	Dow Jones industrial average	NASDAQ composite index
(A) Full sample, Jul.1991–Jun.2019 (241 obs.)			
change in federal funds rate	-0.38***	-0.31***	-0.73***
(std. err.)	(0.09)	(0.08)	(0.12)
change in forward guidance	-0.27***	-0.25***	-0.17*
(std. err.)	(0.07)	(0.07)	(0.10)
change in LSAPs	-0.09	-0.11	-0.05
(std. err.)	(0.12)	(0.11)	(0.17)
Regression R^2	0.12	0.11	0.14
(B) Pre-ZLB sample, Jul.1991–Dec.2008 (157 obs.)			
change in federal funds rate	-0.38***	-0.31***	-0.74***
(std. err.)	(0.09)	(0.09)	(0.14)
change in forward guidance	-0.25***	-0.25***	-0.13
(std. err.)	(0.09)	(0.08)	(0.13)
Regression R^2	0.14	0.13	0.16
(C) ZLB sample, Jan.2009–Nov.2015 (55 obs.)			
change in forward guidance	-0.44**	-0.41**	-0.38*
(std. err.)	(0.22)	(0.19)	(0.22)
change in LSAPs	-0.07	-0.12	-0.06
(std. err.)	(0.18)	(0.16)	(0.19)
Regression R^2	0.08	0.09	0.06
(D) Post-ZLB sample, Dec.2015–Jun.2019 (29 obs.)			
change in federal funds rate	-0.83	-0.75	-1.00
(std. err.)	(0.74)	(0.78)	(0.99)
change in forward guidance	-0.30*	-0.17	-0.36
(std. err.)	(0.17)	(0.18)	(0.23)
change in LSAPs	0.34	0.24	0.09
(std. err.)	(0.52)	(0.54)	(0.69)
Regression R^2	0.14	0.06	0.11

Coefficients are in percentage points per standard deviation change in the monetary policy instrument.

***, **, and * denote statistical significance at 1, 5 and 10 percent levels, respectively.

For the ZLB period (panel C of Table 1.2), forward guidance causes the S&P 500 Index to fall by 0.44 percent. The effects are highly statistically significant, and more importantly they are larger than the pre-ZLB period effects suggesting the relatively important role played by forward guidance during the ZLB period. The coefficient on LSAP surprises is not statistically significant and remains negative. The negative sign of the coefficient however is puzzling, since an increase in LSAP factor corresponds to monetary easing and causes interest rates to fall. Panel D of Table 1.2) provides the estimates for the post-ZLB period. The resulting effects of monetary policy factors are broadly similar to the previous periods, although the sample size remains relatively short. However, the LSAPs coefficient, though not statistically significant, reports the anticipated sign for an expansionary shock.

The full sample effects are given in panel A of Table 1.2, which is an aggregate of the effects estimated for the three sub-samples. Overall, the estimated coefficients for the federal funds rate surprises are very similar to Swanson (2021), which in turn closely follows the estimates in Bernanke and Kuttner (2005) and Gurkaynak et al. (2005). Nonetheless, the resultant coefficients for forward guidance are larger than Swanson (2021), which reports a coefficient of -0.14 for the full sample in comparison to -0.27 reported in Table 1.2. This could suggest that it takes more time to propagate the full impact of forward guidance to stock prices, as Swanson (2021) uses price changes in a shorter 30-minute window. The estimated LSAP coefficients are not statistically significant as in Swanson (2021). However, in contrast to Swanson (2021), coefficients in the full sample as well as in the ZLB sample take negative values.

In order to validate the outcomes discussed above, I perform the same regressions using the Dow Jones Industrial Average and the NASDAQ Composite Index. The results are reported in the last two columns of Table 1.2. The coefficient estimates for the Dow Jones Industrial Average closely correspond to those of the S&P 500 Index in terms of the sign, magnitude and the level of statistical significance. For the NASDAQ Composite Index, some degree of deviation can be observed in the magnitude and the significance level of the coefficient estimates. This could be attributed to the fact that the NASDAQ index is heavily weighted towards companies in the Information Technology (IT) sector. Moreover, some similarities can be found between the estimates for the NASDAQ Index and IT sector estimates of S&P 500, which will be presented in the following section. Overall, it is evident that the surprise changes in the federal funds rate and announcements under forward guidance had meaningful and significant effects on equity prices during the period under review. Nonetheless, the effects of LSAPs on overall equity prices are not statistically significant and may indicate puzzling outcomes as well.

The results indicate that not all unconventional monetary policy tools are effective in influencing the stock market. Forward guidance surprises are shown to be effective in moving stock prices, where its effectiveness during the ZLB period is about as effective as changes in the federal funds rate in normal times. As such, the results support the findings in other studies (e.g., Swanson and Williams (2014), Wu and Xia (2016), Swanson (2018)) that forward guidance, under unconventional monetary policy, is an effective substitute for conventional monetary policy and that U.S. monetary policy remained about as effective as normal during the ZLB period. Studies such as Krishnamurthy and Vissing-Jorgensen (2011) and Swanson (2021) show that the Federal Reserve's balance sheet policies had substantial effects on the long-term Treasury yields and corporate bond rates. However, announcements on LSAPs were not able to materialize significant instantaneous effects on the stock market. Therefore, the results indicate that the argument that LSAPs during the ZLB period were an effective substitute for conventional monetary policy needs to be accompanied with some caveats.

It is noteworthy that for LSAPs, the overall stock price index reports coefficients which are not highly statistically significant, while the sign of the estimated coefficients, in some cases, is not in line with the direct expansionary effects expected from asset purchases. However, there are other studies reporting similar findings. For example, Joyce et al. (2011) find that equity prices in the UK reacted in a less uniform way after the Bank of England's quantitative easing announcements. The authors argue that there are two opposing forces impacting equity prices. Low long-term yields due to LSAPs should increase the present value of future dividends, thereby raising equity prices. Furthermore, as investors attempt to rebalance their portfolios towards more risky assets, the equity risk premium should fall, thus putting further upward pressure on equity prices. On the other hand, LSAP announcements may also give information about the outlook for the economy, and if that is worse than expected, expectations for future dividends could fall and risk premia could rise, thereby putting downward pressure on equity prices. Therefore, the immediate LSAP impact may not be clear. Meanwhile, the negative sign recorded for some of the LSAP coefficients is in line with the findings of Glick and Leduc (2012), whose estimates show that expansionary LSAP surprises resulted in a drop in the S&P 500 Index, while contractionary surprises were accompanied by rising stock prices. Glick and Leduc (2012) attribute this outcome to the signaling effects of LSAP announcements about the future economic outlook.

1.4.2 Sectoral Effects on Equity Prices

Although many studies focus on finding the effects of different monetary policy instruments on the stock market performance as a whole, little attention has been given to sector-wise stock price responses. Therefore, in this section, I assess the impact of monetary policy surprises on different sectors of the stock market. By doing so, one would be able to get an idea as to how different sectors in the economy perceive Federal Reserve's policy actions, both conventional and unconventional.

In order to assess the sectoral equity price movements in response to policy shocks, I repeat the exercise carried out before by estimating OLS regressions of the form given by equation (1.1) for different sectors of the stock market. The set of policy surprises remains the same: i.e., current federal funds rate, forward guidance and LSAP shocks estimated by Swanson (2021). However, instead of the daily change in the overall stock price index, the daily changes in the S&P 500 sector indexes as classified under GICS are used as the left hand side variable (i.e., Δy_t). Estimates are carried out for all 11 GICS sectors of the S&P 500 index. Table 1.3 presents the estimated effects on sector-wise stock price indexes for the full sample as well as its sub samples.

Estimates based on sector-wise stock price indexes reveal that some sectors are more sensitive to interest rate surprises than others, whereas certain other sectors do not show any statistically significant interest rate sensitivity. As shown in Table 1.3, IT and Consumer Discretionary are the most interest rate sensitive sectors both in the full sample (panel A) and in the pre-ZLB sample (panel B). Industrials and Financials exhibit a moderate interest rate sensitivity, while Materials and Communication Services show a low sensitivity. No statistically significant relationships are found for Energy, Consumer Staples, Health Care and Utilities sectors, with the coefficients remaining small in magnitude. The Real Estate sector reports a high level of interest rate sensitivity, however, its coefficients are not statistically significant. Results for the federal funds rate surprises are broadly in line with the findings of Bernanke and Kuttner (2005), though the study uses a different stock price index (the CRSP index) and a different sector classification. Bernanke and Kuttner (2005) find that Telecommunications, High-tech, and Durables are the three most interest rate sensitive industries, whereas Energy, Utilities and Health Care are the three least sensitive industries.

Studies on the interest rate sensitivity of different industrial sectors (e.g., Dedola and Lippi (2005), Skaperdas (2017)) find that the most interest rate sensitive sectors consist of firms that either undertake long-term projects sensitive to the cost of capital or produce goods that require large consumer loans. Accordingly, Skaperdas (2017)finds that Construction, and Mining, Quarrying, and Oil and Gas Extraction are the most sensitive sectors in the U.S. economy, and these are industries that are highly affected by investment funding levels. The author also finds that the part of the manufacturing sector which is highly responsive

Table 1.3: Estimated effects on equity prices: S&P 500 sectoral analysis

	Energy	Materials	Industrials	Consumer discretionary	Consumer staples	Health care	Financials	IT	Communication services	Utilities	Real estate[a]
(A) Full sample, Jul.1991–Jun.2019 (241 obs.)											
change in federal funds rate	0.14	-0.35***	-0.49***	-0.68***	0.11	0.05	-0.49***	-0.86***	-0.27**	0.07	-0.49
(std. err.)	(0.11)	(0.11)	(0.09)	(0.10)	(0.08)	(0.09)	(0.16)	(0.14)	(0.11)	(0.09)	(0.36)
change in forward guidance	-0.36***	-0.32***	-0.26***	-0.28***	-0.32***	-0.31***	-0.35***	-0.17	-0.34***	-0.35***	-0.44**
(std. err.)	(0.09)	(0.09)	(0.08)	(0.08)	(0.06)	(0.07)	(0.13)	(0.12)	(0.09)	(0.07)	(0.19)
change in LSAPs	-0.27*	-0.22	-0.16	-0.14	-0.09	0.00	0.10	-0.06	0.13	0.31**	-0.08
(std. err.)	(0.15)	(0.15)	(0.13)	(0.14)	(0.10)	(0.12)	(0.22)	(0.20)	(0.15)	(0.13)	(0.29)
Regression R^2	0.08	0.10	0.15	0.19	0.11	0.07	0.07	0.14	0.08	0.11	0.04
(B) Pre-ZLB sample, Jul.1991–Dec.2008 (157 obs.)											
change in federal funds rate	0.16	-0.35***	-0.48***	-0.67***	0.12	0.05	-0.49***	-0.87***	-0.29**	0.08	-0.48
(std. err.)	(0.11)	(0.11)	(0.10)	(0.11)	(0.08)	(0.10)	(0.15)	(0.17)	(0.12)	(0.10)	(0.44)
change in forward guidance	-0.34***	-0.28***	-0.25***	-0.26**	-0.33***	-0.32***	-0.37***	-0.14	-0.26**	-0.22**	-0.23
(std. err.)	(0.10)	(0.10)	(0.09)	(0.10)	(0.07)	(0.09)	(0.14)	(0.16)	(0.11)	(0.09)	(0.28)
Regression R^2	0.08	0.10	0.18	0.22	0.12	0.08	0.10	0.15	0.07	0.04	0.03
(C) ZLB sample, Jan.2009–Nov.2015 (55 obs.)											
change in forward guidance	-0.61**	-0.56*	-0.49**	-0.44*	-0.47***	-0.46**	-0.26	-0.33	-0.62***	-0.83***	-0.70
(std. err.)	(0.27)	(0.28)	(0.23)	(0.23)	(0.15)	(0.17)	(0.48)	(0.21)	(0.18)	(0.18)	(0.42)
change in LSAPs	-0.33	-0.09	-0.14	0.04	-0.23*	-0.22	0.55	-0.08	-0.06	0.13	0.30*
(std. err.)	(0.23)	(0.24)	(0.19)	(0.20)	(0.12)	(0.15)	(0.41)	(0.18)	(0.15)	(0.15)	(0.36)
Regression R^2	0.09	0.08	0.08	0.08	0.16	0.12	0.06	0.05	0.21	0.38	0.10
(D) Post-ZLB sample, Dec.2015–Jun.2019 (29 obs.)											
change in federal funds rate	-2.25	-1.88*	-1.23	-0.92	0.35	-0.19	-1.04	-1.22	-0.47	-0.16	-0.05
(std. err.)	(1.44)	(0.99)	(0.95)	(0.95)	(0.91)	(0.89)	(0.84)	(1.12)	(1.44)	(1.10)	(1.17)
change in forward guidance	-0.61*	-0.52**	-0.27	-0.29	-0.32	-0.2	0.18	-0.38	-0.85**	-0.68**	-0.82***
(std. err.)	(0.33)	(0.23)	(0.22)	(0.22)	(0.21)	(0.21)	(0.19)	(0.26)	(0.33)	(0.26)	(0.27)
change in LSAPs	0.30	0.64	0.42	0.09	0.77	0.15	-0.05	-0.04	2.22**	1.86**	1.13
(std. err.)	(1.00)	(0.69)	(0.66)	(0.66)	(0.63)	(0.62)	(0.58)	(0.78)	(1.00)	(0.76)	(0.81)
Regression R^2	0.17	0.25	0.11	0.09	0.12	0.04	0.10	0.11	0.27	0.30	0.28

Coefficients are in percentage points per standard deviation change in the monetary policy instrument.
***, **, and * denote statistical significance at 1, 5 and 10 percent levels, respectively.

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[a] The Real estate sector was introduced in 2016. Before that, Real estate was an industry group in the Financials sector. Therefore, when constructing the data series, Real estate sector index data from September 19, 2016 are combined with Real estate industry group's sub-index level data prior to September 19, 2016. However, such data is available only from October 2001.

composed mostly of durable goods which are intertemporally substitutable. The movements of the sectoral stock price indexes for a shock to the current federal funds rate, as shown in Table 1.3, are mostly in line with the interest rate sensitivity findings for the broader economy stated above. The Consumer Discretionary sector of GICS consists of industries such as Automobiles and Consumer Durables for which most of the customers require large consumer loans. Hence, a low interest rate environment boosts the profitability of such industries. The same logic could be applied to the Real Estate sector of GICS as well. Furthermore, IT and Industrials sectors of GICS comprises industries such as Semiconductors, Technology Hardware, Capital Goods and Transportation, and all such industries undertake long-term investments which are sensitive to the cost of capital.

With regard to forward guidance, estimates reveal that announcements pertaining to the future path of policy actions are having a more "across the board" impact on stock prices, in comparison to the effects estimated for a current federal funds rate shock. In the full sample (panel A), all sectors except IT are having statistically significant coefficients for forward guidance. Further, the variation in the magnitude of coefficient values across sectors is not as large as that for the federal funds rate. Even in the pre-ZLB (panel B) and ZLB (panel C) subsamples, most of the sectors exhibit highly statistically significant coefficients for a forward guidance surprise. Another interesting result is that, compared to the pre-ZLB period, the effects of forward guidance were larger for all sectors in the ZLB period, except the Financials sector. This suggests that in the absence of conventional monetary policy tools with the onset of the ZLB, the Federal Reserve's commitment to a future path of interest rates had a bigger effect on almost all sectors of the economy, compared to the preceding period. Overall, the sector-wise analysis suggests that forward guidance is having a more homogeneous and widespread impact on stock prices than changes to the current federal funds rate, and its impact has amplified during the ZLB period.

It is interesting to note that the patterns observed in terms of interest rate sensitivity of industries for a surprise change in the current federal funds rate are not visible for a surprise change in the future path of interest rates as announced through forward guidance. Therefore, the empirical evidence from the initial regression analysis indicates that although the investors in the stock market weigh the industry-specific effects of short-term interest rate changes, when it comes to changes to the future path of interest rates, investors focus more on the overall macroeconomic effects of such policy actions. This is suggestive, and the variance decomposition analysis performed in the following sections could provide more explanation for this phenomenon.

For LSAPs, most of the sectors are found to have a negative coefficient in the ZLB period (panel C), in line with the puzzling outcome observed for the overall stock price indexes for the same period. A few sectors exhibit positive coefficients during this period supporting the direct effects associated with asset purchases. However, none of the sectors are found to have a highly statistically significant coefficient. This pattern reverses in the post-ZLB period (panel D) where most of the sectors exhibit positive coefficients for LSAPs with some being highly statistically significant. Meanwhile, as highlighted before, “QE1” LSAP announcement on March 18, 2009 has been identified as a very influential announcement made at a time when financial markets were functioning very poorly (Swanson, 2021). Accordingly, the analysis is repeated excluding the LSAP announcement in March 2009. The results for the S&P 500 Index and its sector indexes are reported in the Appendix in Table A.1, respectively. The main change comes through the estimates for the ZLB period. Once the influential data point is removed, the negative coefficients for the LSAP factor become more negative (large in magnitude), while positive coefficients become less positive or turn negative. The reason for this outcome is evident from the last scatter plot in the bottom panel of Figure 1.1, where one can observe that the respective data point, which is the rightmost outlier, is clearly in favor of a positive coefficient. Therefore, the exclusion of the March

2009 FOMC announcement, which contains the “QE1” LSAP announcement, amplifies the puzzling outcome for LSAPs in terms of the coefficient sign.

1.5 Variance Decomposition of Equity Returns

The previous section focused on quantifying the effects of monetary policy shocks on stock market performance. Next, I concentrate on analyzing the channels through which these policy shocks affect stock prices by following the two-stage approach used in Bernanke and Kuttner (2005). Bernanke and Kuttner (2005) states that there are three main reasons for a policy shock to result in a change in stock prices: changes in expected future dividends, a rise or fall in the future expected real interest rates, or a change in the expected excess returns associated with stocks. The first stage of the approach followed by Bernanke and Kuttner (2005) involves performing a variance decomposition analysis by means of a forecasting VAR to ascertain the key factors contributing to the variations in excess equity returns. Section 1.5 elaborates on this and presents the relevant results. The second stage involves estimating dynamic responses to the three types of policy shocks considered above by modifying the VAR structure developed in the first stage, and Section 1.6 focuses on this.

1.5.1 The Methodology Used

I follow the methodology used in Campbell (1991) and Campbell and Ammer (1993) to decompose the excess equity returns during the period from July 1991 to June 2019. As such, a VAR model is used to decompose current period excess stock returns into changes in expectations of future dividends, real interest rates and excess stock returns in the future.

This decomposition, based on Campbell and Ammer (1993), can be written as:

$$e_{t+1}^{y} = \tilde{e}_{t+1}^{d} - \tilde{e}_{t+1}^{r} - \tilde{e}_{t+1}^{y}, \tag{1.2}$$

where y, d and r represent excess stock returns, dividends and real interest rates, respectively. The revision in expectations between periods t and $t+1$ is denoted by e_{t+1}, while the tilde denotes a discounted sum of future values.

The relationship given by equation (1.2) is simple and intuitive. The revision in expectations for the current period's excess stock return is positively related to the revisions in expectations about future dividends. Accordingly, an increase in expected future dividends is associated with an increase in stock prices. However, the current period's excess stock return is negatively related to changes in expected future real interest rates which are used to discount those dividends. Changes in the expected future excess returns are also negatively related to the current period's excess stock return. This is because if the present value of future cash flows remains constant, an increase in stock prices in the future should be accompanied by a decrease in stock prices in the current period.

Campbell (1991) as well as Campbell and Ammer (1993) model expectations using a first order VAR of the form

$$z_{t+1} = Az_t \; + \; \omega_{t+1}, \tag{1.3}$$

capturing the dynamic correlations between the excess equity return and related variables, where z_{t+1} is a vector having the excess stock returns, real interest rates and other forecasting variables. As the VAR in equation (1.3) is specified to obtain proxies for the relevant expectations, innovations related to equation (1.2) are given by

$$e^y_{t+1} = s_y \omega_{t+1}, \tag{1.4}$$

$$\tilde{e}^y_{t+1} = s_y \rho A (1 - \rho A)^{-1} \omega_{t+1}, \tag{1.5}$$

$$\tilde{e}^r_{t+1} = s_r (1 - \rho A)^{-1} \omega_{t+1}, \tag{1.6}$$

$$\tilde{e}^d_{t+1} = e^y_{t+1} + \tilde{e}^r_{t+1} + \tilde{e}^y_{t+1}, \tag{1.7}$$

where ρ is a discount factor, and s_y and s_r are relevant selection vectors[2]. Meanwhile, equation (1.2) implies that the variance of excess stock returns can be written as the following combination of variances and covariances:

$$\begin{aligned} Var(e^y_{t+1}) =& Var(\tilde{e}^d_{t+1}) + Var(\tilde{e}^r_{t+1}) + Var(\tilde{e}^y_{t+1}) \\ &- 2Cov(\tilde{e}^d_{t+1}, \tilde{e}^r_{t+1}) - 2Cov(\tilde{e}^d_{t+1}, \tilde{e}^y_{t+1}) + 2Cov(\tilde{e}^r_{t+1}, \tilde{e}^y_{t+1}). \end{aligned} \tag{1.8}$$

Equation (1.8) gives an idea about the relative contributions of news about real interest rates, dividends, and expected future excess returns to variations in the current excess return associated with holding equities.

1.5.2 Estimation Outcomes

A first-order VAR as given in equation (1.3) is estimated using monthly data from July 1991 to June 2019. Following Bernanke and Kuttner (2005), the state vector, z_t, is specified as

$$z_t = [y_t,\ r_t,\ \Delta i_t,\ s_t,\ d_t - p_t,\ ri_t]'. \tag{1.9}$$

---

[2] Please see Campbell and Ammer (1993) for details of the derivation.

The excess return on equities, y_t, is the total return on equities as measured by the S&P 500 total returns index, minus the risk-free rate (the short-term interest rate). The real interest rate, r_t, is calculated as the short-term interest rate minus the log difference (year-on-year) in the non seasonally-adjusted CPI. The monthly change in the short-term interest rate is given by Δi_t, while s_t is the spread between the 10-year constant maturity Treasury yield and the short-term interest rate. The (log) dividend price ratio (dividend yield) is denoted by $d_t - p_t$, while ri_t denotes the relative interest rate defined as the current 3-month Treasury bill rate minus its 12-month lagged moving average.

In order to estimate the forecasting VAR, the effective federal funds rate is used as a measure of the short-term interest rate. Nonetheless, the ZLB episode from January 2009 to November 2015 could be of concern since the movements in short term interest rates were constrained by the effective lower bound. In order to overcome this issue, the shadow federal funds rate derived by Wu and Xia (2016) is used as an alternative measure of the federal funds rate for the ZLB period [3]. The CPI is based on the price index computed for all urban consumers in the U.S., and the dividend price ratio is based on an updated stock market data set used in Shiller (2015). Following Campbell and Ammer (1993), the discount factor ρ is set to 0.9962.

Once the VAR is estimated, its coefficient matrix (A) together with the innovations (ω_{t+1}) for the estimation period are used to calculate the relevant revisions in expectations as defined by equations (1.4) to (1.7). Then, a variance decomposition of excess equity returns, as specified in equation (1.8), is carried out and the results are presented in Table 1.4. The first column with estimation results provides the absolute value of the respective variances and covariance related calculations. The last column expresses each item's contribution as

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[3] Campbell and Ammer (1993) use 1-month Treasury yield as the measure of short-term interest rate, while Bernanke and Kuttner (2005) use a combination of 1-month and 3-month Treasury yields. However, using such measures during the ZLB period could lead to issues.

Table 1.4: Variance decomposition of excess equity returns

	Value	Share (%)
Var(excess return)	**16.47**	
Var(dividends)	0.66	3.98
Var(real rate)	0.21	1.25
Var(future excess returns)	9.84	59.74
-2 Cov(dividends, real rate)	0.05	0.33
-2 Cov(dividends, future excess return)	4.05	24.61
2 Cov(future excess return, real rate)	1.66	10.08

Decomposition of the variance of excess equity returns based on the relation $e^y_{t+1} = \tilde{e}^d_{t+1} - \tilde{e}^r_{t+1} - \tilde{e}^y_{t+1}$.

a percentage of the variance in the current period's excess return.

The variance in future excess returns dominates, accounting for around 60 per cent of the variation in current equity returns during July 1991 to June 2019. This is in comparison to 70.5 per cent found in Campbell and Ammer (1993) for the 1952-1987 period, and 76.0 per cent found in Bernanke and Kuttner (2005) for the 1973-2002 period. Dividends, however, make a smaller contribution of 4.0 per cent during the period under analysis, which is lower than 14.6 per cent recorded in Campbell and Ammer (1993) and 24.6 per cent in Bernanke and Kuttner (2005). The contribution of the real interest rate remains the smallest at 1.3 per cent. This is in line with 1.3 per cent found in Campbell and Ammer (1993) and 1.4 per cent in Bernanke and Kuttner (2005). The covariances account for the balance, which is about a third of the variance in the current period's excess return.

In addition to the variance decomposition analysis carried out for the overall stock price index, I repeat the variance decomposition procedure for the sectors of the stock market considered before. In order to perform this exercise, first I compute the sector-wise total returns on equities based on the GICS sector indexes of S&P 500 (total returns indexes). Next, I compute a dividend yield series for each sector under consideration as the stock market data

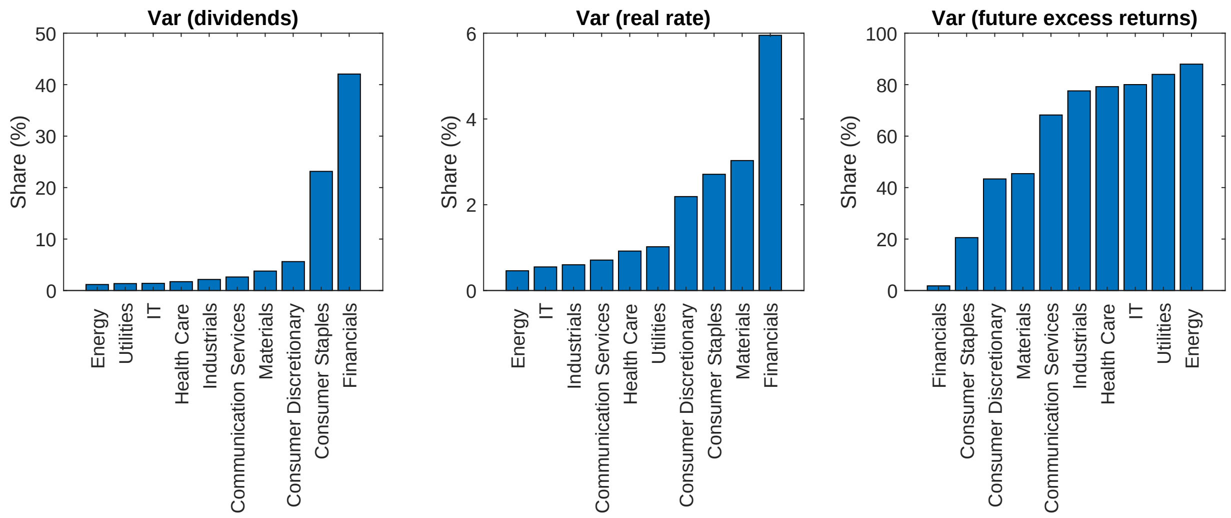

Figure 1.2: Variance decomposition in S&P 500 sectors

set of Shiller (2015) contains dividend yields only for the overall index. Accordingly, a proxy for monthly dividends is derived using the difference between the total returns index and price returns index. Then, the dividend yield is calculated as the sum of dividends for a 12-month period divided by the price returns index for the relevant month. Dividend yield calculated in this manner for the overall S&P 500 Index closely tracks the dividend yield series given in Shiller (2015).

With the excess equity return and dividend yield series calculated for each stock market sector, I repeat the VAR based analysis performed above with the rest of the variables remaining the same[4]. The details of the sectoral variances of expected future dividends, real interest rates and excess returns, and the respective covariance calculations are given in the Appendix in Table A.2. Figure 1.2 summarizes this by depicting the relative contribution of each of the factors for the current period's excess equity returns, arranged in an ascending order. The analysis reveals that even for the individual sectors, the variation in the future excess returns is the key factor driving the current performance of equities. Future dividends

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[4] The Real Estate sector is not considered for this analysis due to the unavailability of a longer data series for the total returns index. For the IT sector, a smoothed series of the total returns index is used (monthly averages instead of the month end values). This is done to overcome the extreme values resulting from excessive volatility in stock prices mainly during the dot com bubble period.

Table 1.5: Effect of policy surprises on forecast errors

Forecast Error Variable (regressand)	Federal funds rate	Forward guidance	LSAP
excess stock return	-0.892	-0.428	0.121
(std. err.)	(0.319)	(0.267)	(0.444)
real interest rate	0.047	0.013	0.006
(std. err.)	(0.03)	(0.025)	(0.042)
change in interest rate	0.06	-0.004	-0.018
(std. err.)	(0.011)	(0.01)	(0.016)
interest rate spread	-0.052	0.037	0.013
(std. err.)	(0.019)	(0.016)	(0.026)
dividend price ratio	0.001	0.002	0.002
(std. err.)	(0.002)	(0.002)	(0.003)
relative interest rate	0.05	0.008	0.03
(std. err.)	(0.012)	(0.01)	(0.017)

Coefficients estimated by regressing one-step-ahead forecast errors of the reduced form VAR on monetary policy surprises that serve as exogenous variables.

and the real interest rates continue to report a relatively low contribution. Financials and Consumer Staples sectors are the only exceptions to this. Financials and Consumer Staples emerge as the sectors with the largest contribution of future dividends for the current period's equity premium, while the Financials sector records the highest relative contribution of the real interest rates as well. Energy sector records the lowest relative contribution of future dividends and the real interest rates, while reporting the highest contribution of future excess returns. However, it is noteworthy that the variance decomposition analysis performed above is for a generic news shock. What is more important is to assess the relative contribution of different components for the three dimensions of monetary policy surprises under consideration and the next section of the study focuses on this.

1.6 The Effects of Monetary Policy Surprises

In this section, I analyze the impact of the monetary policy surprises considered above, following the methodology in Bernanke and Kuttner (2005). Accordingly, the proxies for

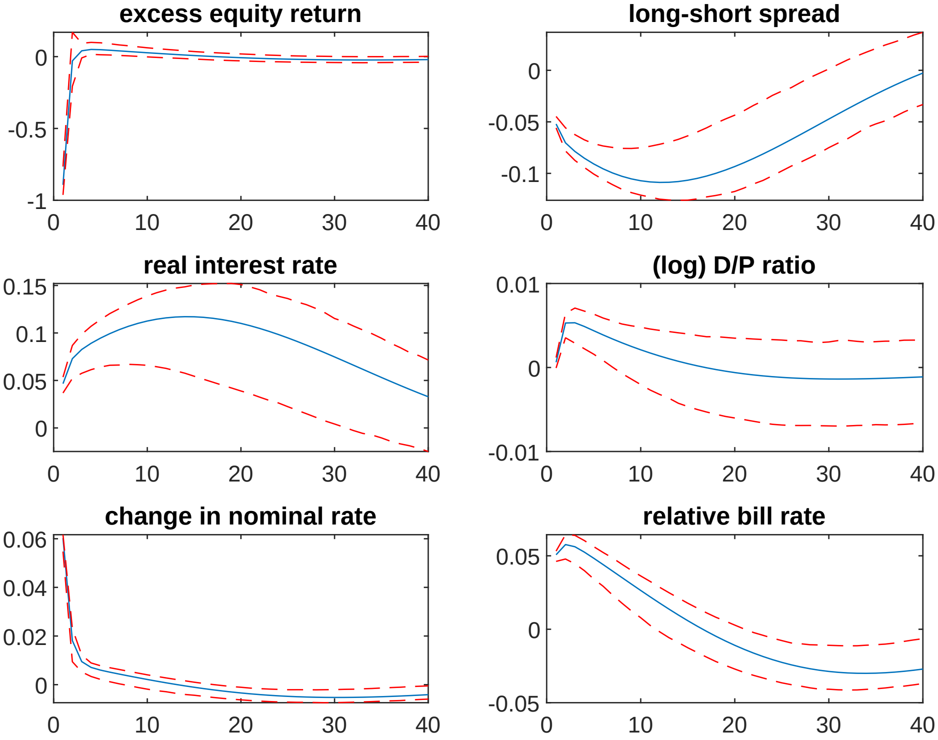

Figure 1.3: Impulse responses estimated for a federal funds rate surprise. Estimated responses are in solid blue lines and the bootstrapped 90 percent confidence bands are in dashed red lines. Interest rates are given in percentage points.

the Federal Reserve's policy surprises are included in the VAR based framework introduced above as exogenous variables. The modified VAR takes the following form:

$$z_{t+1} = Az_t \ + \ \phi \tilde{F}_{t+1} \ + \ \tilde{\omega}_{t+1}, \tag{1.10}$$

where $\tilde{F}$ denotes the monetary policy factors pertaining to surprise changes in the federal funds rate, forward guidance, and LSAPs estimated in Swanson (2021). The contemporaneous response of variables in z_{t+1} to the unanticipated monetary policy changes in period $t+1$ is captured by ϕ. The new error term is denoted by $\tilde{\omega}_{t+1}$ and it is orthogonal to the policy surprises by construction.

Equation (1.10) is estimated separately for each type of policy surprise, in which case ϕ is a 6×1 vector[5]. I follow the two-step approach where an estimate for ϕ is obtained by first estimating the VAR parameters and then regressing the one-step-ahead forecast error of the reduced form VAR (i.e., ω_{t+1} in equation (1.3)) on relevant monetary policy surprises. Similar to Section 1.5, the estimates are based on monthly data from July 1991 to June 2019. However, it is noteworthy that the original policy surprises are calculated for the FOMC announcement days. Therefore, the policy surprises are aggregated across months to perform the second stage of the estimates. The estimated coefficients of the second stage of the regression, which are the constituents of ϕ, are summarized in Table 1.5. Overall, the reported coefficients have the expected sign for each type of policy surprise.

The above estimates are then used to calculate the dynamic responses of the variables in the VAR to the three monetary policy surprises under consideration. As such, the response in the k^{th} month to a one standard deviation monetary policy surprise can be calculated as $A^k\phi$. Figure 1.3 displays the impulse responses calculated in this way for a surprise increase in the federal funds rate. The contractionary funds rate surprise leads to an initial decline in the excess equity returns. The increases in the real interest rate, nominal interest rate, relative bill rate, and the decline in the long-short spread can be attributed to the increase in short term interest rates due to monetary tightening. Meanwhile, the dividend-price ratio (log) shows an increase in response to the contractionary surprise as a result of the fall in equity prices. The direction of the initial responses are intuitive, and they are fairly similar to those reported in Bernanke and Kuttner (2005).

Bernanke and Kuttner (2005)'s analysis is limited to surprises in the federal funds rate. In addition to the federal funds rate, I present the dynamic responses to forward guidance and LSAP surprises. Accordingly, the impulse responses calculated for a contractionary

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[5] If all factors are incorporated in a single estimate, ϕ would be a 6×3 vector.

one standard deviation forward guidance surprise are depicted in Figure 1.4. The responses are somewhat similar to those of a contractionary funds rate surprise, but a few notable deviations could be observed. Despite an initial drop, the short-term interest rates increase with a time lag and remain elevated for a considerable period into the future. This could be attributed to the fact that forward guidance is about the Federal Reserve's commitment to the future path of short-term interest rates. In addition, the long-short spread responses with an increase as a forward guidance surprise results in a larger increase in medium- to long-term interest rates (Swanson, 2021). However, the magnitudes of the excess equity return and real interest rate responses are observed to be small compared to the responses for a federal funds rate surprise, whereas the magnitude of the dividend-price ratio response remains fairly the same. This points to an important change in the relative share of each transmission channel, where we could expect the dividends channel to have a higher relative share. While the subsequent calculations will provide a numerical estimate for these shares, the impulse responses depict that the contribution of the dividends channel is relatively high for a forward guidance shock than a current federal funds rate shock, and this could also provide a possible explanation for the homogeneous nature of the sector-wise stock price responses observed in Section 1.4.2 for a forward guidance shock.

The impulse responses estimated for an expansionary one standard deviation LSAP surprise are depicted in Figure 1.5. The initial response of the excess equity return is positive and consistent with an expansionary policy shock. However, zero is included in the confidence band for the initial response, partly supporting the finding in Section 1.4 that the coefficients estimated for an LSAP surprise are not highly statistically significant. The nominal interest rate responds with a decline, which is also consistent with an expansionary shock. The long-short spread contracts with a time lag, reflecting the effects of balance sheet policies on long-term interest rates. Meanwhile, the dividend-price ratio rises initially, and then shows a gradual decline that persists over a long period. While the initial increase

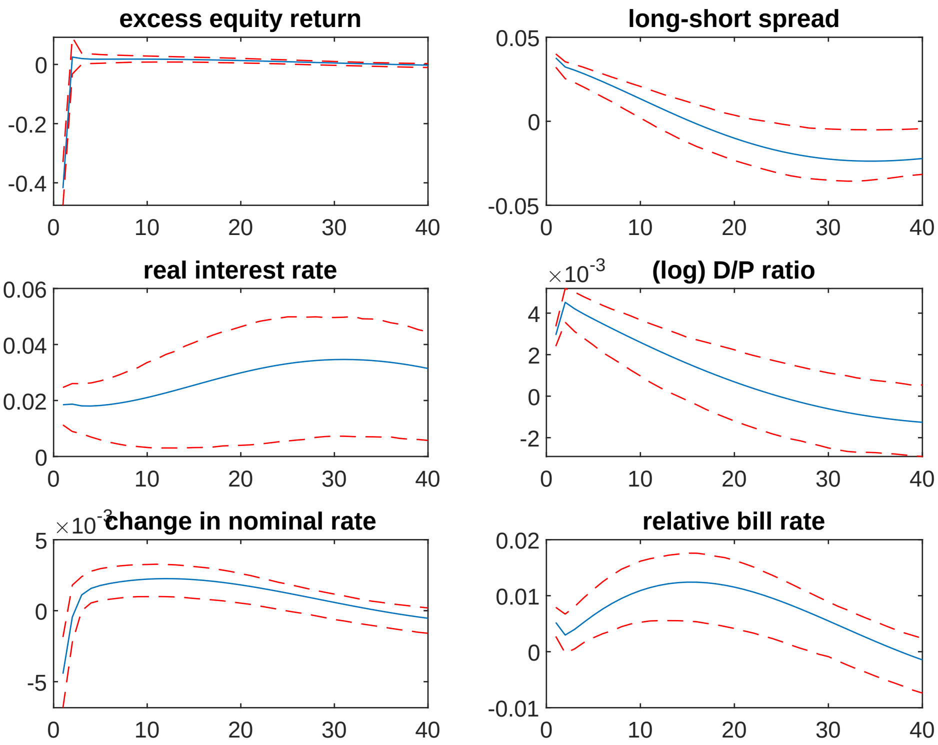

Figure 1.4: Impulse responses estimated for a forward guidance surprise. Estimated responses are in solid blue lines and the bootstrapped 90 percent confidence bands are in dashed red lines. Interest rates are given in percentage points.

in the ratio could be either due an increase in dividend streams or due to a fall in stock prices, which is in contradiction to the expansionary effects, it is not possible to differentiate between the two at this stage.

While a visual analysis of the dynamic responses estimated above provides us with an approximate idea of the relative importance of expected future excess returns, interest rates and dividends in explaining the current period's equity premium, quantifying the discounted sums of these variables would provide a straightforward answer. Therefore, I follow the approach of Bernanke and Kuttner (2005) to calculate the discounted sums of expected future excess returns, interest rates and dividends for the policy shocks considered above.

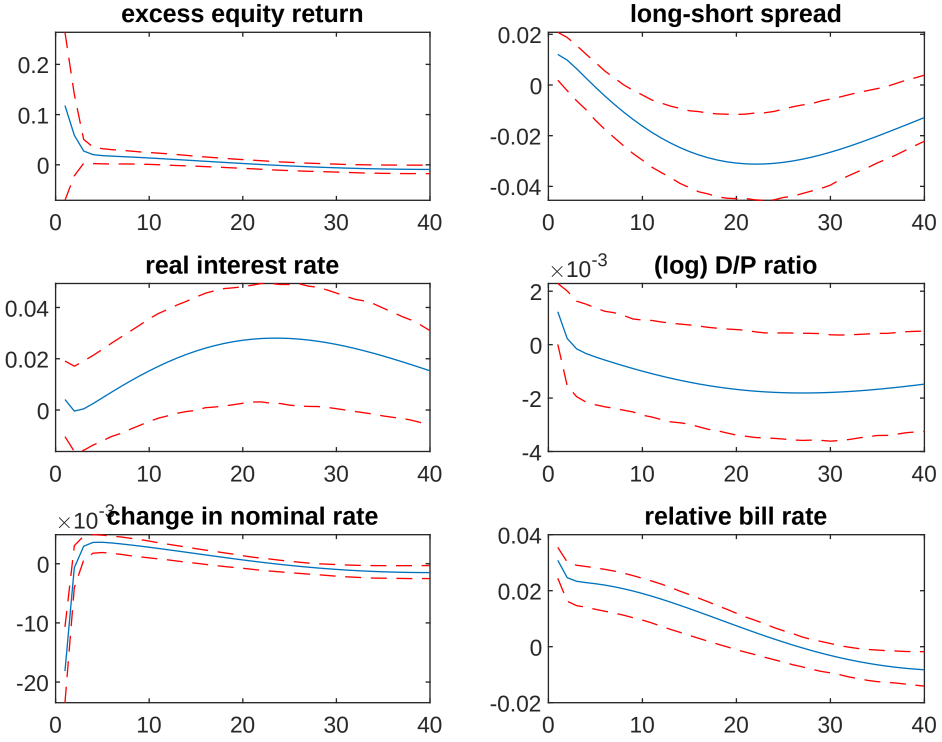

Figure 1.5: Impulse responses estimated for an LSAP surprise. Estimated responses are in solid blue lines and the bootstrapped 90 percent confidence bands are in dashed red lines. Interest rates are given in percentage points.

According to equation (1.4), the response of the current period's excess equity returns to a given policy shock is simply $s_y\phi$. The present value of the response of expected future excess returns to the respective policy surprises is derived by equation (1.5), which takes the following form:

$$s_y\rho A(1-\rho A)^{-1}\phi. \tag{1.11}$$

In a similar way, based on equation (1.6), the present value of the response of current and future real interest rates is given by,

$$s_r(1-\rho A)^{-1}\phi. \tag{1.12}$$

Finally, the present value of the response of current and expected future dividends is calculated as a residual from equation (1.2), which can be stated as:

$$s_y\phi + s_y\rho A(1-\rho A)^{-1}\phi + s_r(1-\rho A)^{-1}\phi. \tag{1.13}$$

The present value estimates for one standard deviation surprises in the federal funds rate, forward guidance and LSAPs are summarized in table 1.6. The first row provides the responses in the current period's excess return for each type of policy shock. The next three rows report the responses of dividends, real interest rate and future excess returns for the given shocks, where the individual responses with the correct signs add up to the value reported in the first row as these are the constituents of the current period's excess return. The results indicate that for all types of monetary policy shocks future excess returns account for a major share of the current period's response in equity premium, while dividends and the real interest rates account for a minor share. With regard to the surprises in the federal funds rate, the real interest rates make a marginally higher contribution than dividends. For forward guidance, dividends record the second largest relative contribution, while the real interest rates record a significantly small contribution. The contribution of dividends for LSAP shocks is surprisingly negative, indicating that an expansionary policy shock results in a contraction in the expected stream of future dividends. The real interest rates, however, make a positive contribution for LSAP surprises, as one would expect. The results for an LSAP shock reaffirm the possibility that there could be opposing forces impacting equity prices due to LSAP announcements as argued by Joyce et al. (2011).

In addition to assessing the impact of monetary policy surprises on the overall stock price index, I repeat the analysis with sector indexes in order to decompose the excess equity returns for different sectors of the stock market. Accordingly, sectoral present value estimates for one standard deviation surprises in the federal funds rate, forward guidance and LSAPs

Table 1.6: The impact of monetary policy on dividends, interest rates, and future returns

	Federal funds rate	Forward guidance	LSAPs
Current excess return (e^y)	-0.892	-0.428	0.121
Dividends ($\tilde{e}^d$)	-0.053	-0.096	-0.046
Share	6.0%	22.5%	-37.6%
Real interest rate ($\tilde{e}^r$)	0.073	0.018	-0.027
Share	8.2%	4.2%	22.4%
Future excess returns ($\tilde{e}^y$)	0.765	0.314	-0.140
Share	85.8%	73.3%	115.2%

Decomposition of the excess equity returns for a given policy surprise based on the relation $e^y_{t+1} = \tilde{e}^d_{t+1} - \tilde{e}^r_{t+1} - \tilde{e}^y_{t+1}$.

are calculated, and the results are summarized in table 1.7. The analysis reveals that all sectors except the Financials sector have the present value of future excess returns as the main contributor to the current period's equity premium. Although the sector-wise decomposition broadly follows the patterns observed for the overall stock market, some notable variations can be observed across sectors. The most notable heterogeneity is evident for the LSAP surprises, where the response of the current period's excess returns is a mix of both positive and negative contributions from different transmission channels.

1.6.1 Relating the Decomposition of Excess Returns to Regression Estimates

In this section, I attempt to relate the sector-wise regression coefficients found in Section 1.4 to the estimated transmission channels for the current period's excess equity return responses. I do this for the three types of monetary policy shocks under consideration. Both approaches try to quantify the effects on equity returns for a given policy shock. However, one should note that the construction of equity returns is different in the two approaches.

Table 1.7: The impact of monetary policy on dividends, interest rates, and future returns: sectoral analysis

	Energy	Materials	Industrials	Consumer discretionary	Consumer staples	Health care	Financials	IT	Communication services	Utilities
(A) Federal funds rate surprise										
Current excess return (e^y)	-0.189	-0.814	-1.133	-1.156	-0.202	-0.499	-0.884	-0.416	-1.109	-0.173
Dividends ($\tilde{e}^d$)	0.076	-0.024	-0.035	-0.157	0.102	0.047	-0.494	0.04	-0.04	0.063
Share	-40.0%	3.0%	3.1%	13.6%	-50.3%	-9.3%	55.8%	-9.6%	3.6%	-36.7%
Real interest rate ($\tilde{e}^r$)	0.020	0.064	0.03	0.149	0.017	0.036	0.221	0.024	0.061	0.009
Share	10.4%	7.9%	2.6%	12.9%	8.3%	7.1%	25.0%	5.9%	5.5%	5.1%
Future excess returns ($\tilde{e}^y$)	0.245	0.726	1.068	0.851	0.287	0.51	0.169	0.431	1.008	0.227
Share	129.6%	89.2%	94.3%	73.6%	142.0%	102.2%	19.1%	103.7%	90.9%	131.7%
(B) Forward guidance surprise										
Current excess return (e^y)	-0.508	-0.648	-0.436	-0.61	-0.34	-0.415	-0.528	-0.159	-0.046	-0.348
Dividends ($\tilde{e}^d$)	-0.063	-0.145	-0.078	-0.157	-0.194	-0.055	-0.386	-0.04	-0.038	-0.035
Share	12.4%	22.3%	17.9%	25.8%	57.0%	13.3%	73.0%	25.0%	81.9%	10.2%
Real interest rate ($\tilde{e}^r$)	-0.02	0.1	-0.011	0.069	0.036	0.003	0.118	-0.013	-0.014	0.003
Share	-4.0%	15.5%	-2.4%	11.2%	10.7%	0.7%	22.4%	-8.3%	-30.7%	0.9%
Future excess returns ($\tilde{e}^y$)	0.465	0.403	0.369	0.384	0.11	0.357	0.025	0.132	0.023	0.309
Share	91.7%	62.2%	84.5%	63.0%	32.3%	86.0%	4.7%	83.3%	48.8%	89.0%
(C) LSAP surprise										
Current excess return (e^y)	-0.353	0.215	0.059	-0.119	0.182	0.583	0.566	-0.12	-0.064	0.019
Dividends ($\tilde{e}^d$)	-0.079	-0.029	-0.051	-0.09	-0.048	-0.026	0.269	-0.084	-0.105	-0.051
Share	22.3%	-13.7%	-85.8%	75.4%	-26.4%	-4.5%	47.6%	70.4%	164.2%	-277.3%
Real interest rate ($\tilde{e}^r$)	-0.022	-0.003	-0.019	0.002	-0.052	-0.058	-0.14	-0.038	-0.038	-0.02
Share	-6.4%	1.6%	32.9%	1.5%	28.8%	9.9%	24.7%	-31.8%	-59.5%	107.9%
Future excess returns ($\tilde{e}^y$)	0.297	-0.241	-0.09	0.027	-0.178	-0.552	-0.157	0.073	-0.003	-0.05
Share	84.1%	112.1%	152.9%	23.1%	97.6%	94.5%	27.7%	61.4%	-4.6%	269.4%

Decomposition of the excess equity returns for a given policy surprise based on the relation $e^y_{t+1} = \tilde{e}^d_{t+1} - \tilde{e}^r_{t+1} - \tilde{e}^y_{t+1}$.

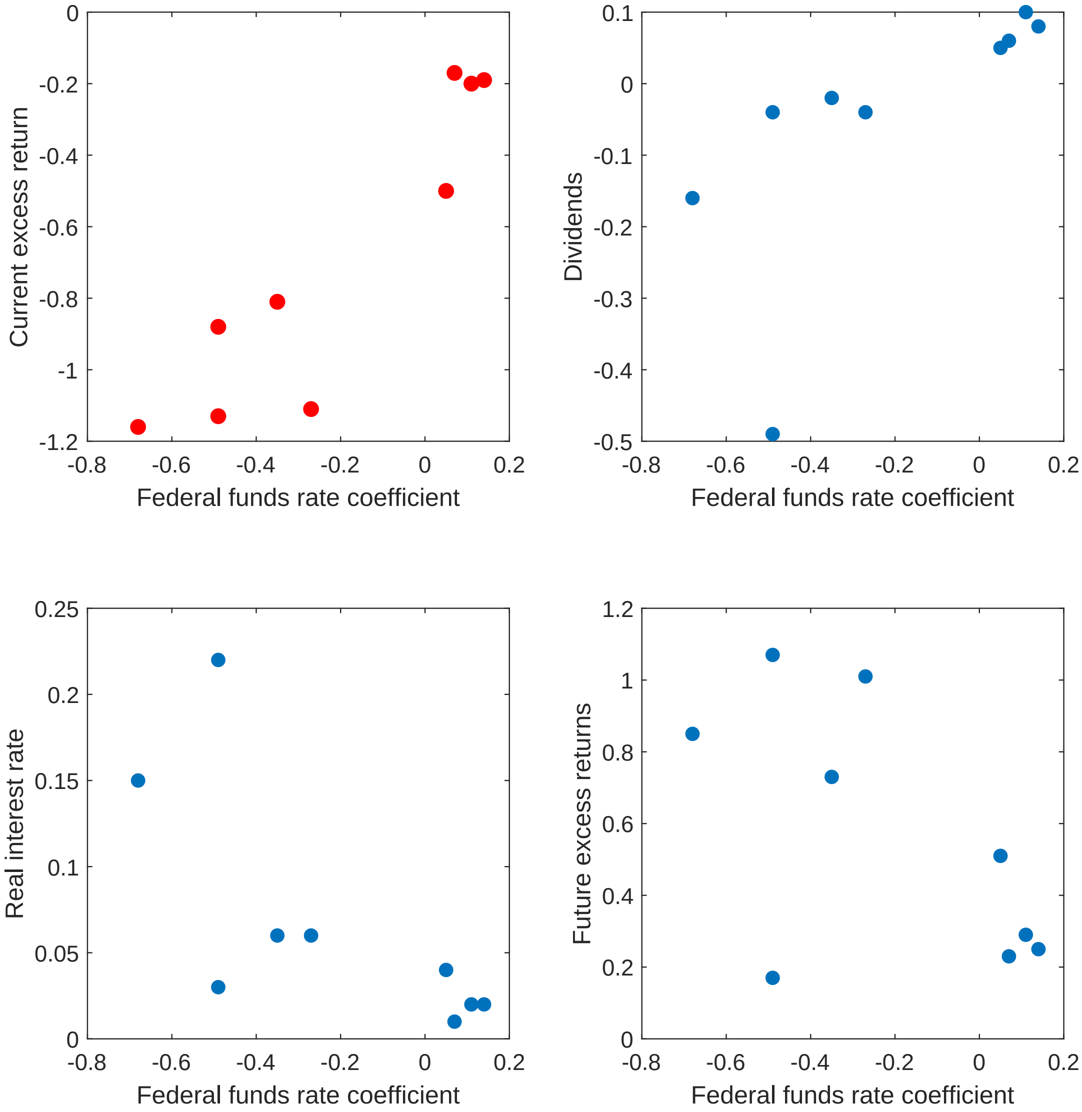

Figure 1.6: Excess equity returns versus estimated regression coefficients: federal funds rate shock

In Section 1.4, I consider daily equity returns, whereas in Sections 1.5 and 1.6, I consider monthly excess equity returns. Therefore, this comparison should be made keeping in mind these differences in construction.

Figure 1.6 relates the regression coefficients estimated for a federal funds rate shock to the response of the current period's excess return and its constituents for the same policy surprise.

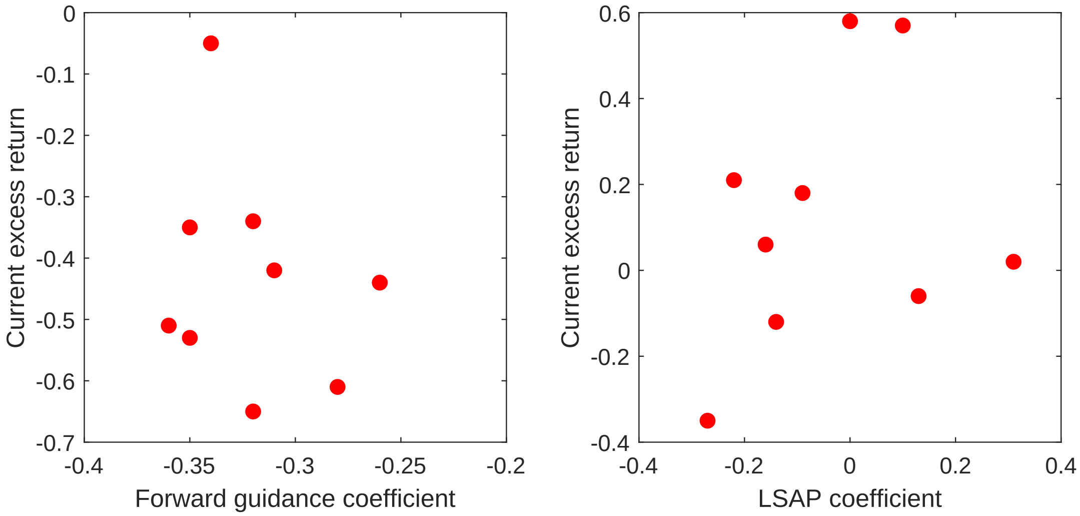

Figure 1.7: Excess equity returns versus estimated regression coefficients: forward guidance and LSAP shocks

Each dot of a scatter plot corresponds to a GICS sector[6]. The x-axis provides the value of the regression coefficients, while the y-axis represents either the excess equity response or the response of its transmission channels. The first scatter plot depicts the response of the current period's excess return, where we can note a clear relationship between the two estimates. The sectors which are more interest rate sensitive than others (i.e., sectors with larger negative coefficients) report large excess equity responses. The constituents of the current period's excess return (i.e., dividends, the real interest rates and future excess returns), which are presented in the next three scatter plots, also depict meaningful and consistent relations with the regression coefficients. Moreover, the sectors which are found to be more sensitive to the changes in the federal funds rate in Section 1.4 are generally found to have a larger contribution from the present value of future dividend flows, supporting the arguments in Dedola and Lippi (2005) and Skaperdas (2017) for interest rate sensitive industries.

In Figure 1.7, I try to visually relate the regression coefficients estimated for forward guidance and LSAP shocks to the respective responses of the current period's excess return.

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[6] The IT sector is excluded because of the use of a smoothed total returns index, thus making it not directly comparable with the other sectors.

The first scatter plot corresponds to a forward guidance surprise, where a clear relationship is not evident. This could be due to the fact that forward guidance is found to have a relatively homogeneous effect on sector-wise stock market performance in Section 1.4. Therefore, what is more important is to examine if this homogeneous nature is present in the excess equity return responses as well. In this regard, the relatively homogeneous nature of the effects of forward guidance can be observed in Table 1.7 as well, where the sectoral excess returns are presented. The standard deviation of current period's excess equity returns across sectors for a one standard deviation federal funds rate shock is 0.38, while that for a one standard deviation forward guidance shock is 0.18. This reduction in the variation in current period's excess returns for forward guidance mainly comes through a reduction in the variation in future equity premiums and dividends. Furthermore, it is important to note that there is a difference in the channels of transmission of forward guidance shocks to the stock market compared to those of the federal funds rate surprises. The results in Table 1.6 for the overall stock price index as well as the results in Table 1.7 for the sector-wise stock price indexes show that dividends make a considerably larger contribution for the transmission of forward guidance shocks in comparison to the current federal funds rate shocks. Further, the relative contribution of the real interest rates is found to be less for forward guidance compared to the federal funds rate. Hence, the above changes in the contribution of different transmission channels for forward guidance could also be a possible reason for the homogeneous nature of the sectoral stock price responses for forward guidance.

The second plot in Figure 1.7 shows a weakly positive relationship between the two estimates, which indicates that a negative LSAP coefficient can be associated with a negative or a small positive response in the current excess returns. This is an important relationship because in Section 1.4, it was not possible to ascertain the reason for having an unexpected negative sign for some of the regression coefficients estimated for LSAPs. At this point, it is worth recalling the two opposing forces associated with LSAP announcements stated in

Joyce et al. (2011). Low long-term yields due to LSAPs should increase the present value of future dividends, and this phenomenon is evident in panel C of Table 1.7 where the signs of the real interest rate responses correspond to an expansionary policy shock. However, if LSAPs indicate that the outlook for the economy is worse than expected, future dividends could fall, and this phenomenon is also evident in Table 1.7 where the signs of almost all the dividend responses correspond to a contractionary policy shock. Furthermore, as investors attempt to rebalance their portfolios towards more risky assets following an LSAP announcement, the equity risk premium may fall. On the other hand, if LSAPs indicate that the outlook for the economy is worse than expected, the risk premium could rise. The combined effect of the above could result in either an increase or a decrease in the risk premium. In Table 1.7, the behavior of risk premiums is captured by the future excess returns, where the results indicate that the sectors record both positive and negative signs implying that the risk premium is perceived in different ways by different sectors. More importantly, the current period's excess equity return is a combination of all the factors mentioned above. In this regard, we can observe that some sectors assign more weight to the expansionary forces, thereby resulting in an increase in excess returns, whereas for certain other sectors, contractionary forces outweigh the expansionary effects, thereby resulting in a decline in excess returns. However, this interpretation is suggestive, and not conclusive.

1.7 Conclusion

In the recent past, the ZLB constraint made many central banks around the world pursue unconventional monetary policies to stimulate their economies. As a result, understanding the effects of unconventional monetary policy, and equally importantly, understanding the policy transmission mechanism has become a top priority. In such context, this research attempts to analyze the impact of Federal Reserve's conventional and unconventional monetary policy surprises on the equities market, both at an aggregate level as well as at economic sector levels.

Even though the overall stock market responds meaningfully to a surprise change in the federal funds rate with a high level of statistical significance, a heterogeneity in responses is observed among different sectors in the stock market. Some sectors display an increased interest rate response, whereas certain other sectors report small coefficients which are not even statistically significant. In general, sectors that either undertake long-term investments which are sensitive to the cost of capital or produce goods that require large consumer loans are found to be more sensitive to the current federal funds rate shocks. Forward guidance is also estimated to have meaningful and highly statistically significant effects on overall stock prices. Interestingly, forward guidance is found to have relatively homogeneous effects on sector-wise stock market performance. Moreover, almost all sectors exhibit statistically significant coefficients for forward guidance shocks, while the variation in the magnitude of coefficient values across sectors is not as large as that for the federal funds rate. Nonetheless, the effects of LSAPs on overall equity prices as well as on sectoral equity prices are not statistically significant. Furthermore, the estimates reveal some puzzling results for the ZLB period.

I assess the relative importance of the channels through which the monetary policy surprises under consideration affect equity prices. A decomposition of excess equity returns shows that the future excess returns emerge as the dominant factor determining the current period's equity premium for both the overall stock price index and most of the sectoral indexes. Dividends and the future real interest rates record smaller contributions. For surprises in the federal funds rate, the real interest rates make a marginally higher contribution than dividends. For forward guidance, dividends record the second largest relative contribution, while the real interest rates record a significantly small contribution. With regard to LSAP shocks, the contribution of dividends is surprisingly negative, which may indicate an information effect associated with LSAPs. Nonetheless, the real interest rates make a positive contribution as expected. Meanwhile, the relative contribution of future dividends, real interest rates and excess returns for the propagation of policy shocks is found to vary across sectors. Moreover, the sector-wise analysis highlighted that for the federal funds rate shocks, the sectors which are more interest rate sensitive tend to report large excess equity return responses. In addition, the sectoral equity premium responses derived for a forward guidance shock reaffirmed the relatively homogeneous effects of forward guidance on equity prices.

The homogeneous nature of forward guidance effects on stock prices indicates that the markets expect the performance of all industries to be affected in a broadly similar way regardless of their level of interest rate sensitivity. Accordingly, while monetary policy decision makers are typically concerned with the overall effects of policy actions, the findings suggest that for a policy maker who prefers a more consistent impact across economic sectors, forward guidance stands out as a better policy tool than changes to the current federal funds rate.

Chapter 2

The Forward Guidance Puzzle in a Small Open Economy Model: Perpetual Youth as a Potential Solution

2.1 Introduction

Under forward guidance, a central bank attempts to influence current macroeconomic outcomes by managing expectations about the future path of the policy interest rate. Studies find that the Federal Open Market Committee (FOMC) announcements containing forward guidance had, on average, meaningful effects on the financial markets (e.g., Gurkaynak et al. (2005), Swanson (2021)) as well as on output and inflation expectations (e.g., Del Negro et al. (2015), Campbell et al. (2017), D'Amico and King (2017), Bernanke (2020)). Nonetheless, it is found that standard small- and medium-scale dynamic stochastic general equilibrium

(DSGE) models tend to largely overestimate the impact of forward guidance on the macroeconomy, a phenomenon known as the *forward guidance puzzle*. Several solutions to this puzzle have been proposed in the literature by modifying standard New Keynesian models to generate some form of discounting in the Euler equation. These solutions include, among others, the introduction of finite life agents Del Negro et al. (2015) or finite-horizon planning Woodford (2019), incomplete markets McKay et al. (2016), sticky information Carlstrom et al. (2015), the lack of common knowledge Angeletos and Lian (2018), and deviations from rational expectations Gabaix (2020). However, such solutions are discussed in the context of closed economy New Keynesian models.

A recent study, Galí (2020), points to an open economy version of the forward guidance puzzle. The paper analyzes the effectiveness of forward guidance policies in an open economy focusing on the exchange rate. It is found that in general equilibrium, the effect of forward guidance policies on the exchange rate is larger the longer is the horizon of implementation of a given adjustment in the nominal interest rate. Then, using empirical evidence the author shows that expectations of interest rate differentials in the near (distant) future are shown to have much larger (smaller) effects on the real exchange rate, highlighting empirical deviations from the horizon-invariance property of the uncovered interest parity (UIP) assumption considered in the open economy model. Galí (2020) uses the term the *forward guidance exchange rate puzzle* to refer to this disconnect between theoretical outcomes and empirical findings. More importantly, the author argues that the solutions to the forward guidance puzzle found in the closed economy literature are unlikely to apply in the presence of an exchange rate channel. Instead, it is suggested that deviations from the UIP condition have a better chance to result in a desirable exchange rate behavior. However, the study does not analyze such a solution within a general equilibrium context.

Given the above, the main objective of this study is to analyze the open economy version of the forward guidance puzzle, and more importantly to explore solutions to it. However, the approach taken is different to what is suggested by Galí (2020), where I introduce one of the solutions proposed to the closed economy version of the forward guidance puzzle to a benchmark small open economy model in order to analyze its effectiveness in solving the puzzle. As such, I introduce the perpetual youth structure of Blanchard (1985) and Yaari (1965) to the small open economy model of Galí and Monacelli (2005). This is expected to serve two main purposes. Firstly, the effects of forward guidance have not been analyzed in the context of an open economy New Keynesian model with the perpetual youth structure incorporated. Therefore, this research fills that void in the literature pertaining to the modeling of central bank forward guidance. Secondly, it is expected to check the validity of the conjecture made in Galí (2020) that the solutions found for the closed economy forward guidance puzzle are unlikely to address the issues related to the exchange rates.

The findings show that the incorporation of a perpetual youth structure to an open economy New Keynesian model weakens the excessive response of output and inflation as shown by Del Negro et al. (2015) for a closed economy model, and also weakens the excessive response of the exchange rates, to a forward guidance announcement. The perpetual youth structure involves more discounting in the aggregate consumption Euler equation than in a standard representative agent model, leading to a dampening of the initial consumption response. While this results in an attenuation of the output response and inflation response to an announced change in the nominal interest rate, the relations linking domestic consumption with the terms of trade and the real exchange rate, due to the assumption of complete securities markets and complete pass-through, points to an attenuation in the response of exchange rates as well. Moreover, I show that any attempt to curb the overreaction of the real interest rate differentials in the near future using a modification such as the perpetual youth structure is effective in attenuating the current exchange rate response, than modifying the

UIP condition to accommodate more discounting for far future interest rate differentials.

The remainder of the chapter is structured as follows. Section 2.2 presents a brief explanation of the forward guidance puzzle in a closed economy setup, and then performs a forward guidance exercise using a standard small open economy New Keynesian model. In Section 2.3, I introduce an extension to the basic small open economy model using the perpetual youth structure of Blanchard (1985) and Yaari (1965), show the equilibrium conditions and present the linearized relations. Section 2.4 presents various simulations of the small open economy model with perpetual youth for forward guidance announcements. In Section 2.5, I provide a discussion of the simulation outcomes, while the effects of relaxing some open economy assumptions are presented in Section 2.6. Section 2.7 summarizes the results and concludes.

2.2 Forward Guidance in New Keynesian Models

In this section, I first introduce the forward guidance puzzle in a closed economy New Keynesian model as discussed in Del Negro et al. (2015) and McKay et al. (2016), and summarize some of the solutions proposed to it in the closed economy literature. Then, I introduce the forward guidance puzzle in an open economy New Keynesian model as discussed in Galí (2020), focusing on the implausibly large reaction of both real and nominal exchange rates.

2.2.1 A Simple Forward Guidance Exercise in a Closed Economy Setup

In standard closed economy monetary models, promises about future interest rate changes have been shown to result in powerful effects on the economy, where the magnitude of such effects is seemingly beyond the limits of credibility. A basic New Keynesian model (e.g., Woodford (2003)) with a Phillips curve and an intertemporal IS equation can be used to provide an explanation to this phenomenon. Let us assume that the Phillips curve takes the form

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \kappa x_t, \tag{2.1}$$

and the IS equation takes the form

$$x_t = \mathbb{E}_t x_{t+1} - \sigma(r_t - r_t^n), \tag{2.2}$$

where π_t denotes inflation, x_t is the output gap as measured by the deviation of actual output from flexible price output, r_t denotes the real interest rate, and the natural real rate of interest is given by r_t^n. Parameters β and σ denote the discount factor of households and the intertemporal elasticity of substitution, respectively, while κ is the slope of the Phillips curve. By solving the IS equation forward and with the assumption that $\lim_{j\to\infty} \mathbb{E}_t x_{t+j} = 0$, we get

$$x_t = -\sigma \sum_{j=0}^{\infty} \mathbb{E}_t (r_{t+j} - r_{t+j}^n). \tag{2.3}$$

In a similar way, by solving the Phillips curve forward we get

$$\pi_t = \kappa \sum_{j=0}^{\infty} \beta^j \mathbb{E}_t x_{t+j}. \tag{2.4}$$

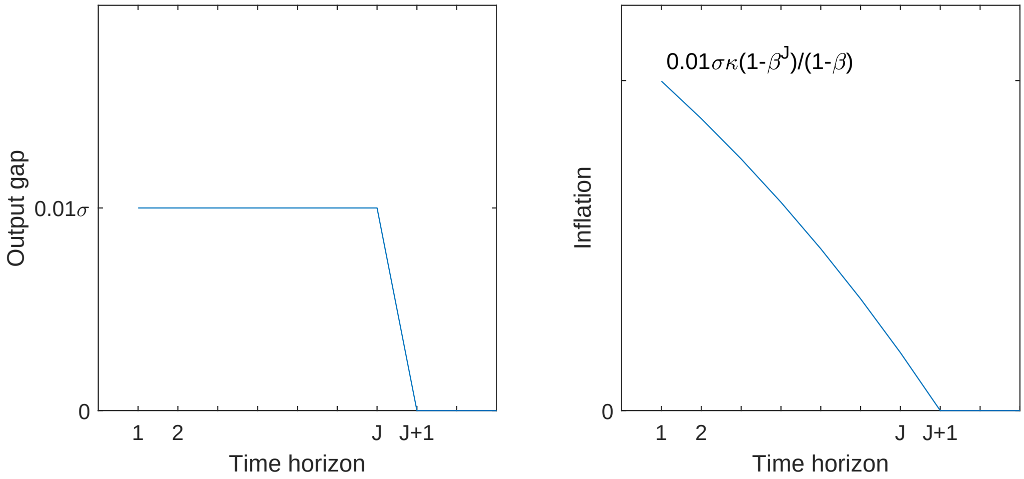

Figure 2.1: Response of output and inflation to a single quarter drop in the real interest rate, J quarters in the future. Adopted from McKay et al. (2016).

The infinite sum in equation (2.3) illustrates that a central bank can influence the current output gap not only by changing the current real interest rate gap (i.e., $r_t - r_t^n$), but also by changing people's expectations about the future path of the real interest rate gaps. For simplicity, suppose that the monetary policy rule is such that the real interest rate follows the real natural rate with some error,

$$r_t = r_t^n + \varepsilon_{t,t-j}. \tag{2.5}$$

A shock to the real interest rate in period t that is known to the public in period $t-j$ is denoted by $\varepsilon_{t,t-j}$. This term can be used to incorporate announcements under forward guidance. In the steady state of the above model, both the output gap and inflation are zero, while the real interest rate is the same as the natural real rate of interest.

Under forward guidance, suppose that the economy is currently in its steady state and the monetary authority credibly announces to the public that the real interest rate will be lowered for a single quarter after a certain period of time. However, the real interest rate will be maintained at the natural rate of interest in all other periods. As such, an announcement of a

1 percent cut in the quarterly real interest rate J quarters in the future means $\varepsilon_{t+J,t} = -0.01$ in equation (2.5). Even though the real interest rate does not change until the J^{th} period, according to equation (2.3), a monetary policy shock of this nature results in an immediate jump in output, and it will remain at the elevated level until the J^{th} period. This phenomenon applies for forward guidance at any horizon. Meanwhile, according to equation (2.4), current inflation is the discounted sum of future output gaps. Therefore, the further out in the future the announced change in interest rate is, the larger is the current response of inflation. Figure 2.1 depicts the step-function shape response of output and the excessive increase in current inflation for the forward guidance announcement under consideration. This unreasonably large response of output and inflation for forward guidance announcements can also be observed in medium scale DSGE models. Hence, this phenomenon that the standard small- and medium-scale DSGE models tend to grossly overestimate the impact of forward guidance on the macroeconomy is called the forward guidance puzzle Del Negro et al. (2015).

Several solutions to this puzzle have been proposed in the literature by modifying standard DSGE models to generate some form of discounting in the Euler equation. These solutions include, among others, the introduction of agents with finite lives, finite-horizon forward planning, presence of non-rational agents, incomplete markets coupled with uninsurable income risks, sticky information models, and the lack of common knowledge. Some selected studies that propose solutions to the forward guidance puzzle in a closed economy context are summarized in Table 2.1. In general, discounting introduced to the Euler equation through various proposed techniques modifies the forward looking representation of (2.3) as follows:

$$x_t = -\sigma \sum_{j=0}^{\infty} \zeta^j \mathbb{E}_t (r_{t+j} - r^n_{t+j}), \tag{2.6}$$

where $\zeta \in (0, 1)$. This implies that the effect of a future interest rate change on today's output attenuates with the horizon of implementation. In addition, some methodologies

Table 2.1: Some selected solutions proposed to the forward guidance puzzle

Study	Proposed Solution
Del Negro et al. (2015)	A perpetual youth structure (finite-life agents)
Carlstrom et al. (2015)	Sticky-information model of the Phillips curve
McKay et al. (2016)	Incomplete markets with households facing uninsurable income risks
Kiley (2016)	Sticky-information price dynamics
Gabaix (2020)	Non-rational agents (bounded rationality)
Angeletos and Lian (2018)	Lack of common knowledge
Michaillat and Saez (2018)	Wealth in the utility function
Woodford (2019)	Finite-horizon forward planning

(e.g., perpetual youth structure) introduce more discounting in the Phillips curve relation as well.

2.2.2 Forward Guidance in an Open Economy Setup

Although many studies have been conducted in proposing and analyzing solutions to the forward guidance puzzle in a closed economy context, little attention has been given to possible issues that could emerge when modeling forward guidance in an open economy setup. Galí (2020), sheds some light on this, highlighting the existence of an open economy version of the forward guidance puzzle, named as the forward guidance exchange rate puzzle. The author analyzes the effects of forward guidance in general equilibrium using the framework for a small open economy developed in Galí and Monacelli (2005), which presents a simple model of a small open economy where the world economy is modeled as a continuum of small open economies. The model features Calvo-type staggered price setting. Further, it assumes complete international financial markets and complete pass-through of nominal exchange rate changes to prices of imported and exported goods.

Following Galí (2020), I assume constant output, consumption, prices and real interest rates in the rest of the world, and hence these variables are normalized to zero for simplicity.

As a result, the linearized relations considered for this analysis is a simplified representation of the model developed in Galí and Monacelli (2005). I present a detailed discussion of the derivation of equilibrium conditions of a small open economy model in the lines of Galí and Monacelli (2005), under a proposed extension, in Section 2.3 of this study.

Equilibrium conditions of the small open economy model can be combined to obtain two equations for domestic inflation and output that are similar in form to the Phillips curve and the IS equation in a closed economy model[1]:

$$\pi_{H,t} = \beta \mathbb{E}_t \pi_{H,t+1} + \kappa_\alpha y_t, \tag{2.7}$$

$$y_t = \mathbb{E}_t y_{t+1} - \frac{1}{\sigma_\alpha}(i_t - \mathbb{E}_t \pi_{H,t+1}), \tag{2.8}$$

where $\pi_{H,t}$, y_t, and i_t denote domestic inflation, output, and the nominal interest rate, respectively. As usual, β denotes the discount factor of households. The composite parameters $\sigma_\alpha \equiv \frac{\sigma}{(1-\alpha)+\alpha\omega}$, $\kappa_\alpha \equiv \lambda(\sigma_\alpha + \varphi)$, $\omega \equiv \sigma\gamma + (1-\alpha)(\sigma\eta - 1)$ and $\lambda \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}$ are functions of the degree of openness (α), the elasticity of substitution between home and foreign goods (η), the elasticity of substitution between goods produced in different foreign countries (γ), the inverse elasticity of intertemporal substitution (σ), the elasticity of labor supply (φ) and the Calvo price stickiness parameter (θ).

Under complete pass-through of nominal exchange rate, the following relation between CPI inflation and domestic inflation can be obtained:

$$\pi_t = \pi_{H,t} + \frac{\alpha}{(1-\alpha)} \Delta q_t \tag{2.9}$$

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[1] Detailed derivations of the equilibrium conditions considered in Section 2.2 can be found in Galí and Monacelli (2005).

where π_t denotes CPI inflation and q_t is the log real exchange rate. Further, combining the market clearing condition and the international risk sharing condition derived under complete markets assumption, the following relation between the real exchange and output can be derived:

$$q_t = \sigma_\alpha (1 - \alpha) y_t. \tag{2.10}$$

The nominal exchange rate can be derived from the simple relation $e_t = q_t + p_t$, where p_t is the overall CPI. Finally, the model is closed using a simple monetary policy rule where the monetary authority sets the nominal interest rate based on domestic inflation:

$$i_t = \phi_\pi \pi_{H,t} + \varepsilon_t + \sum_{j=1}^{J} \varepsilon_{t,t-j}. \tag{2.11}$$

The usual contemporaneous monetary policy shock is given by ε_t, whereas $\varepsilon_{t,t-j}$ denotes a policy shock in period t that is known to the public in period $t - j$ (i.e., known j periods in advance).

Even though the above relations are sufficient for the simple analysis under consideration, I introduce several additional relations in order to lay the foundation for an analysis conducted later in this study. Accordingly, by definition, the effective terms of trade, s_t, is given by

$$\Delta s_t = \pi_{F,t} - \pi_{H,t}, \tag{2.12}$$

where $\pi_{F,t}$ denotes imported inflation. Combining the law of one price with the definition of effective real exchange rate, we obtain the following relation between the terms of trade and the real exchange rate (up to a first order approximation):

$$q_t = (1 - \alpha)\ s_t. \tag{2.13}$$

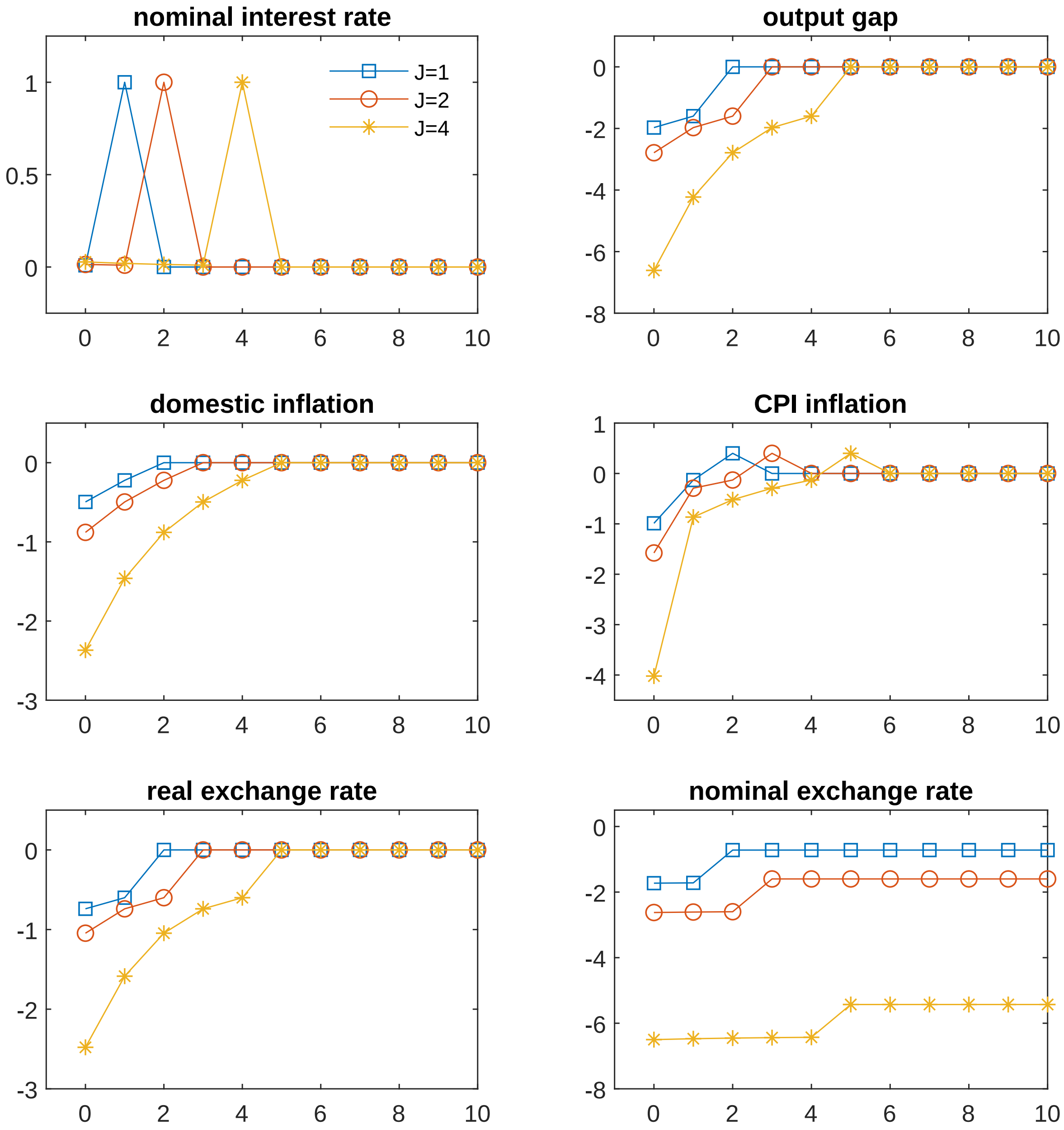

Figure 2.2: The impact of an announced interest rate increase on macroeconomic variables. Adopted from Galí (2020).

In order to carry out a numerical analysis, I calibrate the proposed model with parameters commonly found in the literature (summarized in Table 2.2). The discount rate (β) is set to 0.99 impling a riskless annual return of around 4 percent in the steady state. The Calvo parameter (θ) is set equal to 0.75, implying an average period of one year between price adjustments. With respect to the interest rate rule, I follow the original Taylor estimate

Table 2.2: Structural parameters values: baseline small open economy model

Parameter	Description	Value
θ	Calvo parameter	0.75
β	Discount rate	0.99
σ	Inverse elasticity of intertemporal substitution	1
φ	Labor supply elasticity	1
α	Openness index	0.4
η	Substitutability between domestic and foreign goods	2
γ	Substitutability between goods produced in foreign countries	1
ϕ_π	Taylor Rule coefficient for domestic inflation	1.5

and set $\phi_\pi = 1.5$. Following Galí and Monacelli (2005) as well as Galí (2020), the substitutability between goods produced in different foreign countries (γ) is set to one, and the substitutability between domestic and foreign goods (η) is set to two. In addition, the small economy is characterized by an openness index (α) of 0.4. For simplicity, the labor supply elasticity (φ) and the inverse elasticity of intertemporal substitution (σ) are set to unity.

I perform a forward guidance experiment using the New Keynesian small open economy model presented above to assess the impact of forward guidance announcements on macroeconomic variables, particularly the exchange rates. Suppose that the economy is in its steady state so that the nominal interest rate is zero, and the home central bank credibly announces a one percentage point increase in the nominal interest rate for a single period, J periods ahead in the future, while keeping the interest rate at its initial level of zero until period $J-1$. This means, in equation (2.11), $\varepsilon_{t+J,t} = 0.01$ and every other monetary policy shock from ε_t to $\varepsilon_{t+J-1,t}$ take an appropriate value to maintain the nominal interest rate at the zero lower bound until period $J-1$. The model is solved numerically for different values of J and the response of output, inflation, and the exchange rates to this experiment under alternative time horizons are given in Figure 2.2.

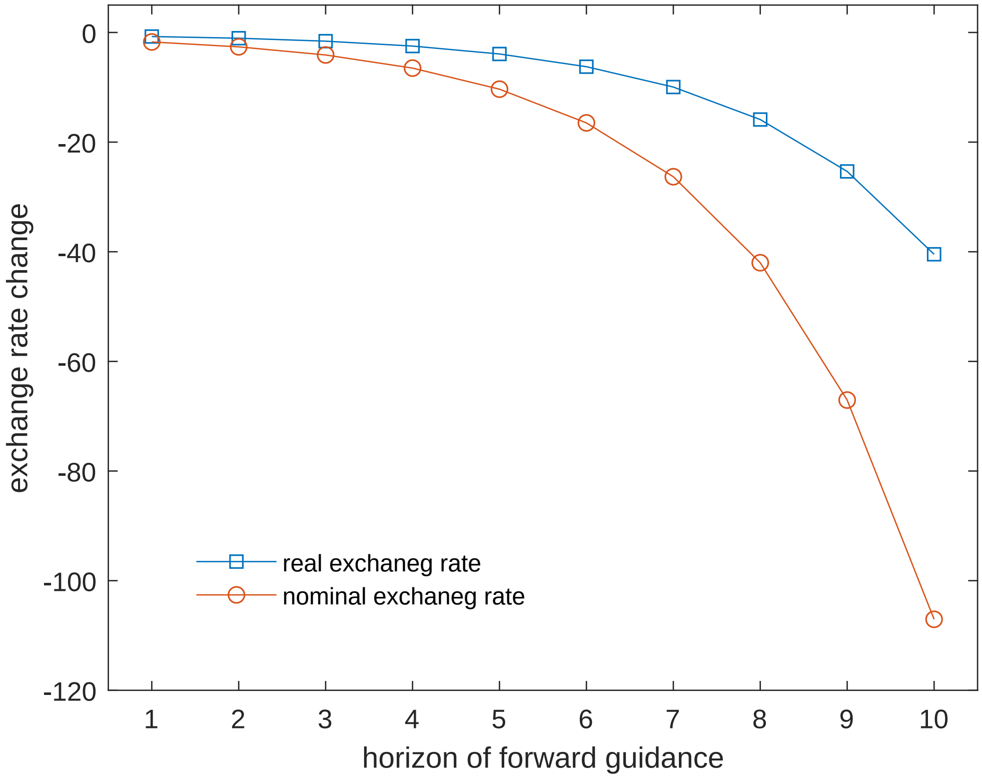

Figure 2.3: The forward guidance puzzle in exchange rates. Adopted from Galí (2020).

As evident in Figure 2.2, the longer is the horizon of implementation for forward guidance, the larger is the impact of the announcement on output and domestic inflation. This phenomenon is identical to the forward guidance puzzle experienced in basic closed economy models. The response of imported inflation follows the changes in the nominal exchange rate due to producer pricing and complete exchange rate pass-through assumptions. The response of CPI inflation to this experiment is a combined effect of the responses of domestic inflation and imported inflation. More importantly, it can be noted that the impact on both the real and nominal exchange rates increase with the time horizon of the announced change in the interest rate. The forward guidance puzzle being applied to the nominal and real exchange rates under different time horizons (i.e., different values of J) is illustrated more explicitly in Figure 2.3. It is observed that the magnitude of the initial change in the (log) exchange rates from their steady states increases exponentially as the time horizon for the future change in interest rate under forward guidance increases. The exponential nature of the exchange rate response is seemingly unrealistic because the only thing that changes in the above experiment is the time horizon of the announced increase, whereas the amount by which the interest rate changes remains constant.

2.3 A Potential Resolution: Perpetual Youth

Even though Galí (2020) introduces the existence of an open economy version of the forward guidance puzzle, the study does not analyze a solution to it within the framework of an open economy New Keynesian model in order to determine whether such a solution, in a general equilibrium context, attenuates the excessive response of the exchange rates as depicted in Figure 2.2. On the other hand, Galí (2020) states that "some of the solutions to the forward guidance puzzle proposed in the closed economy literature are unlikely to apply to the exchange rate channel emphasized". Instead, the paper suggests that deviations from the UIP condition have a better chance to result in a desirable exchange rate behavior. However, I take a different approach in this study, whereby I introduce the perpetual youth structure, which is one of the solutions proposed to the closed economy version of the forward guidance puzzle, to the small open economy model of Galí and Monacelli (2005) in order to analyze its effectiveness in solving the open economy version of the forward guidance puzzle.

The perpetual youth structure along the lines of Blanchard (1985) and Yaari (1965) is introduced to analyze its effectiveness in dealing with the excessive response of macroeconomic variables in the small open economy model discussed above. Incorporation of the perpetual youth model into New Keynesian models is pioneered by Piergallini (2006) and Nisticò (2012). Di Giorgio and Nisticò (2007) develop a two-country extension of the perpetual youth DSGE framework. With respect to forward guidance, Del Negro et al. (2015) insert the perpetual youth structure into the closed economy framework of Christiano et al. (2005)

and Smets and Wouters (2007) in view of finding a solution to the forward guidance puzzle. Nonetheless, the effects of forward guidance have not been analyzed in the context of a small open economy New Keynesian model with the perpetual youth structure incorporated.

I take the small open economy model of Galí and Monacelli (2005) and use a discrete-time version of the Blanchard (1985) and Yaari (1965) overlapping generations model to modify the demand side of the economy. All agents face the same, constant probability of death $\delta \in (0, 1)$ in each period. A constant sized cohort of households with zero wealth enters the economy in each period and there is no population growth. The agents have identical preferences and there is no intergenerational bequest motive. Households enter into an insurance contract as modeled by Blanchard (1985). Accordingly, a perfect insurance market inherits consumers' financial wealth contingent on their death and redistributes it among the remaining agents in proportion to their financial wealth, because there is no bequest motive. The insurance industry earns zero profits implying that the gross return on the insurance contract is $1/(1 - \delta)$. The remainder of the model is broadly similar to Galí and Monacelli (2005). As such, the world economy is modeled as a continuum of small open economies represented by the unit interval. Policy decisions of a single economy do not have any impact on the rest of the world since each economy is infinitesimally small. All economies are assumed to have identical preferences, technology, and market structure, while the probability of death faced by an agent is also assumed to be the same across countries. The sections that follow describe the optimization problems faced by households and firms in one such small open economy, unless otherwise stated.

2.3.1 Households

Households demand consumption goods and supply labor. Further, households can hold two types of financial assets: state-contingent bonds and equity shares issued by domestic firms. Each household is assumed to have preferences over consumption and leisure described by an additively separable log-utility function. Accordingly, a representative household of cohort j chooses its optimal amount of consumption, labor supply, and holdings of financial assets to maximize its lifetime utility conditional on survival, which is given by:

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t (1-\delta)^t \left\{ \log C_t(j) + \log[1 - N_t(j)] \right\} \right\}. \tag{2.14}$$

$C_t(j)$ is a composite consumption index of cohort j defined as

$$C_t(j) \equiv \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}(j)^{\frac{1-\eta}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}(j)^{\frac{1-\eta}{\eta}} \right]^{\frac{\eta}{1-\eta}} \tag{2.15}$$

where $\alpha \in [0,1]$ is related to the degree of foreign bias and therefore is an index of openness, while $\eta > 0$ is the substitutability between domestic and foreign goods. $N_t(j)$ denotes hours of labor supplied by a representative household of cohort j, and β is the discount factor of the household.

The index of domestically produced goods consumed by cohort j ($C_{H,t}(j)$) is given by the following CES function:

$$C_{H,t}(j) \equiv \left(\int_0^1 C_{H,t}(k,j)^{\frac{\varepsilon-1}{\varepsilon}} dk \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2.16}$$

where $k \in [0,1]$ denotes the good variety (or brand), and $\varepsilon > 1$ is the elasticity of substitution between differentiated goods within a country. $C_{F,t}(j)$ is an index of imported goods consumed by domestic households of cohort j defined by the following CES function:

$$C_{F,t}(j) \equiv \left(\int_0^1 C_{i,t}(j)^{\frac{\gamma-1}{\gamma}} di \right)^{\frac{\gamma}{\gamma-1}}, \tag{2.17}$$

where $C_{i,t}(j)$ is an index representing the quantity of goods imported from country i and consumed by a representative agent of cohort j, while γ is the substitutability between goods produced in different foreign countries. The composite index $C_{i,t}(j)$ is given by a similar CES function defined as

$$C_{i,t}(j) \equiv \left(\int_0^1 C_{i,t}(k,j)^{\frac{\varepsilon-1}{\varepsilon}} dk \right)^{\frac{\varepsilon}{\varepsilon-1}} . \tag{2.18}$$

Having defined the consumption indices, the sequence of budget constraints faced by a representative household of cohort j can be written as

$$\begin{aligned} \int_0^1 P_{H,t}(k) C_{H,t}(k,j) dk + \int_0^1 \int_0^1 P_{i,t}(k) C_{i,t}(k,j) dk di + \mathbb{E}_t \left\{ \mathcal{F}_{t,t+1} B_{t+1}(j) \right\} & \\ + \int_0^1 Q_t(k) Z_{t+1}(k,j) dk \ \leqslant \frac{1}{(1-\delta)} \left\{ B_t(j) + \int_0^1 [Q_t(k) + D_t(k)] Z_t(k,j) dk \right\} & \\ + W_t N_t(j) + P_t T_t(j), & \end{aligned} \tag{2.19}$$

where $P_{H,t}(k)$ is the price of variety k produced domestically, and $P_{i,t}(k)$ is the price of variety k imported from country i which is expressed in domestic currency. $B_{t+1}(j)$ is the nominal pay-off in period $t+1$ of a portfolio of state-contingent bonds (including foreign bonds) held by cohort j at the end of period t. $\mathcal{F}_{t,t+1}$ is the relevant discount factor for state-contingent claims, which is assumed to be constant across cohorts. $Q_t(k)$ denotes the nominal price of equity shares of domestic firms indexed by k, and $Z_t(k,j)$ is the amount of equity shares of firm k held by a representative household of cohort j. The corresponding dividend yield in nominal terms is given by $D_t(k)$. W_t is the nominal wage, and $T_t(j)$ denotes real lump-sum transfers (or taxes), which are uniformly distributed across cohorts[2]. P_t is the overall price index (i.e., CPI). Notice that as modeled by Blanchard (1985), the flow budget constraint incorporates the return on the insurance contract, $1/(1-\delta)$, for financial wealth carried over from the previous period.

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[2] While real lump-sum transfers (or taxes) do not depend on j, I use the term $T_t(j)$ to differentiate between transfers to a single cohort versus aggregate transfers, T_t.

Given the CES aggregator for $C_{H,t}(j)$, optimal allocation of expenditure on domestically produced goods results in the following demand function:

$$C_{H,t}(k,j) = \left(\frac{P_{H,t}(k)}{P_{H,t}}\right)^{-\varepsilon} C_{H,t}(j) \tag{2.20}$$

where $P_{H,t} \equiv \left(\int_0^1 P_{H,t}(k)^{1-\varepsilon} dk\right)^{\frac{1}{1-\varepsilon}}$ is an index of prices of domestically produced goods. Similarly, optimal allocation of expenditure on goods imported from country i, for all $i \in [0,1]$, results in the following demand function:

$$C_{i,t}(k,j) = \left(\frac{P_{i,t}(k)}{P_{i,t}}\right)^{-\varepsilon} C_{i,t}(j) \tag{2.21}$$

where $P_{i,t} \equiv \left(\int_0^1 P_{i,t}(k)^{1-\varepsilon} dk\right)^{\frac{1}{1-\varepsilon}}$ is a price index for goods imported from country i, expressed in domestic currency.

Optimal allocation of expenditure on all foreign goods, given the CES aggregator $C_{F,t}(j)$, yields the following demand equation

$$C_{i,t}(j) = \left(\frac{P_{i,t}}{P_{F,t}}\right)^{-\gamma} C_{F,t}(j) \tag{2.22}$$

where $P_{F,t} \equiv \left(\int_0^1 P_{i,t}^{1-\gamma} di\right)^{\frac{1}{1-\gamma}}$ is a price index for imported goods, which is also expressed in domestic currency. Furthermore, the optimal allocation of expenditure between domestic and imported goods yields the following demand equations

$$C_{H,t}(j) = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t(j) \tag{2.23}$$

$$C_{F,t}(j) = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t(j) \tag{2.24}$$

where $P_t \equiv \left[(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}$ is the overall CPI.

Total consumption expenditure for the domestic household is given by $P_{H,t}C_{H,t}(j) + P_{F,t}C_{F,t}(j) = P_tC_t(j)$. Using this relationship, the intertemporal budget constraint in (2.19) can be rewritten as:

$$\begin{aligned} P_tC_t(j) + \mathbb{E}_t\left\{\mathcal{F}_{t,t+1}B_{t+1}(j)\right\} + \int_0^1 Q_t(k)Z_{t+1}(k,j)dk \leqslant W_tN_t(j) + P_tT_t(j) \\ + \frac{1}{(1-\delta)}\left\{B_t(j) + \int_0^1 [Q_t(k) + D_t(k)]Z_t(k,j)dk\right\}. \end{aligned} \tag{2.25}$$

In each period, the representative household from cohort j chooses state-contingent sequences for consumption, leisure, bond holdings and share holdings to maximize its intertemporal utility as stated in (2.14), subject to the flow budget constraint. As such, the necessary first-order conditions associated with this utility maximization problem can be stated as follows:

$$\frac{W_t}{P_t} = \frac{C_t(j)}{[1 - N_t(j)]}, \tag{2.26}$$

$$\beta\frac{P_t}{P_{t+1}}\frac{C_t(j)}{C_{t+1}(j)} = \mathcal{F}_{t,t+1}, \tag{2.27}$$

$$Q_t(k) = \mathbb{E}_t\left\{\mathcal{F}_{t,t+1}[Q_{t+1}(k) + D_{t+1}(k)]\right\}. \tag{2.28}$$

The optimal intratemporal consumption-leisure decision is represented by (2.26), and the optimal intertemporal consumption pattern is given by (2.27). Meanwhile, (2.28) presents the intertemporal optimality condition concerning the holdings of equity shares.

The nominal gross return $(1 + i_t)$ on a riskless one-period discounted bond paying off one unit of currency in period $t+1$ with probability 1 (with $\mathbb{E}_t\left\{\mathcal{F}_{t,t+1}\right\}$ being its price) is defined by the following non-arbitrage condition:

$$(1 + i_t)\mathbb{E}_t\left\{\mathcal{F}_{t,t+1}\right\} = 1. \tag{2.29}$$

Taking conditional expectations on both sides of (2.27) and rearranging using (2.29) yields the familiar stochastic Euler equation for a representative household of cohort j:

$$\beta \mathbb{E}_t \left\{ \frac{P_t}{P_{t+1}} \frac{C_t(j)}{C_{t+1}(j)} \right\} = \frac{1}{(1+i_t)}. \tag{2.30}$$

2.3.2 Aggregation Across Households

Given the overlapping generations structure, the aggregate per-capita levels across cohorts are computed as the weighted average of each generation-specific variable $X(j)$:

$$X_t = \sum_{j=-\infty}^{t} \delta(1-\delta)^{t-j} X_t(j). \tag{2.31}$$

Aggregation can be easily performed if the equation under consideration is linear in cohort-specific variables. Accordingly, aggregation of the demand equation given in (2.23), by multiplying each side by the cohort size and then summing them up, results in:

$$\sum_{j=-\infty}^{t} \delta(1-\delta)^{t-j} C_{H,t}(j) = (1-\alpha) \left(\frac{P_{H,t}}{P_t} \right)^{-\eta} \sum_{j=-\infty}^{t} \delta(1-\delta)^{t-j} C_t(j). \tag{2.32}$$

Since $C_{H,t} \equiv \sum_{j=-\infty}^{t} \delta(1-\delta)^{t-j} C_{H,t}(j)$ and $C_t \equiv \sum_{j=-\infty}^{t} \delta(1-\delta)^{t-j} C_t(j)$, this can be rewritten as the following aggregate demand equation:

$$C_{H,t} = (1-\alpha) \left(\frac{P_{H,t}}{P_t} \right)^{-\eta} C_t. \tag{2.33}$$

Following a similar methodology, aggregation of the remaining demand equations, and the overall consumption index defined in (2.15) yields the following:

$$C_{F,t} = \alpha \left(\frac{P_{F,t}}{P_t} \right)^{-\eta} C_t, \tag{2.34}$$

$$C_{i,t} = \left(\frac{P_{i,t}}{P_{F,t}} \right)^{-\gamma} C_{F,t}, \tag{2.35}$$

where $C_t \equiv \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{1-\eta}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{1-\eta}{\eta}} \right]^{\frac{\eta}{1-\eta}}$.

Aggregation of the first order conditions across cohorts is based on the methodologies used in Piergallini (2006) and Nisticò (2012). Since some first order conditions are intertemporal in cohort-specific variables (e.g., the Euler equation), a simple aggregation as discussed above cannot be performed. Accordingly, following Nisticò (2012), I introduce the nominal financial wealth carried over from the previous period as a separate variable, $\Omega_t(j)$, which is defined as

$$\Omega_t(j) \equiv \frac{1}{(1-\delta)} \left\{ B_t(j) + \int_0^1 [Q_t(k) + D_t(k)] Z_t(k,j) dk \right\} \tag{2.36}$$

for a representative household of cohort j. With the introduction of financial wealth, the sequence of budget constraints in (2.25) can be rewritten as:

$$P_t C_t(j) + \mathbb{E}_t \left\{ \mathcal{F}_{t,t+1} B_{t+1}(j) \right\} + \int_0^1 Q_t(k) Z_{t+1}(k,j) dk \leqslant W_t N_t(j) + P_t T_t(j) + \Omega_t(j). \tag{2.37}$$

Combining (2.37) with the intertemporal optimality condition for equity shares given by (2.28), the budget constraint, holding with equality, can be specified as the following stochastic difference equation in financial wealth:

$$P_t C_t(j) + \mathbb{E}_t \left\{ \mathcal{F}_{t,t+1} (1-\delta) \Omega_{t+1}(j) \right\} = W_t N_t(j) + P_t T_t(j) + \Omega_t(j). \tag{2.38}$$

In line with Nisticò (2012), I define the human wealth for a representative agent of cohort j, $h_t(j)$, as the expected stream of future disposable labor income and transfers discounted by the stochastic discount factor, conditional upon survival:

$$h_t(j) \equiv \mathbb{E}_t \left\{ \sum_{k=0}^{\infty} \mathcal{F}_{t,t+k}(1-\delta)^k [W_{t+k}N_{t+k}(j) + P_{t+k}T_{t+k}(j)] \right\}. \tag{2.39}$$

As described in Piergallini (2006), in order to rule out the possibility of Ponzi schemes, I assume that the present value of financial wealth, conditional on survival, shrinks to zero as time diverges:

$$\lim_{k\to\infty} \mathbb{E}_t \left\{ \mathcal{F}_{t,t+k}(1-\delta)^k \Omega_{t+k}(j) \right\} = 0. \tag{2.40}$$

In the meantime, the optimal intertemporal consumption pattern given by (2.27) can be iterated forward to obtain the following equation for a multiple period discount factor:

$$\mathcal{F}_{t,t+k} = \prod_{i=1}^{k} \mathcal{F}_{t+i-1,t+i} = \beta^k \mathbb{E}_t \left\{ \frac{P_t}{P_{t+k}} \frac{C_t(j)}{C_{t+k}(j)} \right\}. \tag{2.41}$$

The stochastic difference equation in financial wealth given by (2.38) can be solved forward to obtain the following:

$$\begin{aligned} \Omega_t(j) = \lim_{k\to\infty} \mathbb{E}_t \left\{ \mathcal{F}_{t,t+k}(1-\delta)^k \Omega_{t+k}(j) \right\} + \mathbb{E}_t \sum_{k=0}^{\infty} \left\{ \mathcal{F}_{t,t+k}(1-\delta)^k P_{t+k}C_{t+k}(j) \right\} \\ - \mathbb{E}_t \sum_{k=0}^{\infty} \left\{ \mathcal{F}_{t,t+k}(1-\delta)^k [W_{t+k}N_{t+k}(j) + P_{t+k}T_{t+k}(j)] \right\}, \end{aligned} \tag{2.42}$$

which can be simplified using (2.39), (2.41) and the No-Ponzi-Game condition in (2.40) to derive the following equation:

$$\Omega_t(j) = \sum_{k=0}^{\infty} \beta^k (1-\delta)^k P_t C_t(j) - h_t(j). \tag{2.43}$$

Further simplification of (2.43) provides the following relationship between consumption, and financial and human wealth of a representative household of cohort j.

$$P_t C_t(j) = [1 - \beta(1-\delta)][\Omega_t(j) + h_t(j)]. \tag{2.44}$$

The solution of the households' problem provides three equilibrium conditions specific to each cohort j, namely, the labor supply relation (equation (2.26)), the budget constraint specified with financial wealth (equation (2.38)) and the relationship between personal consumption and total personal wealth (equation (2.44)). Since these equilibrium conditions are linear in the cohort-specific variables, aggregation across cohorts yields an identical set of relations. Accordingly, the solution to the households' problem results in the following aggregate relations:

$$\frac{W_t}{P_t} = \frac{C_t}{(1-N_t)}, \tag{2.45}$$

$$P_t C_t + \mathbb{E}_t \left\{ \mathcal{F}_{t,t+1} \Omega_{t+1} \right\} = W_t N_t + P_t T_t + \Omega_t, \tag{2.46}$$

$$P_t C_t = [1 - \beta(1-\delta)](\Omega_t + h_t) \tag{2.47}$$

where aggregate financial wealth is defined as[3]:

$$\Omega_t \equiv B_t + \int_0^1 [Q_t(k) + D_t(k)] Z_t(k) dk, \tag{2.48}$$

and aggregate human wealth is given by

$$h_t \equiv \mathbb{E}_t \left\{ \sum_{k=0}^{\infty} \mathcal{F}_{t,t+k} (1-\delta)^k [W_{t+k} N_{t+k} + P_{t+k} T_{t+k}] \right\}. \tag{2.49}$$

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[3] When aggregating financial wealth, it should be noted that the cohort born in the most recent period does not have any financial wealth carried forward from the previous period. Therefore, only the rest of the cohorts are considered in the aggregation. Accordingly, the gross return on the insurance contract, $1/(1-\delta)$, needs to be considered when aggregating individual financial instruments. For example, aggregate bond holdings is given by $B_t = \sum_{j=-\infty}^{t-1} \delta(1-\delta)^{t-j} \frac{1}{1-\delta} B_t(j)$.

Recall that households enter into an insurance contract where a perfect insurance market inherits consumers' financial wealth contingent on their death and redistributes it among the remaining agents in proportion to their financial wealth. However, aggregate financial wealth as given in (2.48) shows that the aggregate value of the gross return on the insurance contract must be 1 since it is only having redistributive effects, unlike the case for individual households which is having a return of $1/(1-\delta)$ (Nisticò, 2012).

As the final step of aggregation, the equation for aggregate human wealth can be rearranged to obtain

$$h_t = W_t N_t + P_t T_t + (1-\delta)\mathbb{E}_t \left\{ \mathcal{F}_{t,t+1} h_{t+1} \right\}, \tag{2.50}$$

which can be combined with (2.47) to yield the following relation:

$$\frac{P_t C_t}{[1-\beta(1-\delta)]} - \Omega_t = W_t N_t + P_t T_t + (1-\delta)\mathbb{E}_t \left\{ \mathcal{F}_{t,t+1} \left[\frac{P_{t+1} C_{t+1}}{[1-\beta(1-\delta)]} - \Omega_{t+1} \right] \right\}. \tag{2.51}$$

Substituting Ω_t in (2.51) into the budget constraint given by (2.46) we obtain the following equation which describes the dynamic path of aggregate consumption:

$$\beta P_t C_t = \mathbb{E}_t \left\{ \mathcal{F}_{t,t+1} P_{t+1} C_{t+1} \right\} + \frac{\delta}{(1-\delta)} [1-\beta(1-\delta)] \mathbb{E}_t \left\{ \mathcal{F}_{t,t+1} \Omega_{t+1} \right\}. \tag{2.52}$$

Notice that the second term in the right-hand side represents the effects of financial wealth, where such effects fade out as the probability of death (δ) approaches zero. If the agents do not exit the market (i.e., $\delta = 0$), equation (2.52) becomes identical to the standard Euler equation in (2.30).

2.3.3 Inflation, the Real Exchange Rate and Terms of Trade

This section sets out some key relationships between domestic inflation, CPI inflation, the real exchange rate, and the terms of trade. To begin with, the bilateral terms of trade between the domestic economy and country i ($\mathcal{S}_{i,t}$) is defined as $\mathcal{S}_{i,t} \equiv \frac{P_{i,t}}{P_{H,t}}$. As such, the effective terms of trade is given by

$$\mathcal{S}_t = \left(\int_0^1 \mathcal{S}_{i,t}^{1-\gamma} di \right)^{\frac{1}{1-\gamma}} = \frac{P_{F,t}}{P_{H,t}}, \tag{2.53}$$

which can be approximated (up to first-order) by the following log-linear expression:

$$s_t = \int_0^1 s_{i,t} di \ = p_{F,t} - p_{H,t}, \tag{2.54}$$

where $s_t \equiv \log \ \mathcal{S}_t$ denotes the (log) effective terms of trade. Log-linearization of the expression for overall CPI around a symmetric steady state satisfying the purchasing power parity (PPP) condition results in

$$p_t = (1-\alpha) \ p_{H,t} + \alpha \ p_{F,t} \ = p_{H,t} + \alpha \ s_t. \tag{2.55}$$

As such, defining inflation as the change in (log) price levels, the relation between domestic inflation and CPI inflation can be given as

$$\pi_t = \pi_{H,t} + \alpha \ \Delta s_t, \tag{2.56}$$

where the difference between overall and domestic inflation is proportional to the change in the terms of trade, with the coefficient of proportionality increasing with the degree of openness, α.

The bilateral nominal exchange rate, the price of country i's currency expressed in terms of the domestic currency, is denoted as $\mathcal{E}_{i,t}$. Assuming that the law of one price holds for each variety of good, the price of good k imported from country i can be written as $P_{i,t}(k) = \mathcal{E}_{i,t}\ P^{i}_{i,t}(k)$ for all $i, k \in [0,1]$, where $P^{i}_{i,t}(k)$ is the price of good k from country i, expressed in terms of country i's (producer's) currency. Substituting this into the definition of $P_{i,t}$, we obtain $P_{i,t} = \mathcal{E}_{i,t}\ P^{i}_{i,t}$ where $P^{i}_{i,t} \equiv \left(\int_0^1 P^{i}_{i,t}(k)^{1-\varepsilon}dk\right)^{\frac{1}{1-\varepsilon}}$. Next, substitution of this into the definition of $P_{F,t}$ and log-linearization around the symmetric steady state yields

$$p_{F,t} = \int_0^1 (e_{i,t} + p^{i}_{i,t})di \ = e_t \ + \ p^{*}_t, \tag{2.57}$$

where $e_t \equiv \int_0^1 e_{i,t}di$ is the (log) nominal effective exchange rate, and $p^{*}_t \equiv \int_0^1 p^{i}_{i,t}di$ is the (log) world price index. Combining (2.54) with (2.57) gives the following expression:

$$s_t = e_t \ + \ p^{*}_t \ - \ p_{H,t}. \tag{2.58}$$

The bilateral real exchange rate with country i is defined as $\mathcal{Q}_{i,t} = \frac{\mathcal{E}_{i,t} P^{i}_t}{P_t}$, which is the ratio of the two countries' CPIs expressed in terms of domestic currency. Defining the (log) effective real exchange rate as $q_t \equiv \int_0^1 q_{i,t}di$, we obtain

$$\begin{aligned} q_t &= \int_0^1 (e_{i,t} + p^{i}_t - p_t)di \ = s_t \ + \ p_{H,t} - \ p_t \\ &= (1-\alpha)\ s_t, \end{aligned} \tag{2.59}$$

where the last equality provides a relation between the terms of trade and the real exchange rate (only up to a first order approximation).

2.3.4 International Risk Sharing and Uncovered Interest Parity

Under the assumption of complete international financial markets, the intertemporal optimality condition in (2.27) can be equated for domestic and foreign households:

$$\mathcal{F}_{t,t+1} = \beta \frac{P_t}{P_{t+1}} \frac{C_t(j)}{C_{t+1}(j)} = \beta \frac{\mathcal{E}_{i,t} P_t^i}{\mathcal{E}_{i,t+1} P_{t+1}^i} \frac{C_t^i(j)}{C_{t+1}^i(j)}. \tag{2.60}$$

where $C_t^i(j)$ is a composite consumption index of a representative household in country i from cohort j. Combining (2.60) with the definition for the real exchange rate, we obtain:

$$\frac{C_{t+1}^i(j)}{C_{t+1}(j)} = \frac{C_t^i(j)}{C_t(j)} \frac{\mathcal{Q}_{i,t}}{\mathcal{Q}_{i,t+1}}, \tag{2.61}$$

which can be solved backwards to yield

$$C_t(j) = \frac{C_0(j)}{C_0^i(j)\ \mathcal{Q}_{i,0}}\ C_t^i(j) \mathcal{Q}_{i,t} \ = \ \vartheta_i(j)\ C_t^i(j) \mathcal{Q}_{i,t}, \tag{2.62}$$

where $\vartheta_i(j)$ is considered as some constant depending on the initial asset position. Following Galí and Monacelli (2005), without loss of generality, symmetric initial conditions are assumed (i.e., zero net foreign asset holdings), implying $\vartheta_i(j) = \vartheta = 1$. Aggregating (2.62) across cohorts, log-linearizing around the steady state, and integrating over i gives the following relationship linking domestic consumption with world consumption and the terms of trade:

$$c_t = c_t^* \ + \ q_t \ = c_t^* \ + \ (1-\alpha) s_t, \tag{2.63}$$

where $c_t^* \equiv \int_0^1 c_t^i di$ is an (log) index for world consumption.

The assumption of complete international financial markets leads to another important relationship, the UIP condition. For any foreign country i, the asset pricing equation for a riskless one-period nominal bond paying off one unit of currency in period $t+1$ can be written as:

$$(1+i_t^i)\ \mathbb{E}_t\left\{\mathcal{F}_{t,t+1}\frac{\mathcal{E}_{i,t+1}}{\mathcal{E}_{i,t}}\right\}=1. \tag{2.64}$$

Combining (2.64) with the asset pricing equation for the domestic economy given in (2.29), the following relation can be obtained:

$$\mathbb{E}_t\left\{\mathcal{F}_{t,t+1}\left[(1+i_t)-(1+i_t^i)\ \frac{\mathcal{E}_{i,t+1}}{\mathcal{E}_{i,t}}\right]\right\}=0. \tag{2.65}$$

Log linearizing around the steady state and aggregating across countries yield the familiar UIP condition

$$i_t-i_t^*=\mathbb{E}_t\left\{\Delta e_{t+1}\right\}, \tag{2.66}$$

where i_t^* denotes the interest rate for the rest of the world.

2.3.5 Production Technology of Firms

In line with Galí and Monacelli (2005), and Nisticò (2012), I assume that a typical firm produces a differentiated good with a simple linear production function. Accordingly, the production function of a firm producing good variety (or brand) $k\in[0,1]$ in each country is given as:

$$Y_t(k)=A_t\ N_t(k), \tag{2.67}$$

where $a_t\equiv\log\ A_t$ follows the stochastic process given by $a_t=\rho_a\ a_{t-1}+\varepsilon_t^a$, in which ε_t^a is a labor-augmenting shock on productivity. An index for aggregate domestic output is given by

$$Y_t \equiv \left[\int_0^1 Y_t(k)^{\frac{\varepsilon-1}{\varepsilon}} dk\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2.68}$$

which results in the brand-specific demand function, $Y_t(k) = \left(\frac{P_{H,t}(k)}{P_{H,t}}\right)^{-\varepsilon} Y_t$. Aggregation across domestic brands results in

$$Y_t \ \Xi_t \ = \ A_t N_t, \tag{2.69}$$

where $N_t \equiv \int_0^1 N_t(k)dk$ denotes the aggregate level of labor, and $\Xi_t \equiv \int_0^1 \left(\frac{P_{H,t}(k)}{P_{H,t}}\right)^{-\varepsilon} dk$ is an index of price dispersion among domestic firms. Since $\xi_t \equiv \log \ \Xi_t$ is of second-order, log-linearization of the aggregate production function yields:

$$y_t \ = \ a_t \ + \ n_t. \tag{2.70}$$

Each firm enters a competitive labor market and chooses the optimal level of labor that would minimize total real costs, subject to the technological constraint. Therefore, the equilibrium real marginal cost of a firm is given by

$$MC_t \ = \ (1-\tau)\frac{W_t}{A_t P_{H,t}}, \tag{2.71}$$

where τ is an employment subsidy that neutralizes the distortion associated with firms' market power, as discussed in Rotemberg and Woodford (1999).

2.3.6 Aggregate Demand and Output

Goods market clearing in the domestic economy requires that domestic output is equal to the sum of domestic consumption and foreign consumption of home produced goods. This can be expressed as:

$$
\begin{aligned}
Y_t(k) &= C_{H,t}(k) + \int_0^1 C^i_{H,t}(k)di \\
&= \left(\frac{P_{H,t}(k)}{P_{H,t}}\right)^{-\varepsilon} \left[(1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \;+\; \alpha \int_0^1 \left(\frac{P_{H,t}}{\mathcal{E}_{i,t}P^i_{F,t}}\right)^{-\gamma} \left(\frac{P^i_{F,t}}{P^i_t}\right)^{-\eta} C^i_t di\right]
\end{aligned}
\tag{2.72}
$$

for all $k \in [0,1]$, where $C^i_{H,t}(k)$ represents country i's demand for good k produced in the home economy. This together with the aggregate output defined in (2.68) yields[4]

$$
Y_t = C_t \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} \left[(1-\alpha) \;+\; \alpha \int_0^1 \left(\mathcal{S}^i_t \mathcal{S}_{i,t}\right)^{\gamma-\eta} \left(\mathcal{Q}_{i,t}\right)^{\eta-1} di\right] \tag{2.73}
$$

where $\mathcal{S}^i_t$ denotes the effective terms of trade of country i. Using the fact that $\int_0^1 s^i_t di \;=\; 0$, the first order log-linear approximation to (2.73) around its symmetric steady state provides the following relation:

$$
y_t = c_t \;+\; \alpha\omega s_t, \tag{2.74}
$$

where $\omega = \gamma + (1-\alpha)(\eta - 1)$.

A relation similar to (2.74) will hold for every country in the world. Therefore, a world market clearing condition, by aggregating over all countries, can be written as follows:

$$
y^*_t \equiv \int_0^1 y^i_t di \;=\; \int_0^1 c^i_t di \equiv c^*_t, \tag{2.75}
$$

where y^*_t and c^*_t denotes (log) indexes for world output and consumption, respectively. Combining this with the international risk sharing condition given by (2.63) implies

$$
y_t = y^*_t \;+\; \frac{1}{\sigma_\alpha} s_t, \tag{2.76}
$$

---

[4] Please refer Galí and Monacelli (2005) for a detailed derivation.

where $\sigma_\alpha = \dfrac{1}{(1-\alpha)+\alpha\omega}$.

2.3.7 Price Setting, Marginal Cost and Inflation Dynamics

Monopolistic firms are assumed to set prices in a Calvo-type staggered fashion. As such, in any given period, only a fraction $1-\theta$ of randomly selected firms are able to reset their prices optimally, while the other fraction θ cannot adjust prices. When able to set price optimally, each firm seeks to maximize the expected stream of future dividends, conditional on that price being effective. Hence, the dynamic problem faced by an optimizing firm k can be given as:

$$\max_{\bar{P}_{H,t}(k)} \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \theta^i \mathcal{F}_{t,t+i} Y_{t+i}(k) [\bar{P}_{H,t}(k) \ - \ P_{H,t+i} MC_{t+i}] \right\}. \tag{2.77}$$

By taking the appropriate first order conditions and log-linearizing around the steady state, we can describe inflation dynamics with a standard New Keynesian Phillips curve type relation given by[5]:

$$\pi_{H,t} = \tilde{\beta} \mathbb{E}_t \left\{ \pi_{H,t+1} \right\} \ + \ \lambda mc_t, \tag{2.78}$$

where $\tilde{\beta} = \frac{\beta}{1+\Psi}$, $\lambda = \frac{(1-\theta)(1-\tilde{\beta}\theta)}{\theta}$, and $\Psi = \delta \frac{[1-\beta(1-\delta)]}{(1-\delta)} \frac{\Omega}{PC}$ with $\frac{\Omega}{PC}$ representing the steady state level of wealth-to-consumption ratio. Notice that $\Psi > 0$ is related to the probability of death, δ. Hence, the introduction of the perpetual youth structure results in a lower weight on future inflation and a higher weight on the marginal costs compared with the standard representative agent scenario. Also, $\tilde{\beta}$ converges to β as δ approaches zero.

---

[5] Please refer Appendix B of Galí and Monacelli (2005) for a detailed derivation with standard representative agents. A New Keynesian Phillips curve for an economy with representative agents with finite lives as in Blanchard (1985) and Yaari (1965) is discussed in Nisticò (2012).

Log-linearization of the expression for marginal cost given by (2.71) yields

$$mc_t = -\nu + w_t - p_{H,t} - a_t \;=\; -\nu + (w_t - p_t) + (p_t - p_{H,t}) - a_t, \tag{2.79}$$

where $\nu \equiv -\log(1-\tau)$. By log-linearizing the optimal labor-leisure decision of the households, we obtain

$$w_t - p_t = c_t + \varphi n_t, \tag{2.80}$$

where $\varphi \equiv \frac{N}{1-N}$ is the inverse of the steady-state Frisch elasticity of labor supply. Combining (2.79) with (2.63), (2.70), (2.76), and (2.80) we derive the following expression for the marginal cost of a firm:

$$mc_t = -\nu + (\sigma_\alpha + \varphi) y_t + (1 - \sigma_\alpha) y_t^* - (1 + \varphi) a_t. \tag{2.81}$$

The domestic output gap (x_t) is defined as the deviation of (log) domestic output from its natural level (i.e., $x_t \equiv y_t - y_t^n$). The natural level of output is in turn defined as the equilibrium level of output in the absence of nominal rigidities (i.e., flexible price output). The natural level of domestic output is obtained after imposing $mc_t \equiv -\mu$ in (2.81) and solving for domestic output. Here, $\mu \equiv \log\left(\frac{\varepsilon}{\varepsilon-1}\right)$ corresponds to the log of the (gross) mark-up in the steady state. Accordingly, the natural level of output is given by

$$y_t^n = \Gamma \;+\; \Gamma_a a_t \;-\; \alpha \Gamma_y y_t^*, \tag{2.82}$$

where $\Gamma = \frac{\nu-\mu}{(\sigma_\alpha+\varphi)}$, $\Gamma_a = \frac{(1+\varphi)}{(\sigma_\alpha+\varphi)}$, $\Gamma_y = \frac{\Theta\sigma_\alpha}{(\sigma_\alpha+\varphi)}$, and $\Theta = \omega - 1$. From (2.81) it follows that the real marginal cost and the output gap are linked as

$$mc_t = (\sigma_\alpha + \varphi) x_t. \tag{2.83}$$

Combining this with (2.78) we obtain the familiar New Keynesian Phillips curve in terms of the output gap for the small open economy under consideration:

$$\pi_{H,t} = \tilde{\beta}\mathbb{E}_t \left\{\pi_{H,t+1}\right\} \ + \ \kappa_\alpha x_t, \tag{2.84}$$

where $\kappa_\alpha = \lambda(\sigma_\alpha + \varphi)$.

2.3.8 The Linearized Model

Log-linearization of the dynamic path of aggregate consumption given by equation (2.52) follows the exact procedure in Nisticò (2005), and yields (please see Section B.1 of the Appendix for details of the derivation):

$$c_t = \frac{1}{1+\Psi}\mathbb{E}_t \left\{c_{t+1}\right\} \ + \ \frac{\Psi}{1+\Psi}\wp_t \ - \ \frac{1}{1+\Psi}(i_t - \mathbb{E}_t\left\{\pi_{t+1}\right\} - \rho), \tag{2.85}$$

where $\rho \equiv -\log(\beta)$ is considered as the steady state net interest rate, and $\wp_t \equiv \log(\frac{Q_t}{Q})$, where Q is the aggregate real stock-price index. Notice that unlike the standard representative agent scenario, future consumption is discounted in the aggregate consumption Euler equation given by (2.85). This is a key change introduced by the perpetual youth structure. Further, current consumption is also a function of the share price. Since Ψ is related to the probability of death (δ), the effect of the stock price on consumption dissipates and (2.85) becomes similar to a standard consumption Euler equation as δ approaches zero. Meanwhile, substituting for consumption using the relationships between output, the terms of trade and inflation, we obtain:

$$x_t = \frac{\sigma_\alpha}{\Gamma_0}\mathbb{E}_t\left\{x_{t+1}\right\} \ + \ \frac{\Psi}{\Gamma_0}\hat{\wp}_t \ - \ \frac{1}{\Gamma_0}(i_t - \mathbb{E}_t\left\{\pi_{H,t+1}\right\} - r_t^n), \tag{2.86}$$

where

$$r^n \equiv \rho \ + \ (\sigma_\alpha \rho_a + \Psi - \Gamma_0)\Gamma_a a_t \ + \ [(\sigma_\alpha \rho_y + \Psi - \Gamma_0)\Gamma_y \ + \ \Theta\sigma_\alpha(\rho_y - 1)]\alpha y_t^*, \tag{2.87}$$

and $\Gamma_0 \equiv 1 + \Psi - \alpha\Theta\sigma_\alpha$, $\hat{\wp}_t \equiv \wp_t - \wp_t^n$, where $\wp_t^n$ is the natural aggregate real stock-price index that evolves according to $\wp_t^n = y_t^n$.

For the optimality condition on the holdings of equity shares presented in (2.28), following the same steps as described in Nisticò (2005), the following linearized relation can be obtained:

$$\hat{\wp}_t = \frac{\tilde{\beta}}{1+\epsilon}\mathbb{E}_t\left\{\hat{\wp}_{t+1}\right\} \ - \ \frac{\lambda_q}{1+\epsilon}\mathbb{E}_t\left\{x_{t+1}\right\} \ - \ (i_t - \mathbb{E}_t\left\{\pi_{H,t+1}\right\} - r_t^n), \tag{2.88}$$

where $\lambda_q = (1 + \epsilon - \tilde{\beta})\left(\frac{1+\varphi-\mu}{\mu} + \alpha\sigma_\alpha\right)$ and ϵ is the conditional covariance between $\mathcal{F}_{t,t+1}$ and D_t.

The rest of the model is summarized as follows:

$$\pi_{H,t} = \tilde{\beta}\mathbb{E}_t\left\{\pi_{H,t+1}\right\} \ + \ \kappa_\alpha x_t, \tag{2.89}$$

$$y_t = y_t^* \ + \ \frac{1}{\sigma_\alpha}s_t, \tag{2.90}$$

$$\pi_t = \pi_{H,t} \ + \ \alpha\Delta s_t, \tag{2.91}$$

$$\Delta e_t = \Delta s_t \ + \ \pi_{H,t}, \tag{2.92}$$

$$q_t = (1-\alpha) \ s_t, \tag{2.93}$$

$$x_t = y_t \ - \ y_t^n, \tag{2.94}$$

$$y_t^n = \Gamma \ + \ \Gamma_a a_t \ - \ \alpha\Gamma_y y_t^*, \tag{2.95}$$

$$\pi_{H,t} = p_{H,t} \; - \; p_{H,t-1}, \tag{2.96}$$

$$\pi_t = p_t \; - \; p_{t-1}. \tag{2.97}$$

Meanwhile, AR(1) processes are assumed for a_t and y_t^* which are given by:

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a, \tag{2.98}$$

$$y_t^* = \rho_y y_{t-1}^* + \varepsilon_t^{y^*}. \tag{2.99}$$

As before, the model is closed using a simple monetary policy rule where the monetary authority sets the nominal interest rate based on domestic inflation:

$$i_t = \phi_\pi \pi_{H,t} + \varepsilon_t^{mp} + \sum_{j=1}^{J} \varepsilon_{t,t-j}^{mp}. \tag{2.100}$$

The usual contemporaneous monetary policy shock is given by ε_t^{mp}, while $\varepsilon_{t,t-j}^{mp}$ denotes a policy shock in period t that is known to the public in period $t - j$.

2.4 Quantitative Assessment of the Proposed Extension

The basic calibration considered in Section 2.2.2 of this study is carried forward to the extended model as well. Additional parameters introduced during the extension process are calibrated as follows. Following Nisticò (2012), I choose a value of 10 per cent for the steady state markup (μ), implying an elasticity of substitution between differentiated goods (ε) of 11. Parameters pertaining to the perpetual youth framework are based on Nisticò (2005), and Castelnuovo and Nisticò (2010). Concerning the key parameter δ, Castelnuovo and Nisticò (2010) provide a Bayesian structural estimate where they suggest a posterior mean

Table 2.3: Structural parameters values: open economy model with perpetual youth

Parameter	Description	Value
θ	Calvo parameter	0.75
ϵ	Conditional covariance between the stochastic discount factor and stock returns	0.015
β	Discount rate	0.99
σ	Inverse elasticity of intertemporal substitution	1
φ	Labor supply elasticity	1
α	Openness index	0.4
δ	Probability of death/wealth "re-setting"	0.13
μ	Steady state mark up	0.1
η	Substitutability between domestic and foreign goods	2
γ	Substitutability between goods produced in foreign countries	1
ϕ_π	Taylor Rule coefficient for domestic inflation	1.5

of 0.13 for δ. It implies that, on average, 13 per cent of agents trading in the financial market are replaced in each period by newcomers with zero wealth. Del Negro et al. (2015) take a more conservative approach by setting the benchmark value of δ to 0.03, and later raising it to 0.06 to include other forms of wealth "re-setting". Following Castelnuovo and Nisticò (2010), I set δ equal to 0.13 for the initial simulation. However, later on, the response of the model variables is assessed for different values of δ. Meanwhile, following Nisticò (2005), the conditional covariance between the stochastic discount factor and the return on stocks (ϵ) is assumed to be 0.015. The set of parameters used for the analysis is summarized in Table 2.3.

I repeat the forward guidance experiment conducted in Section 2.2.2 using the small open economy model with a perpetual youth structure presented above. Similar to the first experiment, I assume that the home central bank credibly announces a one percentage point increase in the nominal interest rate for a single period, J periods ahead in the future, while keeping the interest rate at its initial level of zero until period $J-1$. Figure 2.4 depicts the response of the interest rate, output, inflation, and the exchange rates for a model simulation carried out for different values of J. It can be noted that the response of macroeconomic

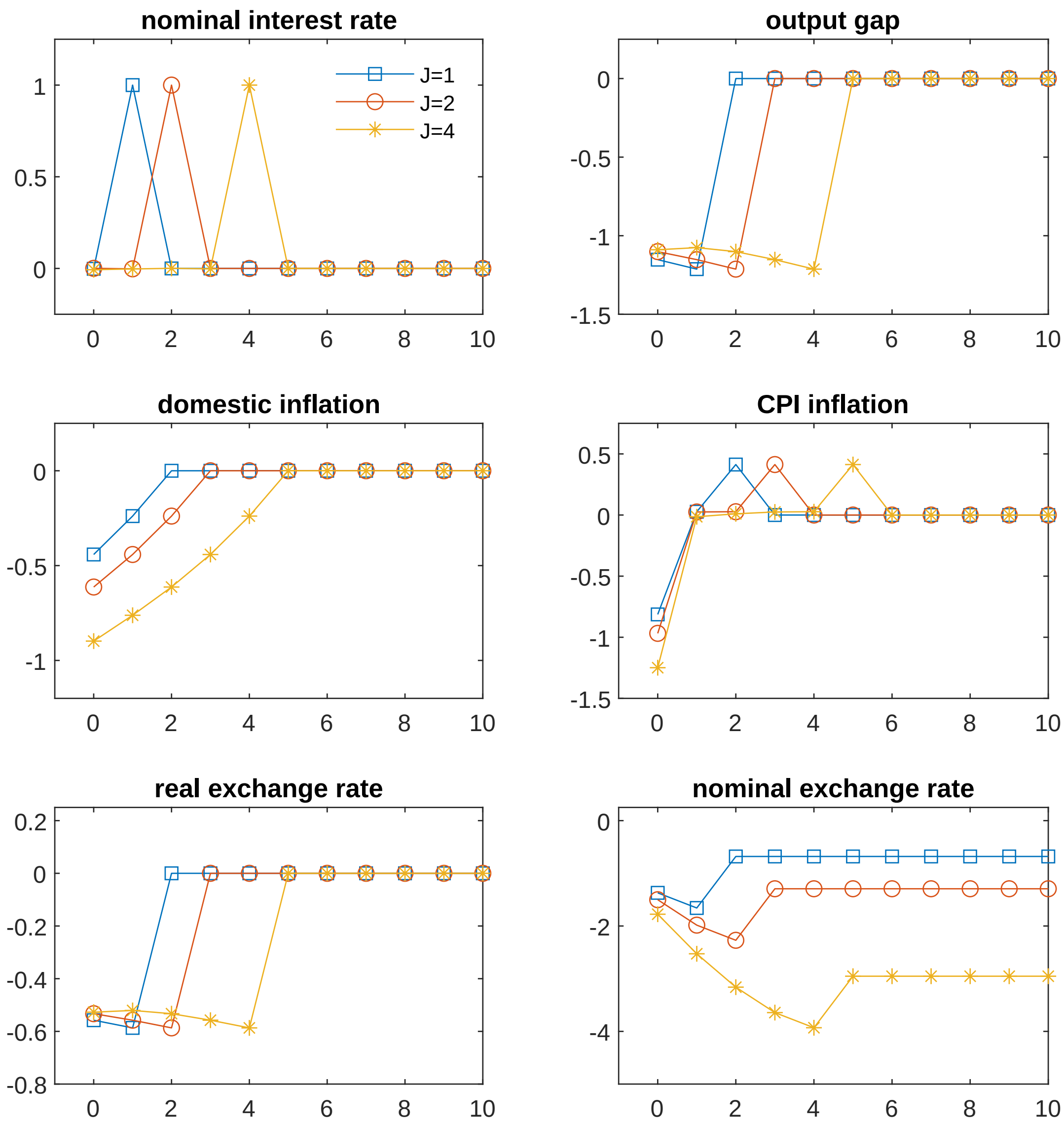

Figure 2.4: Effects of an announced interest rate increase for a small open economy model with perpetual youth. Simulated for different time horizons of the announced future increase.

variables for the announced interest rate increase is different to the response observed for the baseline small open economy model presented in Figure 2.2. Moreover, for the given parameter specification, the initial responses of macroeconomic variables such as output, CPI inflation and the real exchange rate do not exhibit a considerable variation based on the horizon of forward guidance announcements. Nonetheless, the responses of domestic inflation and the nominal exchange rate do exhibit a notable change with the time horizon of the announced interest rate increase.

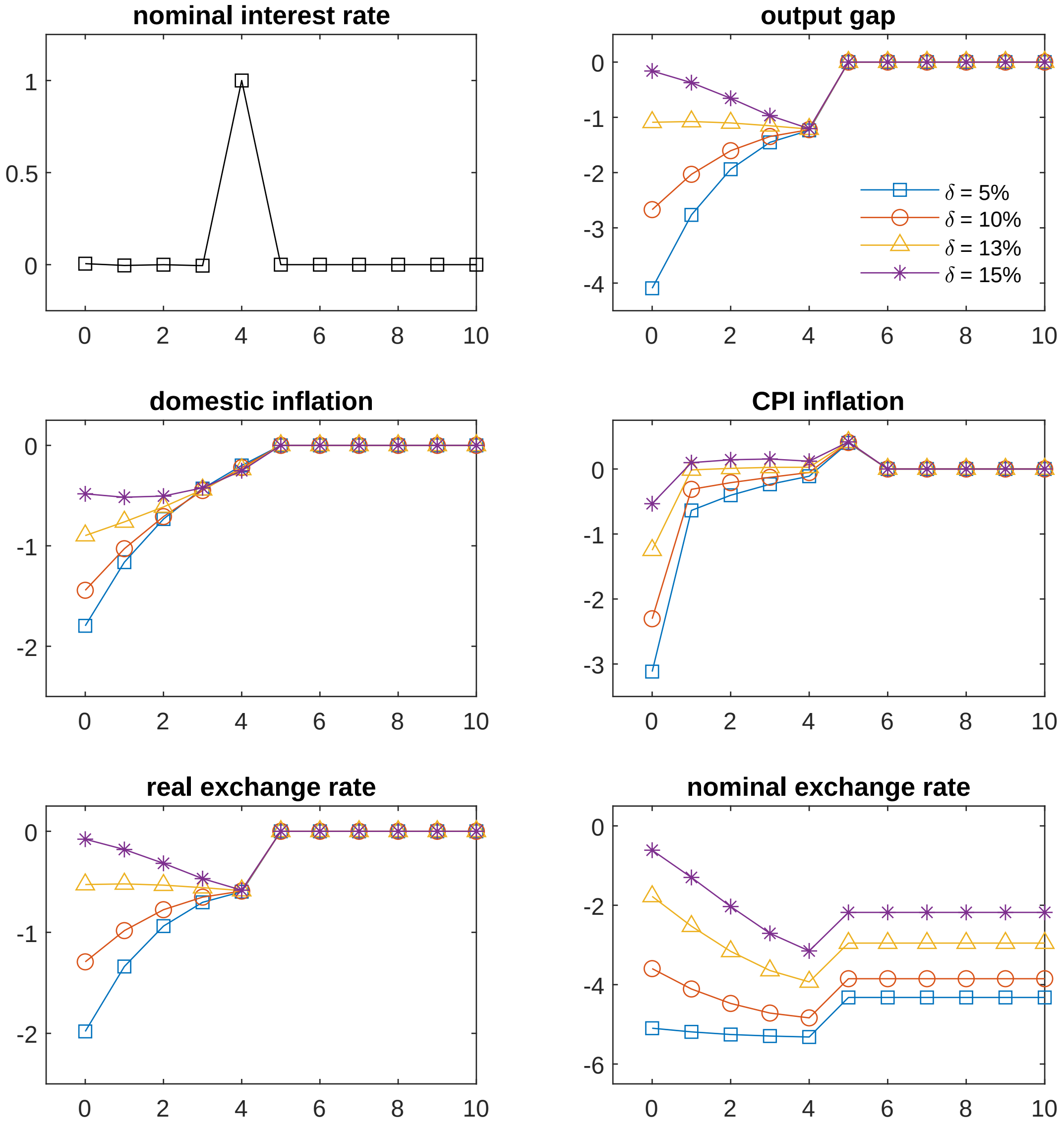

Figure 2.5: Effects of an announced interest rate increase for different values of the probability of death (δ)

In order to analyze whether the incorporation of a perpetual youth structure attenuates the excessive response of key macroeconomic variables, I perform the forward guidance experiment for different values of δ. By doing so we can observe whether the fraction of agents exiting the financial market, or the probability of death, is having any influence on the impact of an announced interest rate increase. As such, I simulate the model for a four period ahead forward guidance announcement (i.e., $J = 4$) for different values of δ ranging from 5 percent to 15 percent. Figure 2.5 illustrates the outcome of this experiment, where we can

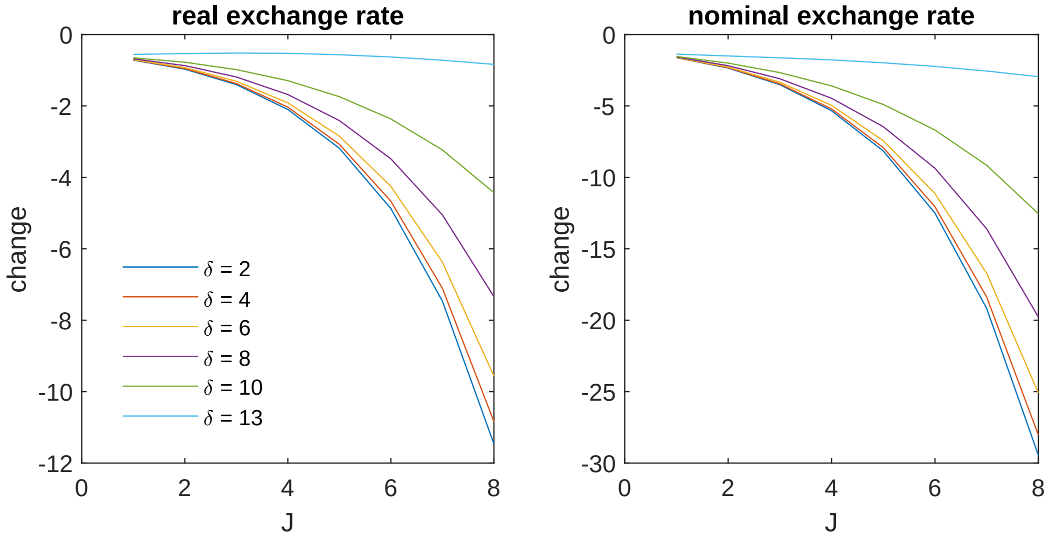

Figure 2.6: Initial change in the exchange rates for different time horizons (J) of the announced rate increase and different values of the probability of death (δ)

clearly see that not only the response of output and inflation, but also the response of the exchange rates is weakened by an increase in δ.

Focusing more on the exchange rates, I assess the the impact of an announced increase in interest rate on the real exchange rate as well as the nominal exchange rate, for different combinations of forward guidance time horizon (J) and the probability of death (δ). Figure 2.6 depicts the outcome of this experiment, which presents the initial change in the exchange rates for an announcement of a 1 percent increase in the nominal interest rate. It is evident that when δ approaches smaller values, the change in exchange rates increases exponentially with the time horizon of forward guidance. This outcome is similar to what we observed in Figure 2.3 under Section 2.2. However, as the value of δ increases, the exponential nature of the exchange rate change dies out.

2.5 Discussion and Possible Explanations

The quantitative assessment performed in Section 2.4 illustrates that the perpetual youth structure dampens the response of the economy to an announced nominal interest rate change. It is useful, at this point, to identify that there are two types of agents interacting in the financial markets in any given period: the 'old agents' who were in the markets at least for one period, and 'newcomers' who entered the markets in the current period. Since the latter enter the economy with no financial wealth, in the initial period they can consume only out of their human wealth. Consequently, the consumption pattern of 'newcomers' is different to that of 'old agents', because they hold a different amount of total wealth, and this distinction is key to the perpetual youth framework.

When a central bank announces a future change in interest rate, agents immediately respond by either accumulating or de-cumulating wealth. Nonetheless, unborn cohorts cannot react to this interest rate announcement until they are born. Moreover, while each existing cohort responds according to a standard Euler equation, those who are not yet born cannot already adjust their consumption in line with the future interest rate changes. This leads to a dampening of the initial consumption response. As such, the perpetual youth structure involves more discounting in the aggregate consumption Euler equation (equation (2.85)) than in a standard representative agent model. This is the reason behind the attenuation of the output response with the increase in δ, in the small open economy model considered above. The Phillips curve relation given in equation (2.89) can be solved forward to get an expression similar to equation (2.4). Since the current domestic inflation is the discounted sum of future output gaps, the attenuated output response results in an attenuation in domestic inflation response as well. This in turn contributes to the weakening of the response observed for the overall CPI inflation.

The small open economy model above assumes complete securities markets at the international level. This leads to a simple relation linking world consumption and the terms of trade with domestic consumption (equation (2.63)). Given the fact that the small open economy has no influence on world consumption, any adjustment in domestic consumption is reflected by a similar change in the terms of trade. The real exchange rate is in turn proportional to the terms of trade as given in equation (2.59). Therefore, any dampening of the consumption response is reflected by a dampening in the response of the real exchange rate. Finally, the nominal exchange rate is given by the relation $e_t = q_t + p_t - p_t^*$. Given that the model treats the world price level (p_t^*) as a constant, the response of the nominal exchange rate depends upon the real exchange rate and CPI inflation. We already know that the perpetual youth structure dampens the response of inflation and the real exchange rate. Hence, the presence of agents with finite lives attenuates the response of the nominal exchange rate to an announced change in the nominal interest rate.

It is evident that the perpetual youth structure tends to attenuate the excessive response of the real exchange rate as well as the nominal exchange rate. However, the response of these variables, mainly the nominal exchange rate, still increases as the time horizon of the forward guidance announcement increases. Hence, one would think whether this outcome is in contradiction with the horizon-invariance property of the UIP condition highlighted in Galí (2020). The key here is that the horizon-invariance property becomes valid only in real terms. If we assume the UIP condition to hold, we obtain the following relation by solving the UIP equation forward in real terms:

$$q_t = \sum_{j=0}^{\infty} \mathbb{E}_t(r_{t+j}^* - r_{t+j}) \; + \; \lim_{T\to\infty} \mathbb{E}_t q_T, \tag{2.101}$$

where r_t^* is the real interest rate in the foreign economy. In the long run, we can assume the real exchange rate to be zero or at least to be well bounded. As such, the real exchange rate

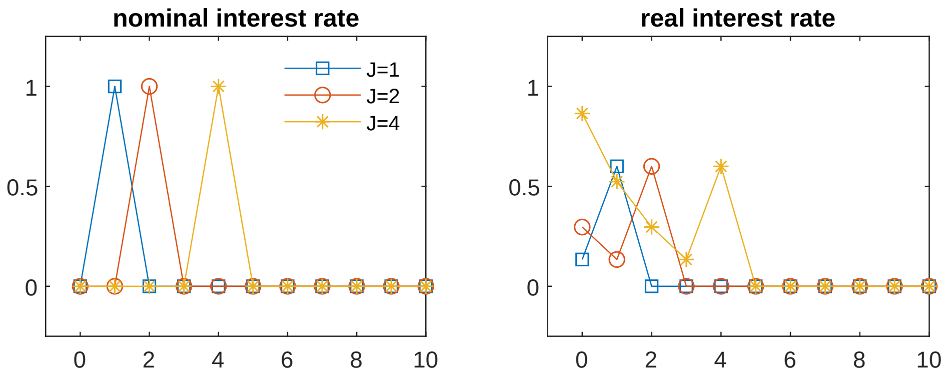

Figure 2.7: Nominal versus real interest interest rate movements

today is a function of current and expected real interest rate differentials only. However, a similar assumption cannot be made to the nominal version of equation (2.101), which takes the form:

$$e_t = \sum_{j=0}^{\infty} \mathbb{E}_t(i^*_{t+j} - i_{t+j}) \; + \; \lim_{T\to\infty} \mathbb{E}_t e_T, \tag{2.102}$$

where the long run nominal exchange rate (i.e., $\lim_{T\to\infty} \mathbb{E}_t e_T$) could experience permanent shifts due to policy actions.

With regards to the forward guidance experiment conducted above, although the change in the nominal interest rate remains the same across horizons (i.e., for different values of J), the timing difference in announced adjustments could result in different permanent shifts in the long run nominal exchange rate in equation (2.102). As a result, the nominal exchange rate today could experience different outcomes. Hence, the horizon-invariance property of the UIP is not valid in this context. Moreover, if one wants to focus on equation (2.101), the resultant changes in the real interest rate have to be analyzed. Figure 2.7 depicts the corresponding movements in the real interest rate for the forward guidance announcements under consideration. It can be noted the cumulative response of the real interest rate changes with the time horizon of the announced change in the nominal interest rate under forward guidance.

It is also important to determine the approach that could be more effective in addressing the issue of excessive response of the exchange rates for forward guidance. Galí (2020) suggests that the lack of discounting of interest rate differentials in equation (2.101) could be the main reason for this over-reaction. Hence, the author focuses on alternatives to the standard UIP assumption, while suggesting that the solutions available to the closed economy forward guidance puzzle are unlikely to apply to the issue under consideration. However, as evident in Figure 2.7, the further out in the future the announced change in the nominal interest rate is, the larger is the near-term response of the real interest rate. This phenomenon, coupled with equation (2.101), suggests that any attempt to curb the overreaction of the real interest rate differentials in the near future using a modification such as the perpetual youth structure is more effective in attenuating the current real exchange rate response, than any attempt to discount real interest rate differentials far into the future as the real interest rate responses in the far future are anyhow small. As such, I argue that some of the solutions proposed to the closed economy forward guidance puzzle can attenuate the cumulative response of the real interest rate, for a forward guidance announcement in nominal terms, thereby dampening the excessive response of the current real exchange rate as well as the current nominal exchange rate. Therefore, incorporation of such a modification should be the first step in addressing the forward guidance exchange rate puzzle rather than modifying the UIP condition to account for more discounting for far future interest rate differentials.

2.6 The Effects of Relaxing some Open Economy Assumptions

Full exchange rate pass-through is a key assumption in the small open economy model employed for this analysis. Therefore, it would be interesting to know how this assumption is impacting the overreaction of the exchange rates. Models with less than complete pass-through have been analyzed by several authors both in the context of two country models as well as models with a continuum of economies. I use the small open economy model of Monacelli (2005) to examine the effect of exchange rate pass-through on the forward guidance exchange rate puzzle.[6]

According to Monacelli (2005), the domestic market is populated by local retailers who import differentiated goods for which the law of one price holds "at the dock". Following a Calvo-type price setting mechanism, only a fraction $1 - \theta_F$ of randomly selected importers are able to reset its domestic currency prices optimally, in any given period of time. This results in a deviation from the law of one price in the short run ($p_{F,t} \neq p_t^* \ + \ e_t$), while complete pass-through is reached asymptotically. The deviation of the world price from the domestic currency price of imports is denoted by $\psi_{F,t}$:

$$\psi_{F,t} = (p_t^* \ + \ e_t) \ - \ p_{F,t}, \tag{2.103}$$

where this measure is defined as the *law of one price gap.* The linearized model considered for the analysis is summarized in Section B.2 of the Appendix.

I repeat the same forward guidance experiment conducted in Section 2.2.2 using the small open economy model with incomplete pass-through. As such, the home central bank announces a one percentage point increase in the nominal interest rate for a single period, J periods ahead in the future, and Figure B.1 in the Appendix depicts the response of the interest rate, output, inflation, and the exchange rates for a simulation carried out for different values of J. Similar to our observations in Figure 2.2, the longer is the horizon of implementation for forward guidance, the larger is the impact of the announcement on output, inflation,

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[6] As the focus of this analysis is to assess the impact of exchange rate pass-through, the benchmark model in Monacelli (2005) is used as it is, without incorporating the perpetual youth structure.

and the exchange rates. However, the response of imported inflation is now gradual owing to the incomplete exchange rate pass-through assumption, and do not exhibit step function shaped adjustments witnessed in Section 2.2. In order to understand the role played by the degree of exchange rate pass-through on the response of key macroeconomic variables, I perform the forward guidance experiment for different values of θ_F (the fraction of importers who are unable to reset their domestic currency prices). Figure 2.8 illustrates the outcome of this experiment. Full exchange rate pass-through is represented by the $\theta_F = 0$ scenario, and the higher values of θ_F correspond to a high degree of incomplete pass-through. It is evident from Figure 2.8 that a high level of import price rigidity exacerbates the overreaction in the real exchange rate, whereas it attenuates the overreaction in the nominal exchange rate.

Meanwhile, the modified small open economy model considered in this study still assumes complete international financial markets and therefore the standard UIP condition. However, there is a vast amount of literature highlighting issues with the standard UIP condition, with some studies presenting strong empirical evidence against it. For example, Engel (2014) examines evidence on the failure of UIP empirically, and the theoretical literature that has been built to account for it. The study offers explanations for the *uncovered interest parity puzzle* using risk premium models, models of market dynamics and market microstructure, and models that deviate from rational expectations. Several studies have been done to address these empirical shortcomings. For example, Adolfson et al. (2008) explore the consequences of modifying the UIP condition to allow for a negative correlation between the risk premium and the expected change in the nominal exchange rate. In addition, Justiniano and Preston (2010) and Christiano et al. (2011) have also taken different approaches to endegonize the risk premium. However, assessing the impact of the deviations from the standard UIP condition on the open economy forward guidance puzzle is beyond the scope of this study, and further research could be directed towards this area.

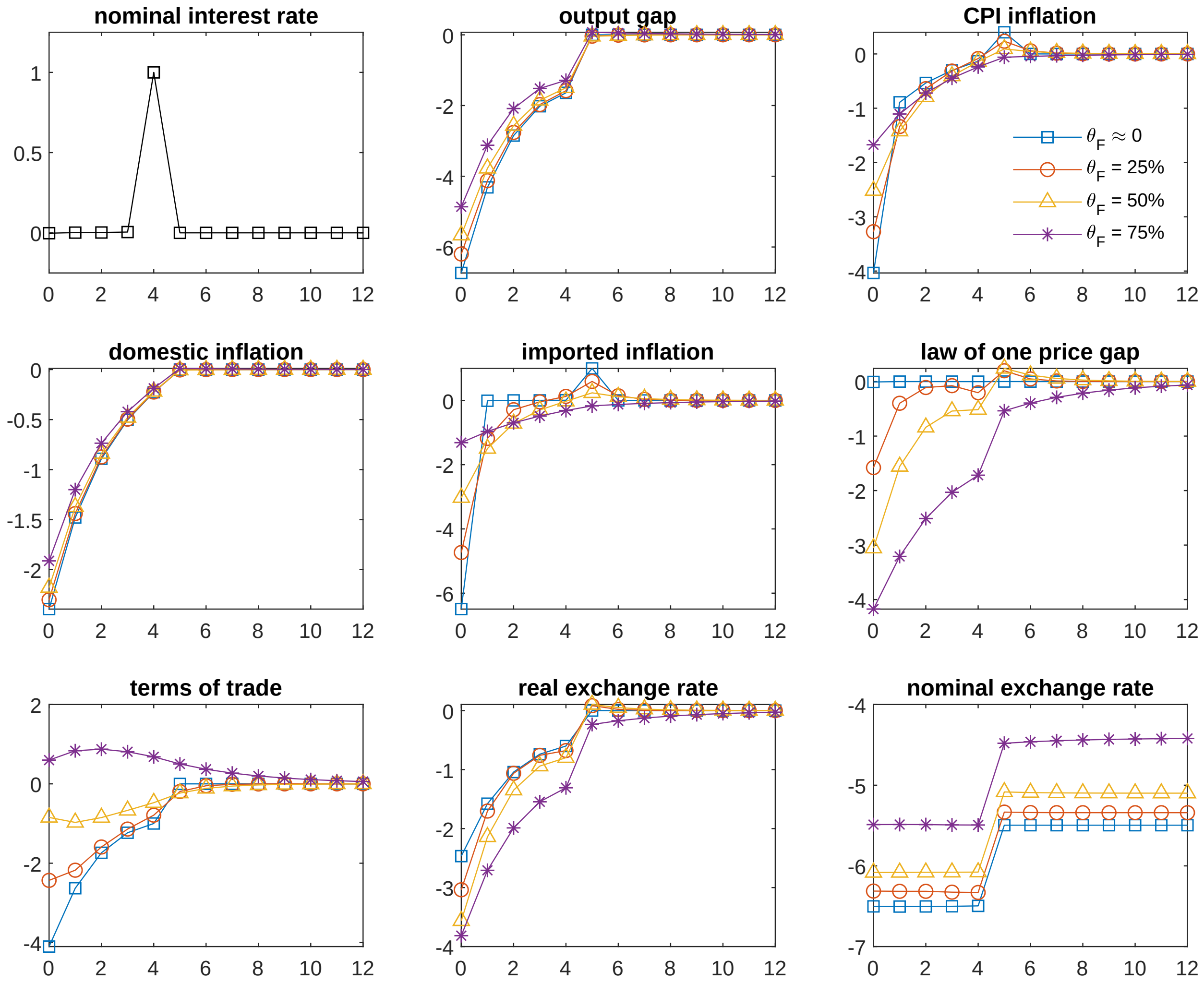

Figure 2.8: Effects of an announced interest rate increase for different levels of exchange rate pass-through $(1-\theta_F)$

2.7 Conclusion

This study attempts to analyze the effectiveness of forward guidance policies in a small open economy model, focusing on an open economy version of the forward guidance puzzle introduced by Galí (2020). In a standard New Keynesian small open economy model with complete international financial markets and complete exchange rate pass-through, not only the output gap and inflation, but also the exchange rates tend to largely overreact to an announced change in the nominal interest rate. This phenomenon is referred to as the forward guidance exchange rate puzzle in Galí (2020). I incorporate a discrete-time version of the perpetual youth structure into this benchmark open economy model to assess whether the presence of agents with finite lives provides a solution to the open economy version of the forward guidance puzzle.

Using the extended model, I show that the incorporation of a perpetual youth structure weakens the excessive response of output and inflation as shown by Del Negro et al. (2015) for a closed economy model, and also weakens the excessive response of the exchange rates, to a forward guidance announcement. The perpetual youth structure involves more discounting in the aggregate consumption Euler equation than in a standard representative agent model, leading to a dampening of the initial consumption response. While this results in an attenuation of the output response and inflation response to an announced change in the nominal interest rate, the relations linking domestic consumption with the terms of trade and the real exchange rate, due to the assumption of complete securities markets and complete pass-through, points to an attenuation in the response of exchange rates as well. While Galí (2020) focuses on modifying the standard UIP condition to seek a solution to the open economy forward guidance puzzle, I argue that any attempt to curb the overreaction of the real interest rate differentials in the near future using a modification such as the perpetual youth structure is more effective in attenuating the current exchange rate response, than modifying the UIP condition to accommodate more discounting for far future interest rate differentials.

Chapter 3

Effects of Monetary Policy Surprises on the Yield Curve through Expectations and Term Premia: Transmission of shocks and the Economic Impact

3.1 Introduction

Monetary policy surprises move the yield curve. How much of these movements is due to expected interest rates and how much is due term premia is an important question in macroeconomics analysis. This study examines the transmission of monetary policy surprises on FOMC announcement dates through the changes in term premia and expected interest rates of the yield curve. In doing so, I assess whether the effects on interest rate expectations could be identified along the lines of both conventional and unconventional monetary policies of the U.S. Federal Reserve. The study also examines how the changes in expectations and term premia relate to changes in the interest rates of other financial assets. Furthermore, I analyze how shocks to expectations and term premia affect the economy by assessing the impact of each type of shock on macroeconomic variables.

Many of the early studies carried out to analyze the effects of monetary policy surprises could be categorized under two distinct approaches. The first approach includes models with monthly or quarterly vector autoregressions (VAR) that combine macroeconomic variables with a measure of short-term interest rates to capture the effects of monetary policy. Bernanke and Blinder (1992) and Christiano et al. (1996) are some early examples for this methodology. The second approach involves using high-frequency data around the Federal Reserve's policy announcements to quantify the policy shocks and to assess the impact of those shocks on the financial markets. Some early studies following this approach include Kuttner (2001) and Gurkaynak et al. (2005), while more recently Campbell et al. (2012) and Swanson (2021) followed similar approaches. A main concern of the VAR-based approaches with conventional identification is that the presence of additional financial variables leads to the simultaneity issue. On the other hand, high-frequency identification also has its own limitations. One main limitation is that its analysis is mostly limited to instantaneous effects on financial market variables such as the interest rates, exchange rates and the stock prices, whereas the longer term effects on the economy in terms of consumer prices, employment etc. are harder to measure.

When quantifying the monetary policy shocks due to FOMC announcements, most of the high-frequency identification approach-based studies considered the overall change in the interest rates. For example, Gurkaynak et al. (2005) use the overall change in federal funds futures rates and Treasury yields to quantify policy surprises under a target factor and a path factor. Taking a different approach, Kaminska et al. (2021) decompose monetary policy surprises around FOMC announcements into term premia and expected interest rates and estimate the effects on macro variables using local projections. Their analysis, however, is limited to the pre-financial crisis period since the term structure model used for the analysis could not provide reliable estimates with the presence of a zero lower bound (ZLB). Avoiding the ZLB and post-ZLB period means that the study misses an important and interesting period of policy analysis, where unconventional monetary policies came to the forefront resulting in additional dimensions of policy analysis.

I begin my analysis by disaggregating the high-frequency changes in the yield curve into changes in interest rate expectations and term premia. This is done for all FOMC announcement days from July 1991 to June 2019. On the one hand, this disaggregation allows us to examine the propagation of various types of monetary policy shocks that are already found in the literature (e.g., Swanson (2021)) to the yield curve. On the other hand, quantifying policy surprises using disaggregated responses allows us to assess whether such disaggregation increases the explanatory power of the set of estimated policy shocks. In addition, it could also reveal whether there are any new dimensions of policy surprises that are useful for macroeconomic analysis.

Several approaches are available to disentangle the changes in term premia and interest rate expectations due to monetary policy surprises[1]. Affine term structure models (ATSMs) are a widely used framework for this purpose. For example, Kaminska et al. (2021) use an ATSM estimated with Bayesian techniques to estimate the changes in term premium on FOMC announcement days. While the simple term structure models rely solely on yield information, some models have included interest rate survey data (e.g., Kim and Wright

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[1] Please see Rudebusch et al. (2007) and Cohen et al. (2018) for a review of methods and models for estimating term premia.

(2005)) and macroeconomic factors in addition to yield information. The biggest concern with ATSMs is that these models could be problematic when the short-term rates are stuck at the effective lower bound. Nonlinear term structure models with shadow interest rates (e.g., Wu and Xia (2016)) could be used to overcome the issues associated with the effective lower bound. However, calculating risk-neutral dynamics for yields in order to estimate term premia poses modeling challenges. Meanwhile, taking a different approach, Gertler and Karadi (2015) use a monetary VAR with external instruments identification to determine the reaction of term premia to policy surprises. Even though simple unstructured VARs can be used for estimating term premiums, assessing the response of term premium for a policy shock requires a structural VAR. Given that these structural VARs are a combination of different macroeconomic and financial variables, identification using recursive ordering could lead to the simultaneity issue. Therefore, a structural VAR with external instrument identification stands out as a good candidate for the task at hand. More importantly, the VAR based approach helps overcome the issues associated with the effective lower bound that followed the financial crisis.

Given that this study decomposes yield curve movements due to FOMC announcements from July 1991 to June 2019, which includes the ZLB period, I follow the approach of Gertler and Karadi (2015) to avoid complications that could arise when the short-term rates are stuck at the effective lower bound. Accordingly, the econometric model is a VAR with a mixture of economic and financial variables using external instruments identification to determine the reaction to a monetary policy shock. The baseline VAR is similar to that of Gertler and Karadi (2015) with the one-year Treasury rate serving as the policy indicator capturing the joint effect of both conventional and unconventional monetary policy. The high-frequency changes in the federal funds futures data are used as an instrument for the structural monetary policy shock. To estimate term premium responses, I do a rolling estimation with the VAR model estimated up to the month preceding the FOMC announcement, and scale the fundamental shock so that the actual movement in the policy indicator is similar to its change in a 30-minute window around the FOMC announcement. Combining the contemporaneous response of yields with the current and future responses of the federal funds rate provides the corresponding term premium response. With this setup, I disaggregate the changes in the yield curve in a 30-minute window bracketing FOMC announcements into changes in term premia and interest rate expectations for maturities ranging from three-months to 30-years.

Once the yield curve responses are disaggregated, I first use that outcome to analyze the propagation of various types of monetary policy shocks to the yield curve via the disentangled components. In the post-financial crisis era, the Federal Reserve has increasingly relied on unconventional monetary policy tools to stimulate the economy. These include forward guidance to affect agent's expectations about the future path of interest rates and large-scale asset purchase (LSAP) programs to influence long term interest rates. Therefore, it is interesting to examine how these different types of policy shocks affect the expectations about interest rates and term premia. As such, I perform a regression analysis with the decomposition of the intra-day movements in Treasury yields and the monetary policy surprises estimated in Swanson (2021), which includes forward guidance and LSAP shocks, in addition to conventional short-term rate shocks, for each FOMC announcement from July 1991 to June 2019. The results show that a shock to the current federal funds rate has a bigger impact on expectations than on term premium for short-term yields. For long-term yields, a forward guidance shock has a bigger impact on expectations than on term premium. An LSAP shock is largely transmitted through expectations supporting the signaling channel of the Federal Reserve's balance sheet policies. However, an expansionary LSAP shock is found to have contractionary effects on term premium for longer maturities, and this could suggest changes in uncertainty or risk perceptions.

In order to assess the relationship between the changes in expectations and term premia, and other financial market and macroeconomic variables, responses estimated for different maturities across the yield curve need to be summarized into a small number of instruments. This is accomplished by performing a factor analysis for the disentangled components. It is found that three factors are necessary to explain the variation in expectations across the yield curve. A structural interpretation is given for these factors along different dimensions of monetary policy surprises of the Federal Reserve using techniques of factor rotation. The resultant structural factors are named as shocks to short end expectations, future path expectations and asset purchase (operational twist) expectations. Meanwhile, a single factor is considered to characterize the variations in term premia across the yield curve.

With the estimated factors, I evaluate the relationship between shocks to expectations and term premia in the term structure, and the movements in the interest rates of other financial assets around FOMC announcements. For this, I consider high-frequency movements in the interest rates of both short- and long-term debt instruments. In the financial markets, a shock to short end expectations is found to be associated with substantial and statistically significant effects on short-term debt instruments, while shocks to expectations about future rate path and asset purchases are associated with substantial and statistically significant effects on long-term debt instruments of the private sector. Meanwhile, I orthogonalize the term premium responses using the factors estimated for expectations to assess the joint impact. Term premium effects, though orthogonalized, relate to positive responses in both short- and long-term debt instruments. However, the effects are substantial and statistically significant only for the short-term instruments.

As the final step, I explore the effects of shocks to interest rate expectations and term premiums on the overall economy. An exogenous variable VAR is used for this analysis, where the factors pertaining to expectations and term premia are introduced as exogenous variables to the baseline VAR considered in prior estimations. Impulse responses estimated to assess the economic impact reveal that a shock to short end expectations brings about usual contractionary effects, while a shock to asset purchase expectations leads to an increase in economic activity without exerting inflationary pressures. A shock to future rate path expectations results in a drop in consumer prices albeit with an expansion in economic activity. Term premium effects on the economy, when orthogonalized against expectations, are similar to those of a policy uncertainty shock.

The rest of the chapter is arranged as follows. Section 3.2 presents the VAR framework with external instruments identification used for estimating the term premia responses. The next section analyzes the propagation of both conventional and unconventional monetary policy shocks to the yield curve through its disentangled components. Further, it contains the factor analysis performed to derive instruments for different dimensions of policy shocks. Section 3.4 provides effects of expectations and term premium shocks on other financial assets. In Section 3.5, I evaluate the macroeconomic impact by introducing an empirical setup and discussing the dynamic responses for policy shocks. Section 3.6 concludes the study with a summary of the main findings and its broader implications. The Appendix to the chapter provides some robustness checks for the estimated results.

3.2 The External Instruments VAR Framework

I adopt the approach introduced in Gertler and Karadi (2015) to identify the effects of monetary policy shocks in a set of VAR models. It employs high-frequency measures of policy surprises around FOMC announcements as external instruments to identify the impact. The general reduced form representation of a VAR is given by

$$Y_t = \sum_{j=1}^{p} B_j Y_{t-j} \ + \ u_t, \tag{3.1}$$

where Y_t is a vector of economic and financial variables, B_js represent the corresponding coefficient matrices and u_t is the reduced form shock. The reduced form shock could be given by the following function of the structural shocks:

$$u_t = S\varepsilon_t, \tag{3.2}$$

where S corresponds to the contemporaneous impact of structural shocks. If s denote the column in matrix S corresponding to the impact due to a structural policy shock ε_t^p, we need to estimate the following representation to compute the impulse responses to a monetary policy shock:

$$Y_t = \sum_{j=1}^{p} B_j Y_{t-j} \ + \ s\varepsilon_t^p. \tag{3.3}$$

Let Z_t be the vector of instrumental variables for the policy shock under consideration. For Z_t to be a valid instrument set, it must be correlated with the structural policy shock ε_t^p, but orthogonal to structural shock other than ε_t^p. Then, the elements in vector s could be estimated using the reduced form residuals u_t from the reduced form VAR and the instrument set Z_t, with a combination of two stage least squares regressions and the estimated reduced form variance-covariance matrix.[2]

The baseline VAR I use is same as the baseline specification of Gertler and Karadi (2015) which uses the one-year government bond rate as the policy indicator, and it is instrumented

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[2] Please refer Gertler and Karadi (2015) for details about identification under this approach.

by the three month ahead monthly federal funds futures rate.[3] The baseline specification of the VAR includes six variables, namely the industrial production index, consumer price index, one-year government bond rate, excess bond premium, mortgage spread, and the commercial paper spread. In addition to the baseline VAR, I employ VARs formed by extending the baseline specification by adding extra interest rates, one at a time. The variables are introduced one at time since interest rates of varying maturity are highly correlated. Therefore, including all at once could lead to the issue of multi-collinearity in addition to over-parametrization. I use a sequence of seven extended VARs with the federal funds rate, and the three-month, six-month, two-year, five-year, 10-year and 30-year Treasury rates as additional variables. A VAR with the monthly effective federal funds rate is required as it is used as the measure of short-term interest rate when calculating term premiums. A sequence of VARs with six additional Treasury rates across the yield curve are considered since term premia are also estimated for these maturities of the Treasuries.

3.2.1 Estimating Term Premia Responses

The data set used in Gertler and Karadi (2015), which is updated up to June 2012, is publicly available. I extended this data set by updating the relevant variables until June 2019 and including data on new variables from July 1979 to June 2019. For the purpose of estimating the reduced form VARs, the industrial production index, consumer price index, government bond rates, mortgage rates and the commercial paper rates are obtained from the FRED database of the Federal Reserve Bank of St. Louis. The excess bond premium is originally obtained from Gilchrist and Zakrajšek (2012). An update of this is retrieved from Favara et al. (2016). The mortgage spread is calculated as the difference between the 30-year fixed rate mortgage average and the 10-year Treasury yield, while the commercial paper spread is taken as the difference between the three-month AA financial commercial

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[3] Assessing the choice of policy indicator and instruments in Gertler and Karadi (2015) is beyond the scope of this study and I adhere to the same setup.

paper rate and the effective federal funds rate.

Under external instruments identification, shocks to the one-year government bond rate are instrumented by changes in the three-month ahead monthly federal funds futures rate in a tight window of 30-minutes bracketing FOMC announcements. Accordingly, I extend the series of high-frequency changes in the federal funds futures rates through June 2019 using data provided by staff at the Federal Reserve Board. The change in the high-frequency market responses which are available for each FOMC announcement date is converted to a monthly data series to be incorporated to the VAR analysis. I follow the same methodology as Gertler and Karadi (2015) to calculate monthly shocks from the data available for individual FOMC announcement dates.[4] This is due to the reason that a surprise that takes place at the end of a month is expected to have a smaller influence on the monthly averages than a surprise that happens at the beginning of the month. Meanwhile, the change in Treasury yields in a 30-minute window around FOMC announcements are also obtained from data provided by staff at the Federal Reserve Board. Intra-daily changes in yields are available for three-month, six-month, two-year, five-year, 10-year and 30-year Treasuries.

As the first step, I estimate the reduced form representation of the VAR given by equation (3.1) for the full period from July 1979 to June 2019. Then, using the reduced form residuals and the high-frequency responses in federal funds futures rates from January 1991 to June 2019, I identify the impact vector s in equation (3.3) using the techniques of external instruments identification. The next step is to estimate the term premium component in the interest rate responses for FOMC announcements during the period of analysis, for the maturities under consideration. For this, I consider a rolling estimation with the VAR model estimated up to the month preceding the FOMC announcement, as it provides a better char-

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[4] This is a two-step approach. First, for each day of the month, I calculate the cumulative value of the surprises on FOMC days during the last 31 days. Secondly, I calculate the monthly average of these surprises for each month.

acterization of the economy at the time of the announcement, while providing more variation to the estimates. Under this approach, the first estimate of the reduced form VAR is done from July 1979 to June 1991 since the first FOMC announcement under analysis falls in July 1991. An extra month of data is added for each iteration until the VAR incorporates the full data set from July 1979 to June 2019. Given that the external instruments identification performed above is based on data from 1991 to 2019, the identified impact vector for a fundamental monetary policy shock for the full sample is used for each iteration of the rolling VAR estimate.

The annualized term premium of an m period zero-coupon government bond, based on a loglinear approximation, is given by

$$\phi_t^m = i_t^m \ - \ \frac{1}{m}\mathbb{E}_t\left\{\sum_{j=0}^{m-1} i_{t+j}\right\}, \tag{3.4}$$

where ϕ_t^m is the term premium, i_t^m is the annual bond yield and i_t is a measure of short-term interest rates. The estimated impact vector s provides the contemporaneous response of the one-year Treasury yield to a fundamental policy shock. Extension of the baseline VAR with the federal funds rate provides the impulse response of the short-term interest rates for the policy shock under consideration. According to equation (3.4), combining the contemporaneous response of the one-year Treasury yield with the response of current and future federal funds rates for 12 periods provides the change in the annualized term premium for a fundamental monetary policy shock.

Estimated term premium response under a rolling VAR approach for a one standard deviation expansionary shock to the policy indicator (one-year Treasury rate) is shown in Figure 3.1. This depicts the evolution of term premium response over time without any reference to a particular set of FOMC announcements. The graph shows that there is a

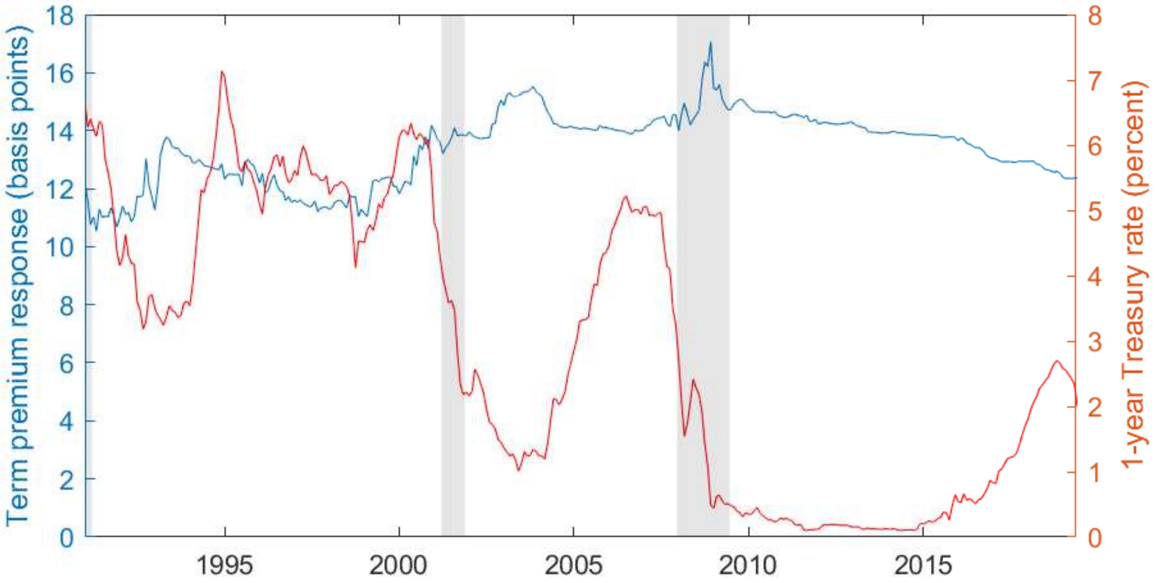

Figure 3.1: Estimated term premium response in a rolling vector autoregression for a one standard deviation shock to the policy indicator (one-year Treasury rate). The actual yield of a one-year Treasury bill over the corresponding period is given by the right axis. Shaded areas indicate U.S. recessions.

notable variation in the term premium responses over time. Given that the impact vector is identified only once for the full sample for a one standard deviation fundamental monetary policy shock, time variation in the term premium responses is purely due to the changes in the reduced form coefficients (i.e., B_j of equation (3.3)) of the rolling VAR. Meanwhile, the actual yield of a one-year Treasury bill over the corresponding period is also given in the right axis of the graph together with the U.S. recessions as indicators for the movements in the term structure and the business cycle. It can be observed that the term premium response for a one standard deviation shock increases when the Treasury yields are reduced with the onset of recessions. Thereafter, the magnitude of the term premium responses declines when the Treasury yields increase with the normalization of economic activity.

The term premium response estimated before is for a one standard deviation expansionary monetary policy shock. Going forward, term premium responses are estimated for each

FOMC announcement date, such that the movements in the policy indicator matches the actual interest rate movements around FOMC announcements. Accordingly, I change the magnitude of the fundamental shock so that the actual movement in the one-year Treasury yield is similar to its change during the 30-minute window bracketing an FOMC announcement.[5] This is achieved by scaling the impact vector s estimated under external instruments identification and generating impulse responses for a fundamental policy shock. Scaling of the impact vector and the subsequent generation of impulse responses need to be carried out in the baseline VAR as well as its extensions.

For each FOMC meeting from July 1991 to June 2019, I estimate the reduced form representation of the VAR for the period from July 1979 to the month preceding the FOMC announcement and scale the impact vector s estimated using the full sample of instruments from January 1991 to June 2019 as described before.[6] Then, I apply the same procedure to the extension of the baseline VAR with the federal funds rate as an additional variable. Combining the contemporaneous response of the one-year Treasury yield and current and future responses of the federal funds rate, I obtain the response of the annualized term premium for the monetary policy shock. Once the term premium response is estimated, the response in interest rate expectations is simply the remainder of the overall interest rate change. By this way, I disentangle term premium and expectations from the movements in the one-year Treasury yield around a 30-minute window bracketing the FOMC announcements.

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[5] Intra-daily responses for the one-year government bond rate are not calculated in the available data set. To overcome this, I generate an estimated response from the changes in other maturities of the yield curve, for which intra-daily movements are available. A regression of the monthly change in the one-year Treasury rate on the monthly changes in the three-month, six-month, two-year, five-year, 10-year and 30-year Treasury rates, using data from 1991 to 2019, show that the other yields explain the change in the one-year rate to a large extent with a regression R^2 value of 0.97. Using these regression coefficients and the actual changes in three-month, six-month, two-year, five-year, 10-year and 30-year Treasury rates in a 30-minute window bracketing announcements, I estimate the response of the one-year Treasury yield for each FOMC date under analysis.

[6] For example, for the FOMC meeting on July 5, 1991, the estimated intra-daily change in the one-year Treasury yield is 0.91 basis points. As such, I scale the fundamental one-year Treasury rate shock to result in a 0.91 basis point change in the actual yield in the first period in the impulse responses generated for the baseline VAR. I repeat this process for all FOMC announcement days using the estimated changes in the one-year Treasury yield.

The next phase is the decomposition of the changes in the interest rates of other maturities in the yield curve. For that, I estimate the reduced form VARs for the extensions of the baseline specification with additional Treasury yields up to the month preceding the FOMC announcement, and apply the same scaling to the impact vector s as done in the case with baseline VAR. Using this setup, I estimate the contemporaneous responses of the three-month, six-month, two-year, five-year, 10-year and 30-year Treasury yields for a fundamental policy shock. Combining the contemporaneous response of the Treasury yields with the response of current and future federal funds rates for the relevant number of periods, I obtain the response of the annualized term premium for each maturity. The change in interest rate expectations is taken as the difference between the actual change in the Treasury rate during a 30-minute window bracketing the FOMC announcement and the term premium response estimated by the VAR. For the rest of the analysis in this study, I use the decomposition done for the three-month, six-month, two-year, five-year, 10-year and 30-year Treasury yields, and avoid using the results for the one-year Treasury yield since its high-frequency interest rate responses are estimates derived from the actual responses of the other maturities of the Treasuries.

3.3 Transmission of Policy Shocks to the Yield Curve

Using the disaggregated yield curve responses, I first examine the propagation of various types of monetary policy shocks to the yield curve via the disentangled components. As the Federal Reserve increasingly relied on unconventional monetary policy tools in the post-financial crisis era, it is interesting to examine how these different policy shocks affect the interest rate expectations and term premia. Various studies attempt to estimate the monetary policy shocks on FOMC announcement days, and out of those I select Swanson (2021), which quantifies forward guidance and LSAP shocks, in addition to conventional short-term rate shocks, for each FOMC announcement from July 1991 to June 2019. With the disaggregated elements of the intra-day movements in Treasury yields and the monetary policy surprises estimated in Swanson (2021), I perform a regression analysis of the following form.

$$\Delta y_t = \alpha + \beta \tilde{F}_t + \varepsilon_t, \tag{3.5}$$

where Δy denotes the change in either the overall Treasury yield or term premium or expectations in a 30-minute window bracketing an FOMC announcement, $\tilde{F}$ denotes the monetary policy factors under consideration, and ε is the residual. Furthermore, t indexes the FOMC announcement dates. The results are given in Table 3.1. The regression coefficients in panel (A) correspond to the overall change in the yield rates, before any decomposition, and are broadly similar to the ones in Swanson (2021). Panel (B) presents a similar regression outcome, but instead of the overall change in the yield, it considers the change in term premiums as the explained variable. Similarly, panel (C) presents regression coefficients considering the change in interest rate expectations as the explained variable.

It is interesting to see from panel (B) that a current federal funds rate shock has a bigger impact on term premium than a forward guidance shock. Then, from panel (C) it appears that a forward guidance shock is having a bigger effect on expectations than a current federal funds rate shock for maturities that are greater than one year. It is also interesting to see that the LSAP shocks have opposing effects on expectations and term premium. The impact on expectations is in line with the standard expansionary effects of the policy shock. However, the impact on term premium is not having the expected sign, and this could mean something about the uncertainty. The overall effect of an LSAP shock is a combination of those opposing forces. That could be a reason for the coefficient on LSAP shocks for the overall change in yields for some maturities such as the two-year Treasury yield to be

Table 3.1: Estimated effects of policy shocks on the U.S. Treasury yields

	3-month	6-month	2-year	5-year	10-year	30-year
(A) Overall change in the yield						
change in federal funds rate	4.11***	4.38***	3.86***	2.32***	1.07***	0.02
(std. err.)	(0.180)	(0.165)	(0.113)	(0.106)	(0.118)	(0.18)
change in forward guidance	1.20***	2.20***	4.49***	4.74***	3.63***	2.18***
(std. err.)	(0.147)	(0.135)	(0.092)	(0.087)	(0.096)	(0.146)
change in LSAPs	0.11	0.69***	0.09	-2.62***	-4.70***	-3.95***
(std. err.)	(0.25)	(0.229)	(0.157)	(0.147)	(0.164)	(0.249)
Regression R^2	0.71	0.81	0.94	0.94	0.91	0.67
(B) Change in term premium						
change in federal funds rate	0.18***	1.80***	3.72***	2.47***	1.45***	0.58***
(std. err.)	(0.014)	(0.054)	(0.110)	(0.090)	(0.055)	(0.027)
change in forward guidance	0.08***	1.32***	2.72***	1.64***	0.92***	0.42***
(std. err.)	(0.011)	(0.044)	(0.090)	(0.074)	(0.045)	(0.022)
change in LSAPs	0.04**	0.36***	0.74***	0.56***	0.34***	0.16***
(std. err.)	(0.019)	(0.075)	(0.153)	(0.125)	(0.076)	(0.037)
Regression R^2	0.48	0.89	0.90	0.84	0.83	0.79
(C) Change in expectations						
change in federal funds rate	3.93***	2.58***	0.14	-0.15	-0.37***	-0.56***
(std. err.)	(0.176)	(0.124)	(0.108)	(0.133)	(0.127)	(0.179)
change in forward guidance	1.12***	0.88***	1.77***	3.10***	2.72***	1.76***
(std. err.)	(0.143)	(0.101)	(0.088)	(0.108)	(0.104)	(0.146)
change in LSAPs	0.06	0.33*	-0.65***	-3.19***	-5.05***	-4.11***
(std. err.)	(0.243)	(0.172)	(0.149)	(0.184)	(0.176)	(0.248)
Regression R^2	0.70	0.68	0.64	0.83	0.86	0.64

Coefficients are in basis points per standard deviation change in the monetary policy instrument. ***, **, and * denote statistical significance at 1, 5 and 10 percent levels, respectively.

relatively small and less statistically significant.

The estimated coefficients for an LSAP shock are considerably large for expectations than for term premia for long-term Treasuries. This indicates that the effects of an LSAP surprise is transmitted to the term structure largely through the changes in interest rate expectations. As such, the results support the argument made by several studies that LSAPs affect the economy by changing expectations about the future path of the federal funds rate, either fully or partly. This is known as the signaling channel for the Federal Reserve's bond purchases.

In this regard, Woodford (2012) argue that much of the effect of balance sheet policies is due to them being taken as a signal about likely future policy. Bauer and Rudebusch (2014) argue that in contrast to the previous findings that a reduced bond supply due to Federal Reserve bond purchases lowers term premia, such purchases have important signaling effects that lower expected future interest rates.

A natural question that could arise by observing results for the overall change in the yield in panel (A) alone is that why would a shock to the current interest rate result in substantial and highly statistically significant movements in long term Treasury yields such as the five-year yield or the 10-year yield. This is because a change in the current period's interest rate, when averaged across many years, is expected to have an effect which is close to zero. The disentangling of term premia and expectations provides an answer to this question. Panels (B) and (C) show that the substantial overall change in the Treasury yields under consideration is mainly due to the change in term premia, while the effects due to expectations are close to zero. Therefore, analysis of the results in Table 3.1 indicates that the disaggregation of the intra-day yield curve changes around FOMC announcements into term premia and expected interest rates provides some important insights about the transmission mechanism of different monetary policy shocks to the yield curve.

Are the results for the term premium in panel (B) surprising, and what sign would we expect those effects to have? A regression of the monthly changes in term premiums estimated by Kim and Wright (2005) on the monthly changes of the respective yields results in a positive coefficient. This indicates that an increase in the Treasury yields is associated with an increase in the term premium measures. Therefore, it is not surprising to have positive coefficients for a contractionary current federal funds rate shock as well as a contractionary forward guidance shock, for all maturities under consideration. Further, it is not surprising for a forward guidance shock to have a smaller impact on term premium than a current federal funds rate shock, because intuitively the former could mean interest rate changes over several periods in the future and such a change is reflected more in the changes in cumulative expectations of the agents and not in the term premium. However, a positive coefficient for an expansionary LSAP shock is surprising as one would expect the term premiums to decline in line with the decline in yields in response to asset purchase announcements. As mentioned before, this could mean something about the changes in uncertainty and risk perceptions associated with significant LSAP announcements. However, further analysis is warranted to figure out the exact reason behind those positive coefficients.

In order to check the robustness of the results obtained for forward guidance and LSAP shocks, I use the shadow federal funds rate derived by Wu and Xia (2016) as an alternative measure of the federal funds rate during the ZLB period. The estimated coefficients under this approach are presented in Table C.1 of the Appendix. The results show that the coefficients reported in panel (B) and panel (C) of Table 3.1 are mostly unchanged for the alternative measure of the short-term interest rates. This indicates that the main features observed above hold true even if a shadow federal funds rate is used to overcome the concerns associated with an effective lower bound.

3.3.1 Instruments for Policy Shocks

In order to examine the effects of the changes in expectations and term premia on other financial market and macroeconomic variables, responses estimated for different maturities across the yield curve need to be summarized into a small number of instruments. This is accomplished by performing a factor analysis for the disentangled components. A factor model takes the form

$$X = F\Lambda \; + \; \eta, \tag{3.6}$$

Table 3.2: Variance shares of the principal components

	Expectations		Term premiums	
Factor	Variance share	Cumulative share	Variance share	Cumulative share
1	0.5400	0.5400	0.8884	0.8884
2	0.3087	0.8487	0.0940	0.9824
3	0.1027	0.9515	0.0103	0.9927
4	0.0239	0.9754	0.0025	0.9953
5	0.0141	0.9895	0.0004	0.9957
6	0.0064	0.9959	0.0002	0.9959

Variance shares for the six principal components calculated separately for the changes in expectations and term premiums in a 30-minute window bracketing the FOMC announcements from July 1991 to June 2019. Yields considered are three-month, six-month, two-year, five-year, 10-year, and 30-year Treasury rates.

where X denote a $T \times n$ matrix, with rows corresponding to FOMC announcement days, columns corresponding to different Treasury maturities, and each element of X reporting the change in either expectations or term premia in a 30-minute window around the announcement under consideration. F is a $T \times k$ matrix of unobserved factors ($k \leq n$), Λ is a $k \times n$ matrix denoting factor loadings, and η is a $T \times n$ matrix of white noise disturbances. Given that the decomposition is done for the changes in three-month, six-month, two-year, five-year, 10-year, and 30-year Treasuries, the maximum number of principal components that could be calculated is six. Accordingly, the variance shares for the six principal components calculated separately for the changes in expectations and term premiums across the yield curve are given in Table 3.2. For expectations, the first three principal components cover 95 percent of the variation. For term premium, a single factor explains 89 percent of the variation, while the first three principal components characterize 99 percent of it.

Following Gurkaynak et al. (2005) and Swanson (2021), I perform the matrix rank test of Cragg and Donald (1997b) as another approach to identify the number of factors sufficient to characterize the changes in expectations and term premia across the yield curve. The results are summarized in Table 3.3. For expectations, the Cragg and Donald (1997b) test rejects ranks of 0, 1 and 2 as the null hypothesis. There are insufficient degrees of freedom to perform the test for a rank of 3. This indicates that three factors are sufficient to explain the variations in expectations. The test gives a similar outcome for term premiums as well, rejecting ranks of 0, 1 and 2 as the null hypothesis. Hence, according to the Cragg and Donald (1997b) test, three factors are needed to better characterize the variations in term premiums as well.

Given the variance shares reported in Table 3.2 and the rank test outcomes, three factors are suitable to characterize the movements in expectations across the yield curve. This means, F in equation (3.6) becomes a $T \times 3$ matrix of unobserved factors, while Λ becomes a 3×6 matrix of factor loadings. Kaminska et al. (2021), using an ATSM framework, find that only two factors are sufficient to explain changes in expectations during the pre-financial crisis period. The requirement of one additional factor compared to Kaminska et al. (2021) could possibly reflect the effects of the unconventional monetary policy tools that came to the forefront during the ZLB period. Furthermore, the need for three factors to characterize interest rate expectations is in line with recent studies (e.g., Swanson (2021)) which argue that the monetary policy actions in recent times are better represented by three types of monetary policy surprises.

The variance shares and the rank test outcomes also suggest that three factors are needed to characterize the changes in term premiums. However, given that one factor accounts for nearly 90 percent of the variations in term premiums, I consider a single factor to represent the movements in term premiums across the maturities under consideration. Accordingly, for the term premium responses, F and Λ in equation (3.6) turn out to be vectors of unobserved factors and factor loadings, respectively. Kaminska et al. (2021) also follow a similar approach where they find that the changes in term premia are explained by two factors but leave out the second factor from the subsequent analysis given that the first factor accounts for 92 percent of the variance.

Table 3.3: Tests for the number of factors underlying the changes in expectations and term premium

Number of factors	Degrees of freedom	Distance	p-value
Expectations			
0	15	82.9697	0.00000
1	9	42.9203	0.00000
2	4	23.1241	0.00012
3	(no degrees of freedom)		
Term premiums			
0	15	78.0651	0.00000
1	9	42.5538	0.00000
2	4	40.1815	0.00000
3	(no degrees of freedom)		

Results from the Cragg and Donald (1997) test for the number of factors underlying the changes in expectations and term premium in response to FOMC announcements from July 1991 to June 2019.

When assessing the joint impact of the interest rate responses and the term premium responses, one needs to be orthogonalized against the other. Therefore, I orthogonalize the term premium responses using the three principal components calculated for expectations. This is performed by regressing the term premiums of each maturity under consideration on the factors calculated for interest rate expectations. The regression residual provides the part of the term premium response that is orthogonal to the changes in expectations. Subsequently, I re-calculate the principal components using the orthogonal part of term premiums for each maturity. It turns out that, as before, the first three principal components characterize 99 percent of the variation. However, now the first factor explains only 77 percent of the variation, while the second one accounts for 19 percent. According to the factor loadings matrix, the second factor has a prominent effect only for maturities that are less than one year. Nonetheless, given that there is still one dominant factor characterizing the variations in term premiums, I continue to consider a single factor to represent the movements in term premiums that are orthogonalized against expectations.

Giving a Structural Interpretation

In this section, I propose a structural interpretation for the three principal components estimated for the change in interest rate expectations around FOMC announcements. These interpretations are summarized as: (1) change in short end expectations, (2) change in future path expectations and (3) change in asset purchase (operational twist) expectations. The first structural factor, change in short end expectations, is defined as a shock to the interest rate expectations for the shortest maturity in the yield curve (i.e., the three-month Treasury yield). Such a surprise resembles a surprise change in the current federal funds rate due to an FOMC announcement. The second structural factor, change in future path expectations, is defined as a surprise change in interest rate expectations for medium- to long-term maturities in the yield curve. This is expected to capture the effects of forward guidance announcements by the Federal Reserve, which is expected to have an impact on the agents' expectations about the future path of interest rates. The third structural factor, change in asset purchase expectations, represents a shock to interest rate expectations that arise in the form of changes to the slope of the yield curve. Therefore, it captures the effects of FOMC announcements about asset purchase or quantitative easing programs to lower the long-term interest rates, and the subsequent tapering of such programs.

A structural interpretation can be obtained by performing an orthogonal rotation of the factors estimated before. This is done by selecting an appropriate 3×3 orthogonal matrix U such that an alternative factor model is derived with the matrix of unobserved factors $\tilde{F} \equiv FU$ and factor loadings $\tilde{U} \equiv U'\Lambda$, with the residuals in equation (3.6) remain unchanged. In order to identify the three structural factors proposed above, I consider two possible approaches. The first approach follows the set of restrictions used in Swanson (2021) to structurally identify the monetary policy surprises. The second approach uses a combination of sign restrictions and some of the identifying restrictions in Swanson (2021).

First approach: Identification as in Swanson (2021)

Under this, I use the approach in Swanson (2021) with zero restrictions and a minimizing restriction to identify the structural factors for the changes in interest rate expectations. The set of restrictions considered under this approach are summarized as: (1) future path expectations shock has no effect on the three-month Treasury bill rate, (2) asset purchase expectations shock has no effect on the three-month Treasury bill rate, and (3) variance of the asset purchase expectations factor is as small as possible in the pre-financial crisis period (i.e., from 1991 to 2008).

Elements of the structural loading matrix derived under this approach are given in panel (A) of Table 3.4. The coefficients are in basis points per standard deviation change in the structural factor. A surprise change in short end expectations is having the largest impact on the three-month Treasury yield and its impact on the 30-year Treasury yield is close to zero. The impact on the yield curve for a change in future path expectations peaks at five years, while having a considerably large impact on the 10-year yield as well. A shock to asset purchase expectations has the largest impact on the 30-year Treasury yield, but the change in the impact from three-months to 30-years is not gradual. Meanwhile, the variance of the asset purchase expectations factor from 1991 to 2008 is found to be 70.1. Since the proposed structural factors for interest rate expectations resemble the features of the monetary policy surprises in Swanson (2021), I calculate the correlation coefficient between the derived structural factors for expectations and the monetary policy factors in Swanson (2021), and the results are given in panel (A) of table 3.5.

Table 3.4: Elements of the structural loading matrix: expectations

	3-month	6-month	2-year	5-year	10-year	30-year
(A) first approach						
short end expectations	3.94	2.68	0.52	0.75	0.34	-0.06
future path expectations	0.00	-0.20	2.06	3.83	3.69	2.63
asset purchase expectations	0.00	-0.27	0.68	-0.20	-2.10	-2.59
(B) second approach						
short end expectations	3.94	2.68	0.52	0.77	0.38	-0.02
future path expectations	0.00	-0.28	2.16	3.51	2.71	1.55
asset purchase expectations	0.05	-0.15	-0.09	-1.53	-3.27	-3.35

Panel (A) reports the structural loading matrix when identified as in Swanson (2021).
Panel (B) reports the structural loading matrix when identified with a combination of sign and zero restrictions.
Given in basis points per standard deviation change in the structural factor.

Second approach: Identification with Sign Restrictions

Under this method, I combine some of the zero and minimizing restrictions assumed above with sign restrictions. The set of restrictions considered under this approach are summarized as: (1) future path expectations shock has approximately zero effect on the three-month Treasury bill rate, (2) asset purchase expectations shock has a positive or no effect on the short end of the yield curve and has a negative effect on the long end and (3) variance of the asset purchase expectations factor is as small as possible in the period from 1991 to 2008.

To implement this, I draw one million random orthogonal 3×3 matrices from the uniform distribution with respect to the Haar measure and select the ones that satisfy the first two restrictions above. In the first restriction, future path expectations shock is assumed to have an approximately zero effect on the three-month Treasury bill rate (the absolute value of the effect on the three-month Treasury rate should be less than 0.00005), rather than it being exactly zero, as otherwise there would be hardly any random matrices satisfying the conditions. In order to satisfy the second restriction, the effect on the three-month Treasury yield should be greater than or equal to zero and the effects on 10-year and 30-year Treasury

Table 3.5: Correlation with the policy factors in Swanson (2021)

	federal funds rate	forward guidance	LSAPs
(A) first approach			
short end expectations	0.795	-	-
future path expectations	-	0.746	-
asset purchase expectations	-	-	0.563
(B) second approach			
short end expectations	0.794	-	-
future path expectations	-	0.721	-
asset purchase expectations	-	-	0.681

yields should be less than zero. Next, from the selected draws, I choose the orthogonal matrix that results in the lowest variance of the asset purchase expectations factor for the period from 1991 to 2008.[7]

Elements of the structural loading matrix derived from the chosen orthogonal matrix are given in panel (B) of Table 3.4. The coefficients are in basis points per standard deviation change in the structural factor. Factor loadings for a short end expectations shock is similar to those under the first approach (panel (A)), where the impact is highest for the three-month Treasury yield and becomes almost zero for the 30-year Treasury yield. Loadings reported for a future path expectations shock show that its effect peaks at five years, while the impact on maturities greater than five years is considerably small compared to the first method. This is closer to findings of Swanson and Williams (2014) and Hanson and Stein (2012) who argue that the forward guidance strategy of the Federal Reserve operates with an approximate two-year horizon. Furthermore, loadings for an asset purchase expectations shock transition from a small positive number to a large negative number resembling a twisting of the yield curve. Under this approach, the variance of the asset purchase expectations factor from 1991 to 2008 is found to be 66.3, a little less than 70.1 found under the first approach. Meanwhile, the correlation coefficients between the factors derived under this approach and

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[7] A more sophisticated version of a zero and sign restrictions approach can be found in Rubio-Ramirez et al. (2016)

Table 3.6: Elements of the loading matrix: term premiums

	3-month	6-month	2-year	5-year	10-year	30-year
First PC of term premia	0.18	2.07	4.30	2.81	1.63	0.70
First PC of orthogonal term premia	0.02	0.75	1.98	1.50	0.86	0.39

Given in basis points per standard deviation change in the PC.

the monetary policy factors in Swanson (2021) are given in panel (B) of Table 3.5. In the rest of the analysis, I use the structural factors for the changes in interest rate expectations derived under the second approach. However, the results do not differ much if one uses the structural factors derived under the first approach.

For the changes in term premiums, I consider only the first principal component of the changes, given that it accounts for a greater share of the variance. Therefore, giving it a structural interpretation through factor rotation is not possible. In this case, the first principal component could be considered to represent the level of term premia across the yield curve. The loadings calculated for the first principal component of term premiums, for different maturities of the Treasuries, are given in Table 3.6. It also contains loadings for the first principal component calculated using terms premiums that are orthogonal to the changes in expectations.

3.4 Effects on other Financial Assets

In this section, I analyze the relationship between shocks to expectations and term premium in the term structure of interest rates, and the movements in the interest rates of other financial assets around FOMC announcements. The set of financial instruments considered comprises LIBOR, Eurodollar futures, commercial papers, and Moody's seasoned corporate bond yields. I regress the change in the interest rate of each instrument on the structural factors estimated for the changes in expectations and the first principal component of term premium responses. As joint effects of expectations and term premia are estimated, when estimating the term premium effects, I use the orthogonalized measure of term premia, as explained earlier.

The estimated coefficients for short-term instruments are presented in Table 3.7. A one standard deviation surprise increase in short end expectations (a 3.9 basis point increase in expectations for the three-month Treasury yield) relates to a 4.7 basis point increase in the three-month LIBOR. A similar response can be noted for the other maturities of LIBOR as well as for the Eurodollar futures rates, while the effect for commercial paper is a little low. A one standard deviation surprise increase in future path expectations (a 2.2 basis point increase in expectations for the two-year Treasury yield) relates to a smaller (approximately zero) interest rate change for the shortest maturity, and the change gradually increases with the maturity period. An increase in the asset purchase (operational twist) expectations corresponds to an expansionary shock. Accordingly, a one standard deviation surprise increase in asset purchase expectations (a 3.4 basis point decrease in expectations for the 30-year Treasury yield) relates to a marginal decline in 12-month LIBOR and Eurodollar rates. However, the effects are not statistically significant. The results are intuitive as we do not expect policies aimed at altering expectations about medium- to long-term interest rates to have substantial effects on short-term debt instruments.

When assessing the term premium effects, I use the first principal component of term premia responses orthogonalized against the interest rate expectations. For the orthogonal measure of term premia, the estimated coefficients are positive, except for commercial papers whose coefficient is not statistically significant. A positive sign is not surprising because an increase in term premia is associated with an increase in the Treasury yields which in turn is associated with increases in other market interest rates. A one standard deviation surprise

Table 3.7: Estimated effects on short-term debt instruments

	LIBOR			Eurodollars			Commercial
	3-m	6-m	12-m	3-m	6-m	12-m	paper
short end expectations	4.68***	5.12***	5.16***	4.74***	5.04***	4.93***	3.45***
(std. err.)	(0.38)	(0.37)	(0.36)	(0.20)	(0.18)	(0.14)	(0.57)
future path expectations	-0.21	0.50	1.56***	0.48**	1.72***	3.21***	-0.99**
(std. err.)	(0.38)	(0.37)	(0.36)	(0.20)	(0.18)	(0.14)	(0.45)
asset purchase expectations	0.50	0.11	-0.35	0.11	-0.10	-0.38***	-0.09
(std. err.)	(0.38)	(0.37)	(0.36)	(0.20)	(0.18)	(0.14)	(0.42)
orthogonal term premium	1.36***	1.57***	2.05***	1.36***	1.87***	2.86***	-0.68
(std. err.)	(0.38)	(0.37)	(0.36)	(0.20)	(0.18)	(0.14)	(0.53)
Regression R^2	0.41	0.47	0.52	0.72	0.81	0.90	0.27

Coefficients are in basis points per standard deviation change in the policy instrument.

Daily change in LIBOR is considered. Since LIBOR is normally released at 11:55 am London time, daily change is calculated by measuring the difference from FOMC announcement day (t) to the following day ($t+1$).

30-minute changes in Eurodollar futures bracketing the FOMC announcements is considered.

Daily change in 90-day AA Nonfinancial commercial paper rates is considered. Since commercial paper rates are usually posted at 1:00 pm, daily change is calculated by measuring the difference from FOMC announcement day (t) to the following day ($t+1$).

*** and ** denote statistical significance at 1 and 5 percent levels, respectively.

increase in the first principal component of orthogonalized term premia (a 0.75 basis point increase in orthogonalized term premium for the six-month Treasury yield) relates to a 1.4 basis point increase in the three-month LIBOR. The value increases with the maturity period, with the 12-month LIBOR reporting an increase of 2.1 basis points. The interest rate changes reported for the Eurodollar futures are broadly similar to the changes in LIBOR. Given that a one standard deviation increase in the first principal component of orthogonal term premia corresponds to a 0.02 and 0.75 basis point increases in term premia for the three-month and six-month Treasury yields, respectively, the reported coefficients indicate that there is a more than proportional increase in the yields of short-term instruments. The more than proportional increase could indicate increasing credit spreads in response to term premium shocks on FOMC announcement days. Moreover, Gertler and Karadi (2015) argue that monetary policy surprises generally result in large movements in credit costs mainly due to the reaction of both term premia and credit spreads.

Table 3.8: Estimated effects on corporate bonds

	Aaa yield	Baa yield
short end expectations	0.93***	0.76***
(std. err.)	(0.29)	(0.28)
future path expectations	1.70***	1.68***
(std. err.)	(0.29)	(0.28)
asset purchase expectations	-2.30***	-2.54***
(std. err.)	(0.29)	(0.28)
orthogonal term premium	0.33	0.38
(std. err.)	(0.29)	(0.28)
Regression R^2	0.32	0.36

Coefficients are in basis points per standard deviation change in the policy instrument.

Daily change in corporate bond yields is considered.

*** denotes statistical significance at 1 percent level.

Under long term instruments, I consider Moody's seasoned corporate bond yields, which are based on bonds with maturities 20 years and above, and the estimated coefficients are presented in Table 3.8. A one standard deviation surprise increase in short end expectations relates to a 0.9 basis point increase in the Aaa index of corporate bond yields, while a one standard deviation surprise increase in future path expectations relates to a 1.7 basis point increase in the Aaa index. An increase in asset purchase expectations by one standard deviation relates to a decline of 2.3 basis points in the Aaa index. All coefficients considered above are highly statistically significant and the deviation of the coefficient values among the Aaa index and Baa index remains small. The sign of the estimated coefficients for the changes in the first principal component of orthogonalized term premia is positive as expected. However, the coefficients remain statistically insignificant and are smaller than the corresponding coefficients reported in Table 3.7. A one standard deviation surprise increase in the orthogonal measure of term premia (a 0.4 basis point increase in term premium for the 30-year Treasury yield) relates to a 0.3 basis point increase in the Aaa index of Moody's seasoned corporate bond yields.

Overall, for long-term debt instruments, the reported coefficients for the changes in short end interest rate expectations are considerably small in comparison to those reported in Table 3.7 for short-term instruments. This indicates that changes in the current interest rate or expectations about short-term interest rates have a smaller impact on long-term yields of private sector debt instruments. In contrast, the effects of asset purchase expectations are larger than the coefficients reported in Table 3.7. This suggests that the twisting of the yield curve due to the Federal Reserve's asset purchase programs is associated with smaller changes in the interest rates of short-term debt instruments and larger changes in that of long-term debt instruments. The results are in line with Swanson (2021) which finds that shocks to the federal funds rate have no significant effect on long-term corporate bond yields, while forward guidance and LSAPs have significant effects with the effects of LSAPs being largest.

I assess the robustness of the results estimated for the term premia responses considering the Kim and Wright (2005)'s measure of term premiums. It provides a market-based estimate of term premia using a three-factor arbitrage-free term structure model, thereby standing as a better candidate for a robustness check exercise. I re-estimate the relationship between the term premia responses around FOMC announcements and the corresponding changes in the interest rates of a set of financial instruments. The procedure I follow, and the results obtained are given in Section C.2 of the Appendix. The outcomes indicate that the coefficient estimates under Kim and Wright (2005)'s approach, when normalized for a one basis point change in term premium, closely correspond to the coefficient estimates reported under external instruments VAR approach with a similar normalization. This demonstrates that the term premium effects found in this study are robust to market-based measures of term premia.

3.5 Evaluating the Macroeconomic Impact

3.5.1 The Empirical Setup

In this section, I analyze the macroeconomic effects of shocks to interest rate expectations and term premia on FOMC announcement days. I use an exogenous variable VAR for this analysis, where the factors pertaining to interest rate expectations and term premia estimated above are considered as exogenous variables. A similar approach is followed by Bernanke and Kuttner (2005) to assess the dynamics of macroeconomic variables for interest rate surprises as measured in Kuttner (2001). A VAR with exogenous variables takes the form

$$Y_t = AY_{t-1} \; + \; \phi\tilde{F}_t \; + \; \tilde{\omega}_t, \tag{3.7}$$

where Y_t represents the vector of macroeconomic variables considered in the VAR and $\tilde{F}_t$ denotes the exogenous variables under consideration. The contemporaneous response of variables in Y_t to the unanticipated changes in exogenous variables in period t is captured by ϕ. The new error term is denoted by $\tilde{\omega}_t$ and it is orthogonal to the exogenous variables by construction. Estimates of A and ϕ can be obtained by first estimating the reduced form VAR and then regressing the VAR's forecast errors on the set of exogenous variables.

Exogenous variables considered for this analysis are the three structural factors estimated for the interest rate expectations and the first principal component of term premium responses. Given that the three factors for expectations are orthogonal to each other by construction, they can be considered either together or separately in $\tilde{F}$. The first principal component of orthogonalized term premia is not related to the three structural factors of expectations by construction. Therefore, it can also be considered either jointly or separately in $\tilde{F}$. Once the matrix (or vector) ϕ is estimated, an impulse response analysis could be carried out to assess the dynamic response of macroeconomic variables for a shock to the exogenous variables under analysis.

The set of variables considered for the VAR are the same as the variables considered in the baseline specification in Section 3.2 to estimate the term premium responses. Accordingly, Y_t includes the industrial production index (log), consumer price index (log), one-year government bond rate, excess bond premium, mortgage spread, and the commercial paper spread. For exogenous variables, estimates available for each FOMC announcement day need to be converted to a monthly series of policy shocks. This is achieved by following the same methodology used in Section 3.2 for calculating monthly external instruments, where the monthly average of daily cumulative surprises is taken. This approach is followed since a policy surprise at the end of a month is expected to have a smaller influence on the monthly averages than a surprise at the beginning of the month. Meanwhile, with respect to shocks to asset purchase expectations, the highly influential March 2009 FOMC announcement is dropped from the analysis for the same reasons stated in Swanson (2021). A monthly VAR is estimated for the period from July 1979 to June 2019. Given that the expectations and term premium responses are available from July 1991 onward, ϕ is estimated using the residuals from July 1991 to June 2019. Once the parameters of the VAR are estimated, the n-month dynamic response to a one standard deviation surprise increase in expectations or term premia is calculated as $A^n\phi$.

In addition to the baseline specification, I use extended VARs by adding extra variables to the baseline VAR, one at a time, to assess the dynamic response of other macroeconomic variables. As such, I estimate extended VARs with the unemployment rate and the S&P 500 index (log) to analyze the effects on the labor market and the stock market, respectively. Furthermore, the structural identification of expectation shocks and the corresponding load-

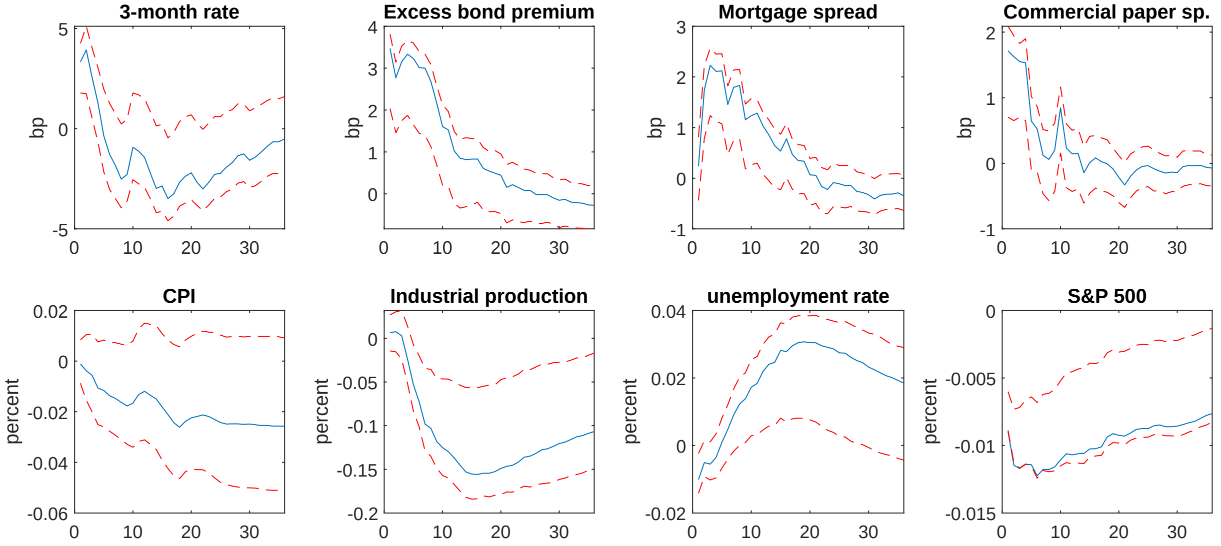

Figure 3.2: Estimated effects of a one standard deviation shock to short end expectations. Estimated responses are in solid blue lines and the bootstrapped 90 percent confidence bands are in dashed red lines.

ing matrices estimated in the previous section provide the 30-minute responses of the yields to each type of structural shock due to FOMC announcements. It is interesting to see if these short-term responses result in movements in the yields that persist over a longer horizon. For this purpose, I include the three-month, 10-year and 30-year Treasury yields as additional variables and estimate the corresponding extended VARs.

3.5.2 Dynamic Responses

Estimated effects of a one standard deviation shock to short end expectations are shown in Figure 3.2. In each panel, the impulse response estimated by the baseline or extended VAR is depicted by a solid blue line. The 90 percent confidence bands computed using bootstrapping methods[8] are given in dashed red lines. The three-month Treasury rate increases by 3.3 basis points in the first period and remains positive for 4 periods, indicating that the increase in short-term yields due to a shock to short end expectations persists for several months. The

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[8] I use wild bootstrap similar to Gertler and Karadi (2015) and Mertens and Ravn (2013)

increase in the excess bond premium reflects the increase in credit costs due to monetary tightening. Both long-term and short-term interest rate spreads rise as indicated by the responses of mortgage spread and commercial paper spread, respectively. Inflation declines as illustrated by a gradual decline in the log consumer price index. Industrial production declines with a time lag, while the unemployment rate increases albeit of a slight drop in the first few periods. The S&P 500 index declines immediately indicating the falling stock prices owing to a surprise increase in short-term interest rate expectations.

Overall, the impulse responses for a shock to short end expectations resemble the response of macroeconomic variables to a conventional contractionary monetary policy shock (see Ramey (2016), for a review). Kaminska et al. (2021) also find a similar outcome in their study with pre-financial crisis data, where they show using local projections that a surprise increase in the *action* results in a rise in the excess bond premium and mortgage rates, while inflation, industrial production and the S&P500 index exhibit a decline. Further, the responses of the excess bond premium, and mortgage and commercial paper spreads are broadly similar to the responses in Gertler and Karadi (2015) for a shock to the monetary policy indicator. Moreover, this is in line with the literature on the credit channel (e.g., Bernanke and Gertler (1995)), which states that the credit channel magnifies the impact of an interest rate adjustment on private borrowing rates via its impact on credit spreads or the external finance premium. The drop in stock prices is consistent with the discount factor channel as highlighted in Bernanke and Kuttner (2005), where shocks to the current federal funds rate are estimated to have a highly persistent positive effect on excess stock returns through discount rate changes.

The impulse responses estimated for a one standard deviation shock to future path expectations are shown in Figure 3.3. A shock to future path expectations corresponds to the changes in interest rate expectations due to the Federal Reserve's announcement of a future

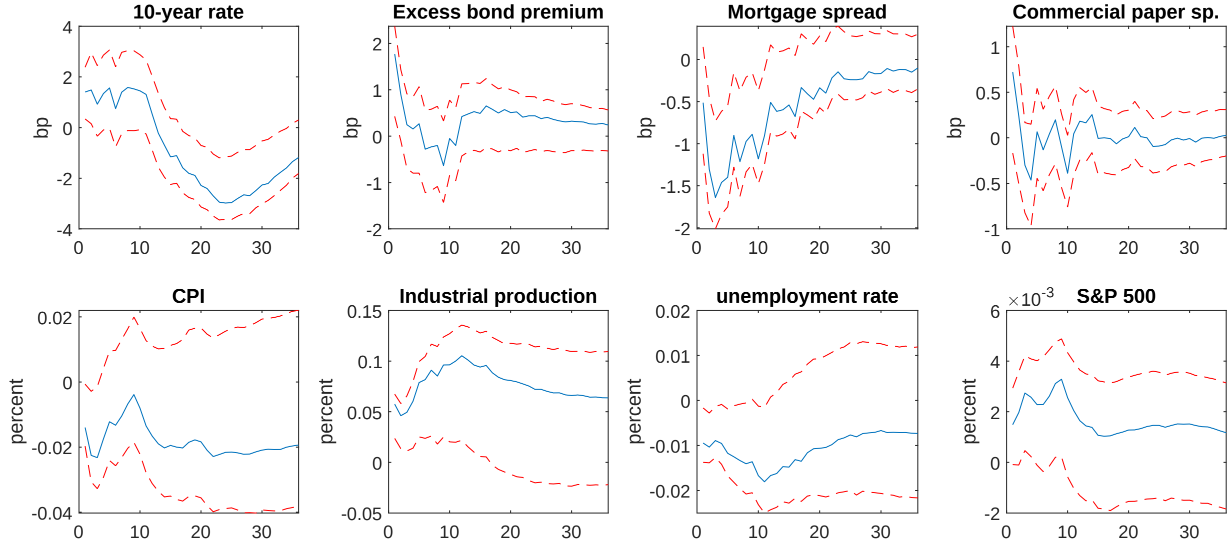

Figure 3.3: Estimated effects of a one standard deviation shock to future path expectations. Estimated responses are in solid blue lines and the bootstrapped 90 percent confidence bands are in dashed red lines.

increase in interest rates. Therefore, such an announcement could be considered as a contractionary policy shock. However, the empirical outcomes as shown in Figure 3.3 indicate that not all variables behave as if they are responding to a conventional tightening of the interest rates. The 10-year Treasury yield increases by 1.4 basis points in the first period and remains positive for around a year indicating a persistent increase in long-term yields. Both the excess bond premium and commercial paper spread rise in line with an increase in medium- to long-term interest rate expectations. Consumer prices decline and remain low throughout the period of analysis despite a transitory increase after several months. What is surprising is the response of the industrial production index, unemployment rate and the S&P 500 index, as they reflect an expansionary outcome. Kaminska et al. (2021) also find a similar outcome where they show that a surprise increase in the *expected path* results in a rise in industrial production and the S&P500 index although the 10-year Treasury yield reports an increase.

Figure 3.4: Estimated effects of a one standard deviation shock to asset purchase expectations. Estimated responses are in solid blue lines and the bootstrapped 90 percent confidence bands are in dashed red lines.

The increase in economic activity due to a shock to future path expectations could suggest either the "Fed response to news" channel as argued in Bauer and Swanson (2020) or the presence of a "Fed information effect" channel as argued in Nakamura and Steinsson (2018). If the Fed response to news channel is present, a shock to future path expectations incorporates incoming, publicly available economic news that causes both the Federal Reserve to change monetary policy and the markets to revise their forecasts of economic activity. If the Fed information effect channel is present, a shock to future path expectations identifies a revelation of positive news about the future state of the economy by the FOMC announcement, which was not in the public domain before. Moreover, the empirical findings have important implications for the monetary policy decision makers, because an announcement about a future change in the interest rates may not result in the desired outcomes in terms of economic activity and employment. However, further research is warranted to assess the robustness of these findings and to discriminate between the two transmission channels stated above.

Estimated effects of a one standard deviation shock to asset purchase expectations are shown in Figure 3.4. The 30-year Treasury yield drops by around 2 basis points and remains in the negative region for more than a year, indicating the effects of the anticipated purchase of long-term assets by the Federal Reserve. The excess bond premium shows a marginal decline in line with this, while the commercial paper spread also responds with a drop suggesting a reduction in the external finance premium for the private sector borrowers. For the mortgage spread, the slight initial drop, however, is followed by an increase in the interest rate spread. A positive mortgage spread response means that the decline in the mortgage rate average is not as large as the drop in the 10-year yield. Industrial production increases, while the unemployment rate declines gradually. The S&P 500 index also responds with an increase reflecting the effects of the expansionary policy shock. However, the shock under consideration does not result in inflation as the consumer price index responds with a drop.

The impulse responses for a shock to asset purchase expectations support prior studies that conclude that the Federal Reserve's LSAP programs did lower longer-term private borrowing rates (e.g., Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011) and Swanson (2011)). The observed increase in industrial production and the drop in the unemployment rate support the idea that the balance sheet policies of the Federal Reserve have the potential to stimulate the economy and generate employment, largely offsetting the effects of the lower bound (Bernanke, 2020). Meanwhile, the drop in the consumer price index could be due to the fact that the asset purchase announcements were typically made at times of recessions where the economy was already deflationary, and the demand pressures remained at substantially low levels.

Finally, the impulse responses estimated for a one standard deviation shock to the first principal component of orthogonalized term premia are shown in Figure 3.5. It is interesting to note that the 10-year yield declines, even though the factor loadings estimated for

Figure 3.5: Estimated effects of a one standard deviation shock to orthogonalized term premium. Estimated responses are in solid blue lines and the bootstrapped 90 percent confidence bands are in dashed red lines.

orthogonalized term premia (Tabel 3.6) are positive.[9] The key here is that the measure of term premia is orthogonalized against the three types of structural shocks for interest rate expectations. Therefore, the residual element of term premia is likely to capture the effects of uncertainty and risks. In this regard, Kaminska et al. (2021) find that the orthogonalized measure of term premia are related to two proxies for monetary policy uncertainty, implied volatility from options on federal funds futures or swap rates and estimated interest rate uncertainty. Given that orthogonalized term premia provides a measure of policy uncertainty, the resultant impulse responses are not surprising because an increase in uncertainty resembles an aggregate demand shock increasing unemployment and lowering inflation (Leduc and Liu, 2016). Further, uncertainty shocks could lower nominal interest rates through precautionary savings. Therefore, the drop observed in the 10-year Treasury yield could suggest an increase in precautionary savings due to some form of uncertainty.

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[9] A one standard deviation shock to the first principal component of term premia before orthogonalization results in an increase in the 10-year yield and the responses of other variables are broadly similar to the responses expected for a conventional contractionary policy shock.

3.6 Conclusion

I examine the transmission of monetary policy surprises on FOMC announcement dates through the changes in expected interest rates and term premia of the yield curve. Disaggregation of yield curve responses to policy shocks into expectations and term premia shows that a shock to the current federal funds rate has a bigger impact on expectations than on term premium for short-term yields. For long-term yields, a forward guidance shock has a bigger impact on expectations than on term premium. In addition, a shock to forward guidance is found to have a larger effect on expectations than a current federal funds rate shock. It is not surprising for a forward guidance shock to have a larger impact on expectations than a current federal funds rate shock, because the former could mean interest rate changes over several periods in the future and such a change is reflected more in the changes in cumulative expectations. However, an LSAP shock is found to have opposing effects on expectations and term premium for longer maturities. Nonetheless, it is largely transmitted to the yield curve through expectations supporting the signaling channel of balance sheet policies. Although term premiums reporting positive coefficients for an expansionary LSAP shock is surprising, this could suggest changes in uncertainty and risk perceptions associated with significant LSAP announcements, and further research could be directed to explore this.

I derive structural factors using the estimated changes in interest rate expectations employing techniques of factor rotation. The resultant factors are in line with different dimensions of monetary policy surprises of the Federal Reserve. Using them, I assess the relationship between the changes in expectations and term premia, and other financial market and macroeconomic variables. Accordingly, a shock to short end expectations is found to be associated with substantial and statistically significant effects on short-term debt instruments, while shocks to expectations about future rate path and asset purchases are associated with substantial and statistically significant effects on long-term debt instruments. Moreover, surprises due to the Federal Reserve's asset purchases are found to have the largest instantaneous effects on long-term debt instruments of the private sector. Meanwhile, orthogonalized term premiums are found to relate to positive responses in both short- and long-term debt instruments, with the effects being substantial and statistically significant only in the short-term instruments.

Impulse responses estimated to assess the economic impact reveal that a shock to short end expectations brings about usual contractionary effects, while a shock to asset purchase expectations leads to an increase in economic activity without exerting inflationary pressures. The observed outcomes support the idea that the balance sheet policies of the Federal Reserve have the potential to stimulate the economy and generate employment, largely offsetting the effects of a zero lower bound. A shock to future rate path expectations results in an increase in long-term yields and a drop in consumer prices, albeit with an expansion in economic activity. The increase in economic activity could suggest the presence of either the "Fed response to news" channel or the "Fed information effect" channel. Meanwhile, orthogonalized term premium effects on the economy are found to be similar to a policy uncertainty shock. All in all, the empirical findings of this study could provide helpful insights for monetary policy decision makers, especially on the impacts of unconventional policy.

Recent literature argued that monetary policy announcement effects are well described by three dimensions representing different types of policy tools (e.g., Rogers et al. (2018), Altavilla et al. (2019), Swanson (2021)). However, the financial market effects as well as the macroeconomic outcomes of this study suggest that there could be more than three dimensions for monetary policy announcement-specific effects. Lewis (2021) is another study highlighting this possibility focusing on information effects.

This study focuses on one specific event of monetary policy communications, that is FOMC announcements. Going forward, there is the possibility of considering other events such as the Chairman's speeches and the release of FOMC minutes. In addition, future research could also be directed at estimating the term premia responses to policy announcements using other market-based econometric techniques to overcome some of the limitations of VAR-based approaches.

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Appendix A

Appendix to Chapter 1

A.1 Estimated Effects on Equity Prices: Excluding the "QE1" Announcement

The "QE1" LSAP announcement on March 18, 2009 has been identified as a very influential announcement made at a time when financial markets were functioning very poorly (Swanson, 2021). Accordingly, the analysis in Section 1.4 is repeated, excluding the LSAP announcement in March 2009. The results for the S&P 500 Index and its sector indexes are reported in Table A.1. The main change comes through the estimates for the ZLB period. Therefore, only the full sample and the ZLB sample (panel C of Tables 1.2 and 1.3) are presented.

Table A.1: Estimated effects on equity prices: S&P 500 sectoral analysis (excluding March 2009 "QE1" Announcement)

	S&P 500	Energy	Materials	Industrials	Consumer discretion.	Consumer staples	Health care	Financials	IT	Comm. services	Utilities	Real estate
(A) Full sample, Jul.1991–Jun.2019 (240 obs.)												
change in federal funds rate	-0.37***	0.15	-0.34***	-0.48***	-0.67***	0.11	0.05	-0.47***	-0.86***	-0.27**	0.08	-0.43
(std. err.)	(-0.09)	(0.11)	(0.11)	(0.09)	(0.1)	(0.08)	(0.09)	(0.15)	(0.15)	(0.11)	(0.09)	(0.36)
change in forward guidance	-0.25***	-0.34***	-0.28***	-0.24***	-0.25***	-0.33***	-0.32***	-0.24*	-0.16	-0.33***	-0.34***	-0.39**
(std. err.)	(0.07)	(0.09)	(0.09)	(0.08)	(0.08)	(0.06)	(0.07)	(0.13)	(0.12)	(0.09)	(0.08)	(0.19)
change in LSAPs	-0.27*	-0.43**	-0.55***	-0.34**	-0.46**	-0.02	0.08	-0.77***	-0.14	0.08	0.27	-0.65*
(std. err.)	(0.16)	(0.19)	(0.19)	(0.16)	(0.18)	(0.13)	(0.16)	(0.27)	(0.26)	(0.19)	(0.16)	(0.38)
Regression R^2	0.12	0.09	0.11	0.15	0.2	0.11	0.07	0.09	0.14	0.08	0.09	0.06
(C) ZLB sample, Jan.2009–Nov.2015 (54 obs.)												
change in forward guidance	-0.46**	-0.64**	-0.6**	-0.52**	-0.47**	-0.46***	-0.46**	-0.36	-0.34	-0.64***	-0.84***	-0.73*
(std. err.)	(0.21	(0.27)	(0.28)	(0.22)	(0.23)	(0.15)	(0.17)	(0.44)	(0.21)	(0.18)	(0.18)	(0.42)
change in LSAPs	-0.41	-0.65*	-0.58	-0.46	-0.43	-0.17	-0.26	-0.84	-0.29	-0.30	0.04	-0.09
(std. err.)	(0.27)	(0.35)	(0.35)	(0.28)	(0.29)	(0.19)	(0.22)	(0.56)	(0.27)	(0.22)	(0.23)	(0.53)
Regression R^2	0.10	0.12	0.10	0.11	0.09	0.16	0.12	0.04	0.06	0.21	0.33	0.06

Coefficients are in percentage points per standard deviation change in the monetary policy instrument.
***, **, and * denote statistical significance at 1, 5 and 10 percent levels, respectively.

A.2 Sectoral Variance Decomposition of Excess Equity Returns

With the excess equity return and dividend yield series calculated for each stock market sector, I repeat the VAR based analysis performed in Section 1.5 with the rest of the variables remaining the same. The details of the sectoral variances of expected future dividends, real interest rates and excess returns, and the respective covariance calculations are given in Table A.2. Figure 1.2 in Section 1.5 summarizes these details by depicting the relative contribution of each of the factors for the current period's excess equity returns.

Table A.2: Variance decomposition of excess equity returns: sectoral analysis

		Var(excess returns)	Var(dividends)	Var(real rate)	Var(future excess returns)	-2 Cov(dividends, real rate)	-2 Cov(dividends, future excess return)	2 Cov(future excess return, real rate)
Energy	Value	28.56	0.33	0.13	25.12	-0.33	3.81	-0.52
	Share (%)		1.17	0.46	87.97	-1.14	13.34	-1.81
Materials	Value	30.73	1.16	0.93	13.96	1.54	6.81	6.34
	Share (%)		3.78	3.03	45.42	5	22.15	20.62
Industrials	Value	23.49	0.5	0.14	18.22	-0.26	4.5	0.38
	Share (%)		2.15	0.6	77.58	-1.11	19.16	1.63
Consumer Discretionary	Value	23.92	1.34	0.52	10.37	1.03	6.68	3.97
	Share (%)		5.62	2.19	43.36	4.29	27.93	16.61
Consumer Staples	Value	12.76	2.95	0.35	2.62	1.14	4.25	1.44
	Share (%)		23.15	2.71	20.56	8.95	33.33	11.3
Health Care	Value	18.15	0.31	0.17	14.38	-0.22	2.4	1.12
	Share (%)		1.72	0.92	79.22	-1.22	13.2	6.16
Financials	Value	35.75	15.04	2.13	0.65	10.55	5.28	2.11
	Share (%)		42.06	5.95	1.81	29.5	14.76	5.91
IT†	Value	29.27	0.41	0.16	23.42	-0.21	4.33	1.16
	Share (%)		1.39	0.55	80.02	-0.72	14.79	3.97
Communication Services	Value	27.64	0.73	0.2	18.85	0.00	5.76	2.1
	Share (%)		2.63	0.71	68.21	0.01	20.85	7.6
Utilities	Value	17.10	0.23	0.17	14.36	-0.25	1.47	1.11
	Share (%)		1.35	1.02	83.99	-1.46	8.62	6.48

Decomposition of the excess equity returns for a given policy surprise based on the relation $e^y_{t+1} = \tilde{e}^d_{t+1} - \tilde{e}^r_{t+1} - \tilde{e}^y_{t+1}$.

† A smoothed data series of the total returns index (monthly average instead of the month end value) is used for the decomposition exercise. This is done to overcome the extreme values resulting from excessive volatility in stock prices mainly during the dot com bubble period.

Appendix B

Appendix to Chapter 2

B.1 Linearization of the Demand Side

The Euler equation given by (2.52) can be stated as

$$C_t = \frac{1}{\beta}\mathbb{E}_t\left\{\frac{\mathcal{F}_{t,t+1}P_{t+1}C_{t+1}}{P_t}\right\} + \frac{\delta}{\beta(1-\delta)}[1-\beta(1-\delta)]\mathbb{E}_t\left\{\frac{\mathcal{F}_{t,t+1}\Omega_{t+1}}{P_t}\right\}, \tag{B.1}$$

of which, the present discounted real value of future financial wealth is given by

$$\mathbb{E}_t\left\{\frac{\mathcal{F}_{t,t+1}\Omega_{t+1}}{P_t}\right\} \equiv \mathbb{E}_t\left\{\frac{\mathcal{F}_{t,t+1}B_{t+1}}{P_t} + \frac{\mathcal{F}_{t,t+1}}{P_t}\int_0^1 [Q_{t+1}(k)+D_{t+1}(k)]Z_{t+1}(k)dk\right\}. \tag{B.2}$$

Following Nisticò (2012), I assume a public sector whose consumption is financed entirely through lump-sum taxation to the households. Therefore, the net supply of state-contingent bonds is assumed to be zero. Further, the aggregate stock of issued shares for each intermediate good producing firm is normalized to 1. Accordingly, (B.2) reduces to

$$\mathbb{E}_t\left\{\frac{\mathcal{F}_{t,t+1}\Omega_{t+1}}{P_t}\right\} \equiv \int_0^1 \frac{1}{P_t}\mathbb{E}_t\left\{\mathcal{F}_{t,t+1}[Q_{t+1}(k)+D_{t+1}(k)]\right\}dk. \tag{B.3}$$

Using the intertemporal optimality condition concerning the holdings of equity shares given by (2.28), the above relation can be further simplified as

$$\mathbb{E}_t \left\{ \frac{\mathcal{F}_{t,t+1}\Omega_{t+1}}{P_t} \right\} \equiv \int_0^1 \frac{Q_t(k)}{P_t} dk. \tag{B.4}$$

The aggregate real stock-price index is defined as the simple integration over the continuum of firms:

$$Q_t \equiv \int_0^1 \frac{Q_t(k)}{P_t} dk. \tag{B.5}$$

As such, the present discounted real value of future financial wealth is represented by the current level of the real stock-price index:

$$\mathbb{E}_t \left\{ \frac{\mathcal{F}_{t,t+1}\Omega_{t+1}}{P_t} \right\} \equiv Q_t. \tag{B.6}$$

With the above simplification, log-linearization of (B.1) around such a steady state yields the following relation:

$$c_t = \frac{1}{\beta(1+i)} \mathbb{E}_t \left\{ c_{t+1} - (i_t - \rho) + \pi_{t+1} \right\} \; + \; \frac{\delta[1-\beta(1-\delta)]}{\beta(1+i)(1-\delta)} \frac{\Omega}{PC} \wp_t, \tag{B.7}$$

where $\rho \equiv -\log(\beta)$ is considered as the steady state net interest rate, $\frac{\Omega}{PC}$ represents the steady state level of wealth-to-consumption ratio, and $\wp_t \equiv \log(\frac{Q_t}{Q})$. Also, note that in the long-run, the stochastic discount factor for one-period ahead payoffs converges to $(1+i)^{-1}$. Meanwhile, recall that Ψ is defined as

$$\Psi \equiv \delta \frac{[1-\beta(1-\delta)]}{(1-\delta)} \frac{\Omega}{PC}. \tag{B.8}$$

The steady state of (B.1) is given by

$$C = \frac{C}{\beta(1+i)} \ + \ \frac{\delta[1-\beta(1-\delta)]}{\beta(1+i)(1-\delta)}\frac{\Omega}{P}, \tag{B.9}$$

which can be combined with (B.8) to result in

$$\beta(1+i) = 1 \ + \ \frac{\delta[1-\beta(1-\delta)]}{(1-\delta)}\frac{\Omega}{PC} = 1 + \Psi. \tag{B.10}$$

Using the relations given by (B.9) and (B.10), the log-linearized Euler equation can be expressed as

$$c_t = \frac{1}{1+\Psi}\mathbb{E}_t\left\{c_{t+1}\right\} \ + \ \frac{\Psi}{1+\Psi}\wp_t \ - \ \frac{1}{1+\Psi}(i_t - \mathbb{E}_t\left\{\pi_{t+1}\right\} - \rho). \tag{B.11}$$

B.2 Incomplete Exchange Rate Pass-through

In Section 2.6, I use the small open economy model of Monacelli (2005) to examine the effects of exchange rate pass-through on the open economy version of the forward guidance puzzle. As the focus of this analysis is to assess the impact of exchange rate pass-through, the benchmark model in Monacelli (2005) is used as it is, without incorporating perpetual youth. The linearized model considered for the analysis is summarized below.

Law of one price gap

$$q_t = \psi_{F,t} \ + \ (1-\alpha) \ s_t \tag{B.12}$$

Imported inflation

$$\pi_{F,t} = \beta\mathbb{E}_t\left\{\pi_{F,t+1}\right\} \ + \ \lambda_F\psi_{F,t} \tag{B.13}$$

Domestic inflation

$$\pi_{H,t} = \beta \mathbb{E}_t \left\{ \pi_{H,t+1} \right\} \ + \ \kappa_y x \ + \ \kappa_\psi \psi_{F,t} \tag{B.14}$$

IS equation

$$x_t = \mathbb{E}_t \left\{ x_{t+1} \right\} \ - \ \frac{\omega_s}{\sigma} (i_t - \mathbb{E}_t \left\{ \pi_{H,t+1} \right\} - r_t^n) \ + \ \Gamma_y \mathbb{E}_t \left\{ \Delta \psi_{F,t+1} \right\} \tag{B.15}$$

International risk sharing

$$c_t = c_t^* \ + \ \frac{1}{\sigma} q_t \tag{B.16}$$

Goods market clearing condition

$$y_t = y_t^* \ + \ \frac{1}{\sigma} (\omega_s s_t \ + \ \omega_\psi \psi_{F,t}) \tag{B.17}$$

Overall inflation

$$\pi_t = (1 - \alpha) \pi_{H,t} \ + \ \alpha \pi_{F,t} \tag{B.18}$$

Terms of trade

$$\Delta s_t = \pi_{F,t} \ - \ \pi_{H,t} \tag{B.19}$$

Monetary policy

$$i_t = \phi_\pi \pi_{H,t} + \varepsilon_t^{mp} + \sum_{j=1}^{J} \varepsilon_{t,t-j}^{mp}. \tag{B.20}$$

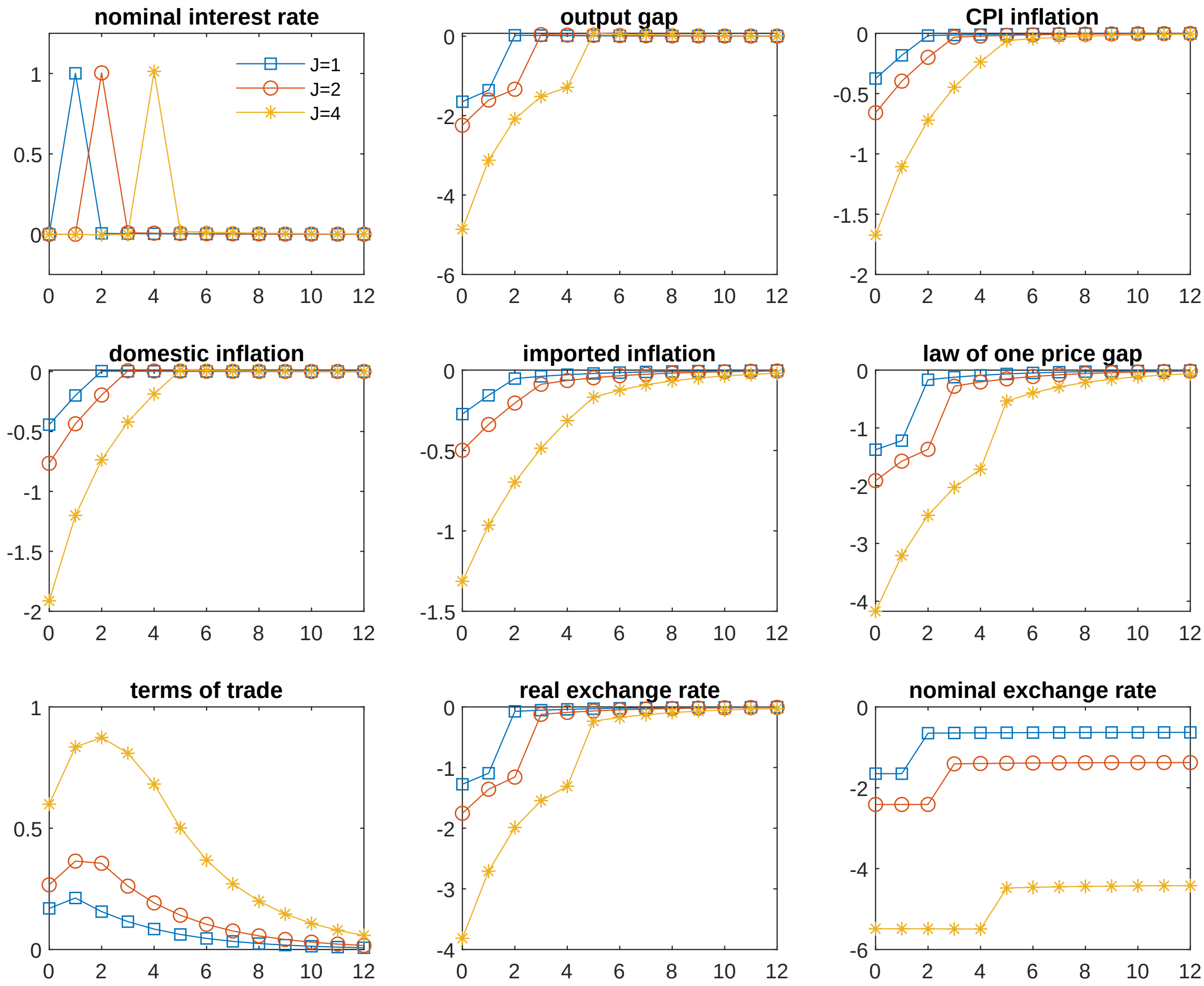

Figure B.1: Effects of an announced interest rate increase with incomplete exchange rate pass-through. Simulated for different time horizons of the announced future increase.

I repeat the same forward guidance experiment conducted in Section 2.2.2 using the small open economy model with incomplete pass-through. As such, the home central bank announces a one percentage point increase in the nominal interest rate for a single period, J periods ahead in the future, and Figure B.1 depicts the response of the interest rate, output, inflation, and the exchange rates for a simulation carried out for different values of J.

Appendix C

Appendix to Chapter 3

C.1 Robustness of Estimated Effects of Policy Shocks

In the estimates carried out in Section 3.2.1, the effective federal funds rate is used as the measure of short-term interest rates. Nonetheless, the zero lower bound episode from January 2009 to November 2015 could be a concern since the movements in the short-term interest rates were constrained by an effective lower bound. Therefore, in order to check the robustness of the effects of policy shocks presented in Table 3.1, I use the shadow federal funds rate derived by Wu and Xia (2016) as an alternative measure of the federal funds rate for the zero lower bound period.

Under this approach, I first examine the evolution of term premium responses under a rolling VAR estimate for a one standard deviation shock to the monetary policy indicator. The estimated responses from 1991 to 2019 are shown in Figure C.1. It is observed that the term premium responses are similar to those in Figure 3.1 in Section 3.2.1 for the pre-financial crisis period. However, the decline in the magnitude of the term premium responses

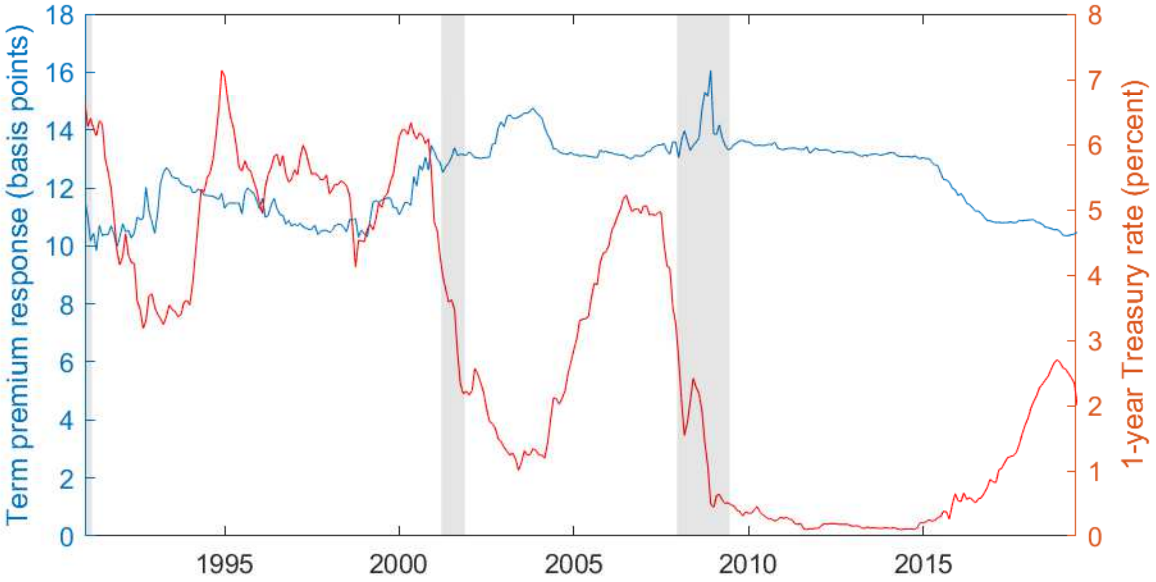

Figure C.1: Estimated term premium response in a rolling vector autoregression for a one standard deviation shock to the policy indicator (one-year Treasury rate). The actual yield of a one-year Treasury bill over the corresponding period is given by the right axis. Shaded areas indicate U.S. recessions.

over the post-financial crisis period is amplified in Figure C.1.

The propagation of various types of monetary policy shocks to the yield curve via its disentangled components under the alternative approach is presented in Table C.1. The results indicate that except for the three-month Treasuries, the estimated coefficients given in panel (B) and panel (C) are mostly similar to those reported in Table 3.1. The coefficients become almost the same as the maturity period increases. Therefore, the main features observed in Section 3.3 hold true under an alternative approach that uses the shadow federal funds rate during the zero lower bound period. Meanwhile, for the three-month Treasuries, the main difference comes from the coefficients estimated for term premia. However, given that three-months is the shortest maturity under consideration, its term premium has less significance and the coefficients pertaining to it are close to zero.

Table C.1: Estimated effects of policy shocks on the U.S. Treasury yields

	3-month	6-month	2-year	5-year	10-year	30-year
(A) Overall change in the yield						
change in federal funds rate	4.11***	4.38***	3.86***	2.32***	1.07***	0.02
(std. err.)	(0.180)	(0.165)	(0.113)	(0.106)	(0.118)	(0.18)
change in forward guidance	1.20***	2.20***	4.49***	4.74***	3.63***	2.18***
(std. err.)	(0.147)	(0.135)	(0.092)	(0.087)	(0.096)	(0.146)
change in LSAPs	0.11	0.69***	0.09	-2.62***	-4.7***	-3.95***
(std. err.)	(0.25)	(0.229)	(0.157)	(0.147)	(0.164)	(0.249)
Regression R^2	0.71	0.81	0.94	0.94	0.91	0.67
(B) Change in term premium						
change in federal funds rate	-0.26***	1.39***	3.65***	2.43***	1.43***	0.57***
(std. err.)	(0.015)	(0.043)	(0.108)	(0.09)	(0.055)	(0.027)
change in forward guidance	-0.24***	1.00***	2.66***	1.64***	0.92***	0.42***
(std. err.)	(0.012)	(0.035)	(0.088)	(0.073)	(0.045)	(0.022)
change in LSAPs	-0.03*	0.29***	0.73***	0.56***	0.34***	0.16***
(std. err.)	(0.02)	(0.06)	(0.15)	(0.124)	(0.076)	(0.037)
Regression R^2	0.75	0.89	0.9	0.84	0.83	0.78
(C) Change in expectations						
change in federal funds rate	4.36***	2.99***	0.21*	-0.12	-0.36***	-0.55***
(std. err.)	(0.183)	(0.134)	(0.107)	(0.133)	(0.128)	(0.179)
change in forward guidance	1.45***	1.20***	1.83***	3.10***	2.71***	1.76***
(std. err.)	(0.149)	(0.109)	(0.087)	(0.108)	(0.104)	(0.146)
change in LSAPs	0.14	0.40**	-0.65***	-3.18***	-5.04***	-4.10***
(std. err.)	(0.254)	(0.186)	(0.148)	(0.184)	(0.177)	(0.249)
Regression R^2	0.74	0.72	0.66	0.83	0.86	0.64

Coefficients are in basis points per standard deviation change in the monetary policy instrument. ***, **, and * denote statistical significance at 1, 5 and 10 percent levels, respectively.

C.2 Robustness of Term Premium Effects

In this section, I assess the robustness of the results estimated in Section 3.4 for the term premia responses. For that I consider the Kim and Wright (2005)'s measure of term premiums and re-estimate the relationship between the term premia responses around FOMC announcements and the corresponding changes in the interest rates of a set of financial instruments. Kim and Wright (2005) provides a market-based estimate of term premia using a three-factor arbitrage-free term structure model, thereby standing as a better candidate

Table C.2: Elements of the loading matrix: alternative term premium measure

	1-year	2-year	5-year	10-year
First PC of term premia	1.04	1.73	2.54	2.70

Based on Kim and Wright (2005)'s measures of term premiums. Given in basis points per standard deviation change in the PC.

for a robustness check exercise.

Even though daily and monthly term premia estimations using the model from Kim and Wright (2005) are available from 1990 until the most recent period, the response of term premia to some event such as an FOMC announcement needs to estimated using an appropriate procedure. I use the actual responses of the Treasury yields in a 30-minute window bracketing each FOMC announcements to estimate the change in the Kim and Wright (2005)'s measure of term premium around announcements. First, I regress the monthly change in Kim and Wright (2005)'s term premia on the monthly changes in three-month, six-month, two-year, five-year, 10-year and 30-year Treasury rates, using data from 1991 to 2019. The estimates show that the Treasury yields explain the change in term premia to a large extent with R^2 values in the range of 0.97 to 0.98. Secondly, using these regression coefficients and the actual changes in three-month, six-month, two-year, five-year, 10-year and 30-year Treasury rates, I estimate the response of term premia in a 30-minute window bracketing announcements for each FOMC date under analysis. Kim and Wright (2005)'s measure of term premiums are available for maturities from one-year to 10-year. Out of that, I select one-year, two-year, five-year, and 10-year term premiums for the analysis and estimate the response in a 30-minute window for those maturities using the above method.

With the term premium responses estimated using Kim and Wright (2005)'s measure for one-year, two-year, five-year, and 10-year Treasuries, I compute the first principal component

Table C.3: Comparison of term premium effects

	LIBOR		Eurodollars		Aaa yield	Baa yield
	6-m	12-m	6-m	12-m		
Kim and Wright (2005) based	1.51***	2.68***	2.76***	4.41***	2.60***	2.62***
(std. err.)	(0.50)	(0.49)	(0.36)	(0.34)	(0.30)	(.30)
external instruments VAR based	5.29***	5.73***	5.55***	6.15***	1.33***	1.21***
(std. err.)	(0.38)	(0.37)	(0.19)	(0.20)	(0.33)	(0.33)

Coefficients are in basis points per standard deviation change in the policy instrument.
*** denotes statistical significance at 1 percent level.

of the changes in term premia. The first principal component is found to explain 93 percent of the variation in term premia and the corresponding factor loadings are given in Table C.2. I regress the change in the interest rates of debt instruments considered in Section 3.4 on the first principal component of term premium responses estimated using Kim and Wright (2005)'s data. The results for some selected instruments and maturities are summarized in Table C.3. The first row of Table C.3 reports regression coefficients when the term premium responses are estimated using the Kim and Wright (2005)'s method, while the third row reports the corresponding coefficients under the external instruments VAR approach followed in this study.

A one standard deviation surprise increase in Kim and Wright (2005)'s measure of term premia relates to a 1.5 basis point increase in six-month LIBOR, while the corresponding coefficient for the external instruments VAR approach is 5.3 basis points. With regard to factor loadings, the shortest common maturity between the two methods is the two-year Treasury yield. A one standard deviation surprise in the first principal component of term premia corresponds to a 1.7 basis point increase in term premium for the two-year Treasury yield for Kim and Wright (2005)'s approach and a 4.3 basis point increase in the two-year yield for external instruments VAR approach. Accordingly, under Kim and Wright (2005)'s approach, a shock to the first principal component of term premia that results in a one basis point increase in term premium for the two-year yield relates to a 0.9 basis point increase in six-month LIBOR. Similarly, under external instruments VAR approach, a shock to the first principal component of term premia that results in a one basis point increase in term premium for the two-year yield relates to a 1.2 basis point increase in six-month LIBOR. The above results become 1.6 basis points and 1.3 basis points, respectively, for the six-month Eurodollar futures rate. With regard to long term Moody's seasoned corporate bond yields, a one standard deviation surprise increase in Kim and Wright (2005)'s measure of term premia relates to a 2.6 basis point increase in Moody's Aaa index. For factor loadings, the longest common maturity between the two methods is the 10-year Treasury yield, and for Kim and Wright (2005)'s approach, a one standard deviation surprise in the first principal component of term premia corresponds to a 2.7 basis point increase in term premium for the 10-year Treasury yield. This means a shock to the first principal component of term premia that results in a one basis point increase in term premium for the 10-year yield relates to a 1.0 basis point increase in Moody's Aaa bond yield. Following similar steps, under external instruments VAR approach, a shock to the first principal component of term premia that results in a one basis point increase in term premium for the 10-year yield relates to a 0.8 basis point increase in Moody's Aaa yield. These outcomes indicate that the coefficient estimates under Kim and Wright (2005)'s approach, when normalized for a one basis point change in term premium, closely correspond to the coefficient estimates reported under external instruments VAR approach with a similar normalization. This demonstrates that the term premium effects found in this study are robust to the other market-based measures of term premiums.