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Is the market always right?
Improving federal funds rate forecasts by adjusting for the term premium

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Non-technical summary

Financial market prices contain valuable information about market participants' expectations. Information on market participants' expectations of future growth, inflation, and interest rates may help policy-makers reflect on the plausibility of their own forecast assumptions, and understand the likely market reaction to any policy announcement.

However, the existence of risk premiums will bias the information content of financial market prices. For interest rate securities, the term premium will create a wedge between market participants' expectation of the future path of the policy rate and the price being traded. Therefore, in order to extract the 'true' underlying policy expectations of market participants, market pricing needs to be adjusted for the term premium.

In theory, adjusting for the term premium should improve forecast performance on average, given that it provides an unbiased measure of market participants' expectations. I therefore use a popular term structure model to test the out-of-sample forecast performance of US market pricing with and without a term premium adjustment. I focus on the short-end of the yield curve, up to two years, as it is directly relevant for policy-makers and financial market commentators.

The results suggest that the short-term forecasting performance of US interest rates over the medium term can be improved by adjusting for the term premium in zero-coupon rates and overnight index swap rates. The current negative term premium implies that market participants at present expect the future policy rate in the United States to be higher than that implied by market prices. I also show how the model can be applied to monitor expectations for the future path of the federal funds rate at a daily frequency.

The analysis has important implications for policy-makers and financial commentators. Adjusting for the term premium should provide a better measure of market participants' actual expectations for the future path of the policy rate, and as such can improve forecast performance over the medium term.

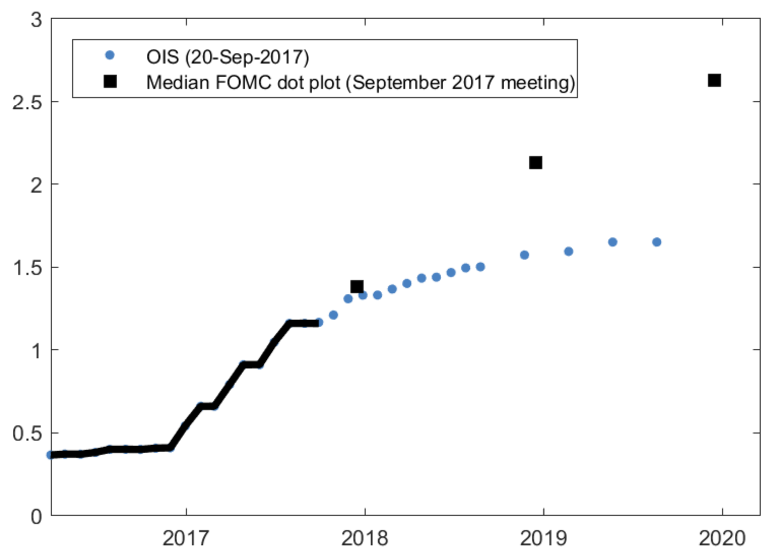
1. Introduction[1]

Financial market prices contain valuable information about market participants' expectations. Policy-makers and market commentators are interested in the information content of financial market variables, to assess market participants' expectations of future growth, inflation and interest rates. For policy-makers, these expectations can be a useful cross-check in any forecasting exercise. For example, understanding market participants' expectations may help policy-makers reflect on the plausibility of their own forecast assumptions, and understand the likely market reaction to any policy announcement.

It is common practice amongst financial market commentators to use federal funds futures or forward rates inferred from overnight index swaps (OIS) as a measure of expectations of the future path of the policy rate of the Federal Reserve, the federal funds rate.[2] Forward rates are also frequency cited by central banks and international institutions as measures of policy rate expectations.[3]

Since January 2012, the Federal Reserve's Federal Open Markets Committee (FOMC) has published projections of their appropriate future path of the policy rate, known as the dot plots.[4] Since 2014, there has been a persistent discrepancy between market pricing for US policy rate increases and other measures of expectations, including the median projection from the FOMC, and analysts' and traders' surveyed expectations. Figure 1 plots a recent example. Some commentators have suggested that the discrepancy between the FOMC dot plots and market pricing is a sign that the central bank is not credible.[5]

Figure 1: Median FOMC dot plot and OIS forward curve



[1] I would like to thank Leo Krippner, Christie Smith, Yuong Ha, Adam Richardson and Gael Price for their useful and constructive comments.

[2] For example, Bloomberg (2016) and Reuters (2017).

[3] For example, IMF (2017) and RBA (2017).

[4] The FOMC's dot plots are a projection of the appropriate or optimal path of policy based on each participants' assessment of economic conditions, rather than an expected path. However, the median dot plot seems a reasonable approximation of 'the committee's expectation', and it tends to be in line with surveys of analysts and market participants (e.g. the surveys of primary dealers and market participants by the Federal Reserve Bank of New York).

[5] For example, Summers (2017).

The pure expectations hypothesis of the term structure of interest rates states that longer-term interest rates are unbiased forecasts of the path of future short-term interest rates. However, the failure of the pure expectations hypothesis is well-established in the finance literature.[6] Interest rate securities typically exhibit a term premium; the compensation that holders of securities demand for bearing risk, or return they are prepared to forego to avoid risk. These term premiums create a wedge between market participants' expectations of future short-term interest rates and the prices being traded.

The use of market forward rates as a measure of market participants' expectation of the future policy rate is correct only under the assumption that the term premium is negligible at short maturities (say, for maturities of 1-24 months). In this note, I show that this assumption is incorrect; the term premium is substantial and time-varying, even at short maturities. This means that a federal funds futures rate often cannot be taken directly as a measure of policy expectations, and that changes in a federal funds futures rate may reflect either changes in expectations or changes in risk preferences.

One way to measure whether accounting for the term premium better captures the information content of financial market prices is to conduct an out-of-sample forecast test, which will provide an ex-post assessment. Consistent with theory, adjusting for the term premium results in an improvement in the out-of-sample forecast performance of US short-term interest rates over the medium term.[7]

The implication for financial market commentators and policy-makers is twofold:

1) Financial market prices often do not purely reflect market participants' expectations, and hence to claim that the market 'expects' an outcome inferred directly from a market price is incorrect, and
2) A discrepancy between the FOMC dot plots and market pricing does not necessarily imply a difference in view, or a lack of central bank credibility.

The results of this analysis suggest that analysts and market commentators would benefit from taking this term premium data into account when drawing implications about market participants' expectations from OIS or federal funds futures rates. Conveniently, the outputs of the term structure model used in this analysis are publicly available at a daily frequency and updated periodically on the Federal Reserve Bank of New York website and Bloomberg terminal.[8]

The rest of the Analytical Note proceeds as follows. Section 2 reviews the theory and literature on the term structure of interest rates and interest rate forecasting. Section 3 discusses the data and model, and Section 4 shows the out-of-sample forecast results. Section 5 provides implications and applications of the time-varying nature of the term premium at the short-end of the US yield curve. Section 6 concludes.

[6] Friedman (1979), Fama and Bliss (1987), Campbell and Shiller (1991).
[7] It is important to note that these results do not suggest that there is a mispricing, or that markets are not efficient. Market prices reflect both expectations and compensation for risk, and adjusting for the term premium provides a measure of the expectation component.
[8] https://www.newyorkfed.org/research/data_indicators/term_premia.html, Bloomberg tickers: ACMTP01, ACMTRY01, ACMTY01, ACMTP02, ACMTRY02, ACMTY02, etc.

2. Theory and literature review

This section provides an overview of modern asset pricing theory, how this applies to interest rates securities, and reviews the literature on short-term term premiums in interest rate securities.

2.1 Asset pricing

In modern finance theory, the price (p) of an asset depends on how the payoffs (x) of the asset co-vary with the stochastic discount factor:[9]

$$p_t = E_t(m_{t+1}x_{t+1})$$

where E is the expectation operator, and m_{t+1} is the stochastic discount factor:

$$m_{t+1} = \beta \frac{u'(c_{t+1})}{u'(c_t)}$$

In turn, the stochastic discount factor depends on the ratio of marginal consumption utilities and the discount factor β.

Marginal utility $(u'(c))$ declines as consumption rises. Therefore, securities with payoffs that are positively correlated with consumption growth have lower prices, i.e. command a positive risk premium, to compensate investors for risk. For example, the prices of equity securities are low relative to expected payoffs (expected returns are high), because equity prices tend to lose value precisely when investors care about the marginal value of a dollar the most, e.g. in recessions when output and marginal consumption growth are low. Conversely, securities with payoffs that are negatively correlated with consumption growth have higher prices than its expected payoff may indicate (i.e. command a negative risk premium), as these assets have valuable hedging (i.e. consumption smoothing) properties.

The asset pricing equation above can also be expressed as:

$$p_t = \frac{E_t(x_{t+1})}{R_t^f} + cov(m_{t+1}, x_{t+1})$$

This expression shows how the market price of an asset, p, differs from the expected average of future payoffs $E_t(x_{t+1})$. The first term is the expected payoff discounted at the gross risk-free discount rate, $R_t^f = 1 + r_t^f$, where r is the risk-free interest rate in decimal terms that applies to the single period. The second term, $cov(m_{t+1}, x_{t+1})$, is a risk adjustment term which will be influenced by investor risk aversion and how the asset payoff correlates with events that investors care about.

Note that $E_t(x_{t+1})$ is often denoted the expectation under real-world probabilities or under the physical, $\mathbb{P}$, measure. Adjusting the $\mathbb{P}$-measure probabilities for risk gives risk-adjusted (market-implied or $\mathbb{Q}$ measure) probabilities, and the expected value of those probabilities (including risk) correspond with asset prices. Hence, market-based probabilities are altered versions of real-world probabilities that account for the risk compensation required by investors.

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[9] See Cochrane (2009).

Intuitively, the probability of certain outcomes inferred from a market price can change because the real-world (actual) probability has changed, or because the risk premium that investors require for holding that asset has changed. For example, the market-implied probability of a certain outcome can be high either because the real-world probability is high or because investors worry a lot about their financial position in that circumstance, and are willing to sacrifice some expected return to hedge against that risk.[10]

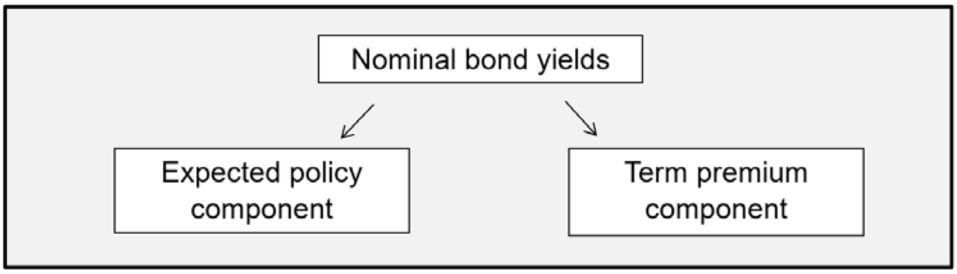
2.2 The term structure of interest rates

The above asset pricing framework can also be applied to interest rate securities. The pure expectations hypothesis of the term structure specifies that long-term interest rates are equal to the average of expected future short-term interest rates. However, numerous empirical studies highlight a substantial, time-varying risk premium.[11] Risk premiums in bond yields reflect a combination of the quantity of risk (i.e. volatility/uncertainty) and the price of risk.

Historically this risk premium has been positive; investors required a positive yield premium as they expected bonds to perform poorly in an economic downturn. During the 1970s, for example, oil price shocks increased inflation and bond yields while economic activity suffered.[12] However, investors will be willing to sacrifice some return (i.e. accept a negative premium) when bonds are expected to perform well in an economic downturn; e.g. if bonds provide some insurance against an economic downturn.[13]

There are numerous methods in the term structure literature that attempt to decompose bond yields into investors' expectations about the path of future short-term interest rates, and a time-varying term premium (figure 2). Note that for interest rate securities I use the terminology 'term premium' rather than 'risk premium' from here to capture anything other than future policy rate expectations, e.g. liquidity risk, market risk, inflation risk, etc.

Figure 2: The term structure of interest rates



[10] Bauer and Rudebusch (2015).

[11] Friedman (1979), Fama and Bliss (1987), Campbell and Shiller (1991). See Gürkaynak and Wright (2012) for a recent literature survey of term structure models.

[12] Even a default-free bond can be risky if its price co-varies with the marginal utility of consumption. For example, if times of high inflation are correlated with times of low output, then households regard the nominal bond as being risky, because it loses value at exactly those times when an investor values consumption the most (Crump et al, 2017).

[13] Callaghan and Krippner (2017) section 3 contains related discussion.

2.3 Related literature

Together the empirical literature suggests that deriving expectations from interest rate securities will be complicated by the presence of time-varying term premiums. The term structure literature has largely focused on the long-end of the yield curve, with particular interest in the effects of unconventional monetary policy on the yield curve since the global financial crisis. The literature is thin on the forecast performance of term structure models, relative to market pricing.

Adrian et al (2016) provide evidence that their no-arbitrage, 5-factor term structure model outperformed direct market-based measures in forecasting interest rates. These authors focus on forecasting the 10-year yield, using different assumptions for the level of the term premium at the end of the forecast.

At the shorter end of the yield curve, Piazzesi and Swanson (2008) show that forecasts from federal funds futures rates are biased by the presence of risk premiums. Ignoring these risk premiums in federal funds futures rates significantly biases forecasts of the future path of monetary policy.

Priebsch (2017) develops a shadow rate model of policy expectations up to the five-year horizon. The model implies that term premiums vary over time and can be substantial in magnitude, even at relatively short horizons. This Federal Reserve Board staff model has been referred to numerous times in the FOMC meeting minutes when analysing movements in short-term forward rates.[14]

Callaghan and Krippner (2016) note that market participants' expectations of the path of the federal funds rate may be higher than that inferred from a straight read of federal fund futures contracts. At the time of publication, the negative risk premium in the short-end of the curve suggested that futures rates should be downwardly biased predictors of future realised short rates. The short-term negative term premium was derived from Krippner's 3-factor shadow rate term structure model.

In the year following publication, the Federal Reserve increased interest rates substantially more than was implied by market pricing at the time, consistent with the conclusions from Callaghan and Krippner (2016). This note follows on from Callaghan and Krippner (2016) by testing more formally whether accounting for the term premium in short-term interest rates can systematically improve forecasts relative to an unadjusted forecast based directly on the yield curve.

3. Data and methodology

This paper focuses on the performance of 1-24 month ahead forecasts of the US policy rate, the federal funds rate. Forecasts over this horizon are relevant for understanding the medium-term outlook for policy rates, and implicitly the outlook for economic growth and inflation.

I test the monthly out-of-sample forecasting performance, from 1990-2017, of:

- Zero-coupon forward rates, from the Gürkaynak, Sack and Wright (2007) dataset
- Expected policy forward rates, derived from the 5-factor ACM model

[14] For example, Federal Reserve Board (2017).

- A random walk

There are numerous models in the term structure literature that attempt to decompose interest rates into expected policy and term premium components. In this note I use estimates from the five-factor, no-arbitrage term structure model of Adrian, Crump, and Moench (2013) to generate term premium-adjusted (expected policy) estimates of US expected policy rates.[15] The Adrian, Crump, and Moench (ACM) term structure model is a popular model, with daily data available at maturities of one to ten years on the Federal Reserve Bank of New York website.

The ACM model uses monthly zero-coupon US Treasury yield data from Gürkaynak, Sack and Wright (GSW), starting in June 1961.[16] The forecast period begins in 1990; a long learning period is desirable to estimate robust model parameters. The decomposition from the term structure model can be subject to revisions over time, therefore this forecast assessment uses the real-time vintage and re-estimates the model monthly as new yield curve data is added. The model is constructed solely based on yield curve data; it does not use macroeconomic or survey data.

The model specification used in this note is the 5-factor model, which describes and forecasts the yield curve through the evolution of 5 factors; the level, slope and 3 curvatures. The 5-factor model is the preferred specification in Adrian et al (2013) and the one used to create the publicly available data.

The ACM model uses principal components to extract pricing factors from the yield curve data. These pricing factors evolve over time according to a vector autoregressive (VAR) process. Interest rates are modelled as linear functions of the pricing factors. The parameters that determine the relationship between the pricing factors and yields are restricted to ensure the absence of arbitrage opportunities.

The expected policy component is calculated by setting the price of risk parameters to zero. The term premiums can then be calculated as the difference between the model-implied fitted yield and the model-implied average expected future short-term interest rate over the relevant horizon, which is computed by forecasting the VAR of pricing factors.

Figure 3 shows the 2-year yield decomposition from the ACM 5-factor model. The model shows a positive term premium prior to 2005, consistent with Piazzesi and Swanson (2009). An interesting feature of the data is that the term premium has been negative since about 2014.[17]

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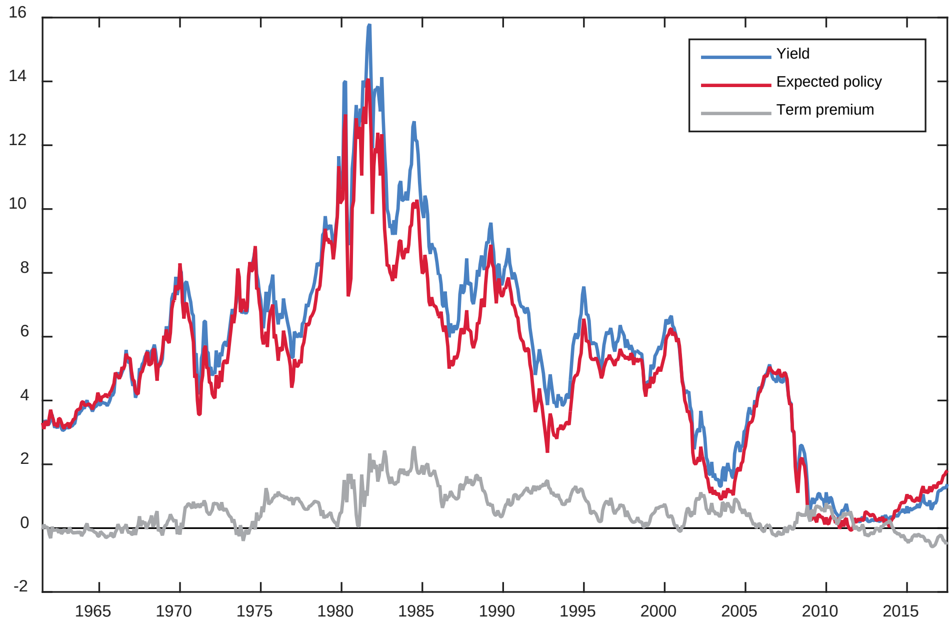
[15] I thank the authors for providing the code for the ACM model.

[16] The zero-coupon yield curve data are publicly available from the Federal Reserve Board website.

[17] An explanation of the negative term premium and its implications are discussed in Callaghan and Krippner (2016).

Figure 3: US 2-year interest rate decomposition (ACM 5-factor model)



The results of term structure models will be model-dependent, but models tend to share common features. Popular term structure models tend to show a decline in the term premium since the 1980s and a negative term premium at the short-end of the yield curve since 2014.[18]

One potential concern about the use of the ACM model to forecast the short-end of the US yield curve is that the ACM model does not account for the zero lower bound (ZLB). An improvement to the model would be adjusting the model using a shadow rate model, similar to Priebsch (2017). However, the results in the next section suggest that the ACM model does perform well, even over the ZLB period.

4. Results

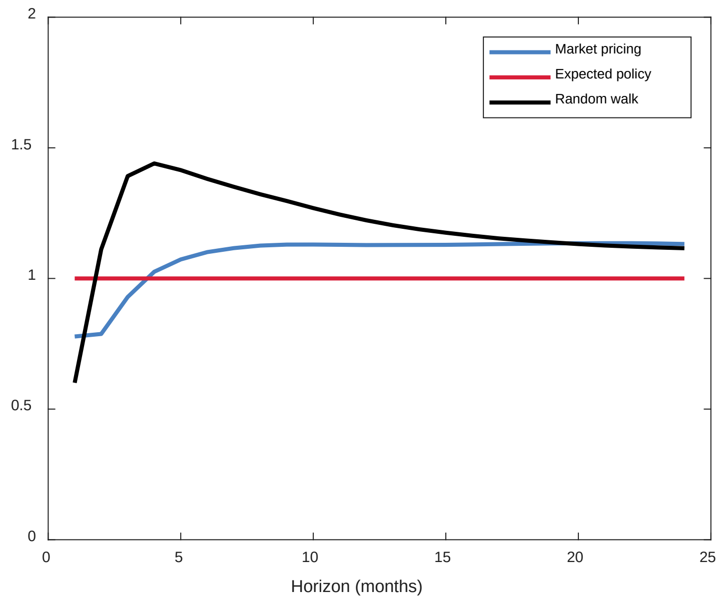
The first part of the results section compares the out-of-sample forecast performance of a random walk, zero-coupon forward rates, and expected policy forward rates over the full 1990-2017 sample period. The monthly forecasts from each measure are shown in Appendix A.5. The relative root mean square errors (RMSE) of the three forecasts up to a 24-month horizon are shown in figure 4, with the expected policy forecast as the baseline.

I also split the sample at 2008Q2 to test the performance over the ZLB period. The results from the different sample periods (1990-2008Q2 and 2008Q2-2017) are shown in figure 5. Table 1 summarizes the forecast performance across all sample periods and selected horizons, including the significance of the results.

As an example of interpreting these results, at a 24-month horizon the relative RMSE of the zero-coupon forward rate (i.e. market pricing) is 1.13. This indicates that the forecast from the expected policy forward rate outperforms the zero-coupon forward rate forecast, with a 13 percent lower RMSE.

[18] For example, the ACM model (2013), Kim-Wright model (2005) and Krippner shadow rate model (see Callaghan and Krippner, 2016) all show a negative term premium in the 2-year yield since early-2014.

Figure 4: Relative RMSE, 1990-2017



Note: Market pricing refers to GSW zero-coupon forward rates. Expected policy refers to the GSW zero-coupon forward rates adjusted for the term premium using the 5-factor ACM model.

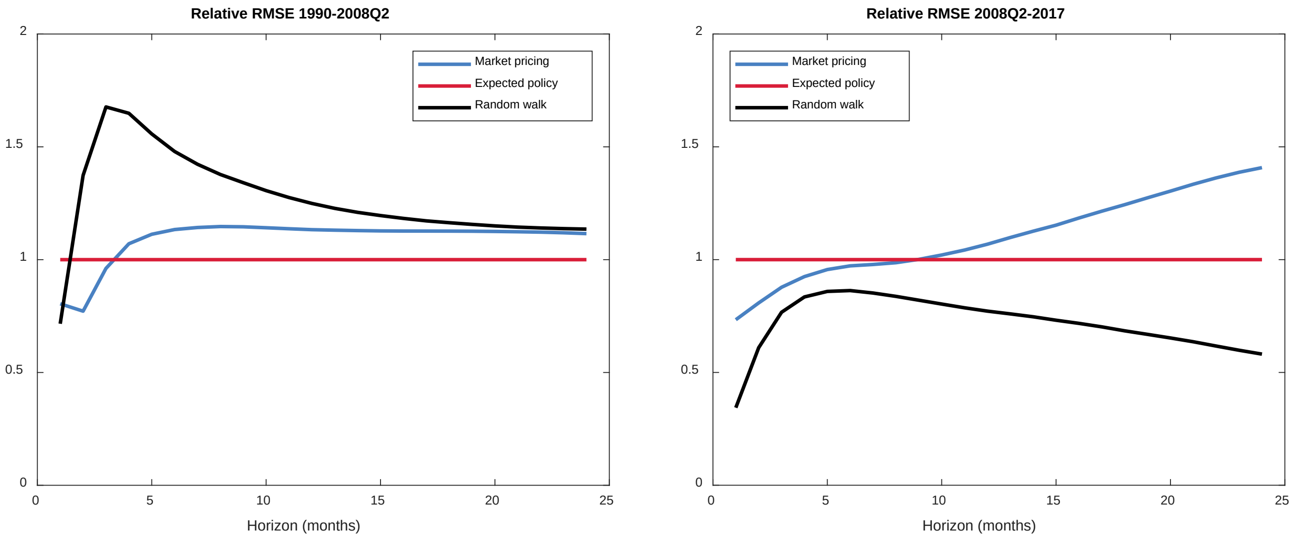
Table 1: Forecast performance: Root mean squared errors

Measures	Horizon	Full sample	1990-2008Q2	2008Q2-2017
Expected policy	24-month	2.07	2.39	0.88
	18-month	1.70	1.98	0.72
	12-month	1.18	1.38	0.59
	6-month	0.58	0.64	0.48
Relative to expected policy				
Zero-coupon	24-month	1.13*	1.12*	1.41*
	18-month	1.13*	1.13*	1.24
	12-month	1.13	1.13*	1.07
	6-month	1.10	1.14	0.97
Random walk	24-month	1.12**	1.14**	0.58***
	18-month	1.15**	1.16**	0.68***
	12-month	1.22***	1.25***	0.77**
	6-month	1.38***	1.48***	0.86*

Note: The first section shows the RMSEs for the expected policy forecasts. For the rows after that, the RMSEs are relative to expected policy. A value greater than 1 implies the expected policy forecasts are more accurate than the corresponding forecast. Test statistics are from the Diebold-Mariano test, corrected for autocorrelation. *, ** and *** indicate statistical significance at 10 percent, 5 percent, and 1 percent level, respectively.

The full sample results show that the expected policy forward rate has the lowest RMSE beyond the five-month horizon, with about a 13 percent forecast improvement over zero-coupon forward rates, and a 12-38 percent forecast improvement over a random walk. The forecast performance of the zero-coupon forward rate is comparable to that of a random walk from the 18-month horizon onwards.

Figure 5: Relative RMSE, sub-sample split



In the subsample analysis, the random walk outperforms in the post-global financial crisis period – a period through which the federal funds rate was constrained at the zero lower bound for an extended period. In both sample periods, the expected policy forward rates have a lower RMSE than the zero-coupon forward rates beyond the six month horizon.

The poor forecast performance of expected policy forwards at the very short-end of the curve (1-3 months) likely reflects the poor fit of the model, and of the GSW zero-coupon rates, to the very short-end of the yield curve. A potential improvement could involve incorporating OIS rates to the yield curve data to provide a better fit.

A potential criticism of this analysis is that market commentators use OIS forward rates (not the zero-coupon rates of Gürkaynak et al) as a measure of market policy expectations. As a robustness check, OIS forward rates are also used alongside zero-coupon rates in the appendix. The forecast errors of OIS rates are similar to that of the zero-coupon rates, and the series co-vary closely. This suggests that the use of zero-coupon rates, rather the OIS rates, does not appear to be driving these results, i.e. a time-varying term premium is a common feature in interest rate securities.

The appendix also shows the performance of the ACM model with varying factors (figure A.7). All factor models tested show similar performance across the sample periods. Figure A.8 also shows that the real-time properties of the 2-year expected policy rate are similar to the current vintage.

5. Implications and applications

The results have important implications for those inferring information from financial markets. This section discusses how the decomposition of market pricing can be used at a daily frequency, how this framework can help avoid policy mistakes and enable better understanding of market movements, and how market information can be used alongside survey measures to provide a more consistent understanding of expectations.

Many financial market commentators appear to assume that the level or the changes in market pricing for interest rate changes in the United States purely reflect the expectation of the marginal investor.[19] By ignoring the presence of the term premium in the curve, commentators may misinterpret, and misrepresent, the expectations of market participants.[20] Attempting to justify movements in forward rates without taking movements in the term premium into account provides a distorted view of market participants' outlook for the future path of US interest rates. A distorted view of the expected path of interest rates also implies a distorted outlook for economic growth and inflation.

There are also important implications for policy-makers from this analysis. Some commentators have advocated a slower pace of Federal Reserve rate increases, in part due to market pricing for federal fund rate increases remaining low. However, such an approach could result in a policy error if the term premium is distorting the information content of prices.

For example, signalling a higher future policy rate in response to a positive term premium may result in policy-makers surprising market participants and inadvertently tightening policy faster than market participants think appropriate. Policy may need to react differently to higher interest rates depending on whether they are driven by:

- A higher term premium, which represents a change in risk preference, e.g. investors' requiring additional compensation for interest rate risk, or
- Expectations of higher future real interest rates, and hence higher future economic growth.

Alternatively, easing or holding policy rates low in response to a negative term premium may cause policy-makers to keep policy easier for longer than market participants deem appropriate.

As an example of how the term structure model can be used at a daily frequency, figure 6 plots the FOMC dot plots, the OIS forward curve, and the expected policy forward curve. A negative term premium at the dates shown in the figure suggest that market participants expected a higher future path of the federal funds rate than that implied from financial market prices. Reasons for the difference between the expected policy forward curve and the FOMC dot plots may include:

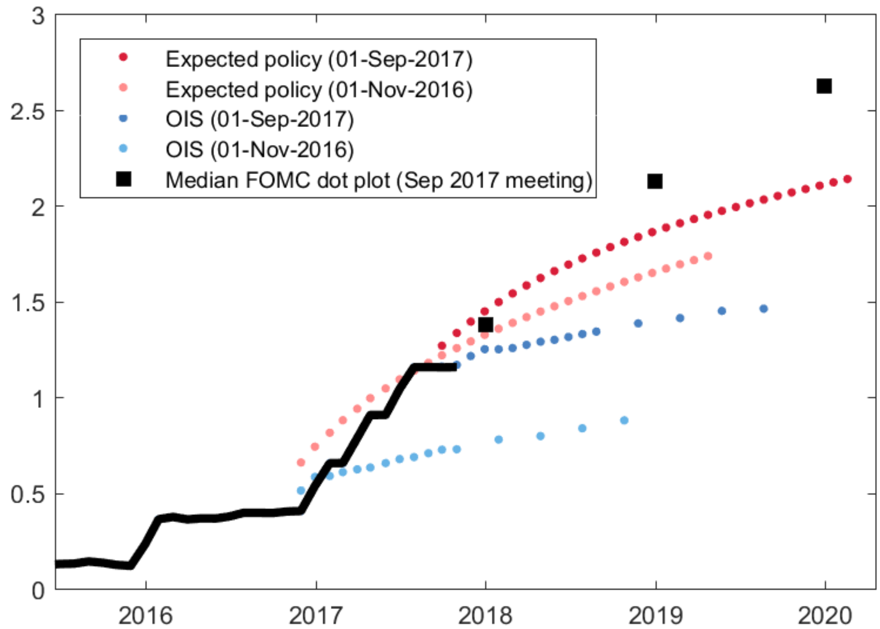
1. A difference in view between the median FOMC participant and the marginal investor
2. A difference between the mean and modal (most likely) expectation for the future path of the federal funds rate
    - For example, the expected policy forward curve may be weighed down in later years by the probability of lower realizations of the federal funds rate
3. Model misspecification
    - The expected policy path may not be producing an accurate measure of market participants' expectations

[19] For example, Bloomberg (2016) 'Forget December. Forget Next Year. The Fed's Done Hiking Until 2018'. The Federal Reserve subsequently hiked rates three times over the next 12 months.

[20] Shin (2017) suggests using caution when extrapolating "market" expectations from movements in asset prices, noting that is it unhelpful to view the "market" as a single individual.

Estimates from term structure models do need to be treated with caution, as estimates can vary according to model specifications and assumptions. It is useful to compare term structure estimates with other information sources, such as analysis from private and official institutions.

Figure 6: Expectations for the future path of the federal funds rate

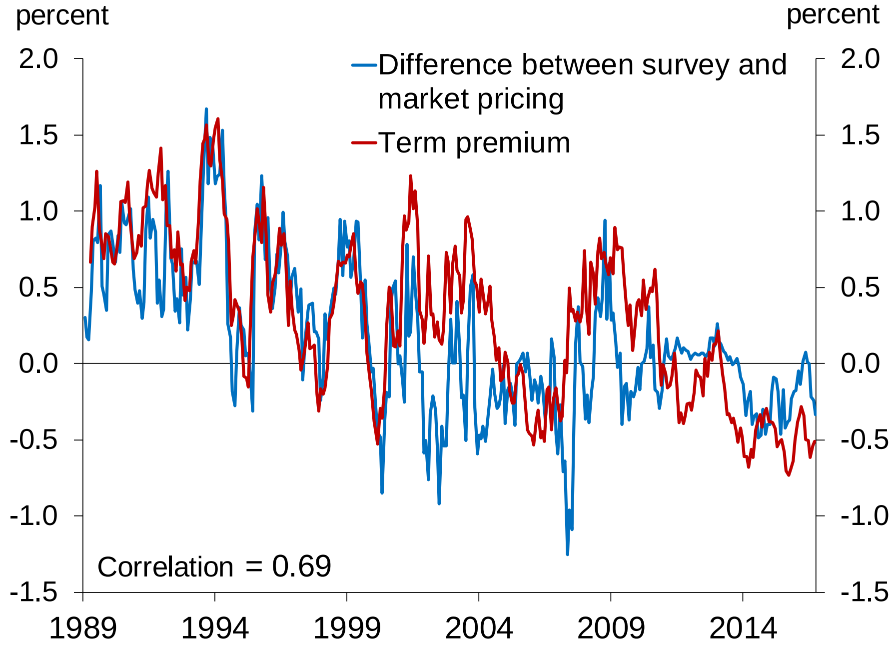


As an alternative to market pricing, survey measures can provide a measure of participants' expectations, without the term premium bias. Figure 7 provides a useful model-free cross-check of the term premium estimate. The estimated term premium is reasonably well-correlated with the discrepancy between analysts' surveyed expectations and market pricing. This is despite the term structure model being derived solely from yield curve data.

This analysis therefore provides some consistency between measures of expectations from surveys (of analysts, primary dealers, and market participants) and market pricing. The discrepancy between analysts' expectations and forward rates may not necessarily reflect a difference in view; it may simply reflect the fact that interest rate securities include a term premium, and therefore the market price will not provide a clean read on market participants' expectations.

The limitations of using survey data are that they are not as timely as financial market data, and may not be representative of active market participants. The appendix discusses how the term structure framework can better identify expectation shocks, with some specific case studies.

Figure 7: Term premium and market pricing-survey discrepancy



Source: ACM model, GSW yields, Consensus Forecasts. Note: The blue line is the surveyed expectation of the 3-month rate in one years' time minus the 1-year, 3-month forward rate from the GSW yield curve. The term premium estimate is the real-time 1-year, 3-month forward term premium from the ACM 5-factor model.

6. Conclusion

The forecasting performance of US interest rates over the medium term can be improved by adjusting for the term premium. This note uses estimates from the term structure model of Adrian, Crump, and Moench (2013) to decompose interest rates into an expected policy component and a term premium.[21] The results are consistent with modern asset pricing theory; accounting for the biases inherit in market pricing and obtaining a better measure of market participants' expectations of future policy. As such, the market is often right, but only once the term premium is taken into account.

The analysis has important implications for policy-makers and financial commentators. When monitoring expectations for central bank policy rates, it is important to recognise the potential limitations of various information sources. The existence of time-varying risk premium is one of the challenges in extracting information from financial market prices. By obtaining a better measure of market participants' expectations, i.e. by adjusting for the term premium, the forecasting ability of interest rates can be improved over the medium term.

The current model used in this analysis could be improved by adjusting for the zero-lower-bound, and adapting the yield curve data to provide a better fit to the very short-end of the curve (i.e. by incorporating OIS rates and more short-term yield data).

[21] Estimates from the ACM model are available at a daily frequency from the Federal Reserve Bank of New York website and the Bloomberg terminal, see footnote 8.

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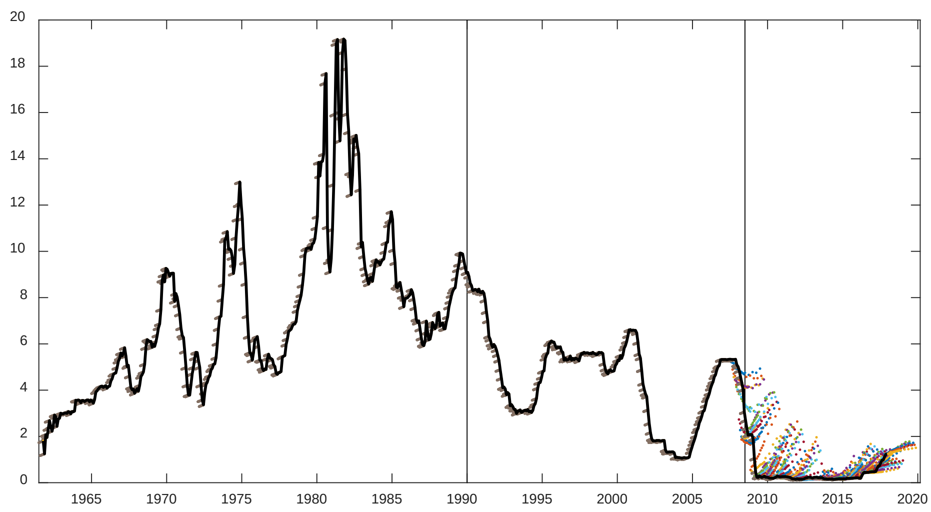
Appendix

How do forecasts from OIS rates compare to that of GSW zero-coupon rates?

Over the period where OIS forward rates are available, the OIS forward rates and GSW zero-coupon forward rates co-move strongly (figure A.3 shows similar forecast errors). This suggests that the use of GSW zero-coupon rates, rather than OIS rates, has not been a factor driving the results. The use of OIS forwards does produce better forecasts over the six month horizon in this sample period. This is likely due to the poor fit of GSW zero-coupon rates at the very short-end of the yield curve.[22]

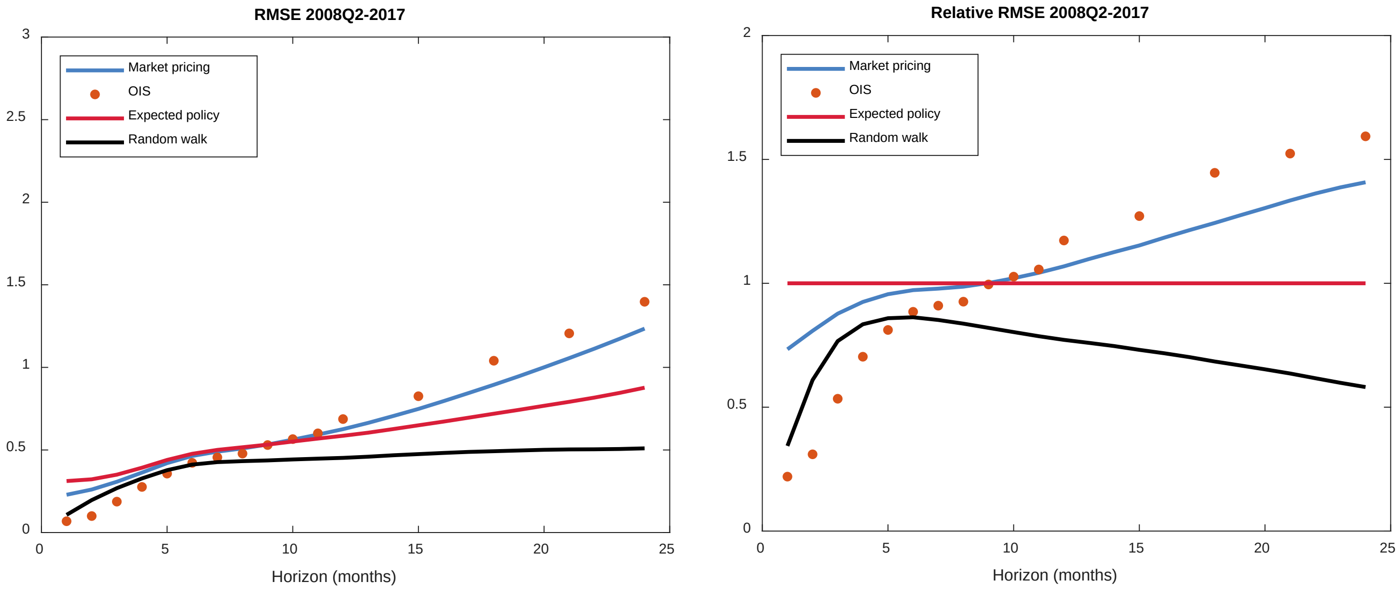
Federal Fund futures rates have not been used due to the lack of, or concern over the illiquidity of, longer-term (i.e. 2-year) forward contracts. However, evidence from Piazzesi and Swanson (2008) suggests a positive risk premium in federal funds futures over the 1990-2006 sample period, consistent with the results of this paper.

Figure A.1: Federal funds rate and OIS forwards



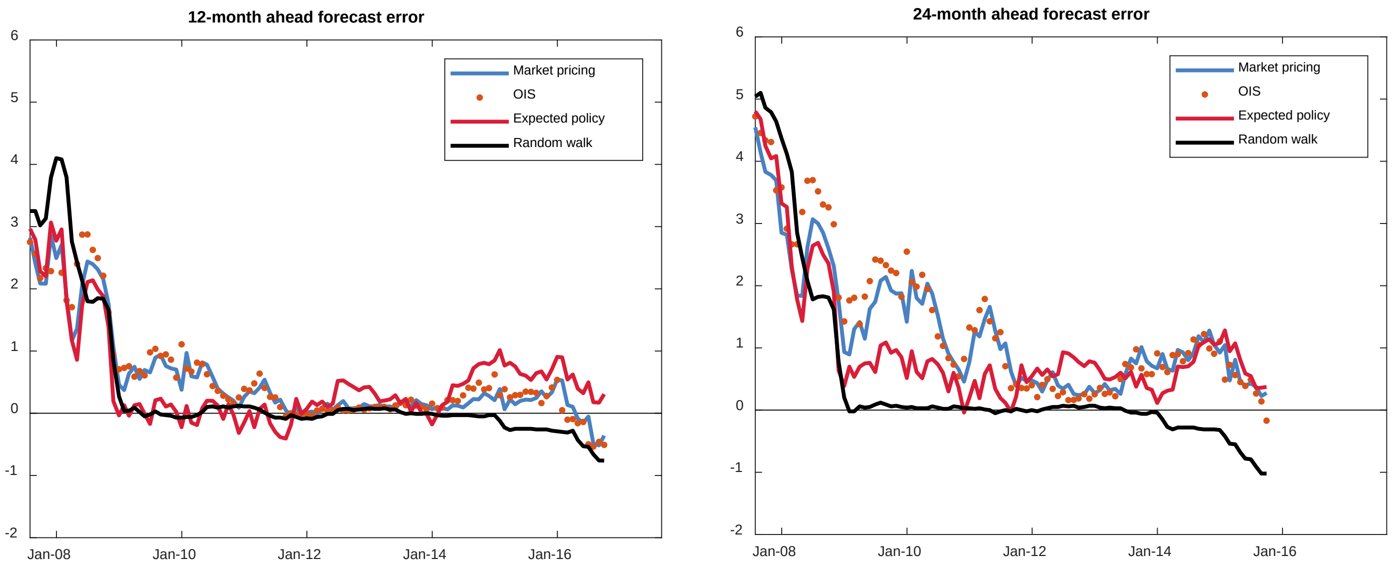
[22] The GSW zero-coupon curve is derived from US Treasury bonds are notes from 3-months of maturity to 30 years. Treasury bills are not included over segmented market concerns. For further information see Gürkaynak et al (2007).

Figure A.2: RMSE and relative RMSE, including OIS forwards



Note: OIS refers to 1-month OIS forward rates. The note on figure 3 describes the other measures.

Figure A.3: Forecast errors



How can this model provide better identification of expectation shocks?

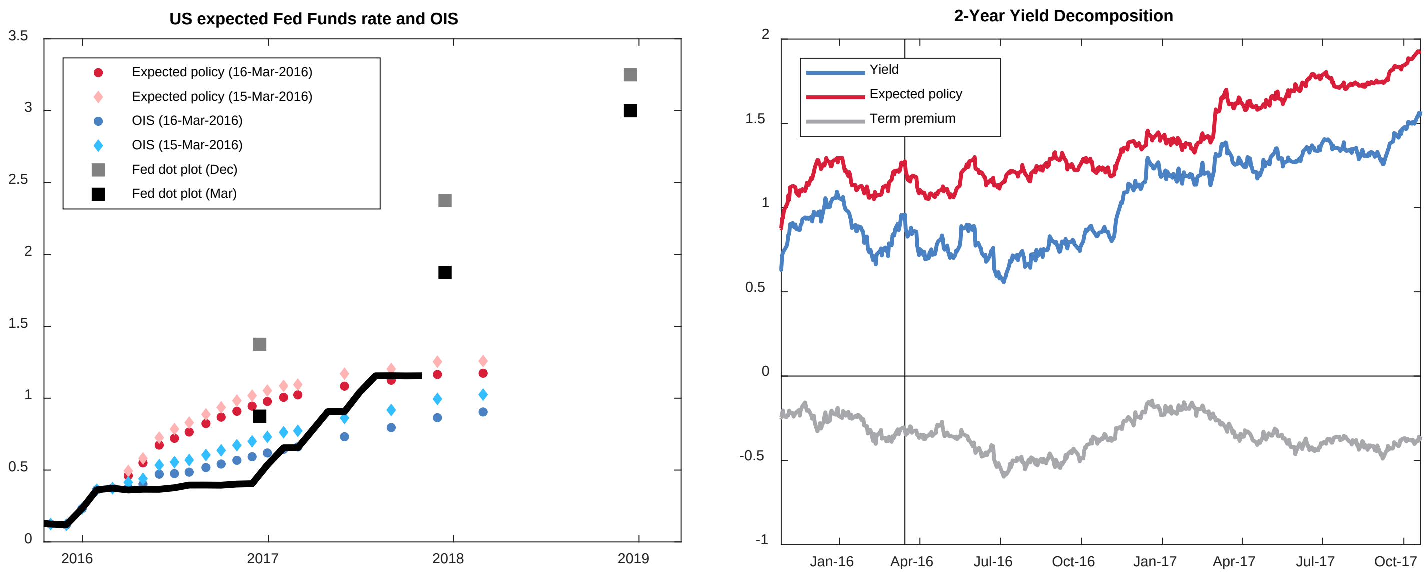
On March 15, 2016, the median dot plot from the FOMC moved from four rate increases in 2016 to two rate increases (grey dots to black dots, figure A.4). OIS market pricing already indicated less than two rate increases in 2016 (light blue diamonds). However, there was a dovish market reaction to the announcement – the US dollar index fell 1 percent on the day and market rates fell.

Even as the FOMC dot plots moved towards market pricing, market pricing moved lower. Essentially, there was a persistent wedge (a negative term premium, grey line) between market pricing and expectations through most of 2016.

This analysis suggests that the information from the March 2016 FOMC meeting was an expectations shock for market participants. Expectations for the path of future interest rates were higher than market pricing indicated (red dots), given a negative term premium.

Figure A.4 also shows that movements in the term premium were important drivers of short-term interest rates following the Brexit vote (23 June 2016) and the US election (8 November 2016), consistent with Priebsch (2017).

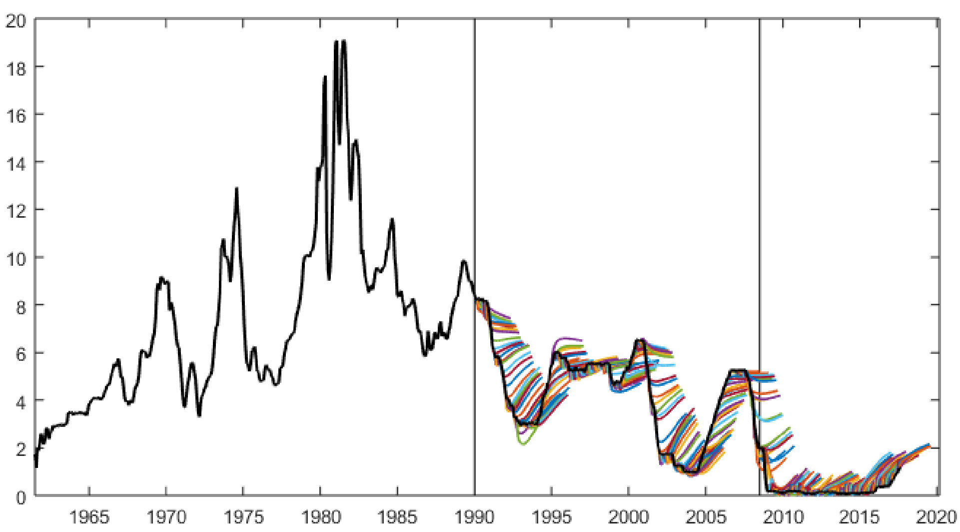
Figure A.4: March 2016 expectations shock



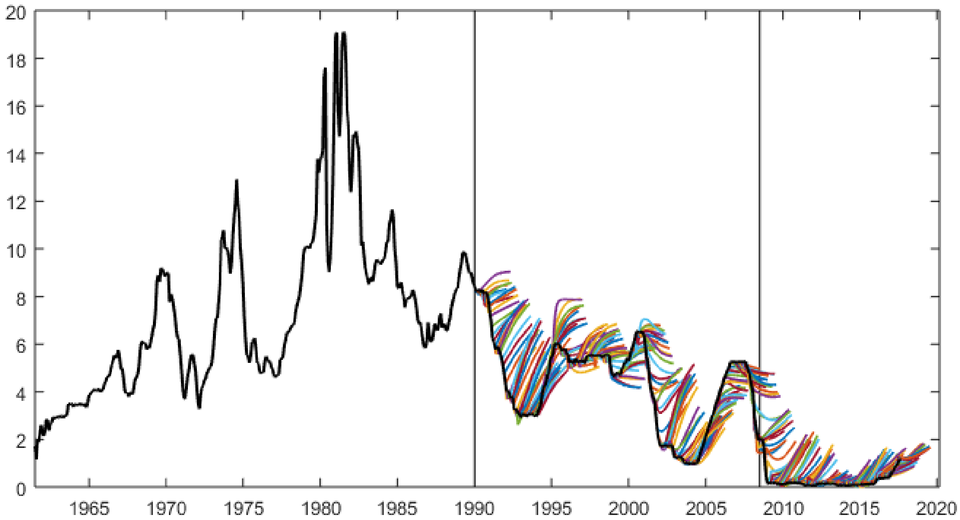
Data Appendix

Figure A.5: Federal funds rate and forecasts

A.5.1 Federal funds rate and expected policy forwards



A.5.2 Federal funds rate and zero-coupon forwards



A.5.3 Federal funds rate and random walk

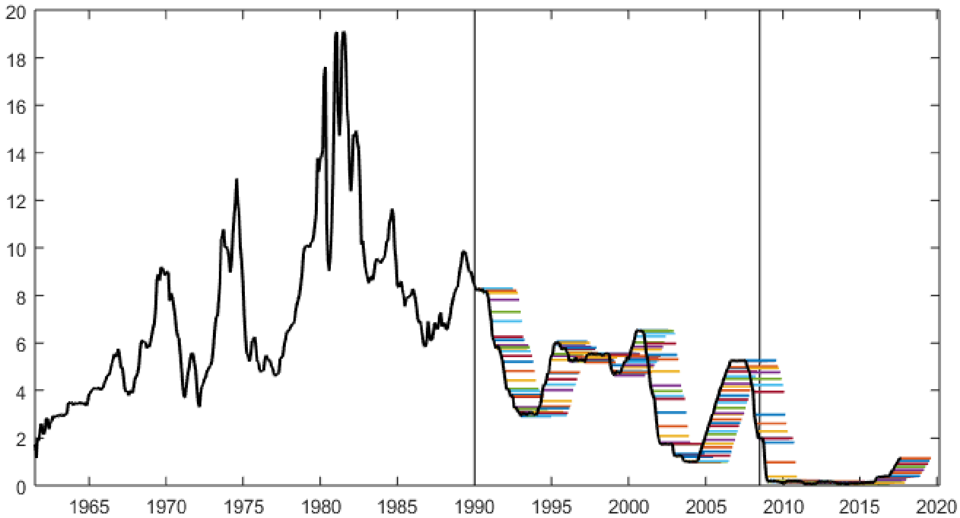


Figure A.6: Forecast errors

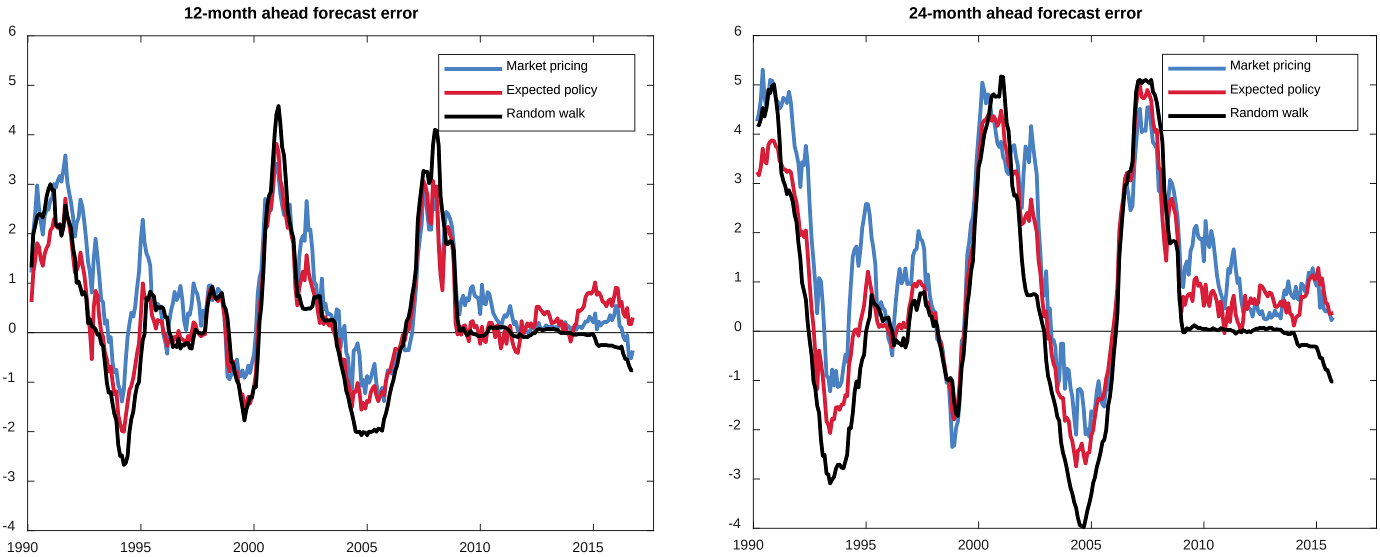
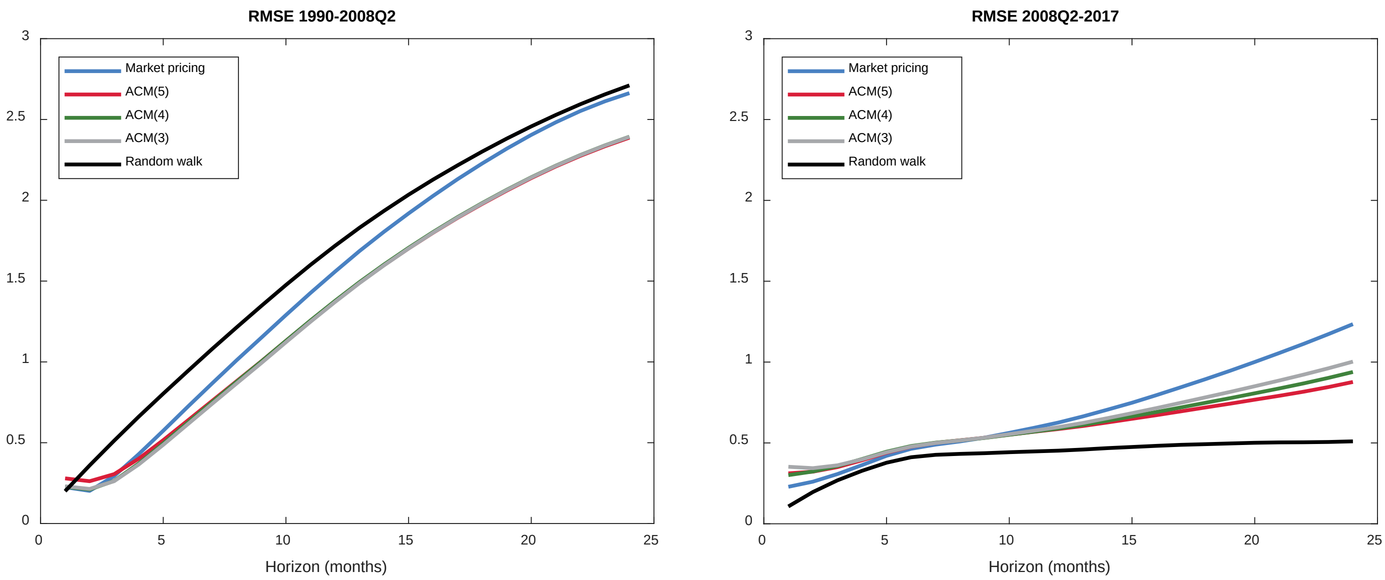


Figure A.7: Root mean squared errors, with varying ACM factors



Note: The results are similar across the different factors tested; the 5-factor model (ACM(5)) has the lowest RMSE across all horizons in the ZLB period, but has a slightly worse fit to the short-end of the curve in the 1990-2008Q2 period.

Figure A.8: Real-time estimate of the 2-year expected policy component