The Market-Perceived Natural Rate of Interest

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Draft paper: 25th April 2026

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Abstract

The natural rate of interest (r*) plays a central role in monetary policy, yet existing evidence focuses mainly on model-based or central-bank estimates, leaving market assessments largely unexplored. This paper provides a systematic attempt to extract the natural rate of interest embedded in financial-market survey forecasts, using vintage U.S. data since the late 1990s. We document a marked secular decline in the rate inferred from market expectations and identify persistent episodes of misalignment between market views and central-bank benchmarks. We further show that macroeconomic shocks and forecast errors significantly shape revisions in perceived equilibrium real interest rates over time.

Keywords: survey forecasts, natural rate of interest, monetary policy

JEL classification: C32, E43, E47, E52

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1 Introduction

The conduct of monetary policy in low-slack environments hinges critically on assessments of the natural rate of interest (r* or r-star), the real equilibrium interest rate consistent with stable inflation and output at potential. Although precise definitions may vary, this ideal has been a key objective and a central reference point for the conduct and evaluation of monetary policy. Years of below-target inflation, particularly in the United States, followed by recent inflation surges that now show signs of receding, has heightened interest in this topic of late (see Figure 1).[1]

For the most part, the existing literature has treated the natural rate of interest as a structural object, reflecting the long-run balance between the supply and demand for savings. This conception of r-star features heavily across a wide range of models used to estimate its historical variation. Regardless of the theoretical framework, however, there is a consensus that the equilibrium interest rate has declined across much of the advanced world. For instance, Laubach and Williams (2003) and Holston et al. (2017) design a semi-structural model to extract measures of the natural rate from observed data and find that r-star has fallen by around 450 basis point since the 1960's in the United States. The authors attribute this decline to secular forces, such as changes in the trend growth rate of potential output and shifts in saving and investment preferences.

The historical evolution of the natural rate is commonly associated with several long-run phenomena, such as an ageing population (Carvalho et al., 2016; Eggertsson et al., 2019; Gagnon et al., 2016), declining productivity (Rachel and Smith, 2017), an increasing scarcity of safe assets (Caballero and Farhi, 2018; Del Negro et al., 2017), and shifts in fiscal and institutional arrangements (Rachel and Summers, 2019). These forces have placed persistent downward pressure on a variable that, for many years, was approximated as constant. Given its latent nature, the equilibrium real interest rate, while theoretically central to monetary policy and market stability, is subject to considerable uncertainty. Consequently, both policymakers and private agents are likely operating with imperfect and heterogeneous beliefs regarding its level. Therefore, just as the FOMC publishes its median projections of the natural rate of interest, market participants are also likely to have a range within which they believe the natural rate lies.

[1] 26-week moving averages of news stories from a wide range of sources in Bloomberg's News Trend (NT) function, indicate a steady rise in mentions of the 'natural rate' of interest before a sharp decline during the coronavirus pandemic. Stories mentioning r-star rise and fall once again around the inflation surges in the United States.

Beyond the uncertainty regarding the level of r-star, several studies have developed methods to estimate its evolution using either structural or time-series techniques. Estimates produced by the New York Federal Reserve are perhaps the most widely cited and routinely used by analysts to assess whether the stance of policy is accommodative or restrictive. When the policy rate exceeds r*, monetary policy is considered contractionary. Conversely, when the policy rate falls below r*, policy is considered accommodative. More importantly, however, is that the natural rate itself is a ‘known unknown’, which depends on expectations of future inflation and output rather than on historical outcomes, rendering it inherently forward-looking. In this regard, r* reflects judgments about the evolving state of the economy rather than a strictly fixed benchmark.

It is therefore notable that the existing literature has devoted comparatively less attention to financial market perceptions of r*. After all, a credible central bank uses the level of the policy rate to signal the stance of monetary policy via implied changes in the natural rate. Yet, financial markets form their own interpretations of the central bank’s stance of monetary policy via the bond market.[2] Accordingly, one should be able to estimate implied financial market perceptions of the natural rate of interest. Indeed, comparisons with estimates of r-star sourced from central banks would then provide an indication of the extent to which policy makers and financial markets see eye-to-eye about the current stance of monetary policy or whether any differences are within the range of uncertainty associated with these estimates. To the best of our knowledge, this paper is the first to provide model-based estimates of the natural rate as perceived by financial markets. That being said, some studies have reported r-star projections by taking Treasury yields and subtracting estimates of expected inflation (Laubach and Williams, 2016).

The availability of survey-based vintage data, as well as the central role played by the Federal Reserve (Fed) in influencing the stance of monetary policy worldwide, are at least two reasons to estimate the perceived levels of r-star in the United States. Nevertheless, our methodological approach can easily be extended to estimating the natural interest rate for other economies assuming a certain degree of theoretical structure. In this regard, our analysis is primarily conducted within a New Keynesian framework. This approach not only allows for greater comparability with existing and widely cited estimates of the natural rate of interest, but also imposes some discipline in distinguishing market perspectives from the Fed’s views on the degree of policy tightness. In doing

[2] Similarly, professional forecasters provide independent forecasts of inflation that are likely informed by the inflation target, in addition to other factors such as the history of inflation and their own assessment of the likely evolution of the stance of monetary policy. These forecasts may also impact inflation expectations formed in bond markets.

so, we provide a highly integrable framework for analyzing private sector expectations about the future state of monetary policy, and, by extension, wider macroeconomic stability.

Briefly, our estimates suggest that the financial market-perceived natural rate follows the same downward trend seen in many other published estimates of r-star. More significantly, we identify periods when markets persistently over- or underestimate central bank estimates of the natural rate. The former defines the period prior to the Great Financial Crisis (GFC) of 2008-9, while the latter is a feature of the post GFC sample. Using local projections and VAR techniques, we also examine the impulse responses between the natural rate and market fundamentals; our findings suggest that inflation, output, and policy rate shocks positively impact the natural rate. We also find, via forecast error variance decompositions, that the history of inflation and the federal funds rate accounts for most of the variation in r-star, with increasing persistence over longer horizons. Moreover, historical decompositions reveal considerable variation over time in how these macro-fundamentals explain movements in the natural rate, which is revealing of the changing focus of markets in their collective thinking about why equilibrium rates change over time.

Finally, we examine the impact of forecast errors on financial markets and find that such shocks can influence perceptions of the stance of monetary policy, the dynamics of the yield curve, and financial stability. We reach these conclusions by considering how the addition of key variables the literature has found is reliably linked to financial sector stability and performance, such as the term spread, the price-earnings ratio, or the credit-to-GDP gap, interact with the perceived natural rate. Although our main conclusions are unaffected, the inclusion of financial sector effects upon r-star amplifies our findings based on the standard model used to estimate natural rates. By recovering a market-based measure of the equilibrium real interest rate within a semi-structural framework, this paper contributes to the literature on monetary policy, expectations, and asset pricing. Our findings suggest that misalignments between the market's and the central bank's views of r* are not merely reducible to measurement noise, but may reflect a systematic feature of the monetary transmission mechanism, with significant implications for policy communication and financial stability.

The rest of this paper is organized as follows. Section 2 briefly reviews the extant literature, which has largely overlooked market perceptions of the natural rate. Section 3 outlines the model framework, implementation, and specification used to estimate the market-perceived natural rate of interest. Section 4 discusses particulars concerning the survey forecast data used in our estimation. Section 5 presents and discusses the main findings of our analysis. Finally, Section 6 concludes.

2 Market Perceptions

Existing research on perceptions and monetary policy has largely concerned market expectations about the future of monetary policy and the implications of incomplete information in its transmission (see for instance Blinder et al., 2008; Eusepi and Preston, 2010; Taylor and Williams, 2010; Cogley et al., 2015). More recently, the literature has focused on policy rules, to estimate market-perceived reaction coefficients. For instance, Hamilton et al. (2011) estimate a "market-perceived policy rule" using macroeconomic news - defined as the difference between the data release value and the value expected by the market prior to its release. The authors identify important trends in the perceived parameters of the rule, namely a reduction in the response to output and a growing response to inflation over the long-run. Subsequent work has incorporated forecast data, both survey and individual forecasts, to estimate constant parameter monetary policy rules (see Carvalho and Nechio, 2014; Andrade et al., 2016; Kim and Pruitt, 2017; Jia et al., 2023).

In more recent work, Bauer et al. (2024) conduct a similar exercise using panel data on market forecasts within a time-varying framework. The authors find substantial variation in the perceived time-varying coefficients associated with the output gap and inflation. Perhaps more importantly, this study suggests that market perceptions about monetary policy respond to high-frequency surprises around FOMC announcements. Finally, the authors prove that shifting market perceptions concerning monetary policy have implications for fundamental asset prices and thus, by extension, the real economy - that is contingent on the magnitude of the perceived responsiveness of the Federal Reserve given by the estimated parameters of the monetary policy rule.

Perhaps more relevant to this study, Rungcharoenkitkul and Winkler (2022) implement a canonical new Keynesian model with incomplete information to identify a feedback loop between the central bank and the private sector, in which each underestimates the impact of their decisions regarding the other's understanding of r-star. The authors suggest that such recursion could potentially drive variation in perceptions of the natural rate of interest away from market fundamentals and may explain much of its decline post Great Recession. Finally, Laubach and Williams (2016) analyse the trend in real short-term forward rates constructed from yields on longer-term securities using a range of univariate statistical filters. In doing so, the authors parenthetically measure "market participants' perceptions of the natural rate", so as to demonstrate the limitations of term premia within forward rates and univariate approaches to estimating r-star.

This analysis is less concerned with such thoroughly treated aspects of the existing literature, particularly studies that are largely centered around the policy-maker's perspective. Instead, we focus our analysis primarily on market perceptions of the natural rate of interest, which are equally as important to the transmission of monetary policy. In doing so, we complement the existing body of literature with an alternative approach to measuring the market's sentiment toward monetary policy and the long-run equilibrium real interest rate.

3 The Model

3.1 Framework

This paper adapts the Holston et al. (2017) framework to estimate implied forecasts of the natural rate $E_t r^*_{t+h}$ or $r^*_{t+h|t}$, where subscript $t+h$ represents the horizon of the forecast at t; we use this notation interchangeably. Given our focus is on the market-perceived natural rate, we preserve the model structure but use survey forecast data for each variable. In particular, we outline the system:

$$\tilde{y}_{t+h|t} = \hat{\alpha}_y(L)\tilde{y}_{t+h|t} + \hat{\alpha}_r(L)\tilde{r}_{t+h|t} + \varepsilon_{\tilde{y},t} \tag{1}$$

$$\pi_{t+h|t} = \hat{\beta}_\pi(L)\pi_{t+h|t} + \hat{\beta}_y(L)\tilde{y}_{t+h|t} + \varepsilon_{\pi,t} \tag{2}$$

$$r^*_{t+h|t} = g_{t+h|t} + z_{t+h|t} \tag{3}$$

$$y^*_{t+h|t} = (L)y^*_{t+h|t} + (L)g_{t+h|t} + \varepsilon_{y*,t} \tag{4}$$

$$g_{t+h|t} = (L)g_{t+h|t} + \varepsilon_{g,t} \tag{5}$$

$$z_{t+h|t} = (L)z_{t+h|t} + \varepsilon_{z,t} \tag{6}$$

where (1)-(2) are the measurement equations, which are reduced forms of the Investment-Savings (IS) curve and Phillips Curve (PC) that permit shocks to the forecast output gap $\tilde{y}_{t+h|t}$ and forecast inflation $\pi_{t+h|t}$; (3) is the law of motion for the perceived natural rate $r^*_{t+h|t}$ that is a function of the forecast trend growth rate $g_{t+h|t}$; and (4)-(6) are transition equations of the state-space model.[3]

[3] The law of motion follows directly from the Ramsey growth model, contingent on representative households with a CES utility function and a constant relative risk aversion. In steady state, r-star is a function of the growth rate of per capita consumption and the rate of time preference. We assume forecasts of the natural rate are driven by similar forces.

3.2 Implementation

The linearity of our unobserved state vector allows us to estimate the perceived or forecast natural rate of interest using the Kalman filter. As market forecasts of the real growth rate of output and the interest rate are equally, if not even more likely, to be influenced by highly persistent shifts as their realised values, maximum likelihood estimation of the model may potentially return estimates of the standard deviations of stochastic innovations that are biased towards zero. In this regard, there are still strong reasons to resolve this specific 'pile-up' problem (see Stock, 1994) outlined in the original framework by Holston et al. (2017). We therefore follow the authors and implement the median unbiased estimator to derive estimates of ratios $\lambda_g = \sigma_g/\sigma_{y*}$ and $\lambda_z = \phi_r\sigma_z/\sigma_{\tilde{y}}$ that are sequentially imposed on the model parameters (Stock and Watson, 1998).

This multi-stage maximum likelihood estimation procedure follows from Holston et al. (2017) (see Appendix A for the complete system). In particular, forecast potential output is first estimated barring the forecast real rate gap and assuming a constant forecast trend growth rate. The median unbiased estimate for the ratio between standard deviations of innovations for forecast output and its trend growth rate is then derived and imposed as a restriction in the second stage of the model that includes the real interest rate gap. Finally, the ratio for the component unrelated to the forecast trend growth rate is analogously imposed in the third stage to estimate the remaining parameters.

3.3 Specification

Our specification of the measurement equations of the state-space model is analogous in that we impose an identical lag structure in the dynamic Investment Savings (IS) equation and Phillips Curve (PC). This decision is purely to facilitate direct comparability between the market-forecast natural rate and r-star. In particular, the measurement equations are specified as follows:

$$\tilde{y}_{t+1|t} = \sum_{i=0}^{1}\sum_{j=1}^{2} \hat{\alpha}_{y,j}\tilde{y}_{t-i|t-j} + \frac{\hat{\alpha}_r}{2}\sum_{i=0}^{1}\sum_{j=1}^{2} \tilde{r}_{t-i|t-j} + \varepsilon_{\tilde{y},t} \tag{7}$$

$$\pi_{t+1|t} = \hat{\beta}_\pi \pi_{t|t-1} + \frac{1-\hat{\beta}_\pi}{3}\sum_{i=1}^{3}\sum_{j=2}^{4} \pi_{t-i|t-j} + \hat{\beta}_y \tilde{y}_{t|t-1} + \varepsilon_{\pi,t} \tag{8}$$

where we incorporate two lags of the forecast output gap within the dynamic Investment Savings equation (7), in addition to the average forecast real interest rate gap between the first and second quarter. Within the Phillips Curve (8), we include the first and the average of the second-to-fourth lag of forecast inflation, in addition to the first lag of the forecast output gap. The law of motion for the forecast natural rate (9) and transition equations (10)-(12) are specified analogously as follows:

$$r^*_{t+1|t} = g_{t+1|t} + z_{t+1|t} \tag{9}$$

$$y^*_{t+1|t} = y^*_{t|t-1} + g_{t|t-1} + \varepsilon_{y*,t} \tag{10}$$

$$g_{t+1|t} = g_{t|t-1} + \varepsilon_{g,t} \tag{11}$$

$$z_{t+1|t} = z_{t|t-1} + \varepsilon_{z,t} \tag{12}$$

where, consistent with Holston et al. (2017), equation (10) defines the forecast of potential output as a random walk with drift g_t, which itself is further defined as a random walk in equation (11), in addition to the unobserved component of the forecast natural rate of interest in equation (12).[4]

4 Survey Data

To estimate the market perceived natural rate, we collect survey-based forecast data on the nominal short-term (three-month) interest rate, real gross domestic product, and consumer price inflation. We employ two well-established resources, namely Consensus Forecasts (CF), published by Consensus Economics, and the Survey of Professional Forecasters (SPF), published by the Federal Reserve Bank of Philadelphia. Our chosen sample ranges from 1982:1-2019:4 for the SPF and from 1989:4-2019:4 for the CF. We splice these forecasts together from 1989:4 by taking the unweighted mean between them for each input, which we then backdate using historical SPF data. In doing so, we are able to incorporate a much larger set of information from both surveys that reflects the views of forecasters regarding key terms across both measurement equations.

[4] We assume that the error terms across these transition equations of the states-space system are contemporaneously uncorrelated and normally distributed as follows: $\varepsilon_{y*,t} \sim (\mathrm{N}, \sigma^2_{y*})$, $\varepsilon_{g,t} \sim (\mathrm{N}, \sigma^2_g)$, $\varepsilon_{z,t} \sim (\mathrm{N}, \sigma^2_z)$. We present the complete specification of the model at each stage of the maximum likelihood estimation procedure in Appendix A.

The Consensus Forecasts and Survey of Professional Forecasters are recorded on a monthly and quarterly basis respectively. For each month or quarter, each forecaster provides their forecasts for horizons ranging from the current month or quarter to the one-year ahead month or quarter. To aggregate this data, we first smooth between horizons and average across months to yield quarterly one-year ahead forecasts in both surveys.[5] The primary motivation to leverage data across these surveys are the similarities between the underlying variables each panellist is requested to forecast. With regards to the interest rate, we focus our analysis on three-month rates, which are consistent across both CF and SPF forecasts. For inflation, we use forecasts of consumer price index inflation, which are also consistent between surveys. Finally, we exploit forecasts on the real growth rate of output to generate a series for real gross domestic product that is initialized with current levels of real output. To generate our forecasts of the output gap, we calculate the deviation in forecasts of real output from their trend using the Hodrick-Prescott (HP) filter.

Despite the slight variation in panellists, these views appear to be largely consistent. Key summary statistics for both surveys are presented in Table 1. The similarities between CF and SPF data reflect a general agreement between forecasters concerning macroeconomic fundamentals that are employed as inputs to measure implicit market-based beliefs about the future real equilibrium interest rate. Forecasted CPI inflation averages approximately 2.4% in Consensus Forecasts relative to 3.0% in Survey of Professional Forecasters data. Forecasted interest rates are higher on average in SPF data at roughly 4.1% relative to CF data at 3.3%, whereas the average forecasts of log real GDP are perhaps the closest between surveys, equal to 8.9% in SPF data and 9.0%. Standard deviations of 3-month interest rates reflect sizeable variation across both surveys in views concerning future short-term nominal interest rates within the United States.

We choose to restrict our sample to the period prior to the coronavirus (COVID-19) pandemic and the subsequent surges in inflation driven by supply and demand pressures within the United States. We make this decision due to the significant uncertainty in estimates of the natural rate of interest following the Great Lockdown (refer to Baker et al. 2023; Benigno et al. 2024) and issues associated with the estimation of the Holston et al. (2017) model during this period. In particular, the pandemic was an extreme-tailed phenomenon generating sharp variations in growth, which

[5] In particular, we use an ad-hoc, albeit common smoothing technique. Given a monthly fixed event (FE) and fixed-year one-year ahead forecast of θ, the conversion to a fixed horizon (FH) is computed as: $\theta^{\text{FH}}_{\text{m,t}} = [(13-m)/12]\theta^{\text{FE}}_{\text{m,t}} + [(m-1)/12]\theta^{\text{FE}}_{\text{m,t+1}}$, where t marks the calendar year of the forecast, and m is the month in which it is released. We use the same method for smoothing quarterly observations, given by the conversion: $\theta^{\text{FH}}_{\text{q,t}} = [(5-q)/4]\theta^{\text{FE}}_{\text{q,t}} + [(q-1)/4]\theta^{\text{FE}}_{\text{q,t+1}}$.

undermines the Kalman filter, in which stochastic innovations are assumed Gaussian in distribution. Furthermore, transitory shocks in the Phillips curve are assumed to be serially uncorrelated, which is also inconsistent with the sequence of restrictions imposed post pandemic.

Holston et al. (2023) adjust their framework along two dimensions to deal with these issues. To resolve the issue of extremities arising due to the pandemic, the authors introduce time-varying volatility in the stochastic innovations to each of the measurement equations during this period, which suppresses outliers in the maximum likelihood estimation of the natural rate of interest that may otherwise be distorted. As for potential serial correlation, the authors introduce a persistent, albeit transitory supply shock within the output gap to capture the impact of sequential lockdowns on economic activity within the measurement equations.

These issues related to the pandemic are just as relevant to forecast data. In fact, it is reasonable to suggest that issues of extreme outliers are even greater in future expectations, and that forecasts of output growth react more sharply to restrictions imposed in response to the pandemic. Whilst it is certainly possible to account for time-varying volatility during this period, it is not clear if such measures resolve the unprecedented pressures faced by the Kalman filter. Furthermore, controlling for sharp variation in forecast output due to the sequences of lockdowns would analogously require forecasts of the stringent measures imposed by government in response to the pandemic, which is simply unavailable for the period in question. For these reasons, and in light of our more general focus on market-perceptions of the natural rate, we omit this specific period altogether, in addition to the subsequent quarters in which restrictions are gradually eased across the United States.

5 Results

5.1 Parameter Estimates

We summarise the core parameter estimates of the model in Table 2. For comparison, we employ the same framework to estimate the natural rate of interest (r^*) using realised time series on real gross domestic product, consumer price inflation, and short-run (three-month) interest rates, which we source exclusively from the Federal Reserve Bank of St. Louis (FRED) database.[6] Parameter

[6] We re-estimate the state-space model using realised data rather than sourcing results directly from the authors due to our alternative sample size, which yields non-trivial, albeit marginal differences in our estimates of the natural rate of interest using the Kalman filter within the maximum likelihood procedure. In addition, we also employ the unadjusted model that does not account for the pandemic given this takes place immediately after the conclusion of our sample.

estimates from this model are presented alongside forecasts in Table 2. Median unbiased estimates of the signal-to-noise ratios λ_g and λ_z suggest substantial variation in forecasts of the trend growth rate of potential output, albeit relatively less variation in the unobserved component.

As it also transpires analogously within the existing literature, the forecast output gap seems to be well identified ($\hat{\beta}_y = 0.432$), whereas the slope coefficient of the IS curve ($\hat{\alpha}_r = -0.030$) suggests it is considerably flat and far less identified. Finally, we note that inflation forecasts react substantially to variation in the forecasted output gap, as suggested by $\hat{\beta}_y$, which itself is persistent as indicated by the cumulative magnitude of the coefficient $\hat{\alpha}_y$ associated with its lags. As regards to standard deviations, forecast inflation seems to be better explained by its own lag than estimates that are associated with realised inflation. However, the spread surrounding the market-perceived natural rate are clearly larger than estimates using realised data.

This greater uncertainty is reflected clearly in average standard errors of our estimates of the forecast natural rate. This is perhaps to be expected given the nature of forecasts and the volatility in expectations of the future time-path of output, inflation and interest rates. Such imprecision is a well known problem within the literature due to parameter and filter uncertainty, and our standard errors for the forecast natural rate are no exception. As there are no clear resolutions to this issue, we approach our estimates with caution and emphasise that this methodology is still able to reveal general trends in the market-perceived natural rate just as it does in the natural rate of interest.

5.2 Forecast Natural Rates

One-sided estimates of r-star and the perceived natural rate are presented in Figure 2. We choose to focus our analysis on the period following the emergence of an implicit inflation target around the mid-1990's, mainly due to the sharp divergence between these series prior (refer to Figure C.1). We believe that this is because market participants simply had fewer anchors to forecast the natural rate of interest over this period. In canonical New Keynesian models, r-star is the real interest rate associated with output at potential and inflation at target. In the absence of the latter, forecasts of the natural rate would be analogously guided only by expectations of the former. In this regard, the United States had been recovering from an unprecedented negative output gap throughout the 80's, which might explain why expectations were so high and why market forecasts persistently decline over this period. Such inflated expectations at the start of our sample are somewhat intuitive given that the effective federal funds rate peaks historically at roughly 1900 basis points during the initial quarter of 1981. The Federal Reserve implicitly pursues an inflation target of around 2 percentage points around 1996:3 (Shapiro and Wilson, 2019; Wells, 2024), which seems to coincide well with when forecasts converge to the approximate neighbourhood of r-star.

Our estimates of the expected equilibrium interest rate are also characterised by a larger degree of volatility relative to analogous estimates of r-star. This is unsurprising given future expectations of the underlying components are more sensitive to transitory pressures within the US economy. It is important to emphasize the nuance in our interpretation of this series; given the use of survey forecast data, these estimates reflect what market-participants believe the natural rate will be in the future quarter. In this regard, we observe sharp declines in natural rate forecasts across both crises during the early and late 2000's. The Great Recession clearly separates itself as an unprecedented event, which is associated with sharp revisions in market expectations of the natural rate of interest. In particular, $E_t r^*_{t+h}$ falls by over approximately 500 basis points during this period.

Despite these transitory pressures, Figure 2 shows a strikingly similar long-run trend in market forecasts of the equilibrium real interest rate as found in estimates of the natural rate of interest (Holston et al., 2017). Such persistent pessimism regarding the future level of r-star is clearly in keeping with secular declines in the underlying equilibrium interest rate itself, caused by long-run shifts to a range of drivers such as productivity, demography, risk preferences, and public policy. These similarities suggest markets are adjusting their long-run expectations of the natural rate of interest and, by extension, the scope of monetary policy in the future.

These trends are largely consistent with alternative survey based measures of the natural rate of interest. For instance, Bauer et al. (2024) highlight a similar decline using Blue Chip Financial Forecast, albeit within the context of the Taylor rule and by extension market perceived fluctuations in the policy rate. Beningo et al. (2024) also identify declines in the perceived natural rate, defined as the difference between the long-run expected policy rate and expected level of inflation, using median responses in the Federal Reserve Bank of New York's Survey of Primary Dealers (SPD). These findings also suggest that markets have persistently reduced their expectations of the natural rate of interest, which seems to corroborate established trends in r-star during this period.

5.3 Forward Natural Rates

To investigate how these multivariate estimates compare to alternative univariate measures of the forecast natural rate, we refer to forward rates associated with yields on longer-term Treasury securities sourced from the Federal Reserve of St. Louis (FRED) database. In particular, we compute the difference between the seven-year-ahead zero-coupon one-year yield and core inflation rate.[7] To decompose the trend in these rates, we use a range of common statistical techniques, namely the band-pass (BP) filter, the Hodrick-Prescott (HP) filter, and the Stock and Watson (2007) unobserved components with stochastic volatility (UCSV) model.

Our findings are presented in Figure 3. Alternative univariate measures of the expected equilibrium interest rate using forward rates clearly exhibit similar long-run trends to our estimates using a multivariate approach. These perceptions of the natural rate of interest fall persistently across our sample and also suggest that markets have become increasingly negative in their forecasts. Whilst forward rates reveal market participants' views about how interest rates might prevail in the future, term premia contained within them are often a significant source of variation that undermine their reliability as a measure of expectations of future rates (Kim and Wright, 2005).

In addition, we note that our estimates are more volatile and far more sensitive to recessionary gaps than those derived using univariate techniques. This is primarily because we employ a semi-structural model that conceives of r-star as a medium- to long-run frequency concept. In contrast, univariate time-series techniques seek to extract the long-run frequency component of the forward real rate without structural imposition. This would generally perform well at times when inflation and economic activity are relatively stable, but are more likely to be unreliable during periods when they are volatile. These techniques therefore struggle to parse transitory pressures in forward rates and simply ascribe any such variation to the trend. Notwithstanding, univariate measures still yield some indication of market views regarding long-run rates, which largely corroborate our findings.

5.4 Market Misalignments

A natural extension of this analysis is to determine the extent to which market participants misperceive the equilibrium interest rate. To achieve this, we simply compute the difference between the forecasted equilibrium interest rate and r-star. This information is particularly useful to monetary policymakers, given that beliefs about the future evolution of r-star likely have contemporaneous consequences for the transmission of monetary policy. The ex-post nature of this exercise therefore makes it an important tool for policy evaluation and future optimal policy rate determination.

[7] Forward rates are computed using seven year ahead zero coupon one year yield using fitted yields on eight and one year bonds provided by Kim and Wright (2005). These are constructed as follows: $((1+a/100)^8/(1+b/100)^1)^{1/7}-1$. We then average on a quarterly basis and subtract from the core inflation rate to derive a series for the real forward rate.

We plot and shade the difference between these two series in Figure 4. Our findings document a rich history of episodes during which market participants either over-predict or under-predict the equilibrium real interest rate. In particular, we observe sustained periods in which forecasters clearly overestimated the natural rate of interest from the start of our sample to the 2001 recession. This overestimation was also the case in the period prior to the 2008 recession, where the market-perceived natural rate of interest is persistently greater than r-star itself. In other words, markets expected r-star to be higher than it was for a number of quarters prior to these crises. We also note that professional forecasters underestimated the natural rate of interest for a sustained number of quarters immediately following these particular crises. This was the case after the dot-com bubble just as it was the case after the Great Recession in the United States.

Given the procyclical nature of the equilibrium interest rate, as shown in Figure 2, these results suggest that market participants are overly optimistic about the future state of the economy prior to crises, and overly pessimistic thereafter. We note, however, the muted reduction in expectations after the dot-com bubble relative to the financial crises, likely due to the limited impact on potential output. In contrast, the Great Recession clearly distinguishes itself as the most significant shock to market forecasts concerning the natural rate of interest over the entire sample, which declines by around 450 basis points below the equilibrium real interest rate. Forecasters soon close this sizeable gap as the economy gradually recovers over the subsequent quarters, albeit there is clear persistence in this pessimism across the remainder of the sample.

5.5 What Drives the Market-Perceived Natural Rate?

Market forecasts of the natural rate of interest are likely driven by a wide range of factors. Beyond the equilibrium interest rate, it is reasonable to suggest that market participants base their estimation of the future evolution of r-star on changes in core fundamentals. In this regard, we investigate how the expected equilibrium interest rate responds to shifts in consumer price inflation, real gross domestic product, short-term nominal interest rates, and the natural rate of interest.

To proceed with our analysis, we use local-projection methods, a structural vector autoregression model, and a vector error correction model to estimate the response of the forecast natural rate to shocks in these variables. We adopt this diverse approach to check the robustness of our results, and due to recent discussions concerning some of the nuanced similarities and differences between these models (e.g. Plagborg-Møller and Wolf, 2021; Li et al. 2024), particularly regarding impulse response identification. Our choice of methods is also informed by the mixed empirical evidence of stationarity across our series, as presented in Table 3. Furthermore, Johansen tests for cointegration identify the existence of a long-run relationship between the market-perceived natural rate and macro-fundamentals that largely conforms to theory, which we unpack further in this section.

For the local projections (LP), we follow the standard approach of Jordà (2005), with optimally chosen lag lengths using the Akaike Information Criteria (AIC). For the vector autoregressions (VAR), we identify shocks using a Cholesky decomposition with the order: interest rate, inflation, output, natural rate, and expected natural rate. The justification for this order is somewhat intuitive and assumes that forecasts of r-star are driven by all variables in the model by descending exogeneity. Finally, the VECM includes two cointegrating vectors as identified by standard Johansen tests, and is estimated with two lags based on the AIC.

Estimates of the impulse response function (IRF) for each model are presented in Figures 5-7. Our results from Local-Projections show that unit shocks to output create a positive response in forecasts of the natural rate, albeit with sizeable uncertainty. This corroborates our earlier procyclical findings, where we observed increases in the expected natural rate during periods of recovery. We observe a slow decay in the response to output suggesting a high level of persistence. Shocks to consumer price inflation initially generate a positive response in forecasts of the natural rate of interest, although this response declines after two quarters, turning negative after four quarters. This suggests that market participants base their views on the future path of equilibrium rates on the reaction of monetary policymakers to an inflationary shock and the associated lagged effects. As regards shocks in estimates of the equilibrium interest rate itself, we generally observe a positive response in forecasts of r-star, which seems to exhibit some persistence over longer horizons, although these estimates do not appear to be significant. This implies that market participants revise their expectations of r-star in the same direction as changes in the underlying measure they are forecasting. As we shall see shortly, the foregoing results persist but their statistical significance becomes clearer when alternative models and estimation techniques are employed.

In all but magnitude, our estimates of the impulse response function in a vector autoregression setting are broadly similar to those estimated using local-projections. Note, however, that the response in forecast natural rates to shocks in price inflation either decays rapidly over the short-run in the SVAR model, or is positive and remains significant over longer horizons in the VECM. In addition, the response to shocks in output appear slightly more persistent in the VECM. Between all models, market participants clearly adjust their future expectations of the natural rate of interest in response to shocks to these fundamentals somewhere between the second and fourth quarter, evidenced by shifts in responses during this period.

To unpack these results further, we present the associated error variance decompositions arising from our SVAR model and VECM in Figures 8-9. As regards the former, our results suggest that shocks to the short-term interest rate explain approximately 40% of the variation in forecast natural rates, which is the largest share. Shocks to inflation and output each account for roughly 20% of this variation, whereas the remainder is explained by shocks to the expected equilibrium interest rate itself. As regards the latter, our results suggest that shocks to inflation explain approximately 40% of the variation in forecast natural rates, which is the largest share. Shocks to the short-term interest rate account for roughly 30% of this variation, whereas shocks to output explain just below 10%, and shocks to the expected equilibrium interest rate itself explain around 20%. Surprisingly, shocks to the natural rate explain a negligible fraction of this variation in the forecast natural rate. In contrast, these findings suggest that certain macro fundamentals, such as inflation, interest rates, and output, collectively explain a large share of the variation in forecasts of r-star.

Finally, to investigate the individual contributions of these fundamentals across time, we compute the historical decomposition of the forecast natural rate arising from our SVAR model, which is presented in Figure 10. Our results suggest that inflation, interest rates, and output play a critical role in explaining the historical variation in forecast natural rates. Interest rates initially appear to be an important reference point for market participants, explaining the largest fraction of this variation prior to the Great Recession. Output and inflation, however, play a much more dominant role in explaining variation in forecasts of r-star during and immediately after the crisis. Clearly, sharp reductions in output during this period exert strong downward pressures on natural rate forecasts. While this pessimism about r-star ultimately subsides, interest rates play a far lesser role in driving market perceptions towards the end of our sample. Finally, forecasts themselves consistently play a small, albeit non-trivial, role in explaining variation in forecast natural rates over time.

5.6 The Contribution of Financial Markets

Variation in the natural rate of interest is thought to have significant implications for the financial sector (Kiley, 2015; Cukierman, 2016, Taylor and Wieland, 2016). Recent literature has focused on incorporating important financial pressures into estimates of the equilibrium real interest rate.

For instance, Akinci et al. (2023) propose the concept of the financial stability interest rate, which reflects the real interest rate consistent with financial, rather than macro stability. Using a macro-financial model with occasionally binding credit constraints, the authors show how real rates affect financial conditions asymmetrically over time. In the short run, interest rate hikes can trigger balance sheet stress via valuation effects, whilst in the medium run, persistently low rates encourage risk-taking and asset reallocation, increasing system vulnerability. These findings imply that monetary policy cannot rely solely on r-star, as the financial stability real rate can embeds the market's capacity to absorb shocks. This introduces an important trade-off wherein the real rate that stabilises inflation and output may come at the cost of greater financial fragility.

Reis (2022) argues that conventional measures of r-star relying on long-term government bond yields offers an incomplete view of macro-financial conditions, overlooking the stable or rising return on private capital. Using a cross-country approach, the author shows that whilst government bond yields have declined over the past two decades (suggesting a falling natural rate of interest), returns on private investment have remained constant if not marginally increasing. This divergence implies that financial markets, particularly private investment, operate under an alternative natural rate - one that is not captured by public bond yields. Reis (2022) identifies both financial frictions and capital misallocation as key factors driving this wedge and warns that relying on bond-based r-star may lead to misleading policy conclusions, particularly regarding investment behaviour.

In related work, Caballero et al. (2025) propose a financial conditions natural analogue to the natural rate of interest, arguing that the stance of monetary policy is more accurately reflected by a broader set of financial variables, than by the policy rate alone. The authors develop a measure of the natural level of financial conditions that would be consistent with output at potential and inflation at target. This rate is shown to be significantly more stable than traditional estimates of the natural rate, particularly during periods of financial stress such as the global financial crisis. Whilst the natural rate declines sharply in response to asset price movements, the natural level of financial conditions remains anchored to macroeconomic fundamentals, indicating that it may offer a more reliable signal for monetary policy. These estimates also closely track optimal policy benchmarks derived from counterfactual simulations, except during major crises.

Given that financial pressures have implications for the natural rate, it is reasonable to assume that variation in expectations of r-star also have meaningful consequences across financial markets. In particular, variation in expectations of the natural rate may influence how market participants interpret central bank decisions, shape yield curves, and affect equity valuations. In this regard, r-star is not merely an outcome of macro-financial forces but an input into the financial sector itself. Understanding this two-way interaction is therefore important to assessing the role of expectations in the transmission of monetary policy. In light of this, we investigate this relationship using local projection methods between our survey-based estimates of the expected equilibrium interest rate and measures of key financial indices across the bond and equity market.

We source quarterly data on the ten-year two-year treasury term spread from the Federal Reserve Bank of St. Louis (FRED), the price-to-earnings ratio from Shiller (2000), and the credit-to-GDP gap from the Bank for International Settlements (BIS).[8] In order to appreciate the general impact of variation in the forecast natural rate of interest, these variables are chosen for their wide coverage of the financial sector, and to also complement the medium- to long-term frequency of our semi-structural estimates. For instance, the price-to-earnings ratio we implement is the cyclically adjusted ratio of stock prices to inflation-adjusted (moving) average earnings, which captures future equity returns over more longer horizons than traditional price-earnings measures. We also choose to focus on the gap between the market-perceived natural rate of interest and r-star, in order to assess the response of financial markets to forecast errors.

To proceed, we use local projection methods to estimate the impulse responses for the system presented in Figure 11. It is important to note that innovations here can be understood as misalignment shocks where market expectations about r-star exceed the natural rate of interest itself. We define this as an overly optimistic belief concerning the future of the equilibrating real interest rate. Such innovations lead to a decline in the term spread (T10Y2Y), which remains negative for several quarters. This is consistent with markets overestimating the future path of short-term rates relative to long-term rates, resulting in a flattening of the yield curve that signals pessimism about future growth or an approaching downturn. This could be explained by misplaced fears of policy rate adjustments by monetary policymakers to maintain price and output stability.

With regards to the equity market, optimism concerning the equilibrium interest rate initially generates a negative response in the cyclically adjusted price-to-earnings ratio (CAPE). Over more longer horizons, we see an increasingly positive response in the ratio, which may suggest that once short-term fears of nominal policy rate adjustments subside, markets believe, consistent with the

[8] The price-to-earnings ratio and credit-to-GDP gap both play central roles in a wide range of modern macro-finance models within the existing literature, see, inter alia, Cochrane (2016), Jordà et al. (2017), and Gabaix et al. (2025).

classical Ramsey growth model, that a higher natural rate of interest is a sign of long-term growth in productivity, leading to overvaluation. The overall response of the credit-to-GDP gap to a shock of optimism is similar in this regard. Markets appear to deleverage in the short-run, albeit increase the level of credit over longer horizons, suggesting excessive credit growth and increased financial instability. Finally, our estimates also suggest that overly optimistic forecasts of the natural rate of interest can breed further optimism regarding r-star. Although this feedback subsides in the long-run, it may exacerbate the impact across financial markets, as participants act upon these residual beliefs over multiple quarters onwards from the initial shock.

These findings clearly demonstrate the impact that misalignments between forecasts of the natural rate and r-star have on financial markets. Our estimates using professional survey forecast data are therefore useful in determining whether financial market participants have been overly optimistic or pessimistic about r-star, and the influence this might have on the bond and equity markets within the financial sector. Policymakers must, therefore, also account for expectations of the equilibrium rate in order to avoid compromising financial stability and improve the transmission of monetary policy when responding to price and output instability in the real sector.

6 Conclusion

This paper presents new time-varying estimates of the forecast natural rate of interest using rich time series data of survey forecasts in the United States. We identify a range of important findings on the predictions of market participants about r-star. First, we detect substantial time variation in the expected natural rate, particularly during the Great Recession. Second, we identify a secular decline in natural rate forecasts across the historical sample, which suggests that forecasters have become increasingly pessimistic about the future equilibrating interest rate. Given that the natural rate of interest has also been in decline, it might be argued that markets are simply responding to trends in the long-run supply and demand for savings that have pressured r-star to unprecedented lows. Third, we document explicit periods when markets either persistently over- or under-predict the natural rate of interest. In particular, forecasters tend to be overly optimistic about the future state of the macroeconomy prior to recessions, evidenced by periods of overestimation preceding both the 2001 and 2008 crisis, and are overly pessimistic following them, evidenced by subsequent periods of underestimation of the natural rate of interest after each crisis.

Fourth, our analysis shows that innovations in market fundamentals, such as inflation, output, and interest rates, have a clear impact on market perceptions of the future natural rate of interest. Our variance decompositions show that shocks to inflation and short-term interest rates account for the largest share of variation in forecast natural rates. Furthermore, interest rates appear to play the dominant role in driving perceptions prior to the Great Recession, after which inflation and output become key reference points for market participants in guiding predictions about the natural rate of interest. Although shocks to the natural rate of interest generate a largely positive response in perceptions of r-star, our results seem to also suggest that they play a relatively negligible role in explaining the historical variation in natural rate forecasts.

Fifth, we show that expectations of r-star can play a significant role in shaping financial market outcomes. Using local projection techniques, we document that overly optimistic forecasts of the natural rate of interest can trigger systematic responses across financial indicators. In particular, we find that such forecast errors lead to a persistent decline in the term spread, a temporary drop followed by a longer-run rise in equity valuations, and short-run deleveraging followed by longer-term credit expansion. These results suggest that forecast misalignments influence perceptions of the stance of monetary policy, yield curve dynamics, and risks of financial instability. Moreover, we identify a feedback channel whereby optimistic forecasts of r-star generate further optimism in subsequent periods, possibly amplifying financial responses, and thus underscoring the importance of managing expectations in preserving macro-financial stability.

These conclusions have significant implications for the transmission of monetary policy and wider macroeconomic stability. In particular, they imply that the impact of monetary policy upon the market cannot be fully appreciated without also taking into consideration the perceptions that participants have about the future natural rate of interest. This also opens opportunities for further research, addressing issues such as how central bank communication and conduct influences market perceptions about future monetary policy, and optimal monetary policy design given shifting expectations about the natural rate. We leave such questions to future extensions of this work.

Table 1. Survey Forecast Summary Statistics

CF	Mean	Std. Dev	Skew	Min	Max	Obs
CPI Inflation	2.44	0.87	0.14	-0.57	5.11	121
3-Month Interest Rate	3.28	2.11	0.08	0.13	7.76	121
Log Real GDP	9.02	0.12	0.16	8.84	9.24	121
SPF	**Mean**	**Std. Dev**	**Skew**	**Min**	**Max**	**Obs**
CPI Inflation	2.95	1.30	1.68	0.27	9.05	154
3-Month Interest Rate	4.12	3.10	0.59	0.07	13.87	154
Log Real GDP	8.89	0.74	-0.76	7.31	9.87	154

Note: Summary statistics for survey forecasts. Consensus Forecast (CF) data ranges from 1989:4-2019:4. Survey of Professional Forecasters (SPF) data ranges from 1981:3-2019:4. All forecasts are transformed to a fixed horizon. CPI inflation forecasts are for inflation four-quarters ahead. 3 month interest rate forecasts are reported in percentage points. Real GDP forecasts are constructed using forecasts of real GDP growth (real GNP growth prior to 1992) and initialised by realised output a quarter prior to the start of the sample.

Table 2. Parameter Estimates

Parameters	R-star	Forecast
λ_g	0.050	0.045
λ_z	0.031	0.008
α_y	0.922	0.917
α_r	-0.054	-0.030
β_y	0.132	0.432
$\sigma_{\tilde{y}}$	0.333	0.334
σ_π	0.752	0.300
σ_g	0.128	0.240
σ_z	0.211	0.891
σ_{r*}	0.247	0.923
Average Standard Errors		
r^*_{avg}	1.787	6.271
y^*_{avg}	1.312	0.496
g_{avg}	0.521	4.205

Note: Final stage parameter estimates of the state space system for the United States from 1982:3-2019:4. Average standard errors of r-star, the market-perceived natural rate, potential output, and trend growth rate are reported in the last three rows. The standard deviation σ_{r*} is calculated as the square root of $\sigma_g^2 + \sigma_z^2$.

Table 3. Augmented-Dickey Fuller Tests

	$E_t r^*_{t+h}$	r^*_t	y_t	π_t	i_t
None	0.02	0.18	0.99	0.01	0.07
+ Drift	0.15	0.73	0.51	0.01	0.28
+ Trend + Drift	0.08	0.68	0.31	0.01	0.30

Note: Final p-values associated with Augmented Dickey-Fuller (ADF) test statistics for the perceived natural rate of interest $E_t r^*_{t+h}$, natural rate of interest r^*_t, gross domestic product y_t, consumer price inflation π_t, and the short-term interest rate i_t. Results are reported for the initial lag across all model specifications.

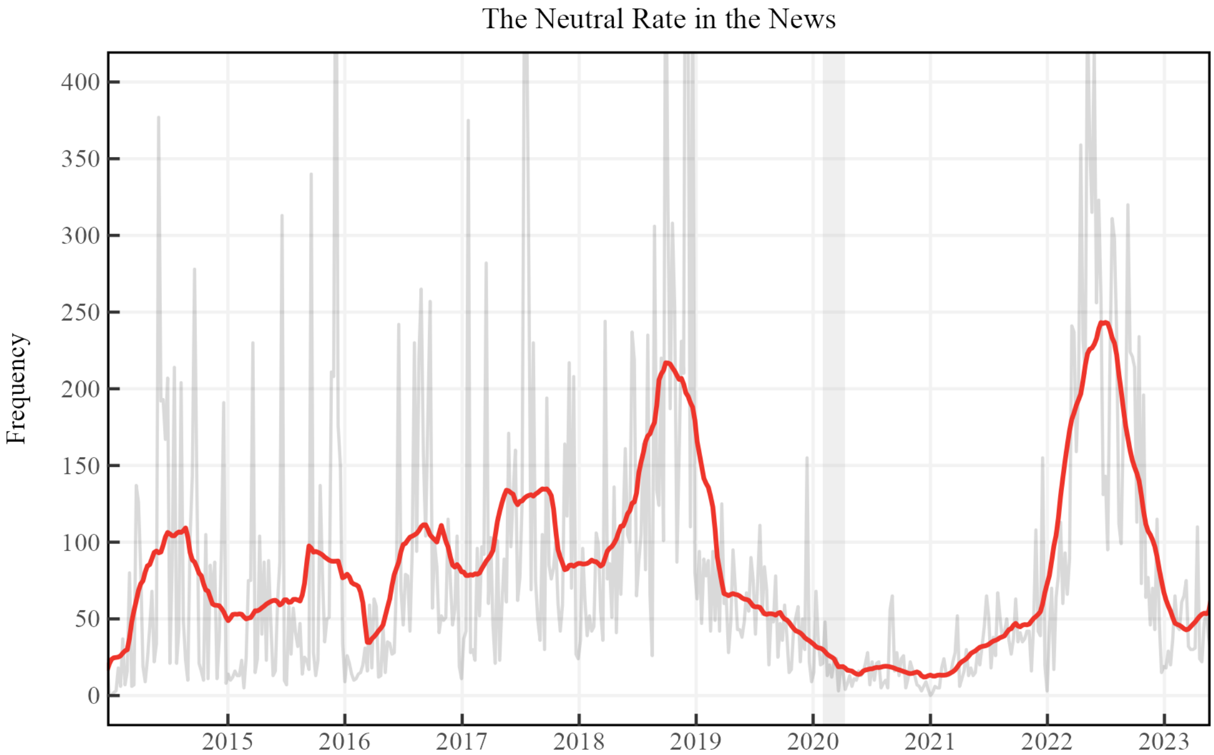

Figure 1. The Natural Rate in the News

Note: News stories mentioning the 'natural rate' from 2013 to 2023. The frequency of news stories across a wide range of sources from Bloomberg's News Trend (NT) function are presented in grey. 26-week moving averages are presented in red. Recession dates in grey are from the National Bureau of Economic Research.

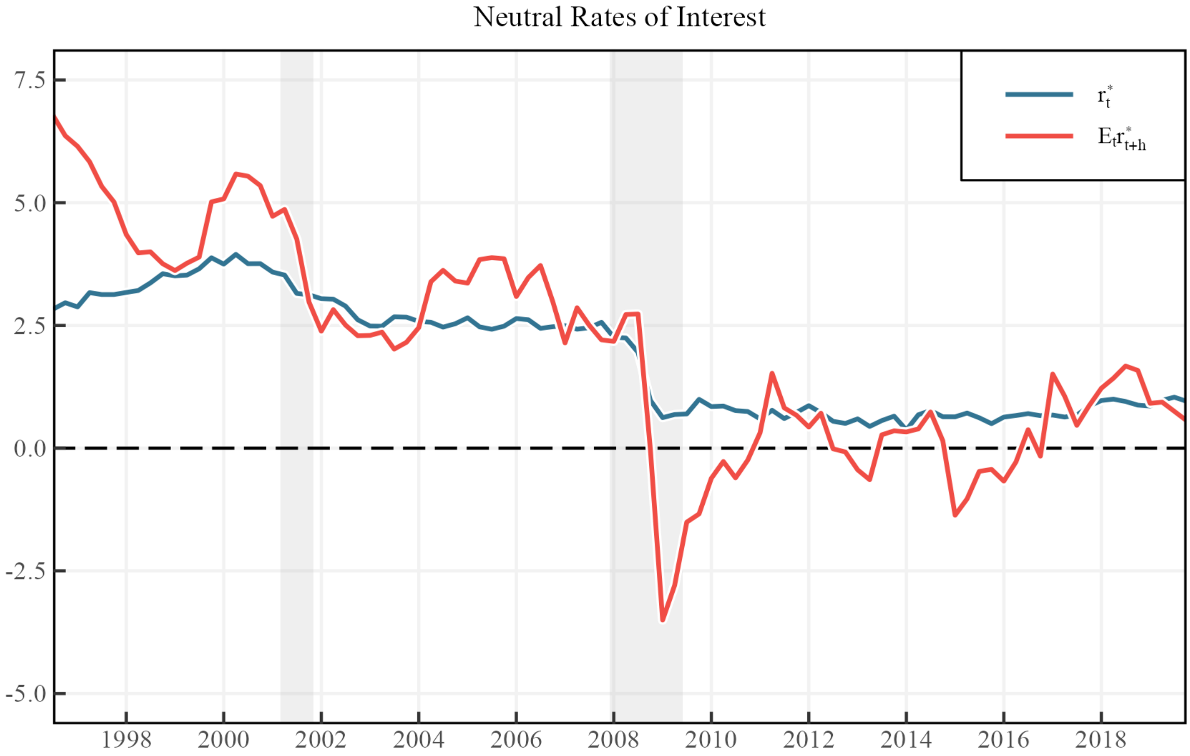

Figure 2. Natural Rates of Interest

Note: One-sided Kalman filter estimates of the market-perceived natural rate of interest and r-star, from 1996:3 to 2019:4. The expected natural rate $E_t r_{t+h}^*$ is presented in red. The natural rate r_t^* is presented in blue. Recession dates shaded in grey are sourced directly from the National Bureau of Economic Research.

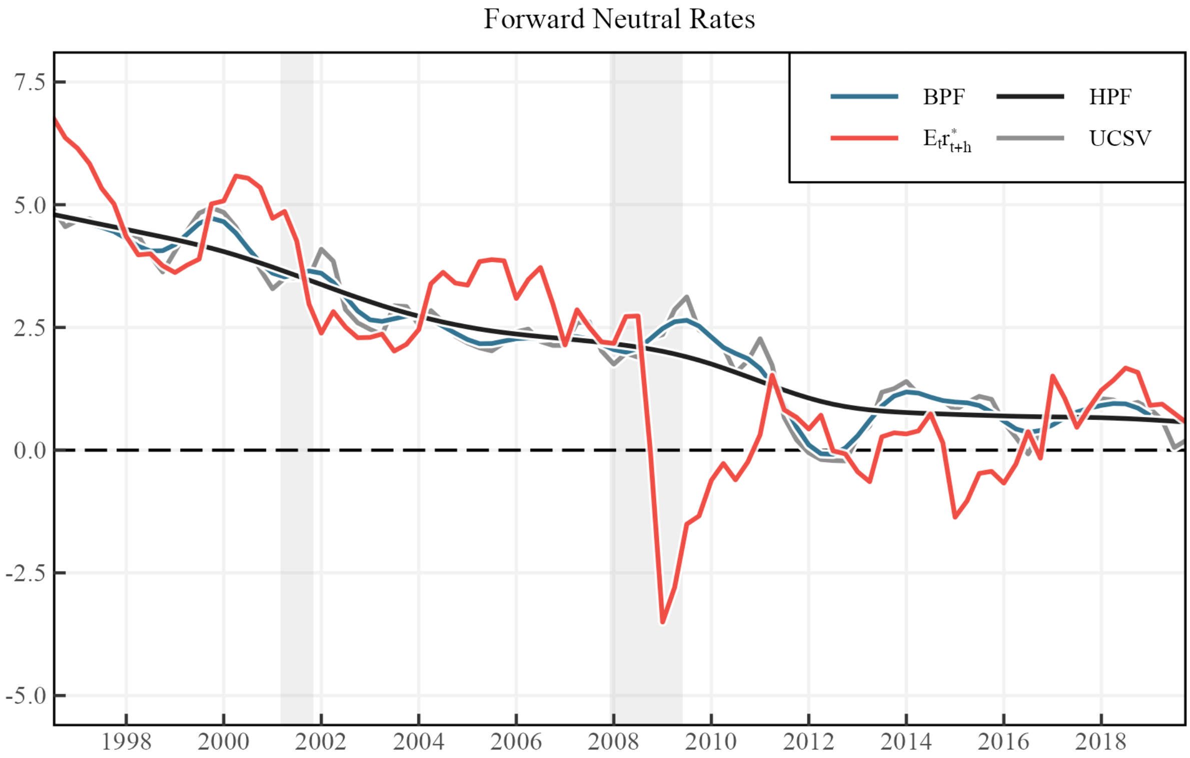

Figure 3. Forward Natural Rates

Note: Univariate measures of the perceived natural rate between 1996:3 to 2019:4. Hodrick-Prescott filter (HPF) estimates are presented in black. Band-pass filter (BPF) estimates are reported in blue. Kalman filter estimates are presented in red. Unobserved components with stochastic volatility (UCSV) model estimates are presented in grey. Recession dates shaded in grey are from the National Bureau of Economic Research.

Market Misalignments

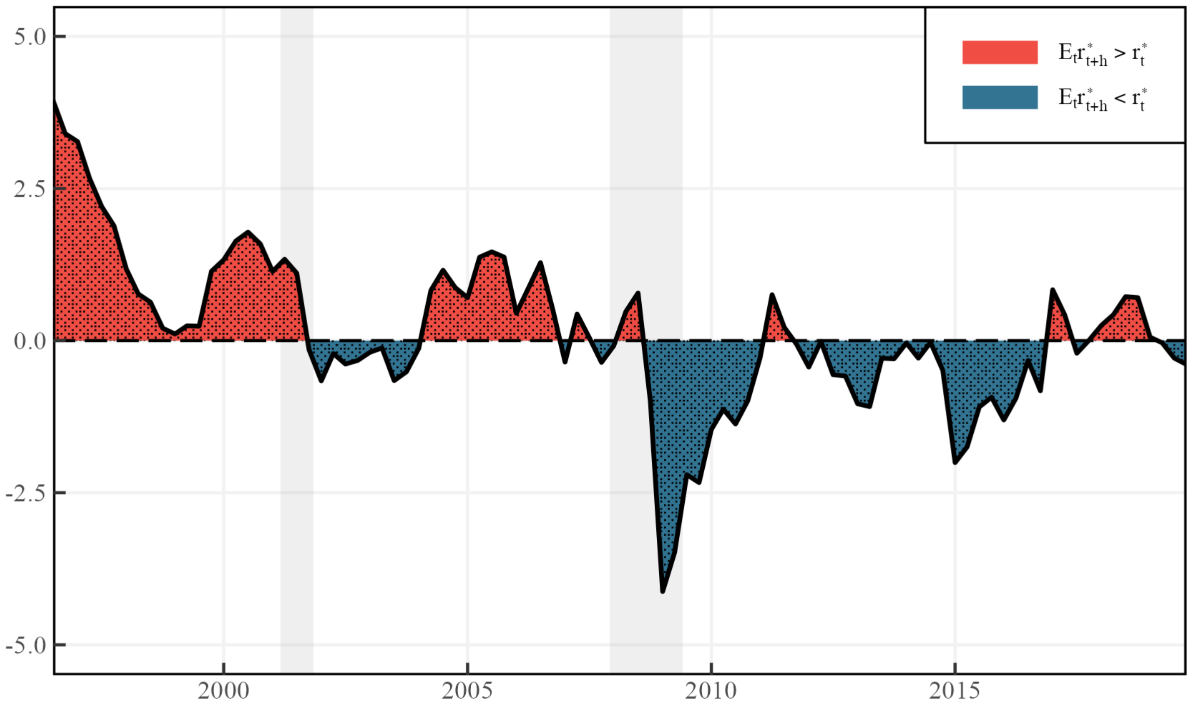

Figure 4. Market Misalignments

Note: Deviations between estimates of the market-perceived natural rate of interest $E_t r^*_{t+h}$ *and the natural rate of interest* r^*_t *between 1996:3 and 2019:4. Shaded regions in red are associated with periods of overestimation, in which* $E_t r^*_{t+h} > r^*_t$*. Shaded regions in blue are associated with periods of underestimation, in which* $E_t r^*_{t+h} < r^*_t$*. Recession dates shaded in grey are from the National Bureau of Economic Research.*

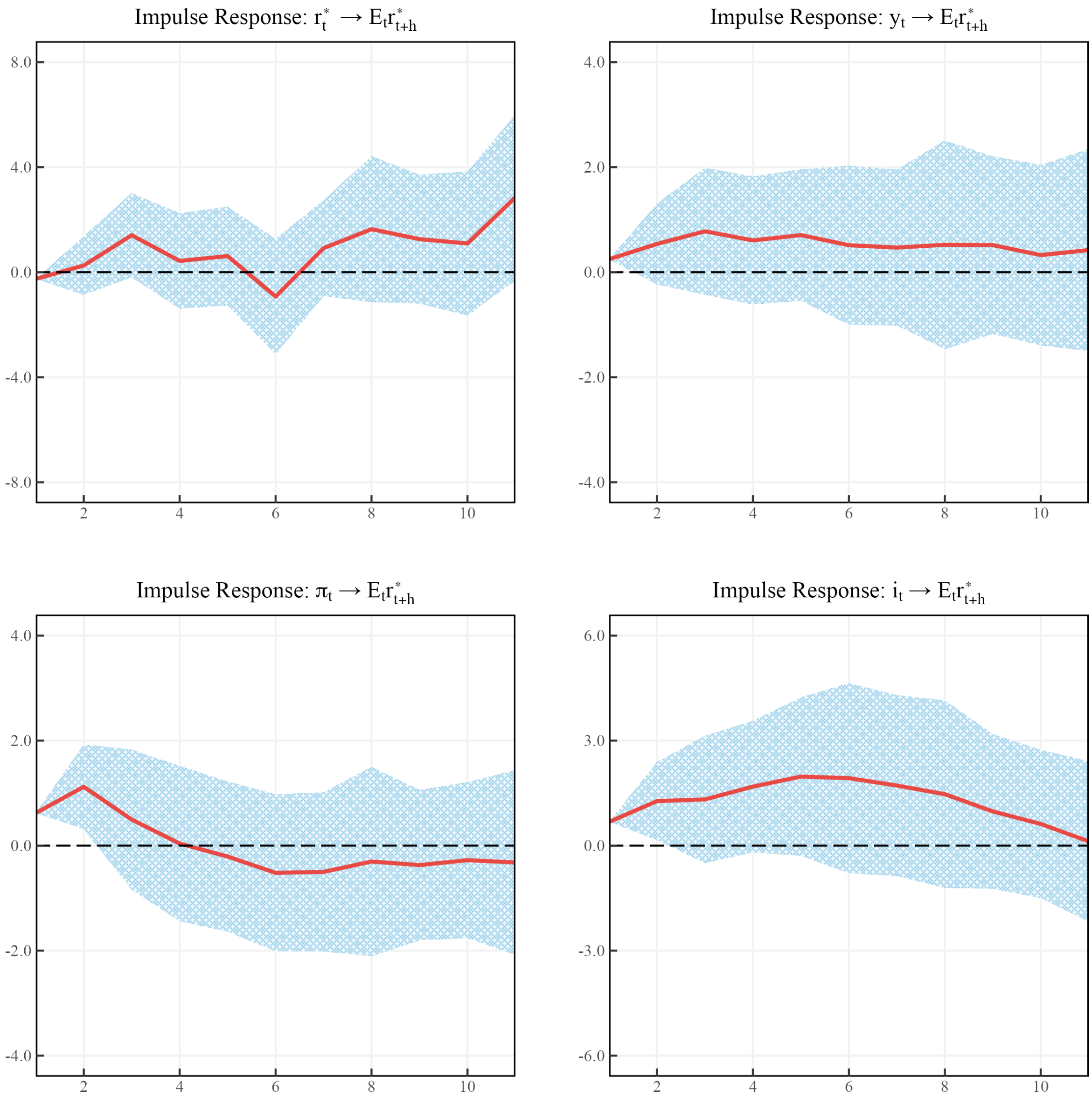

Figure 5. LP Impulse Response Functions

Note: Local projection impulse response functions of a unit innovation in the natural rate of interest r_t^**, real gross domestic product* y_t*, consumer price inflation* π_t*, and the short-term (three-month) nominal interest rate* i_t*, on the perceived natural rate of interest* $E_t r_{t+h}^*$*. Shaded regions represent the 95% confidence band.*

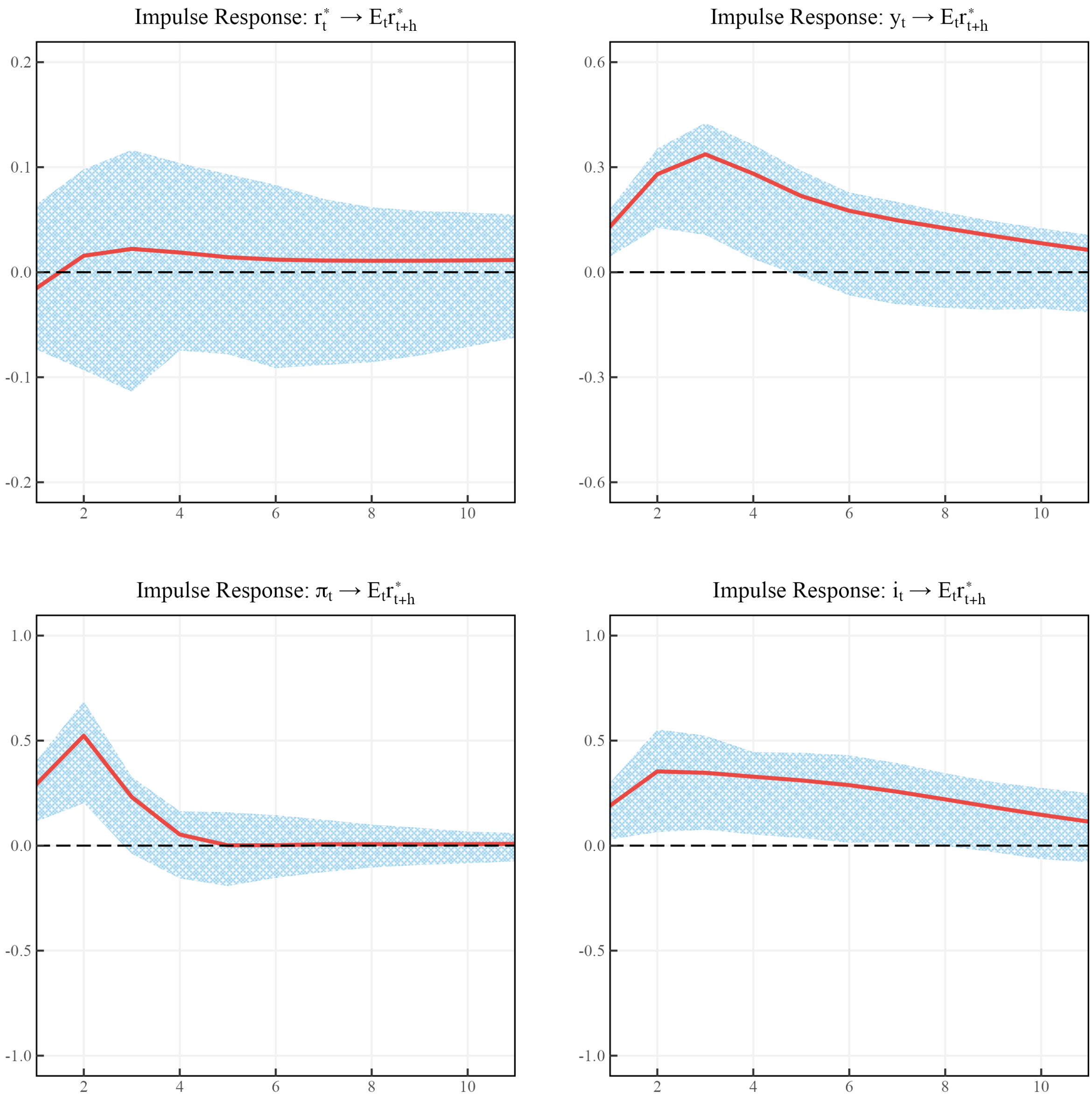

Figure 6. SVAR Impulse Response Functions

Note: Structural vector autoregression impulse responses of an innovation in the natural rate of interest r_t^**, real gross domestic product* y_t*, consumer price inflation* π_t*, and the short-term nominal interest rate* i_t*, on the perceived natural rate of interest* $E_t r_{t+h}^*$*. Shaded blue regions correspond to the 95% confidence band.*

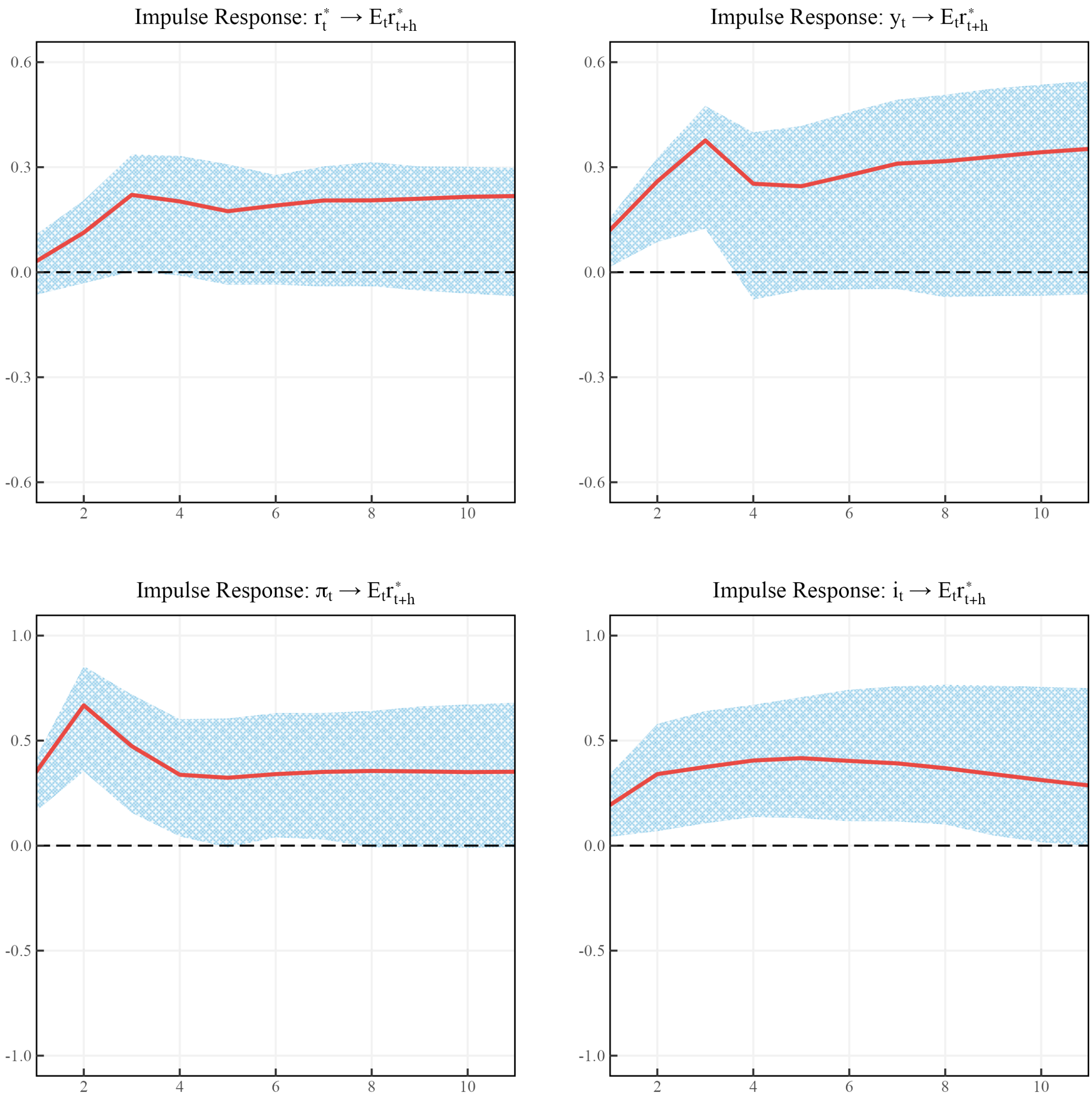

Figure 7. VECM Impulse Response Functions

Note: Vector error correction model impulse responses of an innovation in the natural rate of interest r_t^*, *real gross domestic product* y_t, *consumer price inflation* π_t, *and the short-term nominal interest rate* i_t, *on the perceived natural rate of interest* $E_t r_{t+h}^*$. *Shaded blue regions correspond to the 95% confidence band.*

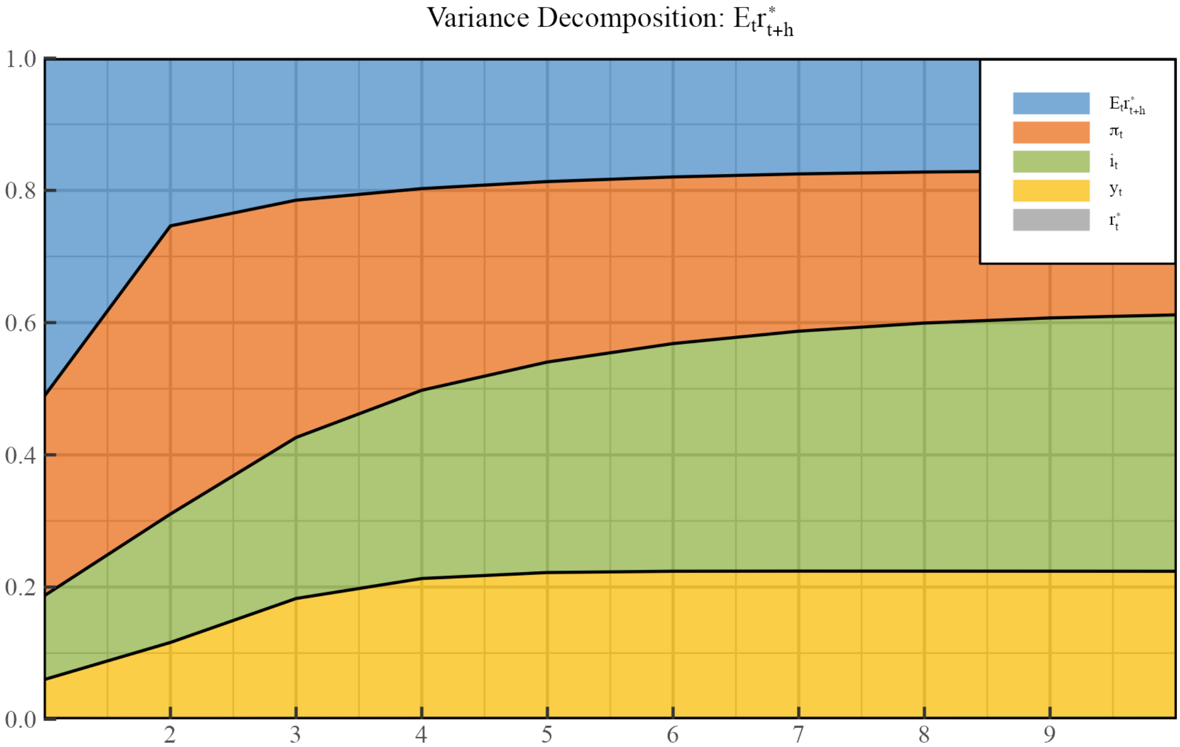

Figure 8. SVAR Forecast Error Variance Decomposition

Note: Structural vector autoregression forecast error variance decomposition of the perceived natural rate of interest $E_t r^*_{t+h}$ over a ten period horizon. Shaded regions represent the individual contributions of a unit shock in each variable of the model to the forecast error variance of the perceived natural rate of interest.

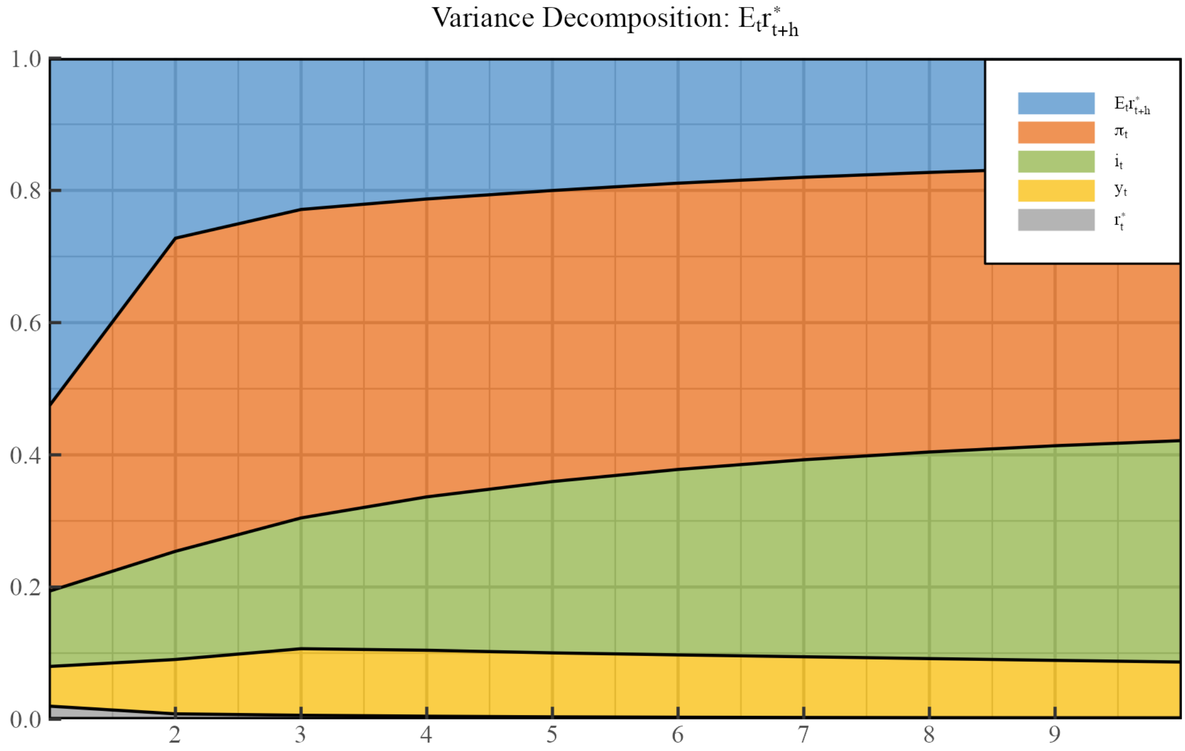

Figure 9. VECM Forecast Error Variance Decomposition

Note: Vector error correction model forecast error variance decomposition of the perceived natural rate of interest $E_t r^*_{t+h}$ over a ten period horizon. Shaded regions represent the individual contributions of a unit shock in each variable of the model to the forecast error variance of the perceived natural rate of interest.

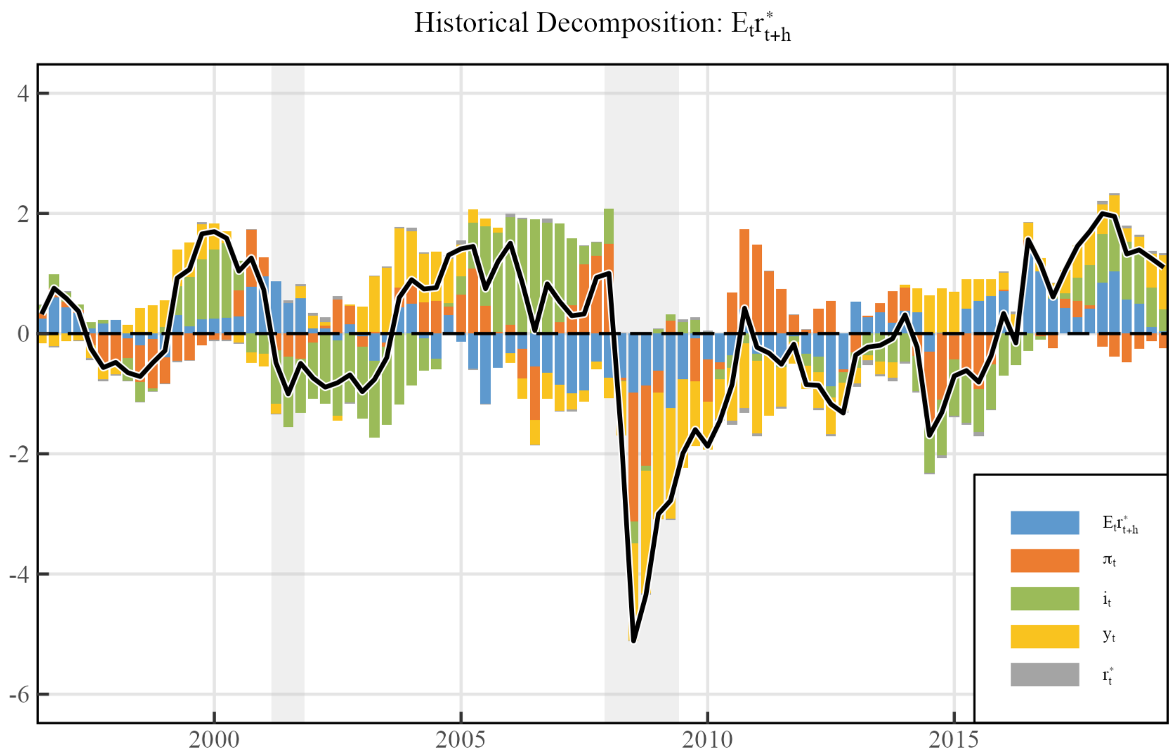

Figure 10. SVAR Historical Decomposition

Note: Structural vector autoregression decomposition of the perceived natural rate $E_t r^*_{t+h}$ between 1996:3 and 2019:4. Shaded bars are associated with individual contributions of innovations in each variable to the perceived natural rate. The stochastic component to which these shocks aggregate is represented in black. Recession dates in grey are constructed using cycle dates from the National Bureau of Economic Research.

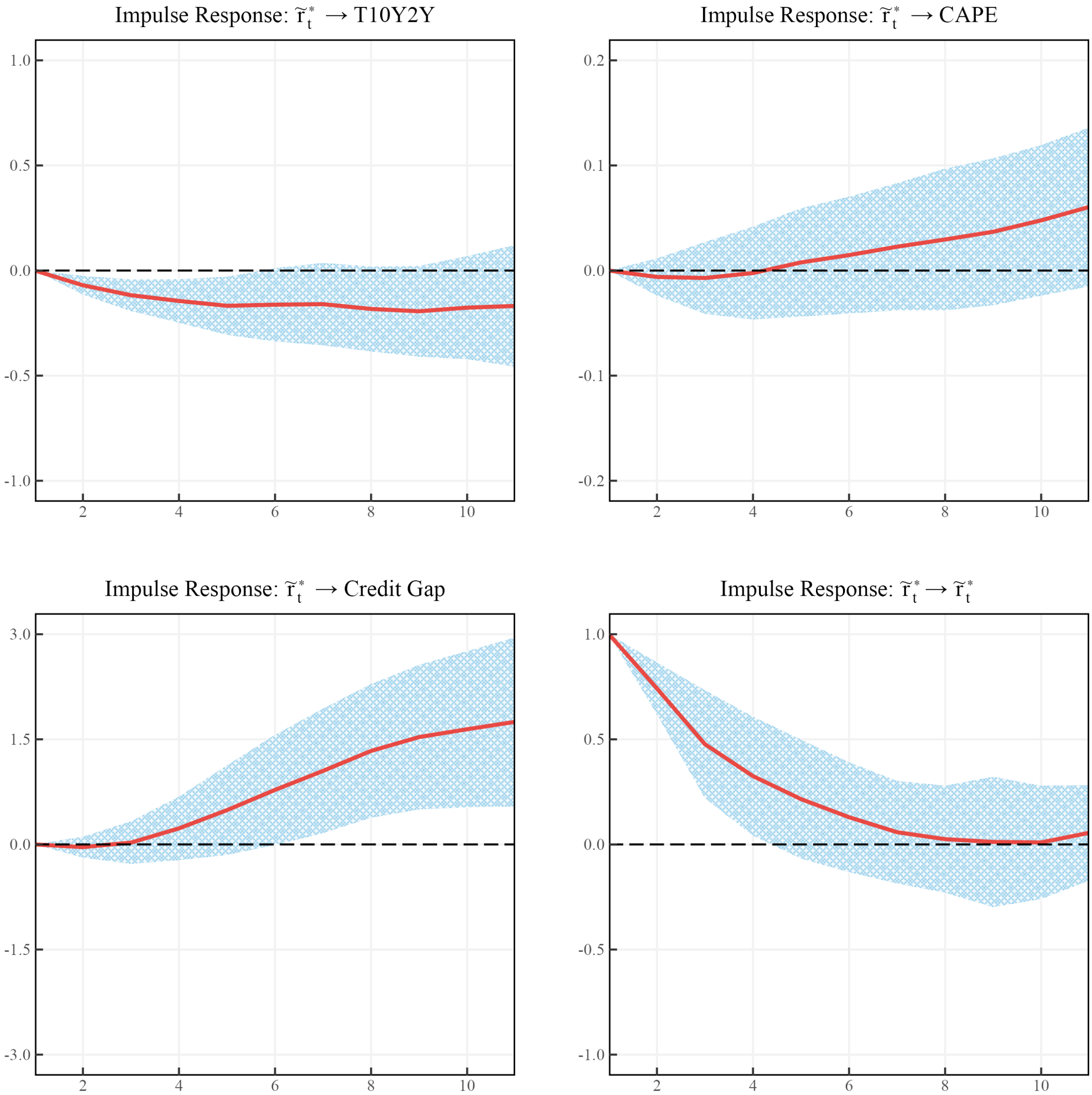

Figure 11. Impulse Response Functions

Note: Local projection impulse response functions of a positive innovation in the gap between the expected equilibrium interest rate and the natural rate of interest $\tilde{r}_t^*$, on the ten-year two-year treasury term spread (T10Y2Y), the cyclically adjusted price-to-earning ratio (CAPE), the credit-to-gross domestic product gap, and the forecast natural rate gap itself. Shaded regions in blue correspond to the 95% confidence band.

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APPENDIX

The Market-Perceived Natural Rate of Interest

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A Model Specification

Stage I Specification:

$$\mathbf{y}_t = \left[y_{t+1|t}, \pi_{t+1|t} \right]' \quad \mathbf{x}_t = \left[y_{t|t-1}, y_{t-1|t-2}, \pi_{t|t-1}, \pi_{t-1,3|t-2,4} \right]'$$

$$\xi_t = \left[y^*_{t+1|t}, y^*_{t|t-1}, y^*_{t-1|t-2} \right]'$$

$$\mathbf{H}' = \begin{bmatrix} 1 & -\hat{\alpha}_{y,1} & -\hat{\alpha}_{y,2} \\ 0 & -\hat{\beta}_y & 0 \end{bmatrix} \quad \mathbf{A}' = \begin{bmatrix} \hat{\alpha}_{y,1} & \hat{\alpha}_{y,2} & 0 & 0 \\ \hat{\beta}_y & 0 & \hat{\beta}_\pi & 1 - \hat{\beta}_\pi \end{bmatrix}$$

$$\mathbf{F} = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix} \quad \mathbf{Q} = \begin{bmatrix} \sigma^2_{y*} & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Vector estimated by maximum likelihood:

$$\theta_1 = \left[\hat{\alpha}_{y,1}, \hat{\alpha}_{y,2}, \hat{\beta}_\pi, \hat{\beta}_y, g, \sigma_{\tilde{y}}, \sigma_\pi, \sigma_{y*} \right]$$

Stage II Specification:

$$\mathbf{y}_t = \left[y_{t+1|t}, \pi_{t+1|t} \right]' \quad \mathbf{x}_t = \left[y_{t|t-1}, y_{t-1|t-2}, r_{t|t-1}, r_{t-1|t-2}, \pi_{t|t-1}, \pi_{t-1,3|t-2,4}, 1 \right]'$$

$$\xi_t = \left[y^*_{t+1|t}, y^*_{t|t-1}, y^*_{t-1|t-2} \right]'$$

$$\mathbf{H}' = \begin{bmatrix} 1 & -\hat{\alpha}_{y,1} & -\hat{\alpha}_{y,2} & \hat{\alpha}_g \\ 0 & -\hat{\beta}_y & 0 & 0 \end{bmatrix} \quad \mathbf{A}' = \begin{bmatrix} \hat{\alpha}_{y,1} & \hat{\alpha}_{y,2} & \frac{\hat{\alpha}_r}{2} & \frac{\hat{\alpha}_r}{2} & 0 & 0 & \hat{\alpha}_0 \\ \hat{\beta}_y & 0 & 0 & 0 & \hat{\beta}_\pi & 1 - \hat{\beta}_\pi & 0 \end{bmatrix}$$

$$\mathbf{F} = \begin{bmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \mathbf{Q} = \begin{bmatrix} \sigma^2_{y*} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & (\lambda_g \sigma_{y*})^2 \end{bmatrix}$$

Vector estimated by maximum likelihood:

$$\theta_2 = \left[\hat{\alpha}_{y,1}, \hat{\alpha}_{y,2}, \hat{\alpha}_r, \hat{\alpha}_0, \hat{\alpha}_g, \hat{\beta}_\pi, \hat{\beta}_y, \sigma_{\tilde{y}}, \sigma_\pi, \sigma_{y*} \right]$$

Stage III Specification:

$$\mathbf{y}_t = \left[y_{t+1|t}, \pi_{t+1|t}\right]' \qquad \mathbf{x}_t = \left[y_{t|t-1}, y_{t-1|t-2}, r_{t|t-1}, r_{t-1|t-2}, \pi_{t|t-1}, \pi_{t-1,3|t-2,4}\right]'$$

$$\xi_t = \left[y^*_{t+1|t}, y^*_{t|t-1}, y^*_{t-1|t-2}, g_{t|t-1}, g_{t-1|t-2}, z_{t|t-1}, z_{t-1|t-2}\right]'$$

$$\mathbf{H}' = \begin{bmatrix} 1 & -\hat{\alpha}_{y,1} & -\hat{\alpha}_{y,2} & \frac{-\hat{\alpha}_r}{2} & \frac{-\hat{\alpha}_r}{2} & \frac{-\hat{\alpha}_r}{2} & \frac{-\hat{\alpha}_r}{2} \\ 0 & -\hat{\beta}_y & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\mathbf{A}' = \begin{bmatrix} \hat{\alpha}_{y,1} & \hat{\alpha}_{y,2} & \frac{\hat{\alpha}_r}{2} & \frac{\hat{\alpha}_r}{2} & 0 & 0 \\ \hat{\beta}_y & 0 & 0 & 0 & \hat{\beta}_\pi & 1-\hat{\beta}_\pi \end{bmatrix}$$

$$\mathbf{F} = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \qquad \mathbf{Q} = \begin{bmatrix} (1+\lambda_g^2)\sigma_{y*}^2 & 0 & 0 & (\lambda_g\sigma_{y*})^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ (\lambda_g\sigma_{y*})^2 & 0 & 0 & (\lambda_g\sigma_{y*})^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & (\frac{\lambda_z\sigma_{\tilde{y}}}{\hat{\alpha}_r})^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Vector estimated by maximum likelihood:

$$\theta_3 = \left[\hat{\alpha}_{y,1}, \hat{\alpha}_{y,2}, \hat{\alpha}_r, \hat{\beta}_\pi, \hat{\beta}_y, \sigma_{\tilde{y}}, \sigma_\pi, \sigma_{y*}\right]$$

B Survey Forecast Data

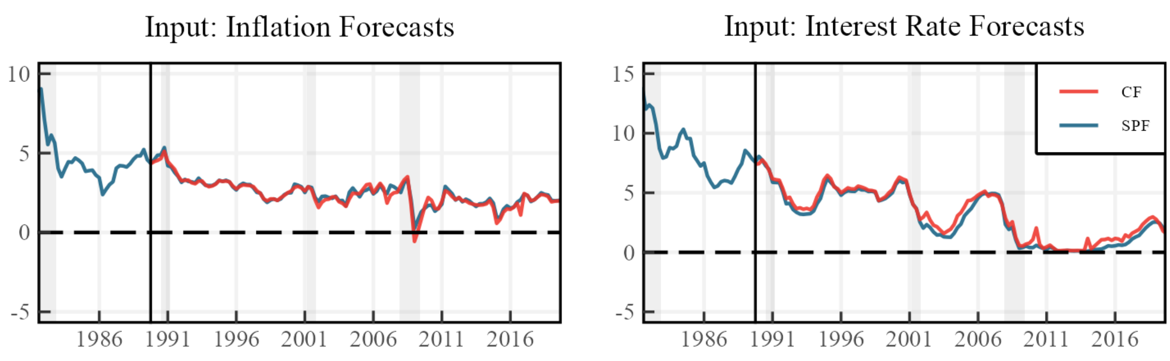

Figure B.1. Survey Forecast Data

C Natural Rates of Interest

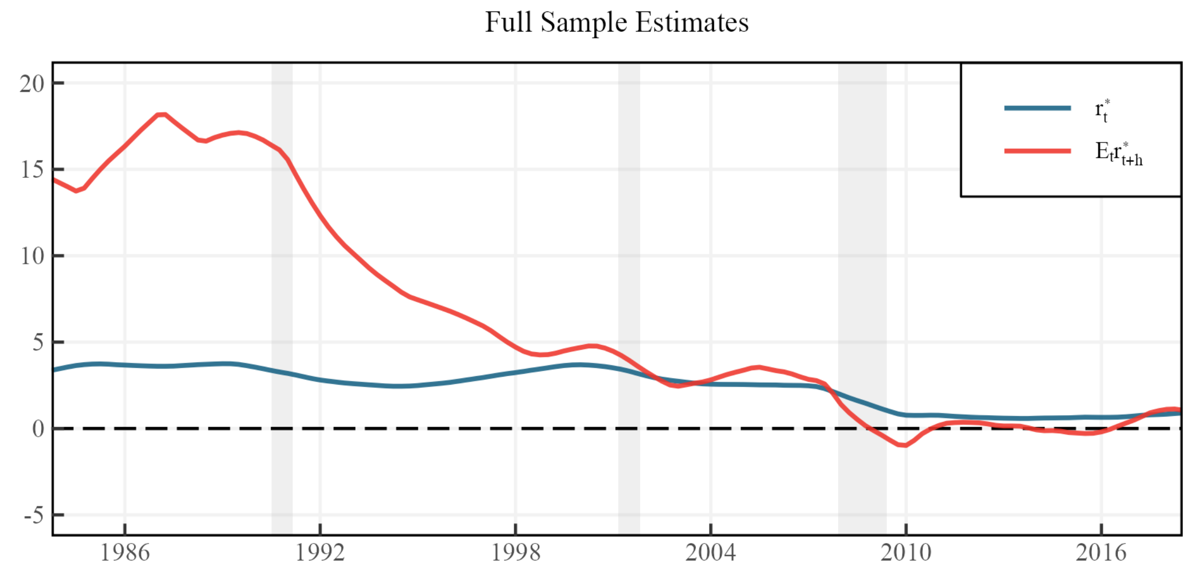

Figure C.1. Full Sample Estimates

Note: Two-sided Kalman filter estimates of the market-perceived natural rate $E_t r_{t+1}^*$ and the natural rate r_t^* from 1982:3 to 2019:4. Recession bands in grey are taken from the National Bureau of Economic Research.

D Bivariate Error Correction Model

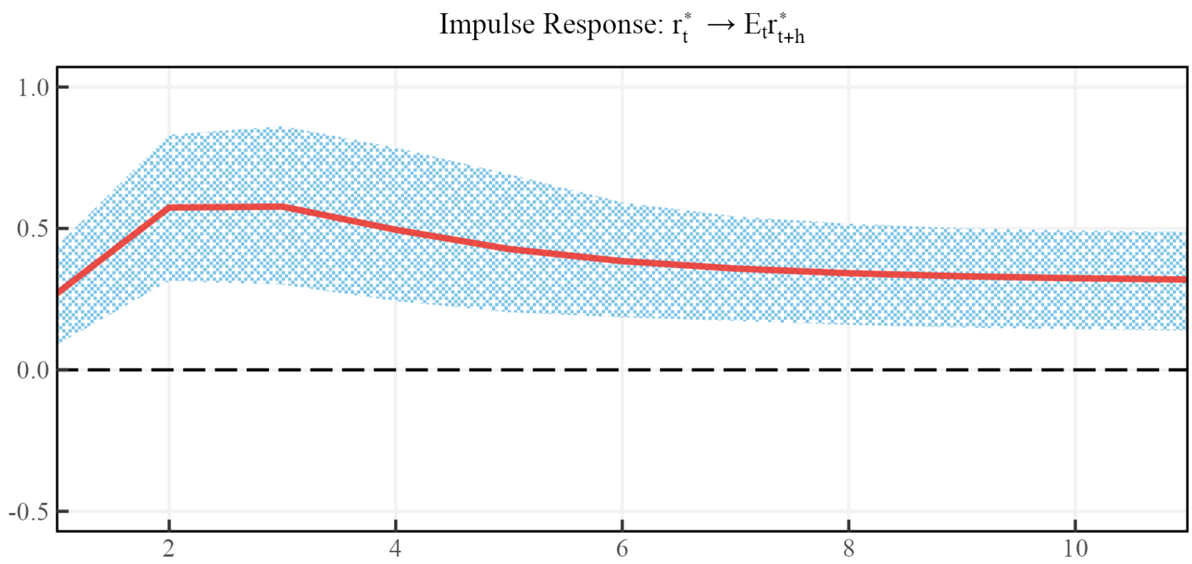

Figure D.1. ECM Impulse Response Function

Note: Bivariate error correction model impulse response of a unit shock in the natural rate of interest r_t^* on the perceived natural rate of interest $E_t r_{t+h}^*$. Shaded blue regions correspond to the 95% confidence band.

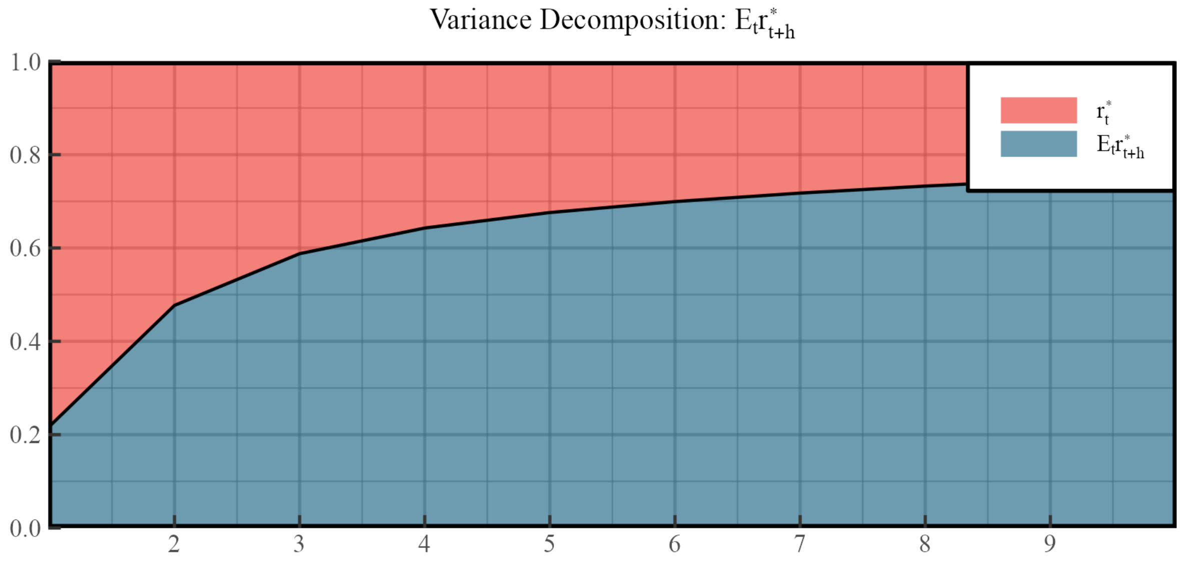

Figure D.2. ECM Forecast Error Variance Decomposition

Note: Bivariate error correction model forecast error variance decomposition of the perceived natural rate of interest $E_t r^*_{t+h}$ over a ten period horizon. Shaded regions represent the individual contributions of a unit shock in each variable of the model to the forecast error variance of the perceived natural rate of interest.

E Vector Error Correction Model

Table E.1. Augmented-Dickey Fuller Tests

	$\tilde{r}^*_t$	T10Y2Y	CAPE	CREDIT
None	0.01	0.21	0.55	0.30
+ Drift	0.01	0.30	0.41	0.67
+ Trend + Drift	0.04	0.60	0.63	0.62

Note: Final p-values associated with the Augmented Dickey-Fuller test statistic for the difference between r-star and the market-perceived natural rate of interest $\tilde{r}^*_t$, ten-year two-year spread T10Y2Y, cyclically adjusted price-to-earning ratio (CAPE), and credit-to-GDP gap. Results are reported for the initial lag.

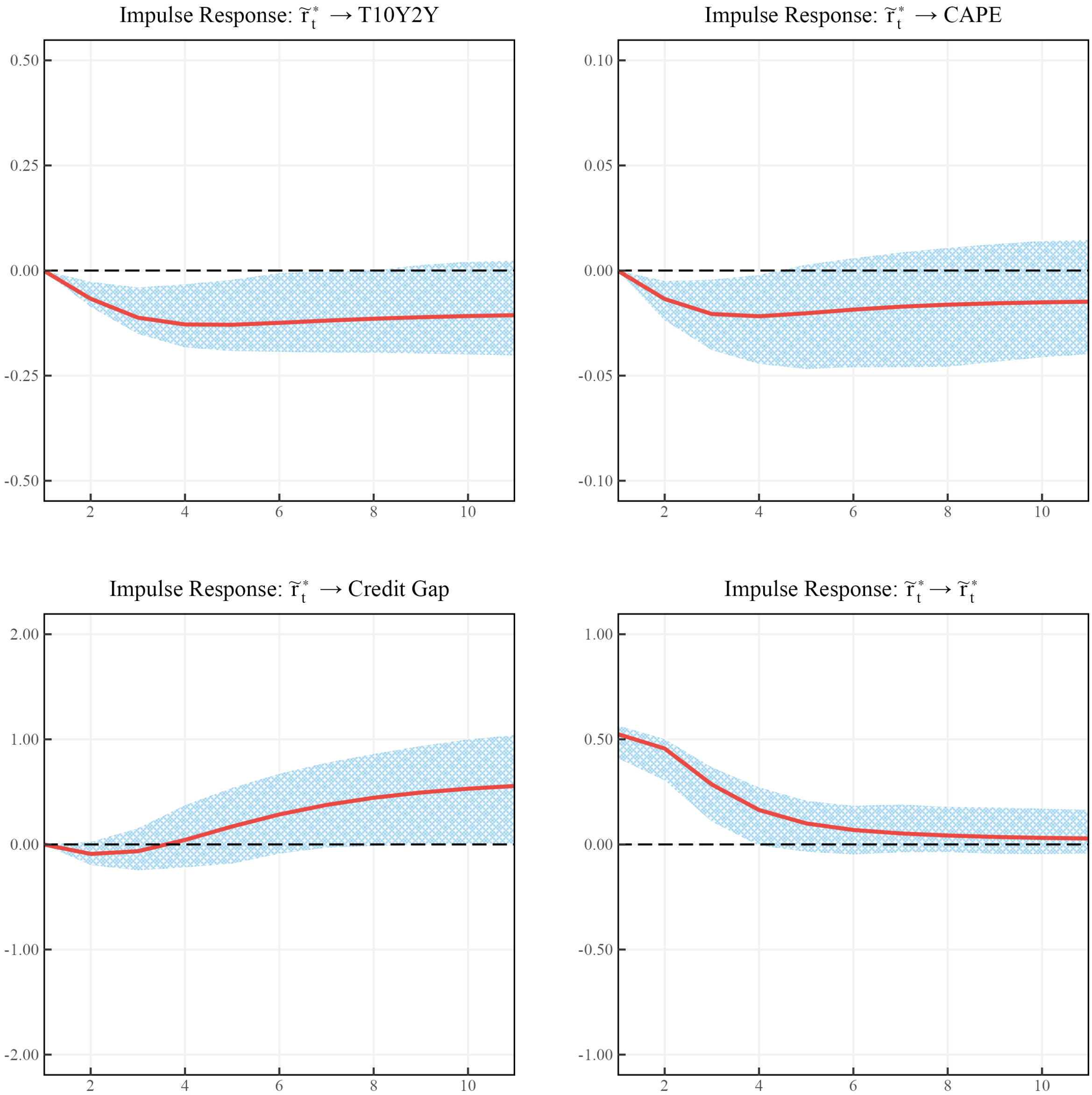

Figure E.1. Impulse Response Functions

Note: Error correction impulse response functions of a positive innovation in the gap between the expected equilibrium interest rate and the natural rate of interest $\tilde{r}_t^*$, on the ten-year two-year treasury term spread (T10Y2Y), the cyclically adjusted price-to-earning ratio (CAPE), the credit-to-gross domestic product gap, and the forecast natural rate gap itself. Shaded regions in blue correspond to the 95% confidence band.