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Star-struck; Monetary Policy and the Neutral Rate

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We disentangle macroeconomic surprises in a structural Bayesian VAR, and show that common measures of the short-term neutral rate underreact to shocks that affect the near-term productive capacity of the economy. In contrast, these measures overreact to transitory demand shocks, such as monetary policy shocks. Their impact is persistent, making short-term shocks hard to distinguish from secular trends. Our findings are robust across a large array of r-star measures. Particularly when the economy is near the effective lower bound, expansionary monetary policy has a forceful downwards impact on r-star. Hence, the neutral rate is not exogenous as in the Neo-Wicksellian paradigm. For our main analysis, we extend the Holston-Labauch-Williams estimate back to the 1920s, thus revealing a non-monotonic time-series. We add to the debate on the use of r-star in the policy realm, and the effectiveness of monetary policy tools when rates are low.

Keywords: Equilibrium real interest rate, R*, long-term rates, cyclical drivers, macroeconomic shocks, monetary policy, structural Bayesian VAR, sign restrictions.

JEL Classification: C11, E43, E52.

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Non-Technical Summary

Since the eighties, the concept of r-star has regained attention. A persistent decline in its trend reduced the policy space for central banks and led to numerous mission reviews. This equilibrium real rate embodies the level at which the economy is balanced, offering a sweet spot where the economy is neither too hot nor too cold. Policymakers often use r-star as a guide while aiming for full employment and stable inflation. However, measuring this rate poses challenges. Since it cannot be observed, it must be derived from the data. Estimates of r-star, which can be based on financial or macro variables; are imprecise, often revised, and show large deviations. Not much is known about how these estimates behave in response to macroeconomic shocks.

An important distinction derives from the fact that r-star has both a long-term, slow-moving part; as well as a short-term, volatile part. The natural rate, or long-run r*, is the risk-free return that balances the supply of savings to the demand for investment. This concept is solely driven by secular drivers. In contrast, the neutral rate, or short-run r*, is the real rate that removes inflationary or deflationary pressures. This component can still be affected by short-term shocks. For our analysis, we focus on this short-term concept.

Our study explores how macroeconomic surprises affect commonly used measures of the neutral rate. We employ a Bayesian vector autoregressive model, which offers a system of equations wherein the variables simultaneously interact with each other. We focus on the U.S. economy, and analyze the impact on r-star over three subperiods, taking into account regime shifts over the estimated period. We are the first to test the validity of r-star measures using an external instrument.

Our results show that the estimate for r-star underreacts to temporary shocks that affect the productive capacity, and overreacts to transitory demand shocks. This finding challenges the widespread belief that the neutral rate is only influenced by non-monetary drivers of near-term growth. When interest rates are near the lower bound, monetary stimulus has a strong downward impact on r-star. This finding is robust across a range of r-star measures. Moreover, the response of the short-run neutral rate to macroeconomic shocks, particularly demand and monetary policy shocks, is persistent. Shocks to the short-run neutral rate can therefore be hard to disentangle from movements in the long-term trend.

Our findings are confirmed when we decompose historical events and analyze the time-specific contributions of each shock. For example, supply shocks due to the oil price hikes in the seventies or during the productivity boom in the late nineties did not contribute substantially to the neutral rate. In contrast, transitory demands shocks contributed strongly and persistently to r-star during every subperiod. Their impact is unexpected, since these surprises had little effect on the growth potential of the economy.

Our analysis adds to the debate on the effectiveness of the neutral rate and its use within central banks. Standard measures of r-star should be seen as short-term concepts that can be affected by cyclical forces; and not as long-term returns absent of shocks. Central banks should therefore be cautious on how they use the neutral rate in their policy decisions, as shocks could determine the path of their so-called ideal policy rate. An additional concern derives from the interaction between monetary policy and r-star, particularly when the economy is at the lower bound. For example, the monetary stimulus after the GFC pushed down the neutral rate, further depleting the policy headroom. In these circumstances, policy should be geared towards long-run growth.

Finally, by incorporating historical data, we illustrate the non-monotic behavior of r-star over the last century, with substantial variation before the eighties. Historically, periods with high neutral rates tend to be outliers and are short-lived, after which they moderate back to their long-run averages.

Our study offers two avenues ahead. On the one hand, we aim to improve the understanding of how standard measures of r-star are affected by macroeconomic shocks, aiding policy makers in reaching the optimal policy mix. On the other hand, our findings can help develop new measures. In this case, it would be useful to model the relation between the neutral rate and monetary policy more explicitly. Similarly, allowing persistent yet temporary shocks to affect r-star would further improve existing estimates.

It is the stars, The stars above us, govern our conditions

(Shakespeare, King Lear)

1 Introduction

Since the 1980s, we witnessed a decline in the equilibrium real rate, which curtailed the policy space for central banks and led to numerous mission reviews (Reis, 2022). This trend has been explained by secular drivers, e.g. productivity, demographics, inequality, and global developments (Platzer and Peruffo, 2022). However, this decline was particularly strong after the Great Financial Crisis (GFC) and the ensuing expansionary monetary policy phase, prompting the idea that the latter can push down the neutral rate (McKay and Wieland, 2021). In contrast, shocks during the post-pandemic period necessitated monetary policy to bridge the gap with r-star by pursuing higher rates. In this case, positive demand shocks and negative supply shocks seem to have pushed up the neutral rate.

Policymakers often turn to r-star as a reference guide when evaluating their choices. This equilibrium rate has a long-run component (the natural rate) governed by secular drivers; and a short-run component (the neutral rate) affected by transitory shocks (Obstfeld, 2023).[1] Central banks may adjust their stance to movements in the neutral rate when striving toward full employment (Brainard, 2018). For example, the Taylor rule prescribes a policy rate based on deviations of output and inflation from their equilibrium rates.

However, measuring r-star poses challenges. Since it cannot be observed directly, it must be derived from the data (Holston et al., 2017). Estimates of the neutral rate are found to be imprecise and often revised. In order to produce such measures, assumptions are needed about the statistical properties of r-star. We observe large deviations across estimates, which can be based on financial or macro variables, and measured using empirical or structural models. Not much is known about how these estimates behave in response to macroeconomic shocks. Moreover, the focus has been on the recent decades, as most measures are only available for limited time-periods.

[1] For our analysis we focus on the latter. In the remainder of the paper, will refer to this short-term concept simply as the neutral rate or as 'r-star'. Moreover, we express this rate in real terms.

Our paper addresses three questions. First, we examine the effect of macroeconomic surprises on the neutral rate. We expect that commonly used estimates of r-star react to shocks that affect the near-term capacity of the economy, e.g. productivity or government spending; but not to transitory demand shocks, such as monetary policy shocks (Kaplan, 2018). Additionally, if the impact of these short-term shocks is persistent, they become hard to distinguish from secular trends. We thus use auxiliary information, in this case external shocks, to validate estimates of the latent neutral rate (Kiley, 2020). Second, we examine the contribution of the various shocks around key historical events. These decompositions assess the forces that moved the neutral rate across different policy regimes and macroeconomic environments. Third, we investigate how the use of r-star for policy purposes is impacted when there is endogeneity between monetary policy and the neutral rate, and whether this interaction restricts the use of monetary stimulus when the economy is at the effective lower bound (ELB).

Our methodology employs a six-variable, structural Bayesian vector-autoregression to examine how macroeconomic shocks affect measures of r-star. We disentangle supply, demand and monetary policy shocks using Baumeister and Hamilton's (2018) identification strategy, which incorporates prior information on the structural coefficients and the impact of the shocks. Our research focuses on the U.S. economy. We report impulse response functions and historical decompositions for three subperiods, as the size of the impact may vary over time. We discern the pre-Volcker period (1962-1978) characterized by the oil shocks; the Volcker disinflation period (1980-1998); and the low-interest rate, low-inflation period (1998-2016).

In order to deal with the complexity around the measurement of r-star, which is both unobservable and subject to short time-series, we take on the following approach. For our main analysis, we extend the Holston-Laubach-Williams (HLW, 2017) measure back to the 1920s. Over the last hundred years, the neutral rate displays a non-monotonic pattern with significant movement before the secular decline since the eighties. In addition, we test the robustness of our results for a broad set of r-star measures.

Our structural impulse response functions (IRFs) show that positive supply shocks lower the values of r-star. This effect is significant but short-lived. In contrast, positive demand shocks raise r-star. Their impact is stronger and more persistent, with the response of the neutral rate in some subperiods lasting two years. The historical decomposition of the structural shocks to r-star similarly highlights the importance of demand shocks over the entire sample, while the contribution of supply shocks is more time-specific.

Additionally, we find that monetary tightening pushes up r-star. While the impact is significant for the whole sample, this effect is strong and protracted for the last subperiod. Since the late 1990s, half of the change in the policy rate due to monetary policy surprises passes through into r-star, with the impact lasting six quarters. This finding is robust across a range of measures. The contribution of these shocks is also present in the historical decomposition. After the GFC, for example, monetary policy stimulus contributed significantly to lowering r-star. Our results confirm the hypothesis that the neutral rate is not exogenous to monetary policy as in the Neo-Wicksellian paradigm.[2] Our mechanism is compatible with secular phenomena, and has reinforced their downward impact.

Central banks should therefore adhere caution when using the neutral rate in their policy choices, as shocks could dictate the path of their seemingly ideal policy rate. The endogenous interaction between r-star and monetary policy can lead to undesirable outcomes. Moreover, the persistent impact of macroeconomic shocks makes it hard to distinguish between cyclical movements with a long memory and long-run secular trends. Our work connects monetary policy and financial stability concerns by illustrating how low rates can be self-sustaining. We witnessed an extraordinary amount of monetary stimulus post-GFC under the assumption that the neutral rate had dropped due to reasons outside the policy realm. However, these programs may exacerbate the long-run outlook when they have the potential to push down r-star, and further restrict the policy space (Billi et al., 2024).

Our work is related to several strands of literature. A number of studies calibrate the importance of monetary policy decisions for the real rate. Hillenbrand (2025) shows that a window around Fed meetings accounts for the secular decline in U.S. Treasury yields; while Aronovich and Meldrum (2021) find no significant pass-through of monetary policy shocks to r-star using an event study. Moreover, changes in the reaction function may matter. Borio et al. (2017) offer a time-series analysis for a set of countries to test which variables

[2] In Wicksell's view, "it is variation in the natural rate of interest due to real disturbances of various sorts, to the extent that such variation is not matched by corresponding adjustment of the central bank's reaction function that causes inflation variation." (Woodford, 2003, p. 52)

best explain the variation in the real rate. They discover an important role for monetary policy regimes. Similarly, Bianchi et al. (2022) assign two-thirds of the fall in real rates since the eighties to shifts in the parameters of the monetary policy function. Adding to this literature, we are the first to show that cyclical forces can have a strong and persistent impact on the neutral rate using a VAR framework.

The theoretical background for our analysis is laid out in studies that examine the endogenous interactions between r-star and monetary policy. Most transmission channels highlight the importance of intertemporal trade-offs for policy decisions. McKay and Wieland (2021) argue that monetary stimulus brings forward the purchase of durable goods, but forces the central bank to preserve low real rates, thus pushing down r-star. Mian et al. (2021) use a model with short-run, debt-driven booms and similarly show that expansionary monetary policy can depress demand and lower neutral rates.

Our empirical procedure is related to work by Coibion et al. (2018), which uses macroeconomic shocks to validate estimates of potential output. These measures are expected to be impacted by supply shocks, but not by transitory demand shocks that cause cyclical movements in employment. However, estimates of potential output are found to respond to both shocks, and their response is extremely gradual; thus making them less useful to draw inference about the persistence of GDP changes.

Finally, our paper is related to the literature that examines r-star as a policy guide, which warns against relying strongly on the neutral rate since its estimates are imprecise and react endogenously (e.g. Borio, 2021b; Ajello et al., 2021). Policymakers have adopted risk-management strategies whereby they analyze an array of r-star estimates, which they cross-validate with a broad set of observables (Powell, 2018).

This paper is organized as follows. Section 2 describes the construction of the neutral rate estimates, and shows the mean-reverting properties of r-star over an extended time-period. Section 3 presents the structural Bayesian VAR model, and highlights the identification strategy. In Section 4, we discuss the results for the impulse response functions and the historical decompositions. Section 5 examines the policy implications and discusses the transmission channels. Section 6 concludes.

2 The Neutral Real Rate

2.1 How Measures of the Neutral Real Rate Are Created

Measuring the neutral rate poses numerous challenges. Since it cannot be observed directly, it must be obtained through assumptions about the statistical properties of r-star (Lewis and Vazquez-Grande, 2019). Any model misspecification affects this process, as omitted variables and structural breaks can lead to measurement issues (Taylor and Wieland, 2016). Similarly, data revisions can cause imprecision in real-time estimates (Clark and Kozicki, 2005).

An important distinction derives from the fact that r-star has both a long-term, slow-moving component; as well as a short-term, volatile component (Linde et al., 2022). The natural rate, or long-run r*, is the risk-free real return that matches the supply of savings to the demand for investment, when the impact of shocks has died out. This concept is solely governed by secular drivers (Platzer and Peruffo, 2022).

In contrast, the neutral rate, or short-run r*, is the real rate that removes inflationary or deflationary pressures, and holds in a world without nominal rigidities (Obstfeld, 2023). This component can still be affected by short-term shocks. For example, in Woodford's (2003) model some transitory shocks (e.g. a temporary increase in the autonomous part of spending, or a temporary drop in the equilibrium output level due to an adverse supply shock) can briefly move the short-term neutral rate away from its long-run trend.[3] The prevailing Neo-Wicksellian paradigm holds that the neutral rate is only impacted by non-monetary drivers of near-term GDP growth (McKay and Wieland, 2021).[4] For our analysis, we focus on this short-term component of r-star.

The literature offers a large set of neutral rate measures, as shown in Figures 1 to 3. We categorize these estimates depending on their underlying data, respectively macroeconomic and financial variables. Within the macro-estimates, we identify structural and empirical measures.[5] Tables 1 to 3 specify their construction method, sample length, and acronyms. At

[3]In this case, both shocks temporarily increase r-star. Brainard (2018) similarly argues that a heightened risk appetite can push up r-star, while increased uncertainty can have the opposite effect.

[4]This view is rooted in the idea of money neutrality, whereby the long-term growth of the economy is considered to be beyond the influence of the central bank.

[5]Appendix C reviews how their long-term, smoothed counterparts differ from short-term measures.

a first glance, these estimates show considerable differences within/across the methodologies, both in their values as well as in their degree of time-variation. Beyond this disparity, there is substantial estimation uncertainty across measures, which makes it hard to ascertain whether the policy rate is above or below the neutral rate (Beyer and Wieland, 2019).[6]

2.1.1 Measures based on Macro-economic data

This category derives the r-star estimate from macroeconomic variables using a Kalman filter, with Bayesian techniques or within a dynamic stochastic general equilibrium (DSGE) model. These models rely on a New Keynesian (NK) framework that incorporates an IS equation, which links real activity to the interest rate gap; and a Phillips curve, which relates inflation to the output gap:

$$\tilde{y}_t = a_{y,1}\tilde{y}_{t-1} + a_{y,2}\tilde{y}_{t-2} + \frac{a_r}{2}\sum_{j=1}^{2}\left(r_{t-j} - r^*_{t-j}\right) + \epsilon_{\tilde{y},t} \tag{1}$$

$$\pi_y = b\pi_{t-1} + (1 - b_\pi)\,\pi_{t-2,4} + b_y\tilde{y_{t-1}} + \epsilon_{\pi,t} \tag{2}$$

where $\tilde{y}_t$ is the output gap (defined as the difference between real GDP y_t and the unobserved natural rate of output y^*_t), r_t the real short-term interest rate, r^*_t the equilibrium rate, π_t consumer price inflation, and $\pi_{t-2,4}$ the average of the second to the fourth lag of the inflation rate. The stochastic disturbances for the output gap and inflation equations are denoted as $\epsilon_{\tilde{y},t}$ and $\epsilon_{\pi,t}$, respectively.

The empirical relationship between the real rate and the output gap, however, seems relatively weak and may not provide much information about r-star (Hamilton et al., 2016). Similarly, the Phillips curve has been comparatively flat in the last decade, which implies a muted response of inflation to economic slack. Both issues aggravate any estimation error in the neutral rate (Borio, 2021a).

In recent years, several authors have produced r-star estimates using a DSGE framework. This approach allows for a decomposition into the drivers behind the secular decline. DelNegro et al. (2017) identify the rising premiums for the safety and liquidity of Treasury bonds together with slower economic growth as the main factors. Similarly, Gerali and Neri (2019) assign an important role to shocks in the risk premium due to changes in the demand for safe assets. Figure 1 gives an overview of r-star measures based on structural

[6] Confidence bands for the figures are not included for readability, but can be requested.

estimates. Table 1 describes their construction method and highlights the different maturities of their underlying debt-instruments. Estimates using long-term yields display more smoothed time-series. Despite the substantial disparity, most measures exhibit a dropping trend over time. This drop becomes more pronounced after 2000, particularly post-GFC.[7] In comparison, structural estimates that incorporate short-run debt-instruments (depicted by a dotted line), e.g. DelNegro et al. (2017) and Roberts (2018), are more volatile. The drop in these measures is again stronger post-GFC.

Alternatively, estimates can be obtained through reduced-form equations, as in HLW (2017). This method is widely used in policy and research, and will therefore feature prominently in our analysis. They transform movements in real GDP, inflation, and the short-term interest rate into estimates of trend growth, the natural rate of output, and the natural rate of interest through a Kalman filter. Practically, they assume r-star is generated by two processes:

$$r_t^* = c.g_t + z_t \qquad (3)$$

where g_t denotes the trend growth rate of the natural rate of output, and z_t captures other determinants of r-star. The first component impacts aggregate supply through the growth rate of potential output, while the second captures disturbances to aggregate demand. The logarithm of the natural rate of output, y_t^*, follows a random walk with a stochastic drift, g_t, which is also assumed to be a random walk:

$$y_t^* = y_{t-1}^* + g_{t-1} + \epsilon_{y^*,t} \qquad (4)$$

$$g_t = g_{t-1} + \epsilon_{g,t} \qquad (5)$$

Similarly, the component z_t is modeled as a random walk

$$z_t = z_{t-1} + \epsilon_{z,t} \qquad (6)$$

Several studies have since built on HLW's approach, proposing adjustments to better align with the neutral rate. First, some authors have introduced statistical corrections.

[7] The majority of this decline happens substantially later than the 1980s, which is the focus for the literature on secular decline (Summers, 2014). For example, the measure by Wynne and Zhang (2018) is 2.9 percent in 1980, 2.7 in 2000, at which point it gradually starts dropping. Similarly, the 30-year estimate by DelNegro et al. (2017) was 1.7 percent in 1980, 2.2 in 2000, and then drops to 0.8 in 2020.

HLW define the neutral rate as a time-varying process that is solely affected by permanent changes (low-frequency, non-stationary processes). They cite shifts in the trend growth of (labor) productivity, the global supply of savings, and fiscal policy as potential sources. This assumption, however, is restrictive. For example, in order for r-star to be driven by permanent movements in productivity, output needs to be integrated of order two, which lacks empirical support (Schmitt-Grohe and Uribe, 2022). The growth rate of trend output is instead shown to be mean-reverting. Some factors that influence r-star might therefore be temporary.[8] In this context, Lewis and Vazquez-Grande (2019) describe how transitory shocks matter for r-star when putting the model to the data. The authors re-estimate the HLW (2017) model using Bayesian methods with less restrictive prior distributions on the unobserved factors of r-star, thus alleviating the pile-up problem. Their model yields a more cyclical estimate, with higher values post-GFC.[9] Buncic (2024) adjusts the HLW procedure by revisiting their execution of Stock and Watson's (1998) Median Unbiased Estimation. He shows that the original trend growth estimates are too low. Several authors further highlight the sensitivity of HLW's method to the starting point (e.g. Clark and Kozicki, 2005). Our analysis shows the benefits of incorporating a longer sample, for which the values of r-star similarly tend to be higher after the GFC.

Second, some studies have added variables to the HLW framework. Hakkio and Smith (2017) incorporate bond premiums to account for the level of tightness in financial markets.[10] Their estimate of the neutral rate is more cyclical than the original HLW series. Doh (2017) estimates a Bayesian VAR with time-varying parameters and stochastic volatility, which tilts the model-implied forecasts to match survey expectations. Zaman (2025) and Gonzalez-Astudillo and Laforte (2020) also highlight the importance of survey forecasts when estimating equilibrium rates. Lopez-Salido et al. (2020) show how different measures of inflation impact the HLW estimates.

Third, in the HLW framework, r-star is considered to be independent from monetary policy. However, the latter indirectly impacts the neutral rate through the 'other factors'

[8]Woodford (2003) argues that any shock to the expected marginal rate of substitution, whether transient or permanent, impacts the equilibrium rate.

[9]Moreover, the data seems informative about the volatility of z, though with significant uncertainty. Kiley (2020) similarly takes a Bayesian approach to deal with the pile-up problem. In contrast, he finds the information content of the data to be considerably small.

[10]Cukierman (2016) argues that neglecting credit rationing and financial stability motives can bias estimates of r-star downwards. Krustev (2019) similarly includes a measure of the financial cycle.

component, despite only being included as an exogenous variable (Buncic, 2024). In our analysis, we quantify the impact of monetary policy surprises on the HLW estimate.[11]

Figure 2 depicts these macroeconomic estimates. As discussed, many of these measures present a modification to the HLW method, e.g. Buncic (2024), Hakkio and Smith (2017), HLW(2023), LW(2023), Krustev (2019), Lewis and Vazquez-Grande (2019), Lopez-Salido et al. (2020); or use similar variables, e.g. Curdia et al. (2015), DelNegro et al. (2017) and Lubik and Matthes (2023). Table 2 offers a detailed description. While we discern a declining trend over the sample, similar to the original HLW (depicted in red), most measures exhibit more stationary behavior, showing an increase post-GFC. The estimates deviate substantially over time, despite relying on a related set of variables for their construction. This divergence makes it hard for policymakers to ascertain how their stance compares to r-star, which is aggravated by the uncertainty around these estimates.

2.1.2 Measures based on Financial Market Data

The neutral rate can also be estimated using financial variables. One approach uses reduced-form time-series models to extract long-horizon expectations for the short-term rate. Christensen and Rudebusch (2019) examine the prices of U.S. Inflation-Protected Securities (TIPS). This type of debt compensates for the loss of purchasing power caused by inflation, and translates into real yields.[12] Johannsen and Mertens (2021) apply a trend-cycle decomposition, and consider the ELB by incorporating a shadow rate. Both studies find a gradual decline for r-star over recent decades. The large confidence bands, however, highlight the uncertainty about this downward trend. What complicates these models is the need for a long-run conditional mean of the real interest rate, which is challenging to pin down (Wright, 2014). The expectations and risk attitudes that underlie these market prices are hard to model. Moreover, signals from market-based prices can get distorted during periods of unconventional monetary policy (Dorich et al., 2017). Given these difficulties, financial estimates of r-star exhibit substantial uncertainty (Kim et al., 2019). An additional challenge is that the underlying time-series are relatively short.[13]

[11] This endogeneity holds for many common measures of r-star, as shown in Section 4.1.1. Allowing for the policy rate to feature endogenously when estimating the neutral rate could potentially solve this issue.

[12] There is a tradition of using TIPS to extract equilibrium real rates. Kim et al. (2019) offer an overview.

[13] The TIPS-instruments have only been available since the early 90s. D'Amico et al. (2019) provide an extension until 1983.

Alternatively, survey expectations can be used to construct financial estimates of the neutral rate. Aronovich and Meldrum (2021) use non-linear regressions to relate survey forecasts of short-term nominal interest rates and inflation expectations to U.S. Treasury yields. They find that r-star declined post-GFC before plummeting to zero during the pandemic, after being relatively stable in the 1990s and the early 2000s. While survey-based studies avoid issues with disentangling the risk premium, they have their own limitations. There can be lags in their measurement, since they are published in intervals. Furthermore, the survey responses need to be representative for the market.

Figure 3 depicts financial estimates of r-star, for which details are provided in Table 3. The sample period is smaller in comparison to macro-based measures, with several estimates only commencing in the eighties and nineties. Overall, we discern a downward trend until the GFC, with the exception of the AACMY (2016) estimate; after which most series increase again. The only measure posting negative values at the end of the sample is the estimate by Han and Ma (2023). We see a range of values for these financial measures, similar to the structural and macroeconomic estimates. However, their divergence seems comparatively smaller, partly as they rely on a smaller set of variables.

3 Analysis

3.1 Methodology

Our empirical model tests whether macroeconomic shocks affect commonly used measures of the neutral rate. Short-term r-star estimates are expected to react to shocks that affect the near-term productive capacity of the economy, such as productivity or government spending; and not to transitory demand shocks, such as monetary policy shocks. In addition, if the impact of macroeconomic shocks to the neutral rate is long-lived, it becomes hard to distinguish between movements in the short-term r-star and its long-run counterpart.

We use a structural Bayesian vector autoregressive (VAR) model to estimate the impact of the shocks. Following Baumeister and Hamilton (2018), we rely on an asymmetric t-distribution for adding information about the signs. The reduced-form VAR is given by

$$y_t = \Phi x_{t-1} + \varepsilon_t \qquad (7)$$

$$\Phi = A^{-1}B \tag{8}$$

The reduced-form residuals and the structural shocks relate to each other as follows

$$\varepsilon_t = A^{-1}u_t \tag{9}$$

$$E\left(\varepsilon_t\varepsilon_t^{'}\right) = \Omega = A^{-1}D\left(A^{-1}\right)^{'} \tag{10}$$

where y_t is a $(n \times 1)$ vector of observed variables, and x_{t-1} a $(k \times 1)$ vector featuring a constant and m lags of y (with $k = mn + 1$), hence $x_{t-1} = (y_{t-1}^{'}, y_{t-2}^{'}, ..., y_{t-m}^{'}, 1)^{'}$. A represents a $(n \times n)$ matrix containing the contemporaneous structural relations, and u_t is a $(n \times 1)$ vector of structural disturbances. We assume that the structural shocks u_t are mutually uncorrelated white noise, with $E\left(u_t u_t^{'}\right)$ given by the diagonal matrix D. The number of lags m is set to four quarters.

We include six variables in our estimation framework. At the core, we rely on three variables to identify the shocks: the output gap, the inflation rate, and the federal funds rate (FFR): y_t, π_t, r_t.[14] Our model can be described using three state equations: a Phillips curve, an aggregate demand equation, and a monetary policy rule.

$$y_t = k^s + \alpha^s \pi_t + [b^s]^{'} x_{t-1} + u_t^s \tag{11}$$

$$y_t = k^d + \beta^d \pi_t + \gamma^d r_t + \left[b^d\right]^{'} x_{t-1} + u_t^d \tag{12}$$

$$r_t = k^m + \zeta^y y_t + \zeta^\pi \pi_t + [b^m]^{'} x_{t-1} + u_t^m \tag{13}$$

where α^s describes the effect of π on supply, β^d the effect of π on demand, and γ^d the effect of r on demand. Equation (13) can be re-written as

$$r_t - \bar{r} = (1-\rho)\,\psi^\pi\left(\pi_t - \pi^*\right) + (1-\rho)\,\psi^y y_t + \rho\left(r_{t-1} - \bar{r}\right) + u_t^m \tag{13'}$$

where ψ^π and ψ^y denote the central bank's reaction to inflation and output, π^* is the long-run inflation target, $\bar{r}$ the long-term real interest rate augmented with π^*, and ρ the level of smoothing. The matrix A, which holds the contemporaneous structural relations, can be formulated as

[14] The output gap is based on the difference between observed and potential real GDP, calculated by the Congressional Budget Office (CBO). The inflation measure is given by the personal consumption expenditures (PCE) deflator. The interest rate is the quarterly average of the FFR.

$$A = \begin{bmatrix} 1 & -\alpha^s & 0 \\ 1 & -\beta^d & -\gamma^d \\ -\zeta^y & -\zeta^\pi & 1 \end{bmatrix} \quad (14)$$

In order to identify supply, demand and monetary policy shocks $\left(u_t^s,\ u_t^d,\ u_t^r\right)$, we use additional information about the elements within A. Next to the priors on the signs, our inference is also guided by prior information about the magnitudes. We allow for uncertainty about the model itself by weighting the elements in the identified set with their prior plausibility, which can be useful for generalizing identification schemes.[15] The priors for the contemporaneous coefficients are given by $\alpha^s > 0$, $\gamma^d < 0$, $\psi^y > 0$, $\psi^\pi > 0$, $(1-\rho) > 0$. Next to these sign restrictions, we include information on the prior mode and scale. Appendix C offers more details on the estimation procedure.

Additionally, we include three external variables to this VAR framework: the neutral rate, commodity prices and earnings. By adding a measure for r-star, we can gauge its behavior in the context of macroeconomic shocks.[16] Our approach is convenient for handling the uncertainty around the neutral rate, as the Bayesian priors assign plausibility to the different magnitudes. To our knowledge, we are the first to test how common measures of r-star respond to macroeconomic surprises in a VAR framework, offering insight into their dynamic properties and their usefulness for policy-making.

Next to the neutral rate, commodity prices and earnings are included as external variables. While the former helps mitigate the price puzzle, the latter offers insight into second-round effects arising from inflation.[17] Our estimation is based on quarterly data, and our full sample runs from the start of 1962 until the end of 2015.[18]

3.2 Time-Series for the Neutral Rate

For our main analysis, we extend the Holston-Laubach-Williams (2017) measure back

[15] Practically, we impose priors on the contemporaneous structural coefficients, the impacts of the shocks and the structural variances. We set plausible values for these parameters, but also take into account their uncertainty.

[16] Baumeister and Hamilton (2018) similarly augment the 3-variable system. In their larger dimensional system, the corporate spread is used instead of r-star. In our model, we add the prior belief that a monetary contraction raises the interest rate and the neutral rate, but lowers all other variables on impact.

[17] These variables are defined as 100 times the year-over-year log changes in the CRB commodity spot price index, and the average hourly earnings of production and non-supervisory employees.

[18] The sample size has been extended compared Baumeister and Hamilton (2018). Their estimation covers 1970Q1 to 2008Q4. Moreover, we estimate the BVAR over three subsamples, as explained in Section 3.3.

to 1924 using historical data.[19] The HLW algorithm can generate a long sample for r-star, which allows us to examine the impact of shocks on the neutral rate over different regimes. While the HLW measure has shortcomings, it remains prevalent in the academic literature and the policy debate.[20] Table 4 highlights the underlying data-series. Figure 4 displays both the original and the extended estimate.

In recent years, several modifications have been proposed for the HLW measure. These adjustments produce a more cyclical measure that increases after the GFC (e.g. Lewis and Vazquez-Grande, 2019; Hakkio and Smith, 2017). Interestingly, extending the starting point of the HLW measure back to the 1920s delivers these changes. The strong trend-wise drop over the last decades becomes less pronounced and the values post-GFC are comparatively higher. Our extension reveals the sensitivity of the HLW filtering method to its starting point (Buncic, 2024), and highlights the non-monotonic behavior of the neutral rate over a longer horizon (Eichengreen, 2015). The last hundred years show a strong mean-reversion, with significant movement in r-star before 1980. For example, from mid-1929 until 1933, the neutral rate decreased with almost 4 percentage points. Appendix B explores the time-series behavior of (ex-post and ex-ante) real rates over lengthy periods. For this purpose, we construct historical series for nominal rates and inflation expectations.

In contrast to the original HLW measure, we find that our extended measure is stationary. Multiple tests are reported in table 5. They all reject the presence of a unit root in our r-star measure.[21] This result is similar to findings in Rogoff et al. (2022). Over their full sample, real interest rates appear to be stationary around a declining trend.

3.3 Subsamples

We estimate separate impulse responses and historical decompositions for three subsamples to account for shifts in the monetary policy regime of the Federal Reserve (Fed) and in the macroeconomic environment of the U.S. during our estimation period. For example, Bianchi et al. (2022) identify a sequence of regimes based on the monetary policy spread.

[19] In subsection 4.1.1, we test the robustness of our results for other short-term r-star measures.

[20] Even if the HLW measure would deviate from the true unobserved value of r-star, it still represents a broad consensus on how society thinks about the neutral rate.

[21] Both the Augmented Dickey-Fuller test (Dickey and Fuller, 1979) and the Phillips-Peron test (Phillips and Perron, 1988) reject the null hypothesis that a unit root is present in the sample, while for the KPSS test (Kwiatkowski et al., 1992) we cannot reject the null hypothesis that an observable series is stationary around a deterministic trend (trend stationary).

The first subsample runs from 1962Q1 to 1979Q4. During this period, the economy was hit by a series of sizable macroeconomic shocks. The most important events were the collapse of the Bretton Woods system, which led to the end of the dollar's convertibility in 1971; and the oil shocks in 1973-74 and 1978-79. At this time, nobody at the Fed "placed a sufficiently high priority on stopping inflation" (DeLong, 1997, p.249). The monetary stance was overly expansionary in response to the shocks, leading to a loss in credibility and double-digit inflation.

The second subsample, from 1980Q1 to 1997Q4, covers the Volcker disinflation during which the Fed re-established its credibility and anchored inflation expectations. Initially, this process was costly in terms of output, causing a double-dip recession in the early 1980s. However, the subsequent Great Moderation period featured substantially lower variability for output and inflation (Kim and Nelson, 1999). This change has been linked to structural changes (McConnell and Perez-Quiros, 2000). Technological and institutional advances combined with improved business practices enhanced the ability of the U.S. economy to absorb shocks. The shocks hitting the economy also became more benign. At the same time, increased globalization put downward pressure on inflation by cutting the pricing power of labor and firms, thus lowering the probability of wage-price spirals (Borio, 2021a). Stable oil prices further helped stabilize the economy (Baumeister and Kilian, 2017).

The final subsample spans from 1998Q1 to 2015Q4. An important shift from the previous period is that the interest rate gap remained negative since 1998.[22] Next to the low-real-rates, this period is characterized by low-inflation and increasing debt levels (Mian et al., 2021). Financial cycles became more prevalent through financial liberalization. A well-known example was the speculative stock market boom spurred by massive investments in technology shares, which collapsed at the end of the 1990s after a period of high productivity growth (Brunnermeier and Schnabel, 2015). Even more consequential was the Great Financial Crisis of 2007-09, which started when problems in the subprime market worsened due to the failure of several subprime originators. Prior to this outbreak, there was a sharp increase in house prices, the build-up of a credit boom, and imbalances in global capital flows (Gorton and Metrick, 2012). During the post-GFC period, the downturn in financial markets spilled over to the real economy, leading to high unemployment and deflationary pressures.

[22] This measure calculates the difference between the real rate and its twenty-year moving-average.

To stimulate the economy, unconventional monetary policy measures were launched, most notably through large-scale asset purchase programs. Since the recovery was markedly slow, policy rates were kept low for an extended period, prompting the question whether low rates were the new normal (Bernanke et al., 2019).

4 Results

4.1 Impulse Response Functions

Figure 5 shows the structural posterior IRFs for the neutral rate. Each row focuses on the successive subperiods. The three columns respectively highlight the effect of a (positive, one unit) supply, demand and a monetary policy shock. The solid blue lines depict the posterior median, the shaded regions indicate the 68% posterior credibility set, and the dotted blue lines represent the 95% posterior credibility set.[23]

Over the three periods, positive supply shocks (featured in the first column of Figure 5) push down the values for r-star. A positive supply shock (e.g. an increase in productivity or a drop in wage mark-up) would lead to a temporary increase in the neutral rate of output, and thus imply a temporary drop in the neutral rate (Woodford, 2003).[24] While significant (within the 95% posterior credibility region), this effect is short-lived for the first and the third subperiod.[25] Moreover, the size of the response is relatively small for both periods.[26] In comparison, the response is larger for the second subsample, but on impact only significant within the 68% posterior credibility set. In this case, a one-unit increase in the supply shock leads to a drop in r-star of 12 basis points (bps); and its impact is longer-lasting.[27] Overall, the response of the neutral rate to supply shocks is relatively subdued. Following Smets and Wouters (2007), we would expect these shocks to have a substantial impact on r-star,

[23]The IRFs are illustrated over a twenty quarter horizon. Here, we focus on the IRFs that impact the neutral rate. The full set of results is reported in Appendix D, and are in line with the findings of Baumeister and Hamilton (2018). The methodology seems robust to the inclusion of r-star and the estimation over subperiods.

[24]Guerrieri et al. (2022) similarly describe how positive labor supply shocks temporarily lower r-star, whereby aggregate demand increases less than aggregate supply at constant interest rates.

[25]The impact of these supply shocks on r-star dies out after four and two quarters respectively.

[26]A unit structural supply shock on impact leads to a drop in the neutral rate of 6 bps (in the first period) and 3 bps (in the third period).

[27]The 68% posterior credibility region highlights a significant impact beyond two years.

as they affect the productive capacity of the economy.[28] However, the HLW estimate does not consistently pick this up for every subperiod.

The posterior IRFs for demand shocks, reported in the second column of Figure 5, show an increase of r-star over all three subperiods. A positive demand shock, e.g. a spike in confidence or an exogenous fiscal stimulus, is generally associated with higher investment and consumption. All other things being equal, this is in line with a higher neutral rate (Linde et al., 2022). The impact on r-star is significant and comparatively larger than for the supply shocks, with the exception of the third subsample. The reaction of the neutral rate to a unit structural demand shock is most pronounced in the second subperiod, reaching close to 15 bps on impact.[29] The effect of demand shocks is also more persistent, with confidence about the signs lasting beyond two years for the first and the third subperiod. For the second period, the impact is more short-lived, lasting up to one year.

Finally, a one-unit increase in the monetary policy shock u_t^m significantly pushes up the neutral rate across the three subperiods, as depicted in the third column of Figure 5. To the extent that restrictive monetary surprises can persistently push down near-term growth prospects, these shocks can lead to an increase in r-star. Several authors (e.g. McKay and Wieland, 2021; Mian et al., 2021) have introduced models in which r-star reacts endogenously to monetary policy. Some of the proposed channels operate through the impact on future consumption, the build up of debt, or via learning between the central bank and markets.[30] However, the prevailing Neo-Wicksellian view holds that r-star is largely exogenous to monetary policy (Woodford, 2003). Similarly, policymakers often claim that the short-term neutral rate is only influenced by non-monetary drivers of near-term GDP growth (e.g. Brainard, 2018; Kaplan, 2018).

Figure 6 offers a closer comparison between the change in the FFR (depicted in the first column) and the response of the neutral rate (in the second column).[31] For the first two subperiods, a one-unit increase in the monetary policy shock leads to a 50 bps response

[28] In their model, wage mark-up and productivity shocks explain most of the variation in output in the medium to long-run.

[29] For period one and period three, this response is respectively 9 bps and 4 bps.

[30] In Section 5.2 we discuss these channels more in-depth.

[31] Without immediate effects on output or inflation, the FFR would rise by 1% due to a one-unit increase in the monetary policy shock. However, the higher interest rates trigger output and inflation to fall on impact, which feeds back into the interest rate. As a result, the immediate increase of the FFR in response to the shock is lower, and differs for every period.

on impact for the FFR.[32] In both cases, the reaction for r-star is significant, but short-lived and small in size.[33] Both periods are characterized by relatively higher (nominal and real) rates (Figure B.2 and B.4). In contrast, the final subperiod represents a low rate-low inflation environment. For long periods, the Fed's stance was expansive and rates were kept low, reducing the available policy space. The pass-through of monetary policy shocks to the neutral rate during this period is much larger (about half of the FFR increase passes through to r-star) and longer-lasting (up to 6 quarters). More specifically, a one-unit increase in the monetary policy shock, which amounts to a rise of 20 bps for the FFR, leads to an uptick in r-star of 11 bps. When the economy is near the ELB, the pass-through of monetary policy surprises to the neutral rate is therefore not negligible.[34] This result holds both for our extended HLW measure as well as for the original HLW series.[35] In the next Section, we test whether this finding is robust for other measures of r-star.

Three observations can be distilled from our analysis. First, while demand shocks produce the expected response, the short-term r-star estimate seems to underreact to supply shocks and overreact to monetary policy shocks. This in part questions the prior assumptions about the HLW measure, as it underreacts to shocks that affect the near-term productive capacity of the economy, and overreacts to transitory demand shocks.

Secondly, the response of r-star to these shocks (particularly demand and monetary policy shocks) is persistent for most subperiods.[36] Their impact can last two years for some subperiods. As a result, shocks to the short-term neutral rate can be hard to distinguish from movements in its long-run trend, especially if they move in the same direction. We

[32] The shape of the FFR's response in the first subperiod, whereby the sign turns negative after several quarters, reflects the stop-go approach of the Fed under Chairman Burns (and in part under Chairman Martin). This affects the response of the neutral rate, which takes on a similar shape. In the second subperiod, this reversal does not occur, as the Fed adapted a new policy framework whereby it adjusted interest rates to stabilize changes in expected inflation.

[33] The response amounts to 3 bps on impact, with confidence about the signs only on impact for the higher posterior credibility region, and one quarter for its lower counterpart.

[34] Various channels can explain this impact. Lansing (2017) links monetary policy to r-star through its interaction with uncertainty and the demand for safe assets. DelNegro et al. (2017) highlight the importance of safety and liquidity. Hakkio and Smith (2017) examine how changes to the balance sheet influence the neutral rate through their effects on bond premiums. Benati (2020) shows that the M1 velocity has been closely related to the permanent component of the short rate.

[35] The response for the latter to the monetary policy shock is slightly smaller on impact, but then increases to its peak after three to four quarters. Respectively one-third and half of the monetary policy surprise is passed through to the 2017 and the 2023 version of the HLW measure. The latter was adjusted post-Covid. These results are not displayed due to space constraints, but can be requested.

[36] Lewis and Vazquez-Grande (2019) highlight that persistent but transitory shocks to the neutral rate better fit with the data-generating process, and can help us better understand its economic drivers.

would therefore caution against making inference about trends in the long-run neutral rate during periods without a similar adjustment in the underlying secular drivers. This difficulty in disentangling persistent short-run shocks from long-run movements may explain the disagreement on what drove low rates after the GFC. For example, Taylor and Wieland (2016) argue that yields remained deflated due to temporary factors such as the headwinds from credit deleveraging; while others (e.g. Asriyan et al., 2024) point at persistent real-side factors such as lower productivity and increased precautionary savings.

Finally, given the role of the neutral rate within central banks, the endogeneity between the FFR and r-star can complicate policy decisions. When the economy is near the ELB, the transmission to r-star is substantial. In this case, expansionary monetary policy may deflate the neutral rate, thus further reducing the headroom for policy (Borio, 2021a). Negative shocks to r-star are contractionary and deflationary, as they lower the trend path of output (Schmitt-Grohe and Uribe, 2022). We discuss these policy consequences in Section 5.1.

4.1.1 Robustness

The structural impulse response functions for the HLW estimate reveal a strong impact of monetary policy shocks at the ELB, which violates the widespread belief that the neutral rate should only be influenced by non-monetary drivers of near-term growth. In order to examine how measure-specific this finding is, we test the robustness for other short-run r-star estimates.

For this analysis, we focus on the final subsample, and report the IRFs for the monetary policy shock. We include the response of the FFR together with the response of the specific r-star estimate under investigation.[37] We examine several measures across the three categories, e.g. macro, structural and financial measures.[38] Overall, our finding that the neutral rate is endogenous to monetary policy surprises is robust across the different proxies.[39]

[37] In case there would be no immediate effect of a one unit monetary policy surprise on output or inflation, the FFR would increase by 1%. In our specification, the shock triggers output and inflation to fall on impact. It also evokes a response of the neutral rate, which is different across measures. These responses feed back into the interest rate. Hence, the immediate increase in the FFR becomes lower.

[38] For each category, we present the IRFs for the main measures in the text, while additional results are displayed in Appendix D due to space constraints.

[39] While most short-run r-star measures exhibit endogenous responses to monetary policy when the economy is at the ELB, this does not hold for long-run or smoothed measures. We test several popular measures, e.g. the smoothed measures of HLW (2017) and the adjusted version by Buncic (2024), and find no response of these long-run r-star measures to monetary surprises.

Macro measures

The top panel of Figure 7 shows the impact for the Lewis and Vazquez-Grande (2019) measure. Similar to our main result, the monetary policy shock triggers a 30 bps policy response, half of which is passed through to the r-star measure (18 bps). The impact peaks after three quarters, and remains significant for four to five quarters.

For the HLW correction by Buncic (2024), we also find an endogenous reaction, but on impact the response is not significant. The IRFs are depicted in the top panel of Figure D.7 in Appendix D. The response becomes significant after three quarters, peaks after four quarters, and lasts up to six quarters. Overall, the reaction of this measure is comparatively smaller, as only 20 percent of the policy reaction is passed on.

Structural Measures

We examine the five-year DSGE measure by DelNegro et al. (2017), as this structural measure is often cited along with the HLW measure. The second panel of Figure 7 shows a strong pass-through. On impact, more than half of the change in the FFR trickles through into the DSGE estimate. At its peak, after two and half quarters, this pass-through becomes complete. Moreover, this effect is long-lasting, up to nine quarters.

For the Roberts (2018) measure we find a smaller response of the neutral rate on impact. However, this response peaks after three quarters, and amounts to three-quarters of the policy response. The IRFs are displayed in the middle panel of Figure D.7.

Financial Measures

For the Han and Ma (2023) measure, depicted in the third panel of Figure 7, the pass-through of the monetary policy surprise is immediate and substantial. At its peak, after two to three quarters, more than 60 percent of the policy response transmits to the neutral rate. For the Christensen and Rudebusch (2019) measure, we find a similar response. The pass-through is almost complete, and significant up to five quarters (as highlighted in the lower panel of Figure D.7).

Finally, we show the results for the Kim et al. (2019) measure in the lower panel of Figure 7. While our list is not exhaustive, this is the only measure in our analysis with a limited response to the monetary policy shock. Only ten percent of the change in the FFR passes through into the r-star measure. Moreover, this reaction is only significant for one to two quarters.

4.2 Historical Decomposition

Figure 8 depicts the portion of historical variation in the neutral rate assigned to each structural shock. These contributions are highlighted by the solid blue lines, while the shaded regions and the dotted blue lines indicate the 68% and 95% posterior credibility sets.[40] The three columns are respectively assigned to supply, demand and monetary shocks. The rows indicate the subsequent subperiods.

Period 1 (1962-1979)

For the first subperiod, the contributions of **demand and monetary policy shocks** to the neutral rate follow a comparable pattern.[41] Positive demand shocks, e.g. unanticipated hikes in government spending, are expected to lift the neutral rate temporarily. Similarly, to the extent that restrictive monetary surprises push down near-term growth prospects, these shocks potentially lead to an increase in r-star. At the start of the subsample, both shocks have a downward impact on the neutral rate. This period coincides with the aftermath of the 1960-61 recession. While economic activity had recovered in 1961, unemployment and unused capacity still remained elevated.[42] From the start of this subperiod in 1962 until 1966, demand shocks contribute negatively to the neutral rate. Around this time, the stance of the Federal Reserve became more expansionary due to a shift in beliefs and a more optimistic assessment of the economy (Bordo and Eichengreen, 2008).[43] Until the mid-sixties, however, policy choices were constrained by the balance of payment deficit. As a result, the downward contribution of monetary policy shocks only peaks around 1966, when the FOMC did not tighten its policy stance despite rising inflation pressures.

From the late sixties onward, the sign of the contribution for both shocks reverses. Fueled by expansionary fiscal and monetary policy, the economy grew strongly. By the

[40] When discussing the results, we focus on the 68% credibility region.

[41] The impact of demand shocks often comes first. The monetary policy responses to these demand shocks in turn generate their own impact on the neutral rate.

[42] In March 1962, 5.5 percent of the labor force was still unemployed, compared to the peak of 7.1 percent in May 1961 (Hirsch, 1962).

[43] From 1951 until 1970, William McChesney Martin was chairman of the Fed. During the first part of his tenure, Martin was concerned with maintaining low inflation to achieve long-run growth and with managing the balance of payments as part of the Bretton Woods System (Bordo and Prescott, 2022). However, the rise of Keynesian economics and the influence of the Kennedy/Johnson administration pushed the Fed to a more accommodative stance (Romer and Romer, 2004).

end of the decade, unemployment fell to 3.5 percent, while inflation increased to 6 percent (Fessenden, 2016). The positive impact of demand shocks peaks in 1968. At that point, the Fed intervened by tightening the money supply from 8 to 2 percent on a year-on-year basis. The FFR increased from 4.5 to 9 percent (Bostic, 2022). For this period, monetary policy shocks contribute positively to r-star, with their largest impact around 1970.

However, as the 1969-1970 recession led to sizable increases in the unemployment rate, the Fed reversed its course (Collins, 1996). By late 1971, the money supply was rapidly expanding again (at a rate of 13 percent year-on-year), while inflation was rising and unemployment was declining (Altig and Robertson, 2022).[44] At this point, the impact of monetary policy shocks on the neutral rate becomes negative. Similarly, the impact of demand shocks turns negative from 1971 onward; with a slight exception at the end of 1974, when the stock market recovers. This period encompasses the collapse of Bretton Woods in 1971-73 and the first oil price shock in 1973-74, which worsened the inflation pressures.

For the final part of the subsample, both shocks contribute positively. While the impact of demand shocks only turns positive in 1978, this already happens in the mid-seventies for monetary policy shocks. FOMC members regained the belief that restraining aggregate demand could lower inflation. In 1974, the Fed's policy became more contractionary while output was declining. However, the positive impact of monetary policy on r-star is short-lived. By the end of 1976, the stance was loosened again, despite rising inflation and lower unemployment (Romer and Romer, 2004).[45] After the appointment of Paul Volcker in August 1979, the Fed committed to lowering inflation. In the last part of our subsample, the impact of monetary policy shocks increases the neutral rate. These positive contributions become significant from mid-1978 onward, but shoot up after Volcker's tenure starts.

Overall, the contributions of demand and monetary policy shocks on r-star are substantial during this period. This goes against the common belief that the neutral rate is only influenced by shocks that affect the near-term productive capacity of the economy. Moreover, the impact of these contributions is persistent. As a result, shocks to the short-term neutral

[44] Arthur Burns took over as chairman of the Fed in February 1970. Burns was pessimistic whether monetary policy could control the high inflation rates, since he believed these hikes were driven by a rise in public sector unions, cost-push shocks, fiscal deficits, monopolistically competitive firms, and inflation psychology (Goodfriend, 2007). As a result, the real interest rate averaged close to zero during Burns' first three years as chairman, and was at times strongly negative (see Figures B.3 and B.4).

[45] This illustrates the stop-go approach in fighting inflation during the tenure of Chairmen Martin and Burns. The expansionary stance continued during G. William Miller's short stint as Chairman in 1978.

rate can be hard to distinguish from movements in the long-run trend.

The contributions of **supply shocks** during the first subsample are comparatively smaller and more volatile. Negative supply shocks (e.g. wage mark-up shocks) typically push up r-star. At the start of the sample, from 1962-64, when the economy was still recovering from the 1961-62 recession, supply shocks contribute positively to the neutral rate. Supply shocks had similar positive contributions around 1968 (coinciding with the economic crisis), 1971, 1974 (during the first oil price shock), and from 1977 until 1978.[46] However, their impact is limited given the importance of supply shocks during this period, thus revealing an underreaction to shocks that temporarily affect the neutral rate of output.

In contrast, the impact of supply shocks to the neutral rate was negative around 1966, 1973 and 1976. While productivity slowed down substantially from the late 1960s onward, these episodes each exhibit sharp drops in the unit labor costs (Blinder and Rudd, 2008).[47]

Period 2 (1980-1997)

For the second subperiod, **demand shocks** again play an important role for r-star. At the start of the sample, their impact is volatile. We discern a strong negative contribution in 1980, which turns briefly positive in 1981.[48] However, their impact continues to be negative until the end of 1983.[49] Akhtar and Harris (1992) argue that the fiscal mix during the early 1980s, which combined a large budget deficit with a reduction in public infrastructure investment, had been harmful for the growth potential. In the subsequent period, between the mid-eighties and 1990, demand shocks push up r-star, with a short exception around 1988. This coincides with a period of elevated sentiment. From 1983 onward, consumer confidence indices soared and remained high for the decade; except for a moderate and short-lived drop due to the stock market crash in October 1987 (Croushore, 2005).

During the 1990-91 recession and the subsequent slow recovery until 1996, demand shocks contribute negatively, with their strongest impact in 1991. This period is characterized by restrictive fiscal policy, low levels of consumer confidence, corporate restructuring, a

[46] In contrast, during the second oil crisis in 1979-80, we cannot detect any significant impact from supply shocks on the neutral rate.

[47] This coincides with periods when real GDP per capita grew strongly.

[48] The outlier in 1981 aligns with a short period when the economy recovered in the midst of the double-dip recession. This recovery began in the second half of 1980 and extended into 1981 (Hetzel, 1986). Moreover, there was a short-lived tax cut by the Reagan administration in 1981 (McCaleb, 1984).

[49] This period covers the double-dip recession at the start of the 1980s during which Volcker's policy shift pushed the FFR considerably higher. By the end of 1982, the unemployment rate had risen to 10.8 percent.

depressed commercial real estate market, and an unwinding of defense spending (Akhtar, 1994). For the last two years of the subsample, from 1996 until 1998, the contribution of demand shocks reverses again, and becomes strongly positive.

The impact of **monetary policy shocks** to the neutral rate for this period is relatively small. At the start of the second subsample, around mid-1980, monetary policy shocks push down r-star.[50] After that, their contribution is positive until the middle of 1982.[51] This corresponds with the period of tighter monetary policy under chairman Volcker. Compared to the importance of monetary policy decisions over this period, the size of the contributions is limited. This subdued impact is in line with our observation from the IRFs that the pass-through is strongest when the policy rates are at the ELB.

For the remainder of the second sample, we observe small negative contributions in 1983 and 1996.[52] These episodes can be associated with the aftermath of slowdowns, when the Fed lowered its policy rate to stimulate the economy. They cover the double-dip recession in the early 80s and the Peso crisis from 1994-1995. In contrast, the contribution is positive from 1988 until the end of 1991.[53] Romer and Romer (1994) highlight that the downturn in 1990-91 was preceded by a Fed tightening that started in December 1988.

Supply shocks have a strong positive impact on the neutral rate at the start of the second subsample. Baumeister and Peersman (2013) show how oil supply disruptions mattered for the real economy during the early eighties. This impact lasts up to 1984, but the effect is smaller after 1981. Hikes in food and oil prices became less pronounced from early 1981 onward (Miller, 1983). After that, the impact of supply shocks turns negative until 1990; except for a brief positive contribution during the stock market crash in 1987, which is not significant. These contributions are strongest in 1986 and 1989.

[50] During the late spring of 1980, as the Special Credit Restraint Program program ended, the FFR was too low to prevent a monetary acceleration. The economy recovered and credit demand surged. Additionally, borrowed reserves increased due to an overshoot of the M1 target in August (Hetzel, 1986).

[51] By October 1982, inflation had fallen to 5 percent, and the long-run interest rates began to decline. The FFR was allowed to drop, and unemployment quickly declined from its peak of nearly 11 percent by the end of 1982 to 8 percent one year later (Goodfriend and King, 2005).

[52] We also find negative contributions during (the second part of) 1987 and 1992, but neither are significant. After the stock market crash in 1987, the Fed acted as a lender to alleviate the demand for certain maturities of US Treasury securities. It also intervened in the rescue of Chicago's largest options clearing firm. The adjustment in the FFR was minor (Bernanke, 1990). Similarly, after the credit crunch in the early 90s, the credit channel of monetary policy shut down, making the real effects of monetary easing less pronounced. The FFR was gradually lowered, and a soft landing was achieved (Bernanke et al., 1991).

[53] We find similar positive contributions from monetary policy shocks in 1984, and from 1985 until 1987. However, these are small in size and not significant.

During the second half of the sample, the impact of supply shocks is mainly positive. However, these contributions are small in size and not significant, except for the peak in 1990Q3.[54] Only by the end of the subsample in 1997, the contributions turn negative again. However, their impact is not significant. During this period, the economy experienced a marked acceleration in productivity growth, averaging 2.8 percent from 1996 to 2000. Rapid advances in information technology spurred positive supply shocks, which improved the outlook for inflation and boosted potential growth (Jorgenson et al., 2008). Despite the importance of these shocks for the near-term productive capacity of the economy, they do not contribute to the neutral rate.

Period 3 (1998-2015)

During the first half of the final subsample, the contribution of **supply shocks** is relatively subdued. We observe small positive contributions around 2001 and similarly for 2003; albeit not significant. Since the early 2000s, the relevance of oil supply shocks for macroeconomic fluctuations gradually increased (Baumeister and Peersman, 2013). However, their contribution to the neutral rate remains limited. After that, the contributions turn marginally negative until 2004; but these are not significant. Fernald (2015) argues that after 2004 productivity moved from a high-growth to a low-growth state. While the impact of supply shocks is positive from mid-2004 until mid-2006, this effect is small in magnitude and not significant. For the first part of the subsample, the neutral rate again seems to underreact to shocks that affect the near-term growth potential.

In contrast, supply shocks have a more profound impact in the second part of the subsample, with a strong positive contribution from mid-2007 until mid-2009. Hamilton (2009) identifies an oil price shock during this period, which led to a substantial price run-up in 2007-08.[55] Additionally, we observe negative contributions in mid-2010 when unit labor-costs dropped markedly; with their year-on-year growth rates reaching a trough in the second quarter of 2010. Similarly, supply shocks have a small negative contribution from mid-2012 onward until the end of the sample. This is most pronounced in 2013 and 2015. Baumeister and Kilian (2017) report a sharp and prolonged drop in the global price of crude

[54]Baumeister and Peersman (2013) argue that oil supply shocks contributed to the 1991 recession.

[55]This supply shock had a substantial impact on consumption spending, and specifically on the purchase of domestic automobiles.

oil and the U.S. price of gasoline after June 2014.

At the start of the second subsample, from 1998 until mid-2001, **demand shocks** contribute positively. However, this impact dies out rapidly. At the time, the U.S. economy was facing a speculative stock market boom; as households invested massively in new technology shares (Brunnermeier and Schnabel, 2015). Baker and Wurgler (2007) report that investor sentiment was high before the collapse of the dot-com bubble in 2000. During this period, the neutral rate reacts strongly to transitory demand shocks. From mid-2008 onward, the contributions turn significantly negative, and remain so until the end of 2011. Most measures of uncertainty increased during the GFC, and stayed elevated during lengthy parts of the recovery. Leduc and Liu (2016) argue that these surges worsened the recession and impacted the slow recovery. These demand shocks affected the productive capacity more profoundly, hence their strong contribution to r-star is in line with expectations. For the latter part of the subsample, the impact of demand shocks is not significant.

While the contribution of **monetary policy shocks** is positive in 1998, their impact is otherwise not significant for the first part of this subsample.[56] Subsequently, from 2006 until mid-2007, we can discern a significant positive impact of monetary policy shocks.[57] The sign of the contributions reverses during the GFC, when the Fed lowers its policy rate and engages in quantitative easing (QE) programs.[58] The largest negative contributions can be observed in 2008 and 2010. Hence, at the time of the GFC both demand and monetary policy shocks significantly push down the neutral rate. There is a comparable negative impact of monetary policy surprises from mid-2014 until the end of 2015.

During most of the post-GFC period, the FFR was kept near the ELB, as inflation remained below target and the recovery was anemic. Overall, the neutral rate seems to react strongly to monetary policy shocks when the policy space is constrained. This finding contradicts the prevailing Neo-Wicksellian view that r-star is exogenous to monetary policy.

[56] Bordo and Haubrich (2010) describe how the recession of 2001 was preceded by a modest monetary policy tightening. The policy rate went from 4.5 percent in November 1998 to 6.5 percent in June 2000.

[57] Before the GFC, the Fed engaged in a tightening cycle starting in June 2004. This contrasts with the preceding three years, during which rates were kept markedly low.

[58] Here, we focus on the impact of conventional monetary policy shocks on the neutral rate.

5 Discussion

Our results raise several policy questions. How should the Federal Reserve deal with r-star given its imprecise estimates and its endogeneity with monetary policy? Additionally, given the strong pass-through of the FFR to r-star when the economy is at the ELB, how should we think about the effectiveness of monetary policy during these periods?

5.1 Role of r-star in policy making

When choosing the optimal stance, policymakers often turn to r-star as a reference guide, especially at times of increased uncertainty. By adjusting the policy rate to movements in the short-term neutral rate, central banks may aim to stabilize the economy (Brainard, 2018). For example, the Taylor rule prescribes a policy rate based on the values of output and inflation relative to their equilibrium rate (Taylor, 1993). R-star can thus indicate whether the monetary stance is accommodative, neutral or restrictive (Kaplan, 2018).

However, two caveats should be considered when using r-star in a policy framework. First, estimates of the neutral rate are found to be inaccurate and often revised with incoming data (Beyer and Wieland, 2019). Figures 1 to 3 show a strong divergence between these estimates. Since equilibrium rates are unobservable, they are subject to a substantial amount of estimation uncertainty. Policymakers may therefore make costly policy mistakes by misconstruing r-star (Ajello et al., 2021). For example, the high inflation during the mid-sixties and seventies was partly caused by a focus on imprecise and overly optimistic real-time estimates of the natural rate of unemployment, while ignoring rising inflation expectations (Orphanides and Williams, 2013).

Second, our analysis shows that standard estimates of the short-run neutral rate also react to monetary policy surprises, and hence to transitory demand shocks. This endogeneity questions the widespread assumptions about these measures, and complicates their use. Policymakers should be cautious when using r-star to justify their policy decisions, as shocks can dictate the trajectory of their seemingly optimal policy rate.[59]

[59] Friedman (1968, p. 10) phrases this concern as follows: *"The "market" rate will vary from the natural rate for all sorts of reasons other than monetary policy. If the monetary authority responds to these variations, it will set in train longer term effects that will make any monetary growth path it follows ultimately consistent with the rule of policy. The actual course of monetary growth will be analogous to a random walk, buffeted this way and that by the forces that produce temporary departures of the market rate from the natural rate."*

Moreover, the response of short-run neutral rate measures to macroeconomic shocks is persistent, and can be confounded with movements in the long-run neutral rate, especially when they move in the same direction. For example, post-GFC it was hard to distinguish whether short-term shocks or long-run secular drivers were driving down r-star. In contrast, when they diverge, shocks can create a persistent wedge in the term-structure of r-star, which may necessitate a policy response (Beaudry et al., 2025). Policymakers have acknowledged the dangers of such persistent deviations. For example, during the post-pandemic inflation period, Powell (2022, p.2) highlighted that "in current circumstances, with inflation running far above 2 percent and the labor market extremely tight, estimates of longer-run neutral are not a place to stop or pause." The short-run neutral rate was believed to have transcended its long-run counterpart due to the shocks hitting the economy, as indicated by real-time inflation pressures and labor market shortages.

Given this complexity, we need to consider the risks of misperceiving the neutral rate. Ajello et al. (2021) highlight that whenever the economy is close to the lower bound, the cost of overestimating the neutral rate is higher than the converse cost. In this case, choosing a lower r-star estimate becomes a safer policy choice since overestimation is harder to correct. This asymmetry is due to the limits on the policy space arising from the ELB. Bhattarai et al. (2022) focus on the interaction between monetary and fiscal policy. They caution against a monetary policy rule that targets r-star when the fiscal space is constrained, stating that this could lead to macroeconomic instability and welfare loss.

How should policymakers best deal with these concerns? Powell (2018) discusses a risk-management strategy, whereby multiple Reserve Banks produce estimates of r-star. Working with a range of measures allows policymakers to assess how changes in the assumptions impact the estimates (Sablik, 2018). Moreover, the Federal Open Market Committee takes a careful approach whereby it waits to see whether the information from the equilibrium rates translates into the observable variables. This entails the monitoring of a broad set of variables beyond inflation to detect the build-up of pressures. Lane (2025) adds a time-dimension to the usefulness of r-star for policy decisions, acknowledging the benefits of demonstrating that policy is accommodative/restrictive relative to neutral whenever inflation runs far below/above its target. However, when inflation moves closer to target, he advocates for shifting the focus to observables and the strength of monetary transmission, since the medium-term outlook becomes more reliant on the shocks hitting the economy.

5.2 Monetary Policy Transmission to R-star

The literature offers several transmission mechanisms to explain how monetary policy can impact the neutral rate. Our analysis shows that this pass-through is strong when the economy is at the ELB. In this case, monetary policy accommodation may further deplete the available policy space by lowering r-star. Most of these channels involve an inter-temporal trade-off at the expense of durable consumption, financial fragility, or debt accumulation in the future. Other channels operate through information feedback between the central bank and financial markets, or entail some degree of capital misallocation.

McKay and Wieland (2021) argue that monetary stimulus prompts households to bring forward the purchase of durable goods. While this shift helps demand today, fewer households require goods going forward, forcing interest rates to remain low. Accommodative monetary policy thus lowers $r*$ in the next period. Moreover, prolonged periods of low policy rates risk the build-up of financial imbalances, and may lead to larger future output losses. Rungcharoenkitkul et al. (2019) coin this process as monetary hysteresis. The ensuing financial vulnerability involves a self-perpetuating feedback between credit conditions, asset prices and risk-taking. Akinci et al. (2021) therefore propose an alternative r-star measure (known as r**) as a benchmark for financial stability, similar to using the neutral rate as a metric for macroeconomic stability.

Another channel operates through the build-up of debt. Mian et al. (2021) show that expansionary monetary policy can cause debt-driven booms in the short-run, while leading to depressed demand and lower neutral rates when the stimulus fades and the debt repayments are due. Central banks may then face pressure to maintain their level of accommodation, pushing policy rates lower to the ELB. Additionally, high levels of private and public debt make the economy more vulnerable to rate hikes, as they can cause deleveraging shocks that depress aggregate demand (Eggertson and Krugman, 2012).

Rungcharoenkitkul and Winkler (2021) show how the interaction between the central bank and the private sector can create a hall-of-mirrors effect that explains much of the decline in real rates since the eighties. Their model contains endogenous beliefs and learning feedback, whereby each side tries to discover the counterpart's private information. In this setting, expansionary monetary policy shocks can trigger downward revisions in the perceived r-star, thus causing a secular trend without changes in the fundamentals.

When interest rates are low, the pass-through of monetary policy is typically weaker. For example, monetary stimulus has less impact on external financing constraints of banks (Heider and Leonello, 2021). Banks also find it harder to pass on reductions in the policy rates to depositors (Brunnermeier and Koby, 2018). Moreover, low-rate environments affect investment patterns and lead to capital misallocation. They allow less productive entrepreneurs to invest more; which raises the equilibrium price of capital, crowds out more productive entrepreneurs, and triggers a fall in aggregate output (Asriyan et al., 2024).

This overview highlights that aggressive monetary policy accommodation may be less effective when the economy is at the ELB. Policymakers may then need to revert to less conventional macroeconomic policies in order to escape a liquidity trap (Garga and Singh, 2021; Fornaro and Wolf, 2023). These could range from redistribution policies and fiscal interventions (aimed at boosting investment) to moving away from a strict inflation targeting rule. Ohanian (2018) argues that the focus of central banks should be on long-run growth policies instead of short-term stabilization.

6 Conclusion

The contributions of the paper are threefold. First, we test the reaction of commonly used estimates of the short-term neutral rate to macroeconomic shocks in a structural Bayesian VAR. For our main analysis, we extend the HLW(2017) measure by incorporating historical data. Our structural impulse response functions produce the expected outcome for demand shocks, but the estimate for r-star seems to underreact to supply shocks and overreact to monetary policy shocks. This result challenges the widespread beliefs held on the behavior of the neutral rate, as the HLW estimate underreacts to shocks that affect the near-term productive capacity of the economy, and overreacts to transitory demand shocks. When the economy is in a low-rate environment, expansionary monetary policy has a forceful downward impact on r-star. This finding is robust across a range of r-star measures; based on macroeconomic, structural and financial estimates. Moreover, the response of the short-run neutral rate to macroeconomic shocks, particularly demand and monetary policy shocks, is relatively persistent. As a result, shocks to the short-term neutral rate can be hard to distinguish from movements in the long-run trend. During the period post-GFC, declines in the short-term r-star may have reinforced the declining long-run trend in the neutral rate. Our main results are confirmed by the historical decompositions. For example, supply shocks due to the oil price hikes in the seventies or during the productivity boom in the late nineties did not contribute substantially to the neutral rate. In contrast, transitory demands shocks often contributed strongly and persistently to r-star. Their impact is surprising, as many of these shocks had little effect on the near-term growth potential of the economy.

Second, we construct expanded time-series for the neutral rate (as well as for nominal and real rates) in the U.S. by combining historical data sources, thus yielding monthly and quarterly series that are useful for macroeconomic analysis. There has been a lot of attention for the secular decline in the real rates since the eighties. However, when we expand our sample, the eighties appear to be an aberration driven by period-specific shocks, which rules them out as a suitable benchmark. Historically, periods with high real interest rates tend to be outliers and are mostly short-lived, after which the yields moderate back to their long-run averages. We unravel similar non-monotic behavior when we extend HLW's estimate of the neutral rate back to the 1920s, with significant movements in r-star before 1980. Hence, the drop in r-star over the past three decades is not unprecedented.

Third, our analysis adds to the current debate around the efficacy of the neutral rate and its use within central banks. Estimates of the neutral rate are found to be unstable and imprecise. Moreover, standard measures of r-star should be interpreted as short-term concepts that can be influenced by cyclical forces; and not as long-term returns absent of shocks. Unexpected changes in the economic environment thus have the potential to alter the term-structure of r-star. In case monetary policy focuses on short-term stabilization, it may be committed to respond when the short-term neutral rate deviates persistently from its long-run trend. Central banks should therefore be cautious on how much weight they put on the neutral rate when making or deliberating their policy decisions, as shocks could dictate the trajectory of their seemingly optimal policy rate.

An additional concern emanates from the endogeneity between monetary policy and r-star, particularly when the economy is at the lower bound. For example, the monetary stimulus post-GFC pushed down the neutral rate, thus further depleting the policy headroom. In these circumstances, the policy response should be geared towards long-run growth, since negative shocks to the neutral rate are found to be deflationary and contractionary. The transmission channels for this endogeneity involve an inter-temporal trade-off at the expense of durable consumption or debt accumulation in the future. Moreover, low rates have been associated with financial fragility concerns, and in particular with increased risk-taking, over-leveraging and asset price misalignment. Other channels operate through the feedback of information between the central bank and financial markets, or entail some degree of capital misallocation.

Our analysis offers two potential paths forward. On the one hand, an increased awareness with policymakers about the interaction between monetary policy and the neutral rate can facilitate finding the optimal policy mix. At times of uncertainty about the future rate path, the neutral rate plays an important role in the policy debate. We aim to improve the understanding of how commonly used measures of r-star are affected by macroeconomic shocks. On the other hand, our findings can be conducive for the development of new measures. In this case, it could be useful to model the relation between the neutral rate and the monetary policy surprises more explicitly when producing estimates of the neutral rate. Similarly, allowing persistent yet temporary shocks to affect the neutral rate could further improve existing estimates.

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Tables and Figures

Table 1: R-star based on Macro Data - Structural Estimates (regular/smoothed)

Research Paper	Abbreviation	Period	Explanation
Del Negro et al. (2017)	DGGT(2017)-DSGE	1960q1-2016q3	Medium-scale DSGE model with nominal, real, and financial frictions; r* is calculated as the real return to an asset that is as safe/liquid as a 3m U.S. Treasury bill in a counterfactual economy without nominal rigidities;[60]
Ferreira and Shousha (2023)	FS(2023)	1990q1-2020q1	Estimate r* from 1960 to 2019 for 11 advanced economies based on a measure of the global supply of sovereign safe assets that takes into account the government's accumulation of international exchange reserves in sovereign safe assets;[61]
Gonzalez-Astudillo and Laforte (2020)	GL(2020)	1962q1-2020q1	Semi-structural model to estimate trend/cyclical factors of key macro variables; includes a monetary policy rule and an equation for the 10y Treasury yield to infer r*; uses Bayesian estimation with a Tobit-like specification to deal with the censoring problem, as the sample spans the GFC period
Roberts (2018)	R(2018)	1990q1-2017q4	SR and LR r* estimates, using an adjusted IS curve equation and simplified DSGE framework. Different estimates are presented, using CBO outputgap, testing the interest rate sensitivity, and with a 4 month moving average;[62]
Wynne and Zhang (2018)	WZ(2018)	1961q1-2014q3	2-country version of the semi-structural LW (2003) model; assumes perfect risk sharing and complete international asset markets; a simple natural rate determination equation links the countries: r* is therefore related to the trend growth in both the home and foreign country; the estimation avoids the "pile-up" problem by properly incorporating the prior information
Zaman (2025)	Z(2025)	1960q1-2022q1	Flexible semi-structural model to jointly estimate several macroeconomic stars, i.e., unobserved LR equilibrium levels of output (and growth rate of output), the unemployment rate, the real rate of interest, productivity growth, the price inflation, and wage inflation; explicit role of LR survey forecasts in the econometric estimation of the stars

[60] The model also produces an r-star yield curve: forecasts of the short-term natural rate of interest at the 20- and 30-year horizons for the DSGE. This allows to isolate persistent movements in real interest rates. The 30y forecasts are naturally more smoothed than SR versions

[61] This framework accounts for the supply of sovereign debt, demand for safe assets, trends in productivity growth, demographic changes, and global spillovers in the determination of neutral rates

[62] We only include the main SR and LR r* estimates in the figure. The additional measures can be requested.

Table 2: R-star based on Macro Data - Empirical Estimates (regular/smoothed)

Research Paper	Abbreviation	Period	Explanation
Bauer and Rudebusch (2020)	BR(2020)-UC	1960q1-2018q1	Simple univariate unobserved components model with moving averages of real GDP and labor force growth
	BR(2020)-SSM	1960q1-2018q1	Based on the nominal short-term rate and inflation in a state-space model with a latent real rate and r*
	BR(2020)-Prox	1960q1-2018q1	Model-free estimate of r*, using a exponentially-weighted moving average of past real rates
Buncic (2024)	B(2024)	1961q1-2019q4	Correction for HLW's (2017) use of Stock and Watson's MUE
Curdia et al. (2015-JME)	CFNT(2015)	1987q2-2016q3	Bayesian estimation (using a Kalman filter) of a model with real GDP, Core PCE deflator, and the FFR
Del Negro et al. (2017) (updated to 2021q2)	DGGT(2017)-VAR	1960q1-2018q1	VAR with common trend; uses data on nominal bond returns, inflation, and their LR survey expectations; extracts the permanent component of the real interest rate
Hakkio and Smith (2017)	HS(2017)	1962q1-2018q3	Augment LW(2003) model with both a term premium and a risk premium
Holston, Laubach and Williams (2017)	HLW(2017); HLW(2023)	1961q1-2023q2	Simplification of LW(2003); applies a Kalman filter to real GDP, inflation, and the SR interest rate to extract persistent components of the natural rate of output, its trend growth rate, and r*. HLW (2023): accounts for time-varying volatility; incorporates a persistent COVID-19 supply shock
Kiley (2015)	K(2015)	1965q1-2018q1	Augments the LW model with changes in financial conditions. Features the baseline and augmented model, referred to as model (1) and (3) in the paper
Krustev (2019)	Kr (2019)	1961q1-2016q4	Extends LW (2003) model by introducing an explicit role for the financial cycle in the joint estimation of r*, unemployment and output, and the sustainable growth rate
Laubach and Williams (2003)	LW(2003), LW(2023)	1961q1-2023q2	Simple New Keynesian macro model with Kalman filter to extract r*; HLW (2023) adapts the model for COVID-19
Lewis and Vasquez-Grande (2019)	LV(2019)	1961q1-2018q2	Re-estimate benchmark HLW (2017) model with less restrictive prior distributions on the parameter space regions. Data seem to prefer r∗ to be affected by transitory shocks
Lopez-Salido et al. (2020)	LSSW(2020)-BCS-LIV	1962q1-2019q4	3 specifications of the HLW model with different inflation expectation terms: the Livingston Survey ("Liv"), the Blanchard, Cerutti, and Summers (2015) survey ("BCS"); or past inflation as in HLW. The first term is the LR measure, whereas the second gives the SR measure;[63]
Lubik and Matthes (2015, 2023)	LM(2015, 2023)	1967q1-2023q2	Simple 3 variables TVP-VAR (real GDP growth, PCE inflation rate, and real interest rate); uses the conditional LR (5y) forecast of the real rate as a measure of r*

[63] We only report the BCS-Liv measure in order to keep the figure readable. The additional measures can be requested. Similarly, the authors also estimate the HLW model using core PCE and core CPI inflation.

Table 3: R-star based on Financial Market Data

Research Paper	Abbreviation	Period	Explanation
Abrahams et al. (2016)	AACMY (2016)	1999q1-2018q3	Term structure model that relies on TIPS yields to generate real-time measures of inflation expectations; model the TIPS liquidity premium as a function of observable liquidity metrics;[64]
Ajello, Benzoni, and Chyruk (2012)	ABC(2012)	1985q3-2018q4	No-arbitrage term structure model of nominal yields and inflation used to generate real-time measures of inflation expectations; does not use either inflation swap or TIPS; model has both latent and observable factors, with multiple inflation series as the observable factors
Christensen et al. (2010)	CLR(2010)	2003q1-2018q2	Term structure model used to generate real-time measures of inflation expectations; relies on TIPS yields; ignores the lower liquidity of TIPS and excludes the earlier TIPS sample;[65]
Christensen and Rudebusch (2019)	CR(2019)	1998q2-2016q4	Term structure model of real yields that accounts for time-varying term and liquidity risk premiums, estimated directly from prices of TIPS; the model assumes that the LR expectations embedded in TIPS prices reflect views about the steady state of the economy including the r*
	CR(2022)	1998q2-2022q2	Update of CR(2017) estimates provided by Kim et al. (2019)
Han and Ma (2023)	HM(2023)	1972q1-2021q2	Shadow rate no-arbitrage term structure model with drifting trends
Haubrich et al. (2012)	HPR(2012)	1983q1-2018q3	Term structure models used to generate real-time measures of inflation expectations; the model uses nominal Treasury yields, survey inflation forecasts and inflation swaps (instead of TIPS yields);[66]
Johannsen and Mertens (2021)	JM(2021)	1960q1-2018q1	Non-linear state space model with a shadow rate; uses a flexible time-series model that incorporates the effective lower bound (ELB); follows the approach of Diebold and Li (2006), as it does not impose rigid no-arbitrage restrictions across the term-structure of interest rate
Kim et al. 2019 update for D'Amico, Kim, and Wei (2018)	KMW(2019); DKW(2018)	1983q1-2018q4	No-arbitrage term structure model; nominal yields, real yields, and inflation expectations all assumed linear functions of latent factors that follow normal distributions; decomposes nominal yields or forward rates into 3/4 components—expected real short rate, expected inflation, inflation risk premium (and a real term premium); the model parameterization is specified in a "maximally flexible" way

[64] Assumes that the nominal Treasury and TIPS yields are driven by 6 observable factors: the first 3 principal components (PCs) of nominal Treasury yields, a TIPS liquidity factor, and the first 2 PCs of the part of TIPS yields not explained by the nominal or liquidity factors.

[65] Assumes that nominal and TIPS yields are driven by 2 separate level factors, but shares the same slope and curvature factors.

[66] Assumes that nominal and real yields are driven by 3 factors representing the SR real interest rate, expected inflation, and LR inflation, respectively, as well as 4 volatility factors that follow GARCH processes.

Table 4: Historical Data for HLW Extension

	Sources	
Core CPI	m04052 (NBER) From 1922 to 1958q4	PCEPILFE (Fred) From 1959q1 to 2019q4
CPI	CPIAUCNS (Fred) From 1922 to 2019q4	
RGDP	Balke and Gordon (1986) From 1922 to 1946q4	GDPC1 (Fred) From 1947 to 2019q4
Policy	INTDSRUSM193N (Fred) From 1922 to 1965	FEDFUNDS (Fred) From1966q1 to 2019q4
ST IR	M1329AUSM193NNBR (Fred) From 1922 to 1934q1	TB3MS (Fred) From 1934q2 to 2019q4

Table 5: Stationarity test: Historical vs. Original HLW Measure

	Historical HLW	Original HLW	5% Level
Augmented Dickey-Fuller	-4.074 (0.008)	-2.701 (0.238)	-3.431
Phillips-Perron	-4.074 (0.0080)	-2.749 (0.218)	-3.431
Kwiatkowski et al.	0.248	0.178	0.146
The stationarity test focuses on the specific sample size used for the estimation of the BVAR Model n=216 (trend and intercept)			

Figure 1: R-star Measures based on Structural Estimates

The figure plots r-star measures based on structural estimates. Table 1 offers a description for these measures. Structural estimates of r-star that focus on the short-run are depicted by a dotted line.

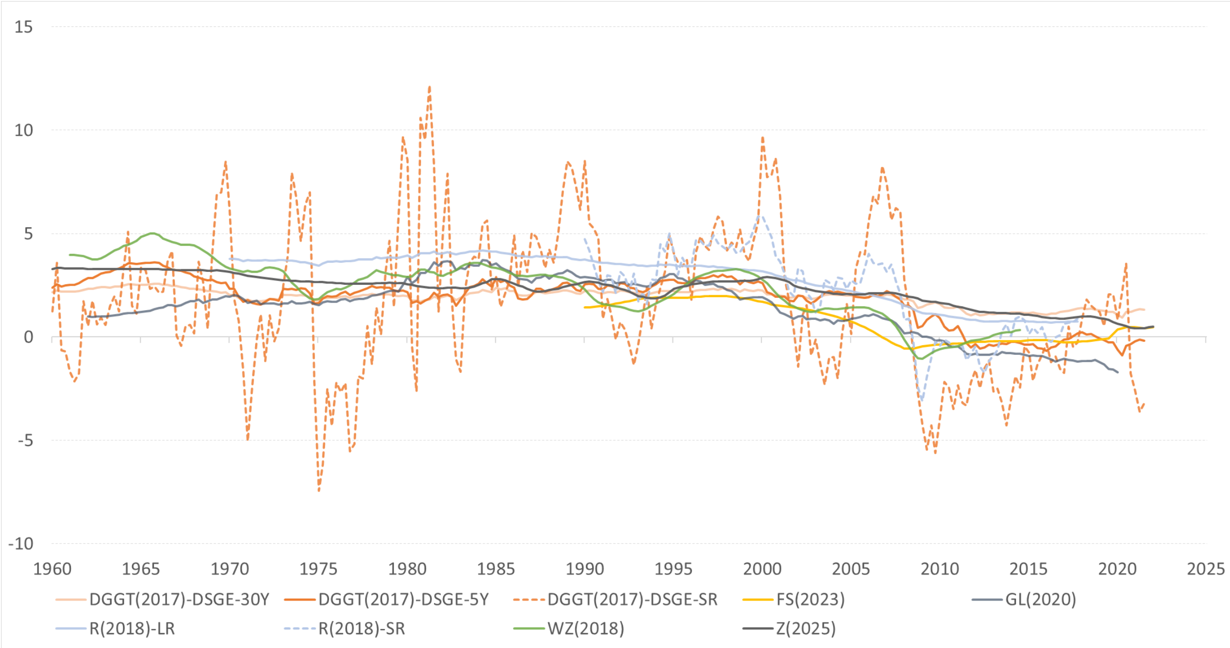


Figure 2: R-star Measures based on Macro-Variables

The figure depicts macroeconomic estimates of r-star. Table 2 offers a description for these measures. Many of these estimates present slight modifications to the existing HLW methodology, or use similar variables.

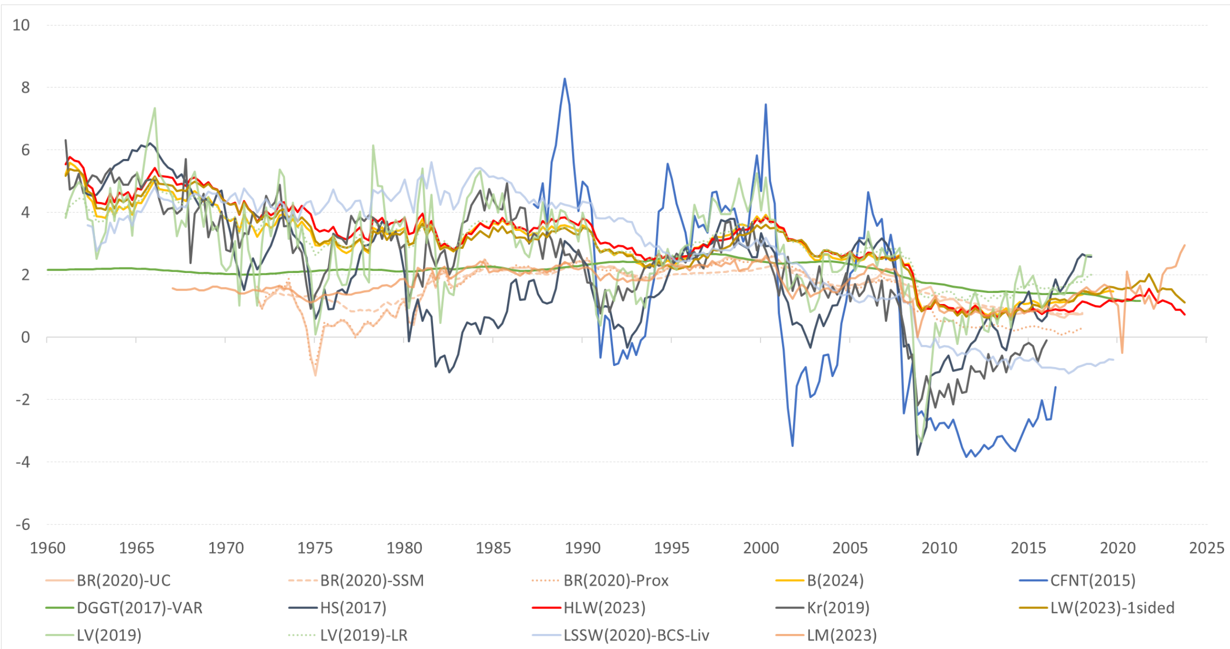


Figure 3: R-star Measures based on Financial Variables

The figure plots financial estimates of r-star. Table 3 offers a description for these measure. Due to limitations in the underlying time-series, the sample period for these measures is comparatively shorter.

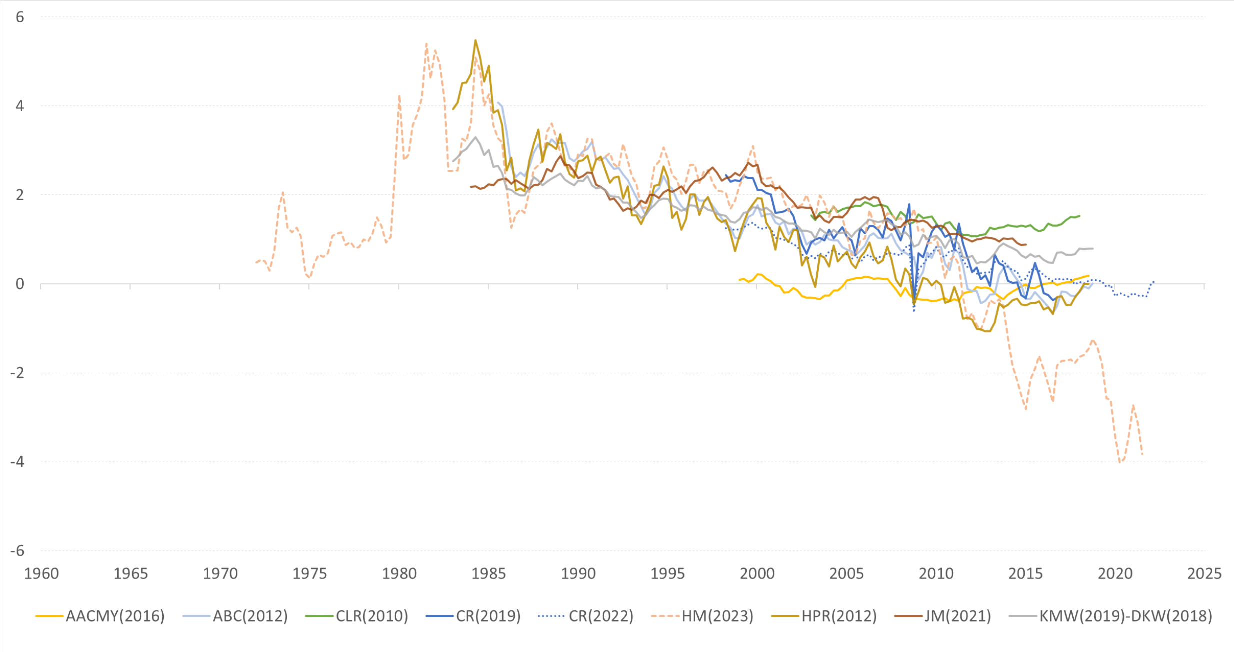


Figure 4: Holston, Laubach, Williams Measure with Historical Data

The figure depicts the original HLW measure (yellow line) and our extended version (blue line). Using historical data, we expand the starting point to 1922 (Table 4). This series displays substantial mean-reversion. As a robustness check, we calculate r-star using the historical dataset but mimic HLW's starting point (abridged sample, red line). The slight deviations with the original HLW estimate are due to data-revisions.

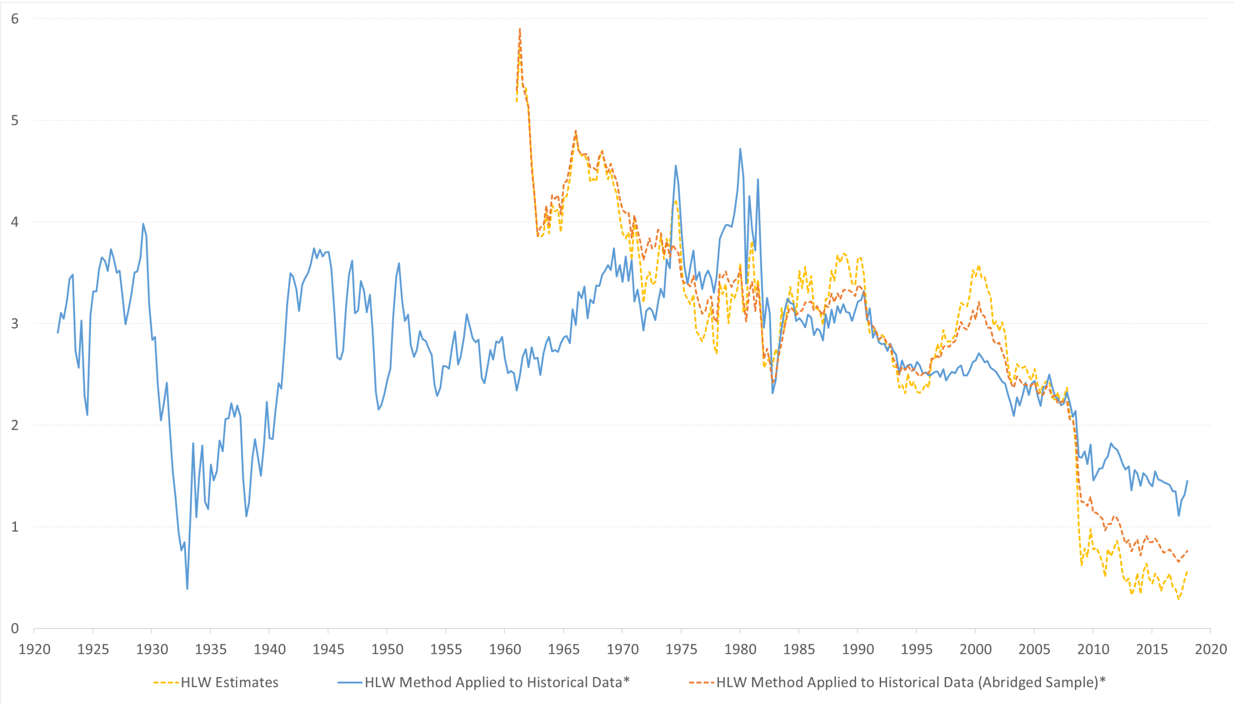


Figure 5: Impulse Response Functions

The figure shows the structural impulse response function for the neutral rate to a supply, demand and monetary policy shock. Every row portrays the consecutive subperiods. The shaded regions and the dotted blue lines depict the 68% and 95% posterior credibility set respectively.

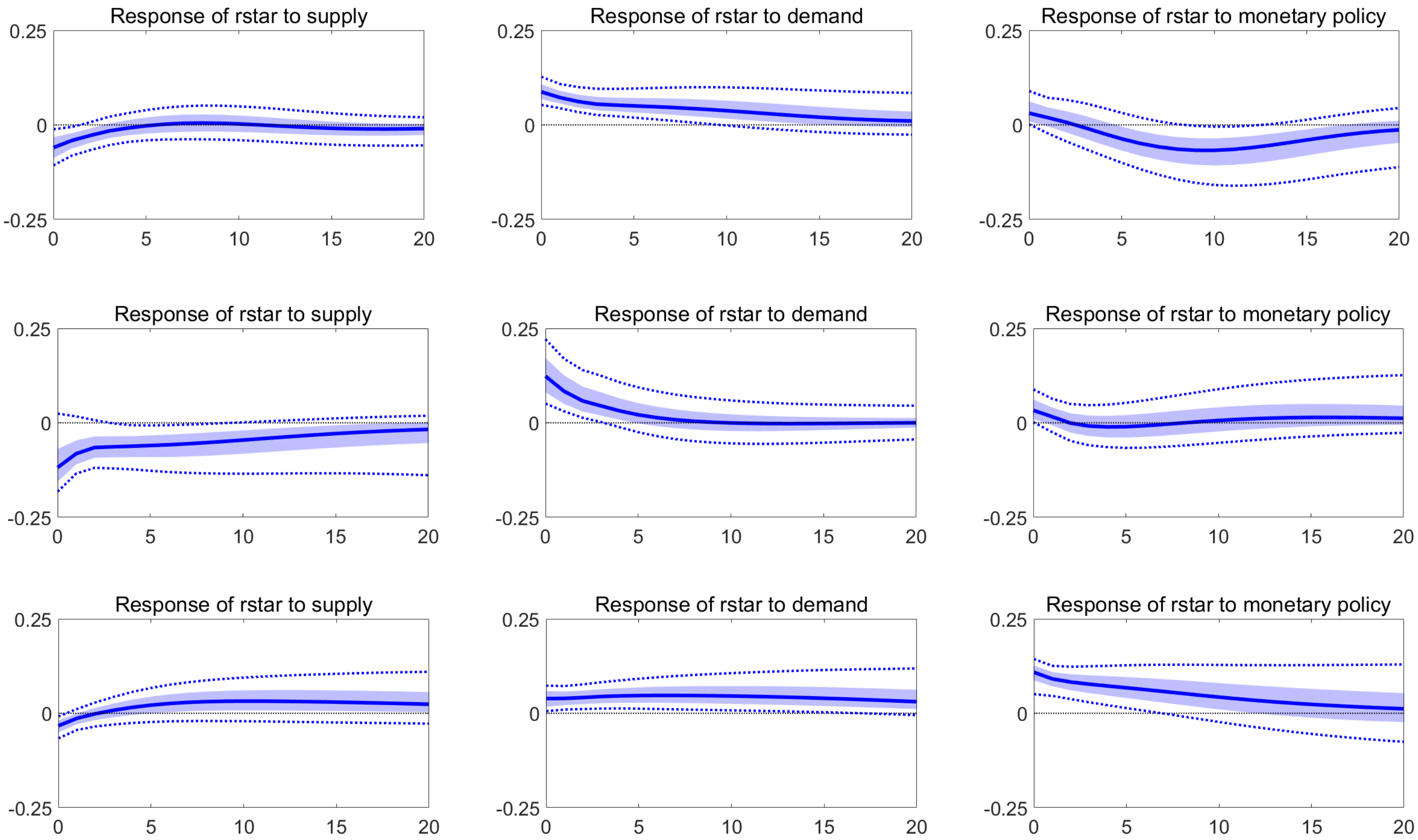


Figure 6: Impulse Response Functions - Monetary Policy Shocks

The figure shows the structural impulse response function for the policy rate and the neutral rate after a one unit monetary policy shock. Every row portrays the consecutive subperiods. The shaded regions and the dotted blue lines depict the 68% and 95% posterior credibility set respectively.

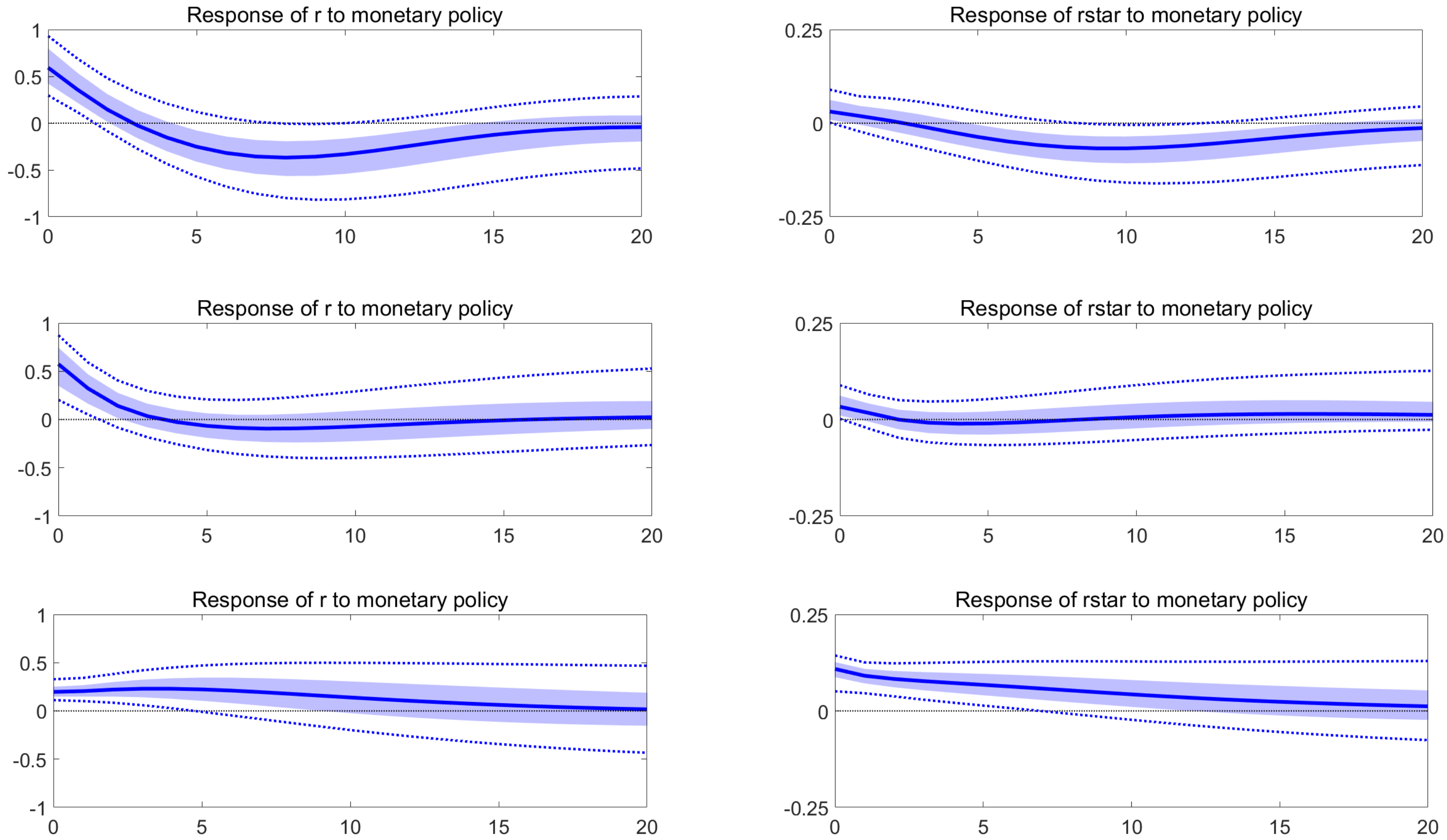
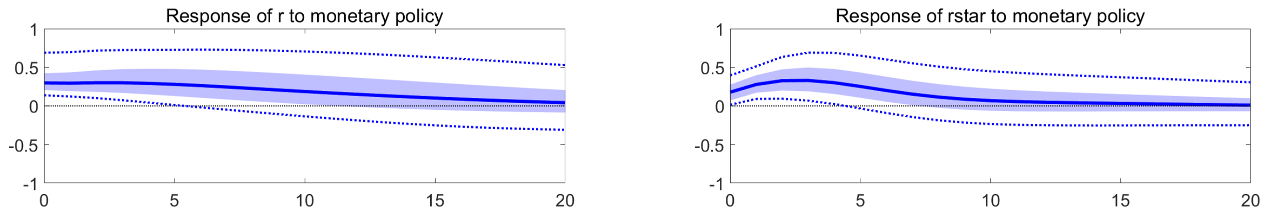


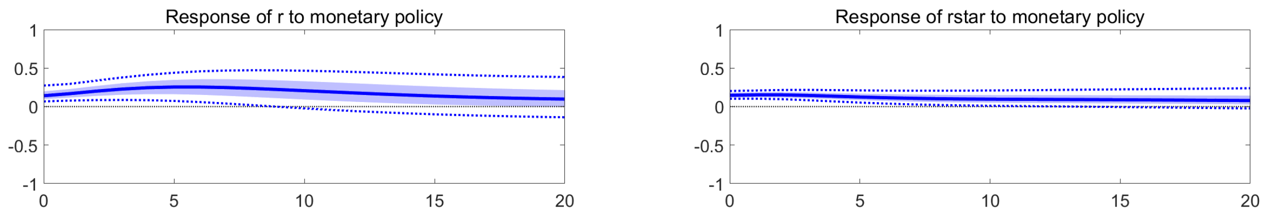
Figure 7: Impulse Response Functions - Robustness

The figure shows the structural IRFs for the policy rate and the neutral rate measures after a one unit monetary policy shock, as a robustness test. The shaded regions and the dotted blue lines depict the 68% and 95% posterior credibility set respectively. Every row portrays a different measure.

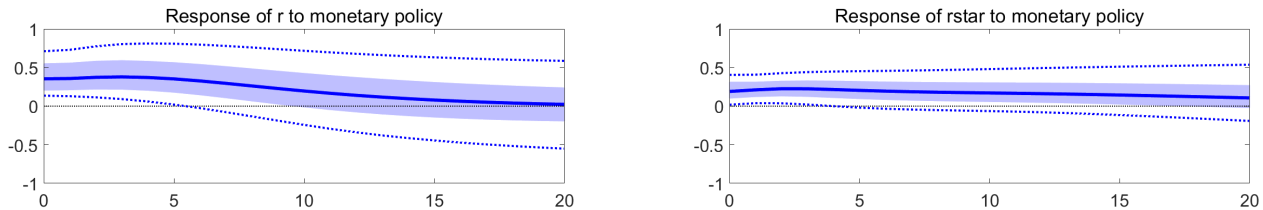
Lewis and Vazquez-Grande (2019)



DelNegro et al. (2017)



Han and Ma (2023)



Kim et al. (2019)

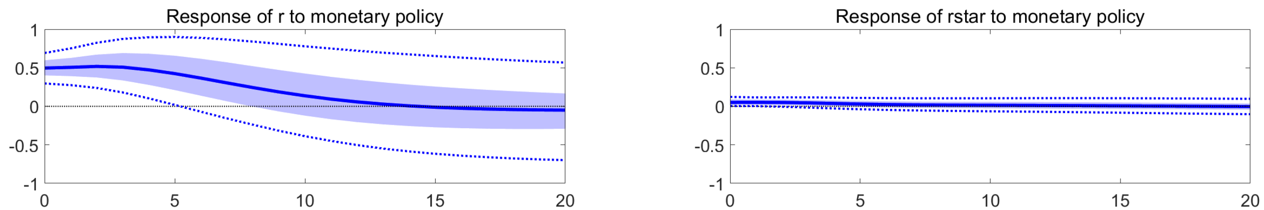
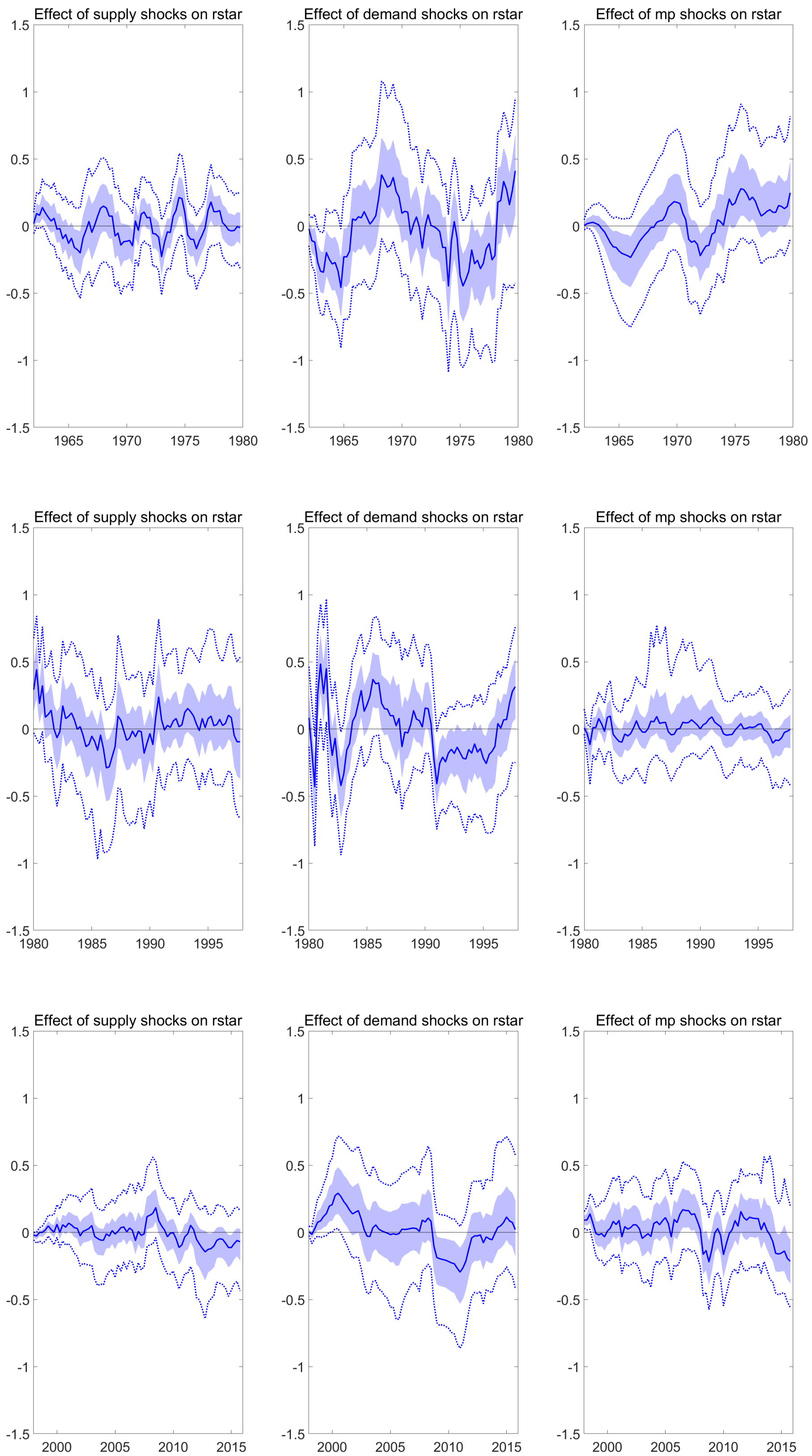


Figure 8: Historical Decomposition

The figure depicts the portion of historical variation in the neutral rate attributed to each structural shock (solid blue line). The shaded regions and the dotted blue lines indicate the 68% and 95 posterior credibility sets respectively. The rows highlight the subsequent subperiods.



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