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Real Equilibrium Interest Rates in the Euro Area

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ABSTRACT: Updated estimates of real equilibrium interest rates in the euro area, derived from eight prominent methodologies proposed in the academic literature, deliver a wide range of estimates, partly because they vary in time horizon and economic complexity. By the end of 2024, shorter-term equilibrium rates mostly exceeded longer-term rates, with foreign spillovers contributing positively to euro area equilibrium rates. Given the wide range of estimates and their high uncertainty, a judgment-based assessment should be based on three criteria and consider their conceptual fit, robustness, and alignment with other economic indicators. Even then, the uncertainty surrounding the estimates represents a specific form of model uncertainty that necessitates the formulation of robust conclusions and policy recommendations. Our results show that ECB policy rates are broadly aligned with short-run efficient rates and suggest that monetary policy remained restrictive at the end of 2024.

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Contents

Introduction

There is renewed interest in equilibrium interest rates for two reasons. First, as inflation in the euro area approaches its target, attention is shifting to the value of the policy interest rate that is neither restrictive nor accommodative—the short-term neutral rate (Kaplan 2018). To quantify this neutral monetary stance, it is necessary to determine the real short-term interest rate that, in the absence of new shocks, maintains output at its potential and inflation at its target. Second, the prominent debate on secular stagnation prior to the COVID-19 pandemic (Summers 2015) has transitioned to discussions about a potential rise in long-term equilibrium rates. Increased public spending on climate initiatives and defense, as well as expectations of a productivity boost from the wider use of artificial intelligence, contribute to this shift (Schnabel 2025). Long-term equilibrium rates have crucial implications for the likelihood of monetary policy being constrained by the effective lower bound and the sustainability of public finances.

A single definition of the equilibrium rate does not exist, as it encompasses various concepts. Importantly, definitions of equilibrium interest rates vary according to the time horizon and therefore vary in their drivers and volatility over time. In a neoclassical growth model, for instance, this rate is associated with a very long-term concept and constant, jointly determined by the discount factor and productivity growth.[1] In more complex models, this rate can fluctuate, for example with demographic trends that influence the size and quality of the labor force, a changing propensity to save from aging and longevity, and long-run productivity trends. The seminal semi-structural model in Holston, Laubach, and Williams (2017 and 2023)—henceforth HLW2017 and HLW2023, respectively—aims to estimate a policy-relevant medium-term neutral rate, linked to time-varying trend growth and other temporary factors. Short-term estimates of a hypothetical interest rate without price and wage rigidities in DSGE models are sometimes referred to as the neutral rate as well (Platzer et al. 2022). However, a policy rate following this rate could be above or below the neutral rate and would contribute to stabilizing the economy, thus—depending on the underlying shocks—serving as an upper or lower bound of the neutral rate for determining the monetary stance.[2] Additionally, this rate can be viewed as a guide for optimal monetary policy: Curdia (2015) and Barsky (2024) refer to it as the short-term efficient rate, since it leads to efficient stabilization within the model (if the central bank possesses complete information about all shocks).

This paper aims to clarify the various—and often confusing—concepts of equilibrium interest rates, and to examine their interrelations and practical applications. It offers updated estimates of euro area equilibrium rates derived from eight prominent methods proposed in the academic literature, including time series, semi-structural, and DSGE models. Additionally, we provide and discuss estimates of term-structure models, which conceptually differ significantly as they estimate *expectations* about future short-term risk-

[1] This concept is closely related to the constant in the Taylor rule. In the original version, the constant is exogenously determined by past U.S. trend growth (Taylor, 1992).

[2] For instance, with inflation above target due to an expansionary fiscal shock, this rate increases and becomes restrictive, thus only providing an upper bound to inform the monetary stance.

free rates. Subsequently, we propose a general framework for selecting appropriate models[3] and explore the implications of estimation uncertainty and recent findings for monetary policy.

We have four main insights. First, we find that estimates for the euro area using different methods vary significantly, but we observe two general patterns: current short-term equilibrium rates mostly exceed longer-term rates, and foreign spillovers contribute positively to euro area equilibrium rates. Second, we argue that different estimates of equilibrium interest rates serve distinct purposes. For instance, longer-term measures provide insight into the likelihood of hitting the effective lower bound in the future, while short-term estimates are valuable for guiding policy rates and determining the monetary stance. The model selection hence depends greatly on the analytical and policy questions. Third, we suggest that a judgement-based assessment of equilibrium interest rates should evaluate individual estimates based on their time horizon, robustness, and consistency with other economic information. By doing so, we assess the real short-term neutral rate at the end of 2024 to likely be around 0 to 0.25 percent. Finally, we draw from the literature on model uncertainty to discuss how to incorporate uncertainty about equilibrium real rates.

The remainder of the paper is structured as follows. Section 2 clarifies some concepts and discusses prominent estimation strategies. Section 3 presents updated estimates of euro area equilibrium rates and compares them. Section 4 suggests criteria to rank them, synthesizes practical implications for monetary policy, and discusses implications. Section 5 concludes.

Estimation

Notable Features

In this section, we discuss a few notable features of equilibrium interest rates that are particularly important at the current juncture or not sufficiently appreciated in ongoing policy discussions referring to such rates. Specifically, we emphasize that the short-term neutral rate can fluctuate strongly, that it is inherently difficult to measure, and that foreign developments matter.

The short-term neutral rate can fluctuate due to factors such as fiscal policy, risk appetite and perceptions, overall financial conditions, capital flows, and the degree to which inflation expectations are anchored (Obstfeld 2023). This implies that policy rates may, at times, need to rise (or drop) above (or below) their medium-term levels (Harrison and Nguyen 2025). For example, during the recent ECB tightening episode, real interest rates had to increase significantly above pre-pandemic estimates of the medium-term neutral rate to become restrictive. This was driven by cyclical factors related to expansionary fiscal policy (IMF 2024) and slower-than-usual pass-through of policy rate hikes to bank rates (Beyer, Chen, Misch, Li, Ozturk, and Ratnovski 2024).

[3] Similar to Beyer, Boer, Hassan, and Fedderke (2025), who propose specific criterions to select a measure of the equilibrium rate to assess the monetary policy stance.

Estimating equilibrium interest rates is fraught with difficulties, as they are—just like potential output and the equilibrium rate of unemployment—unobservable, which raises two types of problems. The first pertains to the ability to recover the latent variables in models with more shocks than observable variables.[4] The second relates to econometric issues like robustness to model misspecification, sample dependence, reliance on identification assumptions (Buncic 2024), or simply parameter uncertainty, structural shifts, and low power. Significant efforts have gone into their estimation, but many of the most well-established models in the literature do not fare well on either dimension (e.g., see Buncic et al. 2024). All estimates suffer from substantial uncertainty.

Moreover, foreign developments and their spillovers are crucial for equilibrium interest rates in an integrated global economy. When capital can move freely across borders, interest rates are influenced by international trends and developments (Obstfeld 2023). Despite its size and significant trade linkages, many studies of real equilibrium rates treat the euro area as a closed economy (e.g., the models used by Benigno et al. 2024). While this simplification may be valid in some cases, the euro area's financial markets are well integrated globally, and developments affecting equilibrium rates in other countries can impact rates there. Ex-ante short-term real interest rates in euro area member states, for instance, share substantial variation with those in the United States: on average, ex-ante rates in the United States explain nearly 40 percent of the variation in euro area ex-ante real rates, especially in larger, more sophisticated economies.[5] Global real and equilibrium interest rates share significant common trends worldwide. Although China's significant savings surplus may have lowered global equilibrium rates in the past, robust economic growth and expansionary fiscal policy in the United States could elevate them in the future.

Estimation Strategies

The estimation strategies proposed in the literature include time series and model-based approaches. There are at least five common approaches. *Univariate Statistical Filters* define the equilibrium interest rate as the trend component of real interest rates and can feature stochastic volatility (e.g., Fiorentini et al. 2018 and Beyer and Milivojevic 2023). *VAR Models* also compute trends and cyclical variations but include more than one variable and some econometric relationships between them. Del Negro et al. (2017), for example, include Treasury and corporate yields, inflation, and long-term survey expectations of inflation and interest rates. These models can feature time varying parameters to capture a variety of nonlinearities (e.g., Lubik and Matthes 2015 and 2023). *Semi-Structural Models* feature more economic structure but involve reduced-form equations that capture relationships between variables without fully detailing the underlying mechanisms. HLW2017 and HLW2023's model is fundamentally a closed-economy linearized New Keynesian framework that incorporates a Phillips curve

[4] I.e. in "short" systems as in Forni et al. (2019).

[5] The explained variance is based on a factor analysis of ex-ante real rates for all euro area member states and the Unites States. Ex-ante real rates are the 3-month money market rate for the euro area and the United States minus the country-specific expected inflation. We use inflation expectations from the Survey of Professional Forecasters for the euro area and from the Survey of Consumer Expectations for the United States. The share of real interest rate variance explained by the United States' real interest rate ranges between 57 percent (Finland) and 2 percent (Slovakia).

and an investment-saving (IS) curve, in which trend output influences the equilibrium rate through the household's Euler equation.[6] *Fully Structural Models* allow for endogenous dynamics where the behavior of economic agents is derived from optimizing decisions within the model. Examples include heterogeneous agent overlapping generations models for understanding long-term equilibrium rates (e.g., Peruffo and Platzer 2024) and DSGE models for estimating short-term efficient rates (e.g., Neri and Gerali 2017). *Term Structure Models* explore the relationship between interest rates of different maturities and risk premia to gauge market expectations about current and future equilibrium rates, with the latter defined as the risk-free interest rate (e.g., Hördahl and Tristani 2014, and Christensen and Rudebusch 2019).

Numerous extensions add open-economy elements to these different estimation strategies. In VAR models, joint estimation for different countries with common factors (e.g., Del Negro et al. 2019) or global spillovers (Ferreira and Shousha 2023) introduce an open-economy element. The HLW2017 model has been extended to open-economy contexts in several ways, with foreign growth or exchange rate fluctuations affecting domestic rates (Mesonnier and Renne 2007; Hledik and Vlcek 2018; Wynne and Zhang 2018; and Bulir and Vlcek 2024). DSGE models can be extended to an open economy setting, with domestic and foreign productivity shocks impacting the domestic short-term efficient rate (Zhang et al. 2021).

One purpose of this paper is to offer updated estimates of euro area equilibrium rates by employing various methods. We strive to include at least one model from each major estimation strategy, covering different time horizons,[7] and both closed and open economy models. We select eight models—including some of the most cited and widely used ones—based on the replication codes being available, ease of implementation, and data requirements, but this does not indicate a preference for these models over others not included. The Annex provides details for each of these models.

Updating estimates from these models is more complex than it may appear. Even though these strategies are published in academic journals, updating them can be challenging. This difficulty persists even when authors provide replication codes and input data. Even minor changes in sample size or variables can lead to convergence issues or result in significantly different estimates due to weak identification of model parameters. Moreover, relative to published results, updating the estimates with variable definitions that are aligned across models poses significant challenges. We aim to alter the original specifications as little as possible but align definitions of interest rates and inflation expectations and adjust starting values and priors when necessary.

[6] Relative to the Laubach and Williams (2003), HLW2017 extends the analysis to other advanced economies. HLW2023 have revised the estimation to account for the large shocks during the COVID-19 pandemic.

[7] The horizon and associated volatility of estimates are not necessarily predetermined by a specific model but can vary based on the chosen calibration of the smoothing mechanisms within the models. For instance, in the HLW framework, Bayesian priors determine the variability of temporary factors and trend growth and the stability of the Del Negro et al. (2017) estimates is influenced in part by the priors concerning the variance of the trend components. A proper analysis of different horizons within a model is out of the scope of this paper.

Data

We use consistent estimation periods across different models, spanning from 1995Q1 to 2024Q4, and to the extent possible use consistent data definitions. Most data are from Eurostat: (i) inflation is based on seasonally adjusted HICP inflation excluding energy and unprocessed food; (ii) real GDP data is adjusted for the initial Covid-19 shock by modifying real GDP from 2020Q1 to 2021Q2 assuming a constant-parameter univariate VAR for GDP growth and different covariance matrices (Lenza and Primiceri 2022);[8] (iii) for interest rates, we primarily use the 3-month money market rate but account for the influence of quantitative easing on monetary conditions by splicing this rate with Krippner's (2013) shadow rate for the period from 2011Q2 to 2023Q1; (iv) the long-term interest rate is defined as the GDP-weighted 10-year government bond yield of selected euro area economies; (v) the real effective exchange rate is based on the CPI and considers 120 trading partners; (vi) Brent oil prices; and (vii) import prices, export prices, and terms of trade, with earlier periods using a GDP-weighted average of selected euro area economies. For models incorporating inflation expectations, we utilize dynamically weighted 1-year and 2-year ahead inflation expectations from Consensus Economics. For earlier periods, we use the GDP-weighted average of inflation expectations from Germany, Italy, France, and Spain, predicting missing data for these countries based on linear predictions from available data. Data that are only available semi-annually or annually are linearly interpolated to a quarterly frequency.

To highlight the implication of these data choices, we also provide estimates using backward-looking inflation expectations (using the previous year's actual inflation) as in HLW2023 and the 3-month money market rate without the shadow rate adjustment.

Results

Closed Economy Estimates

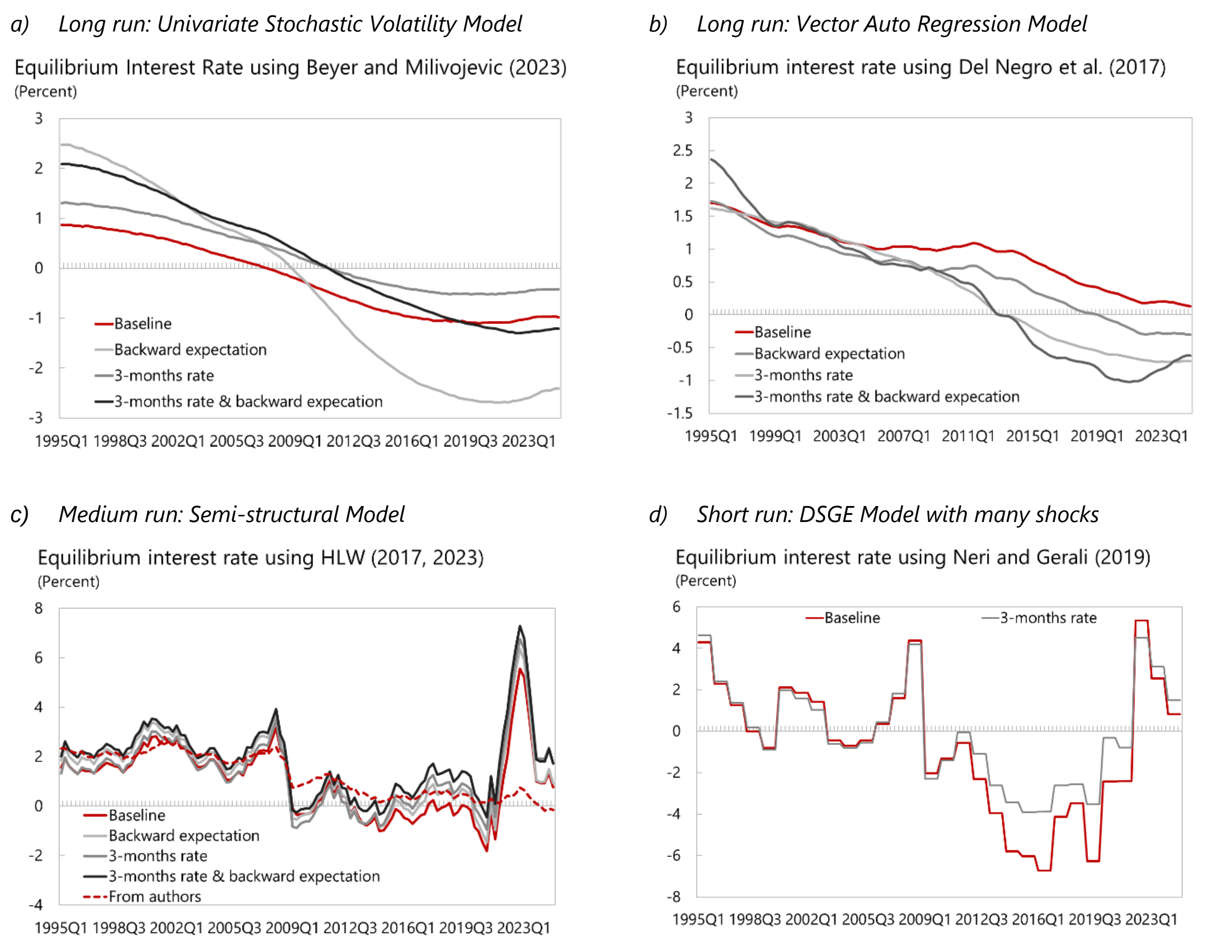
In the following, we discuss the updated results for four different closed economy models with varying time horizons and economic complexity: Beyer and Milivojevic's (2023) univariate stochastic volatility model, Del Negro et al.'s (2017) VAR model, versions of Holston, Laubach, and Williams's (2017, 2023) semi-structural model, and Neri and Gerali's (2019) DSGE model.

The univariate filter captures slowly declining real rates over time, with the baseline rate falling from just below 1 percent in 1995 to around -1 percent in 2016. It stabilized thereafter and slightly increased recently, though most of the change in real rates is attributed to higher volatility. The decline is much larger using backward-looking inflation expectations, with the rate falling from over 2 percent to below -2 percent. Ignoring quantitative easing (i.e., using the policy rate instead of the shadow rate during the effective lower bound period) results in a near-parallel upward shift to the baseline of around 0.6 percentage points. For the end of 2024, the baseline estimate for the equilibrium rate is -1.0 percent.

[8] A proper analysis of how different adjustments for the Covid-19 period would be very interesting but is beyond the scope of this paper. We leave it for future research.

The updated baseline estimates from Del Negro et al. (2017) are somewhat higher, starting at 1.5 percent at the beginning of the sample and falling to around 1 percent in the 2000s. The estimates do not react much to the Global Financial Crisis and slightly increase in 2010 and 2011, in line with models with more structure. Subsequently, the estimated neutral rate declines close to 0 percent before the COVID-19 pandemic and then stays there. The versions with backward looking expectations behave similar to the univariate estimates, hence giving very little weight to the other variables in the VAR.

Figure 1: Closed Economy Estimates of Euro Area Equilibrium Rates

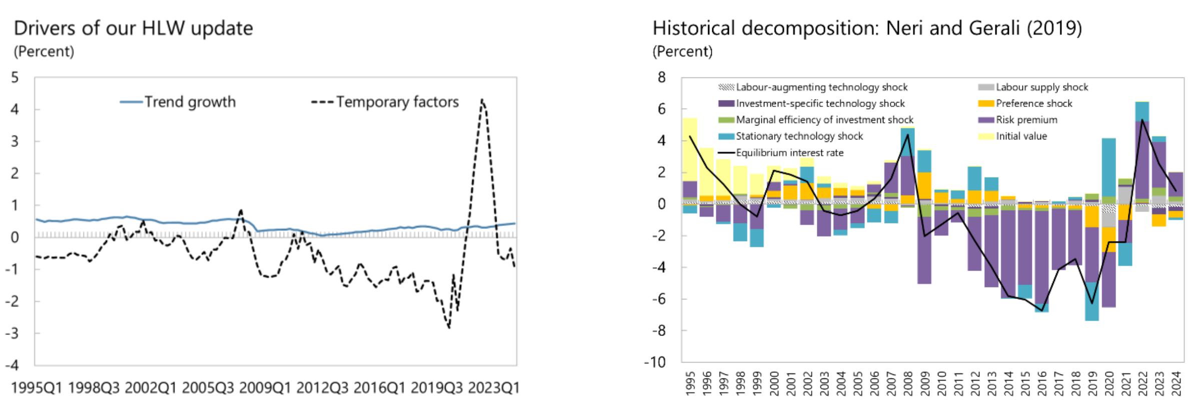


The HLW2017 model employs a medium- to long-run concept, with the estimated rate driven by trend growth and temporary factors. Figure 1 (bottom left panel) shows both estimates from HLW2023 (from the authors using data starting in 1961 with backward looking inflation expectations), and HLW2017 estimates following the conventions in this paper (including the COVID adjustment of the GDP series) using the Bayesian estimation approach from Arena et al. (2020). The results are broadly similar until the recent inflation surge, with rates around 2 percent until the Global Financial Crisis and rates around 0 before the Covid-19 pandemic. However, our estimates increase strongly from early 2022 to mid-2023 and then fall again quickly. The approach taken by HLW2023 to control for the Covid-19 pandemic mitigates this strong fluctuation, suggesting that our approach may require additional adjustments. The estimates are somewhat higher than those from the statistical models during the 2000s and feature a more significant drop during the Global Financial Crisis. Although declining trend growth has significantly contributed to the long-term trend, recent fluctuations are primarily related to changes in temporary factors (Figure 2, left panel).

The original model and all its variations feature considerable estimation uncertainty, leading to very wide error bands. The average standard error of the authors' estimates, for example, is 3.4 percent, but even jumps to 5.0 percent for the last estimate in 24Q4. This implies that all estimates using other methods fall comfortably within the error band. In addition, depending on the estimation strategy, point estimates can fluctuate significantly with minor changes to the estimation strategy and data (Beyer and Wieland 2019; Buncic 2024). The lack of precision and robustness of these approaches casts doubt into their ability to produce estimates that can be used for policy making.

In Gerali and Neri's (2019) DSGE model, the equilibrium rate is characterized as the real interest rate that, when attained through monetary policy, maintains inflation at its target level and output at its potential across all time periods and in response to every shock. It measures a short-term rate in the near term and exhibits the largest fluctuations. It reached 4.4 percent right before the Global Financial Crisis and then quickly dropped below 0 percent. It fell below -6.0 percent during the European Debt Crisis, and shortly rose to 5.3 percent during the inflation period in 2022. At the end of 2024, it had declined again to 0.8 percent. Most of the variation is explained by the risk premium shock, an approximation of changes in agents' preference for safe assets and their scarcity, with portfolio rebalancing toward safe (risky) assets moving the short-term efficient rate down (up). It significantly lowered the equilibrium rate from 2009 to 2021 and has significantly raised it in the last three years (Figure 2). Using the DSGE model presented in Del Negro et al (2017), Farkas and Jakab (2025) show that accounting for forward guidance shocks and the convenience yield increases the estimates from the very low levels both in the US and euro area.

Figure 2: Drivers of HLW2017 and Neri and Gerali (2019) Estimates



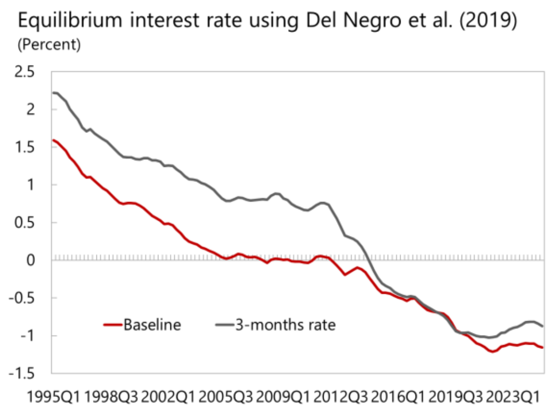
Open Economy Estimates

In the following, we discuss the updated results for four open economy models with varying time horizons and economic complexity: Del Negro et al.'s (2017) VAR model with common factors, the recent medium-term model from Ferreira and Shousha (2023), the Wynne and Zhang (2018) extension of HLW2017, and the small open-economy DSGE model from Zhang et al. (2021).

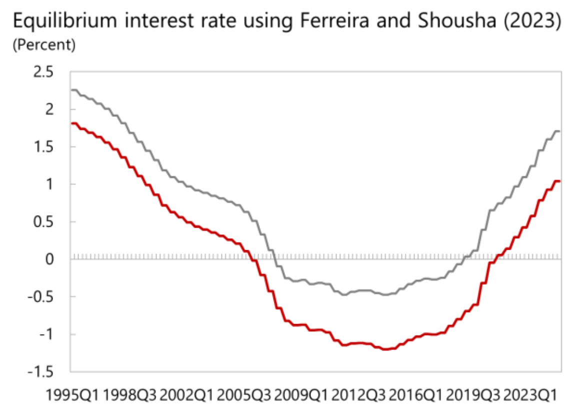
We apply the model of Del Negro et al. (2019) to the euro area and the United States, with the common factors interpreted as global trends. Different from the original specification, we estimate this model with quarterly data. The baseline estimates fall quickly from 1.5 percent in 1995 to 0 percent in 2005 and then remain around 0 percent before declining to -1 percent between 2015 to 2020, after which it stabilized at that level (Figure 3, top left panel). Using only the short-term interest rate results in similar dynamics but generally higher estimates, especially from 1995 until 2012. As in the case for the closed-economy version of the model, the estimates depend strongly on the starting values and priors used in the algorithm.

Figure 3: Open-economy Models

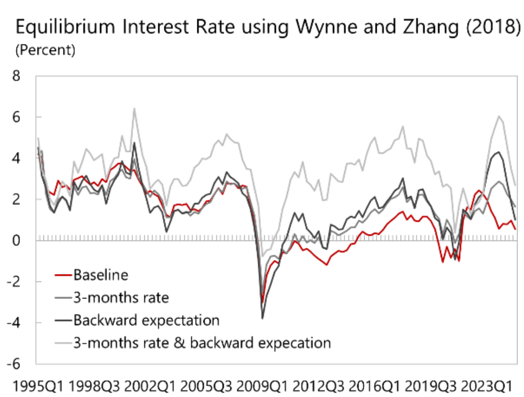
a) Long run: VAR Model with Common Factor



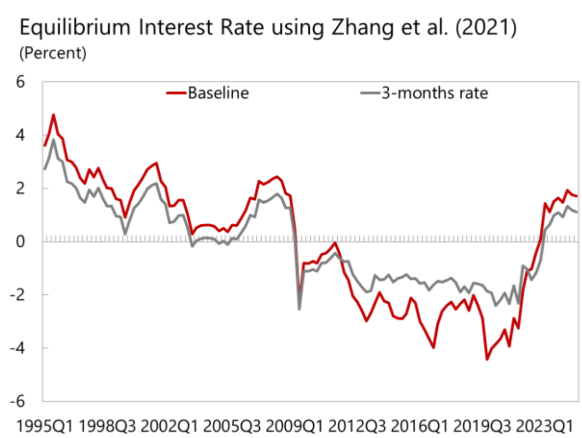
b) Medium run: State Space Model with spillovers



c) Medium run: HLW2017 with Foreign Trend Growth



d) Short run: DSGE model with spillovers



Ferreira and Shousha (2023) use a similar estimation strategy but add significantly more economic structure. They estimate their model simultaneously for different countries and consider productivity, demographics, the global supply of safe assets, demand factors for safe assets, and global spillovers that each economy encounters due to developments in the rest of the world. The dynamics in our updated estimates are broadly similar to those from Del Negro et al. (2019) at the beginning but drop into negative territory in 2005. Importantly, the rates start increasing again in 2017 and reach 1 percent at the end of the sample. The historical decomposition reveals key contributions from the supply of safe assets and the convenience yield in the last years (Table 1).

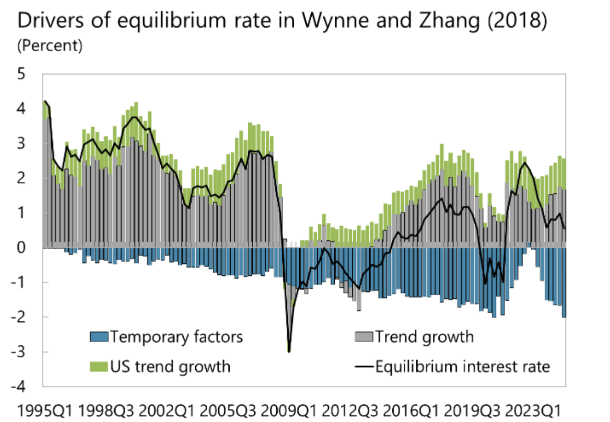
Table 1: Driver of the Equilibrium Rate in Ferreira and Shousha (2023) Over Time

	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2024
Safe Asset Supply	-0.1	-0.2	0.4	0.3	0.4	0.8
Safe Asset Demand	0.0	-0.1	-0.1	-0.1	0.0	0.1
Convenience Yield	-0.5	0.1	-0.3	-0.4	0.4	1.0
Productivity	-0.5	-0.4	-0.2	0.2	-0.2	-0.2
Working Age Share	0.0	0.0	-0.1	-0.2	-0.2	-0.3
Global Spillovers	0.2	-0.2	-0.7	0.0	0.0	-0.1
Other Factors	0.0	-0.1	-0.2	-0.1	0.1	0.3
Total Change	-0.9	-0.7	-1.2	-0.2	0.6	1.6

The equilibrium rate estimated with Wynne and Zhang's (2018) model—a version of HLW2017 that allows for foreign trend growth to impact domestic equilibrium rates—shows a slighter higher point estimate of the equilibrium rate but not statistically different than HLW2017, given the wide confidence bands associated with it. The decomposition shows that foreign trend growth adds around 0.5 percentage points to the euro area natural rate, with relatively little fluctuations over time. The results are similar whether the foreign trend growth measures the rest of the world or only the United States. However, the estimates are very sensitive to other modifications and suffer from the same weak identification as in the closed-economy version of HLW.

The small open economy DSGE model of Zhang et al. (2021) features less economic structure (and much fewer structural shocks) than the closed economy DSGE model of Neri and Gerali (2019) but incorporates foreign developments. It allows for foreign productivity and inflation shocks and accounts for changes in exchange rates and terms of trade. The estimates fluctuate around a similar trend as other estimates—the equilibrium slowly declined from around 4 percent in 1995 to around 2 percent before the Global Financial Crisis, then dropped significantly below 0 percent and increased again sharply during the recent inflation period. At the end of the period, the estimated baseline equilibrium rate is 1.7 percent. Ignoring the effective lower bound results in somewhat higher estimates during the effective lower bound period and a lower estimate at the end of the sample (1.1 percent). A variance decomposition shows that foreign growth explains about half of the variation at short-horizons and about 90 percent in the long run. Although this may seem like a lot, these numbers are in line with those found by the authors for the United Kingdom and Canada.

Figure 4: Drivers of Wynne and Zhang's (2018)



Comparison

Estimated equilibrium rates exhibit significant variation, ranging from -1.2 to 1.7 percent in 2024Q4. This range was even broader in 2022 and 2023 and narrowed in 2024. Table 1 summarizes the key characteristics of the different rates, along with the latest estimates. First, the rates exhibit variations not only in their dynamics but also in their averages. This can be attributed, in part, to the substantial uncertainty surrounding the levels, which is likely exacerbated by the relatively short estimation period. There appears to be no clear correlation between the time horizon or the complexity of the model and the mean values. Second, the volatility of the estimates is influenced by the time horizon. Longer-term equilibrium rates—derived from univariate and VAR models—show the lowest volatility, as they smooth out temporary shocks. In contrast, estimates from DSGE models demonstrate the highest volatility, as these rates are responsive to all types of shocks. Semi-structural models' variation is somewhere in between that of filter and time series approaches and that of DSGE models, reflecting a medium-term focus. Third, the more volatile short-term estimates tend to be the highest at the end of the estimation period, reflecting temporary shocks that have raised short-term equilibrium rates in 2024. This is especially true for the open economy models. Finally, ECB policy rates closely followed the short-term efficient rate estimated with Zhang et al.'s (2021) approach, especially when considering unconventional monetary policy during the effective lower bound period (Figure 5).

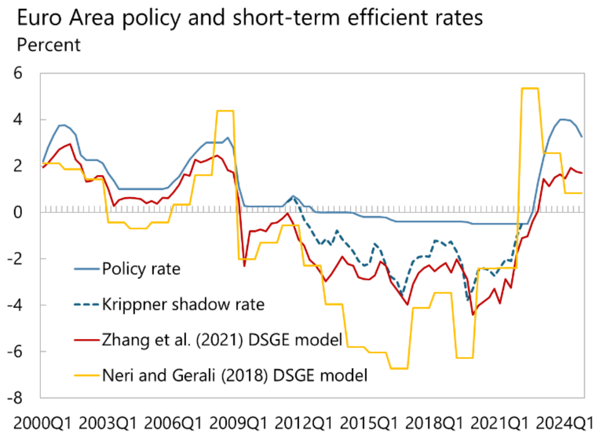
Table 2: Overview of Latest Estimates of Different Estimations

Model	Source	Mean	St.D.	24Q4
Closed economy				
Univariate SV Model	Beyer and Milivojevic (2023)	-0.15	0.53	-1.15
VAR	Del Negro et al. (2017)	0.86	0.43	0.13
Semi Structural	Holston, Laubach, Williams (2023)	1.26	0.87	-0.14
	Our estimation of HLW2017	1.04	1.38	0.77
DSGE model	Neri and Gerali (2019)	-0.72	3.18	0.83
Open economy				
Factor VARs with CF	Del Negro et al. (2019)	-0.04	0.73	-1.15
HLW2017 with foreign growth	Wynne and Zhang (2018)	1.26	1.48	0.55
VAR with Spillovers	Ferreira and Shousha (2023)	-0.02	0.94	1.04
Small DSGE	Zhang et al. (2021)	-0.00	2.29	1.71
Market implied				
TSM: 5y5y	IMF internal	-1.05	0.30	-0.81
TSM: 1y5y	IMF internal	-1.02	0.47	-0.65
TSM: 1y1y	IMF internal	-0.95	1.19	-0.03

Note: The mean and standard deviation refer to the baseline equilibrium rate over the entire period.

Estimation and model uncertainty are very high. Most models exhibit significant estimation uncertainty characterized by large standard errors (e.g., ±5 percent for HLW2023 in 2024Q4). Estimates are also highly sensitive to changes in data definitions, such as those related to interest rates or inflation expectations, as well as to the selection of starting values and priors. Further, even minor alterations in the sample can lead to substantial impacts. But some estimates, demonstrate greater robustness than others. Univariate filters are typically the least affected by adjustments in the sample length. VAR estimates tend to be more stable, especially when parameters are permitted to change over time. In contrast, the semi-structural model of HLW2017 and variants are very sensitive to sample changes, as adding or removing observations can yield entirely different and potentially nonsensical equilibrium rate estimates. The sensitivity of fully structural models varies with the tightness of priors, but the DSGE models tested here show relatively robust estimates.

Figure 5: Policy and Short-term Efficient Rates

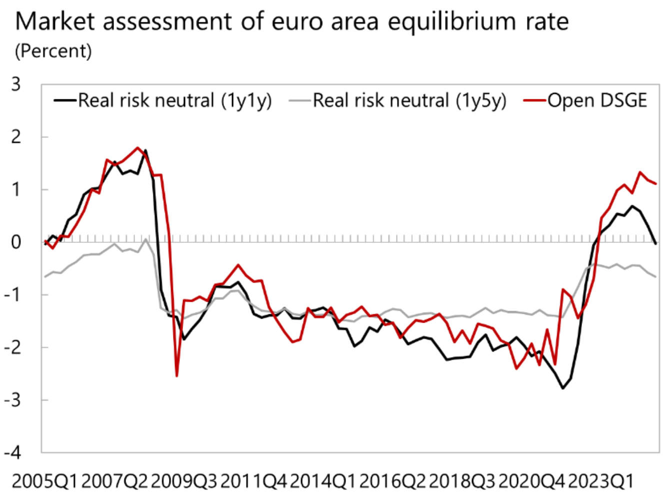


Comparison with Implicit ECB and Market Expectations

The ECB does not explicitly publish an estimate of the real neutral short-term rate. Since the ECB does not publish its output gap forecast either, the implicit neutral rate can only be approximated. With inflation at target in 2026 and only a small negative output gap in the IMF forecast (and a 0 percent output gap in the European Commission's Autumn 2024 forecast for the euro area), ECB projections suggest an implicit neutral euro area real rate of around 0.1 percent in 2026. This prediction has significantly varied throughout 2024, ranging from 0.6 percent in June to 0.1 percent in December.

Financial markets form expectations about equilibrium rates as well. They can be estimated based on term structure models that decompose the nominal yield curve into expected future real short-term rates, expected inflation, and a term premium (e.g., Kim and Orphanides, 2012). Importantly, these can be estimated for clearly defined time horizons, which is an advantage relative to most of the models before. The 1y1y market-implied risk-free rate—so the one for the period starting one year from now and lasting for one year—is conceptually closest to the short-term efficient rate two periods ahead estimated in DSGE models. While the two rates strongly co-move, the market-implied rate is currently considerably lower at 0 percent, suggesting that financial markets expect the risk-free rate to decline in 2025 (Figure 6). In other words, markets expect the temporary factors that drove up the rate to continue to decline. At the same time, the 1y5y implied rate for the period starting one year from now and lasting for five years—a concept closer to the long-term equilibrium rate—is now even lower and remained negative throughout. The 5y5y implied rate looks very similar to the 5y1y rate. In summary, while markets believe the equilibrium rate has increased relative to pre-pandemic levels, they expect it to remain negative in the future. This is in line with some of the negative longer-run estimates presented in this note before.

Figure 6: Implicit ECB and Market Expectations About Equilibrium Interest Rates



Source: IMF staff

The external validation that estimates from term structure models provide is questionable. First, there is no consensus on the model best suited to identify the short-term risk-free rate that estimates the correct risk premium in the bond market. Second, it is important to note that they reflect market expectations, which likely depend on central bank guidance and are of limited use to inform central bank estimates. This is because of short-term rates with maturities of up to one or two years mostly reflect central bank communication about the path of policy rates over the policy horizon (Kaplan 2018). In this setting, extracting information from market prices becomes a beauty contest between the central bank and market participants in which higher-order beliefs (i.e., the expectations of the other agent's expectations) and information environment (i.e., the noisiness and private vs. public information of price signals) matter (e.g., Cisternas and Kolb 2024). Concisely, the inference problem becomes very complex and dependent on assumptions.

Implications

A Ranking of Estimates

Given the wide range of estimates and their high uncertainty, a set of criteria is needed for evaluating the different estimates for policy purposes (Table 2). Since these estimates measure equilibrium rates across varying horizons, it remains unclear what the mean, median, or range of these estimates would signify. Instead, we propose three criteria to evaluate the estimates: (i) choose estimates that are conceptually most fit for purpose (e.g., from a time horizon perspective); (ii) give higher weight to more robust estimates; (iii) compare the consistency of the implied result (e.g., the implied monetary policy stance) and additional model output (e.g., the output gap) with other indicators external to the model and assign more weight to estimates that are aligned with everything else we know about the economy. [9]

Table 3: Criteria to Assess Models

Model	Source	Horizon	Robustness	Notes
Closed economy				
Univariate SV Model	Beyer & Milivojevic	long	good	No economic structure
VAR	Del Negro et al.	long	good	Little economic structure
Semi Structural	HLW	medium	weak	Large role of temporary factors
DSGE model	Neri & Gerali	short	medium	Large role for risk premium shocks
Open economy				
Factor VARs with CF	Del Negro et al.	long	good	Little economic structure
VAR with Spillovers	Ferreira & Shousha	medium	good	A lot of economic structure
HLW2017 with PS	Wynne & Zhang	medium	weak	Little variation of spillovers
Small DSGE	Zhang et al.	short	good	No impact of EA on internat. prices
Market implied				
TSM: 5y5y	IMF internal	long	medium	Depends on CB guidance
TSM: 1y5y	IMF internal	medium	medium	Depends on CB guidance
TSM: 1y1y	IMF internal	short	medium	Depends strongly on CB guidance

Notes: The mean and standard deviation refer to the baseline equilibrium rate over the entire period. SV stands for stochastic volatility, CF for common factor, PS for productivity spillovers, TSM for term structure model, and CB for central bank.

Regarding the latter, measures of employment and productivity growth, income inequality, government saving, and uncertainty could provide discipline when applying judgment on model estimates to determine the monetary policy stance. A qualitative assessment of the several drivers of investment and savings (i.e., for the demand and supply of loanable funds) can help inform policymakers about the likely trends of the neutral rate when model uncertainty is high (e.g., see Benigno et al. 2024, and Seim 2024). Sustained public spending pressures financed through debt should push the equilibrium real rate up. Likewise, high productivity growth or increases in the size of the workforce raise the estimate of potential output and, thus, the real neutral rate, whereas increased inequality would lower it. Also, heightened risk perceptions increase precautionary savings and push equilibrium rates down.

[9] For example, one proposal is to rank estimates of neutral rates by their explanatory power to predict future inflation developments (Beyer, Boer, Hassan, and Fedderke 2025).

Finally, developments in economies that are intricately connected through trade in goods and assets can also have a material effect on the neutral rate. Views gathered in the bank lending survey can provide insights into bank's assessment of the impact of the general level of interest rates on lending demand and hence the monetary stance.

Implications for Monetary Policy

The uncertainty surrounding equilibrium real rates is a particular kind of model uncertainty that central banks often must deal with. A general guidance for dealing with model uncertainty is for central bankers not to rely on any model-specific optimal rule in setting their monetary policy tools (Orphanides and Wieland 2013). There are several ways to implement this guidance in practice. One is to abandon altogether the neutral rate and follow a gaps approach to setting interest rates (Svensson 2003). This approach is best characterized by a simple first-differences rule in which changes to the policy rate depend linearly on the forecasted inflation gap (i.e., the difference between the inflation forecast and the target) and the forecasted deviation of output growth from trend growth. Alternatively, the rule could be set in terms of current outcomes if the central bank does not trust the performance of its forecasts (i.e., the rule becomes data dependent instead of forward looking), which could be relevant when there are regime shifts or when macroeconomic models fail to capture important features of the economy (e.g., when policy rates were at the effective lower bound). An important benefit of this approach is that it does not require estimates from latent variables like the equilibrium rate of interest or of the output gap. A drawback is that it is too simple an approach to work in practice and requires judgment on the part of the central banker.

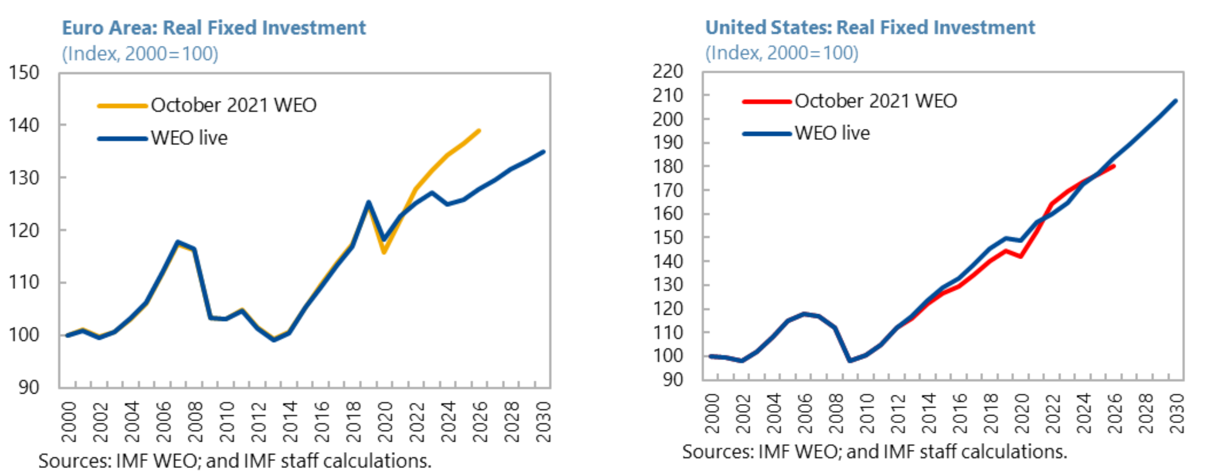
A second approach is to use a model averaging rule. This would be closer to what central bankers do in practice as they compare different interest rate rules and then use judgement to deviate from them (Svensson 2013). A prominent option is to use Bayesian model averaging, in which the policy rule is a (weighted) average (across models) of the possible model-specific optimal simple rules. If the model uncertainty is well structured, Bayesian model averaging can perform well and is intuitive for policy makers who may have strong priors, but when the set of possible models is vast, it will be difficult to "conjure up a unique well behaved prior" (Hansen and Sargent 2008, page 14).

A third approach is to determine a robust rule that behaves well in alternative models. The application of a robust control approach to model uncertainty yields the max-min approach according to which the policy maker should choose the optimal rule under the worst-case model. This calls for the central bank to be more aggressive in response to inflation gaps (and less so to the output gap) and to do more interest-rate smoothing (Orphanides and Williams 2007). This could mean, in practice, to adopt a tightening or easing bias depending on whether inflation is above or below target. However, tailoring the policy response to the worst case may seem unpalatable to the policy maker if she perceives this to be very implausible or extreme. In this case, she could follow a penalized approach that restricts the search of the worst case to a subset of models that are difficult to distinguish from each other with the available data (i.e., models that are close to each other in the sense that they lie inside an entropy ball; see Hansen and Sargent 2008). Informally, this could be achieved by choosing values for the neutral rate that lie inside a Bayesian credible interval (e.g., see Brandao Marques et al. (2024) for an application using the persistence of wage and price inflation as the source of model uncertainty).

Implications for the Current Monetary Stance

The criteria discussed in Section 4.1 can guide assumptions about the current short-term neutral rate suitable to gauge the monetary stance.[10] Criterion (i) suggests that short- to medium term equilibrium rates with diverse drivers may be more useful to guide monetary policy than those that deliver only long-run estimates.[11] HLW2017 and related estimates of the neutral rate are oriented toward the medium term and currently serve as a lower bound as short-term factors likely still push the short-run neutral rate above it. In contrast, estimates from DSGE models for the short-term real monetary policy rate that stabilizes the economy provide an upper bound for the short-term neutral rate. This is because the DSGE models track the equilibrium real interest rate that is consistent with the flexible prices and wages steady state and stabilizes the economy, which with inflation still above target would need to be above the neutral rate. Accordingly, a short-run neutral rate above 0 percent but below 1 percent seems aligned with the points estimates for 2024. Criterion (ii) suggests not putting too much weight on estimates from approaches that are very sensitive to slight changes in data and assumptions (e.g., HLW2017).

Figure 7: Investment in Euro Area and U.S.



Criterion (iii) further suggests that model estimates must be checked against observable trends in the economy. Specifically, for the euro area, unlike in the U.S., weaker-than-expected investment (Figure 7) and low demand for loans suggest that, everything else equal, the neutral rate may now be lower

[10] For assessing the monetary policy stance, real time estimates are the relevant reference. We are hence only discussing the stance at the end of the sample. For a proper analysis of the stance over time, one would need to derive vintages of estimates based on data available at that time.

[11] Instead of choosing the proper horizon of the model, an alternative is to control for variables that move the relevant shorter-term rate around the estimated longer-term rate (e.g., financial conditions) as in Arena et al. (2020).

than one year ago. Moreover, since these estimates are backward-looking and some models indicate a downward trend in 2025, it is possible that the euro area's neutral rate has come down since 2024. This trend reflects and aligns with subdued private investment due to low expected productivity growth, persistently higher-than-normal precautionary household savings resulting from high uncertainty, a moderation in migration flows influenced by a changing political environment, and modest fiscal consolidation as European fiscal rules are implemented. Consequently, by applying judgment to the econometric analysis, the real neutral rate at the one-year horizon could now be between 0 and 0.25 percent, implying a monetary stance policy close to neutral in April 2025. This range is in line with the implicit assumption of the short-term equilibrium rate (Section 3.3.) as well as with Brand, Lisack, and Mazelis's (2025), who find a range of estimates for the real neutral rate between -0.5 and 0.5 percent when excluding HLW2017 estimates, and from -0.5 to 1 percent when including them.

Implications for Equilibrium Rates in the Future

Longer-term estimates have stabilized and the estimates in this paper suggest that the recent hikes in equilibrium rates are likely to be temporary. Higher inflation and inflation expectations may have lowered the likelihood of hitting the zero lower bound relative to the pre-COVID period for now, but the results indicate that the risks of hitting the effective lower bound have not materially changed in the long term. While this may seem at odds with the intensifying debate about a permanent increase in equilibrium rates, it reflects that these estimates are backward-looking and therefore do not incorporate any information about the future. To say more about future rates requires insights from model simulations. In the following, we summarize and assess some key developments based on such research.

Some developments are likely to decrease equilibrium rates. First, in the euro area, trade fragmentation (due to lower potential growth) and financial fragmentation (given the excess savings signaled by persistent current account surpluses) are likely reducing the equilibrium rate. The impact of lower trade would differ by region, but overall effects are expected to be minor (IMF 2023). The effects of financial fragmentation hinge on countries' external positions. If surplus countries repatriate excess savings (lowering their equilibrium rate), deficit countries could face higher rates. Regional effects may range from a 40-bps decline to a 20-bps increase (IMF 2023). A durable shift in investor perceptions regarding the relative appeal of safe haven currencies, with the euro gaining in status relative to the dollar, would reduce the equilibrium rate in the euro area. Following recent changes in US trade policies and an uptick in policy uncertainty, the euro has appreciated to a three-year high against a basket of other major currencies. But it is premature to assert that a structural shift in investment portfolios or a strengthening of the euro's safe haven status has occurred. Second, while demographic trends dominated by aging and increased longevity may reduce the equilibrium rate, immigration could mitigate the impact or even reverse it, as it would raise the marginal product of capital in advanced economies. A decline in baby boomer savings could add further upward pressure (though the downward pressure caused by the past accumulation of savings by baby boomers is usually thought to have been small). Overall, the net effect of these changes is uncertain, but depending on assumptions, it could lower the equilibrium rate by around 0.5 percentage points by 2030 (Bodnár and Nerlich 2022).

Other developments are likely to increase the equilibrium rate. First, anticipated technology improvements from AI may raise consumption, investment, and GDP, as well as inflation should there be significant supply chain impairments, requiring higher interest rates for many years (Aldasoro et al. 2024). However, in the euro area, data do not suggest a consumption boom. If unanticipated, it does not result in higher inflation and interest rates (as consumption increases more slowly). If future productivity increases in the euro area due to AI are either small (Acemoglu 2024) or large (Korinek 2024) but unanticipated, in neither case would the equilibrium rate have already increased. Whether it will increase in the future will depend on AI's effect on productivity, which is still unclear. Second, increased uncertainty would raise the demand for savings, driving the equilibrium rate downward. But the dynamic could shift dramatically if higher uncertainty changes the perception of advanced economy sovereign bonds as safe assets. An erosion of the convenience yield could have a large impact on the equilibrium rate, with the opposite effect on private sector yields (IMF 2023). Third, higher defense spending could increase the equilibrium rate if financed by deficits. There could also be productivity spillovers in military exporters and benefits from reduced uncertainty, further raising the equilibrium rate. On the other hand, crowding out of more productive government spending could reduce it. Finally, markups have risen over the past few decades, increasing the income share for capital owners at the expense of workers (Akcigit et al. 2021). As workers' bargaining power strengthens post-pandemic, a return to 1970s labor shares in advanced economies could elevate the equilibrium rate by 6 to 19 basis points by 2050 (IMF 2023).

In conclusion, several slow-moving forces are likely to drive the equilibrium rate in opposite directions, with the net impact likely tilted to the upside. However, the 5y5y market-implied equilibrium rate, which incorporates expectations about future developments, remains in negative, which suggests that markets currently do not expect a rebound in the equilibrium rate. While some of these changes will be captured by the models discussed in this paper, others are likely to introduce structural breaks that will require new models with additional channels.

Conclusion

This paper establishes the significance of estimating real equilibrium interest rates in the euro area, highlights the complexities inherent in such estimations, and details various approaches used to calculate equilibrium interest rates. These include univariate statistical filters, VAR models, semi-structural models, and fully structural models, with each method presenting unique strengths and weaknesses, contributing to the varied results observed in the literature. It is essential to refer to equilibrium interest rates with caution since this rate should always be understood as a specific theoretical construct that makes sense in a specific model or approach. Different models often use different and not strictly comparable concepts of equilibrium rates. This diversity underscores the importance of selecting appropriate estimates tailored to specific contexts, for example by considering their conceptual fit, robustness, and consistency with other economic indicators.

The range of estimates derived from both closed and open economy models shows that recent short-term equilibrium rates are likely above longer-term rates in the euro area. These findings reflect the underlying dynamics of the euro area economy and external influences.

Rather than accumulating more methods to estimate specific equilibrium rates, future research could focus on developing unifying frameworks and cohesive approaches that synthesize existing models. One good example of such an approach is the recent work by Reis (2025), who provides a general framework that conceptually distinguishes between four equilibrium rates and establishes what fundamentals separately or jointly drive them, and how they relate to each other in general equilibrium.

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Annex: Some More Model Details

Closed Economy Models

Univariate Stochastic Volatility Model

The trend component of the real interest rate can be interpreted as a measure of the equilibrium interest rate, as discussed in Fiorentini et al. (2018) and Beyer and Milivojevic (2023). Therefore, we decompose the real interest rate into two components: a slow-moving component, denoted as (r_t^*), and a transitory component, denoted as ($\widetilde{r_t}$). More specifically, we estimate an unobserved component local level stochastic volatility model for the real interest rate using the following specification:

$$r_t = r_t^* + \widetilde{r_t}$$

$$r_t^* = r_{t-1}^* + e_t, \qquad e_{it} \sim N(0, \sigma_e^2)$$

$$\widetilde{r_t} = \epsilon_{it}\sqrt{e^{\ln h_t}}, \qquad \epsilon_{it} \sim N(0,1)$$

$$\ln h_t = \alpha_{01} + \alpha_1 \ln h_{t-1} + v_t, \qquad v_{it} \sim N(0, \sigma_v^2)$$

where the real interest rate is the sum of the equilibrium rate and the interest rate gap, the equilibrium rate is represented by a random walk, and the interest rate gap features stochastic volatility, with the logarithm of the latent parameter h_t following a stationary process.

We use a Bayesian approach and Markov chain Monte Carlo (MCMC) methods to estimate the unobserved state variable r_t^*, the stochastic volatility, and the unknown parameters. For more details about the estimation procedure and the setting of priors, see Beyer and Milivojevic (2023). We estimate the model with quarterly data from 1990Q1 to 2024Q3.

VAR by del Negro et al. (2017)

As in the univariate model, the trend component of a short-term interest rate is regarded as a measure of the equilibrium rate of interest. But instead of relying only on one variable, different observable variables—with some economic structure among them—are decomposed into cyclical and trend components.

Del Negro et al. (2017) estimate a VAR using Bayesian techniques with inflation (π_t), short-term (i_t^{3m}) and long-term interest rates (i_t^{10y}), and expected inflation (π_t^e) and expected short-term rates (i_t^e). The model features a measurement equation $y_t = \Lambda\overline{y_t} + \widetilde{y_t}$, where $y_t = (\pi_t, \pi_t^e, i_t^{3m}, i_t^e, i_t^{10y})$ are the observables, $\overline{y_t} = (\pi_t^*, r_t^*, tp_t^*)$ are the (possibly correlated) trends, and $\widetilde{y_t}$ are the stationary components. Both latent variables $\overline{y_t}$ and $\widetilde{y_t}$ evolve according to a random walk $(\overline{y_t} = \overline{y_{t-1}} + e_t)$ and a VAR $A(L)\widetilde{y_t} = \widetilde{y_{t-1}} + u_t$, where $A(L)$ is a parameter matrix polynomial in a lag operator and e_t and u_t are the reduced-from errors. For identification, the following relations from y_t to $\overline{y_t}$ are assumed:

$$\pi_t = \pi_t^* + e_t^{\pi}$$

$$\pi_t^e = \pi_t^* + e_t^{\pi^e}$$

$$i_t^{3m} = \pi_t^* + r_t^* + e_t^{i,3m}$$

$$i_t^e = \pi_t^* + r_t^* + e_t^{i^e}$$

$$i_t^{10y} = \pi_t^* + r_t^* + tp_t^* + e_t^{i,10y},$$

The relationship between the nominal short-term rate, trend inflation, and the equilibrium interest rate is grounded in the Fisher equation, which holds in the long run. To differentiate movements in trend inflation from those in the equilibrium interest rate, trend inflation is derived from both actual inflation and expected inflation. Additionally, to improve the inference on the equilibrium rate of interest, we incorporate information on expected short-term rates and long-term rates. Long-term rates are assumed to be influenced by trend inflation, the equilibrium rate of interest, and an exogenous trend term premium. Furthermore, inflation and inflation expectations are cointegrated, as are short-term rates and their expectations.

We estimate the model from 1999Q1 to 2024Q3 using data from Haver.

Holston Laubach Williams Model

The semi-structural model of Holston, Laubach and Williams (2017, 2023), is a linearized New Keynesian model including a Phillips curve and an investment-saving (IS) curve, where trend output is the key driver of the equilibrium rate via the households' Euler equation. The model equations are as follows:

$$y_t = y_t^* + \tilde{y}_t$$

$$\pi_t = b_\pi \pi_{t-1} + (1 - b_\pi)\, \pi_{t-1,4} + b_y \tilde{y}_t + \epsilon_t^{\pi}$$

$$\tilde{y}_t = a_{y,1}\, \widetilde{y_{t-1}} + a_{y,2}\, \widetilde{y_{t-2}} + \frac{a_r}{2} \sum_{j=1}^{2} \left(r_{t-j} - r_{t-j}^* \right) + \epsilon_t^{\tilde{y}}$$

$$y_t^* = y_{t-1}^* + g_{t-1} + \epsilon_t^{y^*}$$

$$g_t = g_{t-1} + \epsilon_t^{g}$$

$$z_t = z_{t-1} + \epsilon_t^{z},$$

where y_t and y_t^* are the equilibrium logarithms of real GDP and its unobserved trend component, $\tilde{y}_t$ is its cyclical component, π_t is the annualized inflation rate and $\pi_{t-1,4}$ the average of its second to fourth lags, r_t is the ex-ante real interest rate. The equilibrium rate of interest is r_t^*, with its law of motion given by

$$r_t^* = c\, g_t + z_t,$$

where $c > 0$ is a constant, g_t is trend growth and z_t captures other determinants (often referred to as temporary factors). The shocks $\epsilon_t^{\pi}, \epsilon_t^{\tilde{y}}, \epsilon_t^{y^*}, \epsilon_t^{g}, \epsilon_t^{z}$ are i.i.d. normally distributed.

We estimate the model with the official replication codes from the authors and the codes from IMF (2023). The author’s code is very sensitive for even small changes to the time period. The Bayesian estimation in IMF (2023) is less sensitive to shorter sample length. Since we aim to estimate all models from 1995Q1 for comparability, we decided to use this code.

Neri and Gerali (2019) DSGE Model

In this model, a representative household maximizes utility by selecting consumption, labor supply, capital, investment, and a safe nominal bond, while adhering to a budget constraint and capital accumulation law. The household rents capital, supplies labor to firms, and prefers gradual changes in consumption and work hours, with habit formation in labor resembling learning-by-doing. Shocks to patience, work disutility, and bond preferences influence utility. A representative firm produces a homogeneous good using Cobb-Douglas technology, subject to permanent and transitory technology shocks. Monopolistically competitive firms set prices based on demand and changing price costs, influenced by past inflation, with mark-ups subject to independent shocks. The central bank uses a Taylor rule for policy rates, adjusting rates in response to monetary policy shocks.

The equilibrium rate is defined as the real short-term rate where output is at its flexible price level and inflation aligns with the central bank's target. It represents the real rate in an economy free from nominal price rigidities, maintaining inflation at its target and output at its potential across all periods and shocks. Upon a shock, the neutral rate adjusts immediately and gradually returns to its steady state, differing from lower-frequency equilibrium rate concepts like HLW2017.

The model is estimated with seven observable variables—per capita real consumption growth, per capita real investment growth, changes in the relative price of investment, inflation, the short-term nominal interest rate, labor input growth relative to population, and an inflation target measure—at annual frequency using Bayesian methods in Dynare. For more details on the model and estimation, refer to Neri and Gerali (2019) and the paper's appendix. We appreciate the authors for sharing replication codes and an updated dataset.

Open Economy Models

Del Negro et al. (2019)

This estimation uses a very similar set-up to the closed-economy estimation in Del Negro et al. (2017). However, expectations of inflation and the short-term rate are dropped, and the model uses only three variables: inflation as well as short- and long-term interest rates. The crucial difference is the introduction of a common trend. In the original paper, trends in the Euro Area countries are estimated jointly, with common (i.e., Euro Area) factors for trend inflation, the equilibrium rate, and the trend term premium estimated together. We use this approach to add a global factor estimated jointly for the Euro Area and the US.

Wynne and Zhang (2018)

Wynne and Zhang (2018) extend the original HLW2017 model such that the equilibrium interest rate is not only determined by domestic trend growth but also foreign trend growth. The equilibrium rate is thus determined as follows:

$$r_t^{h,*} = c_h^h g_t^h + c_f^h g_t^f + z_t^h,$$

where g_t^f is foreign growth with an analogous equation for the foreign equilibrium rate $r_t^{f,*}$. Higher foreign growth increases foreign rates of return, requiring higher returns on investments in the domestic economy. Likewise, changes in domestic interest rates spillover to foreign countries. The model is extended via a symmetric foreign region subject to the same set of structural equations.

We use the foreign region is a GDP-weighted average of foreign country variables that includes around 70 percent of world GDP. The Philips curves include additionally import prices and oil prices. We used replication codes from the authors. The estimations are very sensitive to different starting values and priors.

Ferreira and Shousha (2023)

Ferreira and Shousha (2023) estimate a cross-country model that simultaneously account for productivity, demographics, global supply of safe assets, demand factors for safe assets, and global spillovers faced by each economy (from the rest of the countries in the estimation). Building on Uribe (2022) they estimate the following model.

Their benchmark model closely follows the small open economy setup of Galí and Monacelli (2005) and Lubik and Schorfheide (2007).

Cyclical unemployment, inflation, and policy rates follow a vector autoregression of first order subject to structural shocks. Specifically, for economy *j* at time *t*, they model the cyclical and trend components of the unemployment, $u_{j,t}$, inflation, $\pi_{j,t}$, and policy, $i_{j,t}$, rate as follows:

$$\begin{bmatrix} u_{j,t} \\ \pi_{j,t} \\ i_{j,t} \end{bmatrix} = \begin{bmatrix} \hat{u}_{j,t} \\ \hat{\pi}_{j,t} \\ \hat{\imath}_{j,t} \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} X_{j,t}^u \\ X_{j,t}^m \\ X_{j,t}^r \end{bmatrix},$$

$$X_{j,t}^s = X_{j,t-1}^s + X_{j,t}^s, \qquad for\ s \in \{u, m\}$$

where $\hat{u}_{j,t},\ \hat{\pi}_{j,t}\ and\ \hat{\imath}_{j,t}$ are the cyclical components of the unemployment, inflation, and policy rates, respectively; $X_{j,t}^u$ is the trend in the unemployment rate; and $X_{j,t}^m$ is a common trend in inflation and policy rates, referred to as the monetary trend. We assume that these two trends follow simple random walk processes.

There are shocks to the stochastic trends: permanent unemployment rate shocks, permanent monetary shocks, changes in longer-run real neutral interest rates, temporary monetary shocks, temporary demand shocks, and temporary supply shocks. For simplicity, they assume that the temporary demand shock follows an autoregressive process of order one, while all other shocks are independent and identically distributed with normal distributions. For the identification of these shocks through sign and other restrictions refer to their paper.

They model changes in longer-run real neutral interest rates $x_{j,t}^{r}$ as depending on the following determinants:

$$x_{j,t}^{r} = \beta_{pt}\Delta pt_{j,t} + \beta_{\omega s}\Delta\omega s_{j,t} + \beta_{cy}\Delta cy_{t} + \beta_{ss}\Delta ss_{t} + \beta_{sd}\Delta sd_{t} + \beta_{gs}g_{j,t-1} + \epsilon_{j,t},$$

Where $\Delta pt_{j,t}$ is economy *j*'s change in trend-productivity growth; $\Delta\omega s_{j,t}$ is economy *j*'s change in the working-age share; Δcy_{t} is the change in the trend convenience yield; Δss_{t} is the change in the supply of safe assets; Δsd_{t} is the change in our proxy for policy-driven demand for safe assets; $\epsilon_{j,t}$ are shocks that account for unobserved determinants; and $g_{j,t-1}$ is our measure of *global spillovers*,

$$g_{j,t-1} = \sum_{i\neq j}\omega_{i}^{j}\left(\beta_{pt}\Delta pt_{i,t-1} + \beta_{\omega s}\Delta\omega s_{i,t-1}\right)$$

calculated as the trade-weighted rest-of-the-world productivity and working-age share from economy j's perspective. Thus, by using this measure of global spillovers, we can decompose the contributions from productivity and demographics into economy-specific and rest-of-the-world components.

They assume that the determinants of neutral rates are unrelated to each other and to the cyclical state of their economies, which allows them to decompose changes in longer-run neutral rates as originated from each one of these determinants. Finally, they close the model by stipulating relationships between model variables and observable variables and estimate the model with Bayesian techniques.

Zhang et al. (2021)

Zhang et al. (2021) estimate the equilibrium rate of interest using a structural New Keynesian model that incorporates exogenous domestic technological progress, referred to as trend growth, and a more flexible representation of preferences for domestic households, including a domestic preference shock. To account for growth, albeit exogenously, they introduce an underlying non-stationary technological productivity shock process while retaining the structural representation of business cycles that the small open economy model provides. The evolution of this economy is specifically determined by a dynamic IS curve obtained from log-linearizing the Euler equation arising from the domestic household's optimization problem, a Phillips curve following from the optimal price-setting behavior of domestic firms under monopolistic competition and staggered pricing, and two supplementary equations describing domestic and foreign inflation. The latter is treated as a residual and estimated with the rest of the model, assuming it follows an AR(1) process.

They refer to the equilibrium rate of interest and the potential output of the small open economy as the real interest rate and level of economic activity that would prevail in the domestic economy absent all nominal rigidities, under perfect competition and flexible prices. It depends positively on the forecastable components of future productivity growth, expected changes in preferences, and expected world output growth. The model also includes an interest rate feedback rule capturing monetary policy's response to domestic economic developments. While their paper presents different rules, we choose a standard Taylor-type interest rate rule, with the central bank adjusting its policy rate in response to deviations in the domestic inflation rate and output gap. They estimate the model using Bayesian techniques, and for details about the data used and the estimation strategy, refer to their paper.

PUBLICATIONS

Real Equilibrium Interest Rates in the Euro Area

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