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The fall in real long-term
government bond yields:
Disentangling different
drivers

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ECONOMICS DEPARTMENT

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By Łukasz Rawdanowicz, Mohamed Hammouch and Makoto Kasai

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ABSTRACT/RÉSUMÉ

The fall in real long-term government bond yields: Disentangling different drivers

This paper contributes to the empirical literature investigating reasons for the fall in real interest rates in advanced economies. It focuses on selected drivers from three broad categories: demographic changes; imbalances between supply of and demand for safe assets; and monetary policy at home and abroad. Several country-specific error-correction models are estimated for the G7 countries, starting in the early 1970s. Results support the expected relationship with demographic variables. However, this is not corroborated by models with household saving, raising questions about transmission mechanisms of demography. For most countries, there is little robust evidence about the role of proxies of the supply of and demand for government bonds. However, real long-term government bond yields are closely linked with real policy interest rates, with little evidence that real policy interest rates followed secular declines in real potential GDP growth – a proxy of a neutral interest rate. Domestic real yields are also affected by foreign real rates, indicating the role of spillovers and common global trends.

JEL Classification: C22, E43, E52, E58, F31, J11.

Keywords: Real interest rate, demographic transition, saving rate, demand for safe assets, monetary policy

**Baisse des rendements réels des obligations d'État à long terme :
distinguer entre les différentes causes**

Notre étude contribue à la littérature empirique examinant les facteurs liés à la baisse des taux d'intérêt réels au sein des économies avancées. Se concentrant notamment sur une sélection de déterminants correspondant à 3 catégories de facteurs : l'évolution démographique, les déséquilibres concernant l'offre et la demande d'actif sûr ; et la politique monétaire, d'une part au niveau national et d'autre part à l'étranger. Nous estimons pour les économies membres du G7 des modèles spécifiques à correction d'erreur, à partir du début des années 1970. Les résultats confirment une relation significative avec les variables démographiques. Toutefois, les modèles intégrant l'épargne des ménages rejettent cette hypothèse, ce qui soulève la question des mécanismes de transmission des facteurs démographiques. Pour la plupart des pays, le rôle de l'offre et de la demande d'obligations souveraines n'est pas significatif. Concernant la politique monétaire, bien que les taux d'intérêts réels à long terme des obligations d'états soient intrinsèquement liés aux taux directeurs, les résultats ne soutiennent pas que ces derniers aient suivi une baisse séculaire, évaluée à l'aune de la croissance du PIB potentiel réel - utilisée comme proxy du taux d'intérêt réel d'équilibre. Les rendements nationaux réels sont également affectés par les taux d'intérêt réels étrangers, mettant en lumière la présence d'effets transfrontaliers et de tendances globales communes.

Codes JEL : Taux d'intérêt réel, transition démographique, taux d'épargne, demande d'actifs sûr, politique monétaire

Mots Clés : C22, E43, E52, E58, F31, J11.

TABLE OF CONTENTS

Introduction and main findings	5
Estimation strategy	7
Saving-investment imbalances: Demographics	9
Supply of and demand for safe assets	12
Monetary policy	14
Estimation strategy	15
Estimation results	16
Demographics	16
Supply of and demand for safe assets	17
Monetary policy and international spillovers	17
Robustness checks	18
Conclusions	19
REFERENCES	20
ANNEX 1. STATISTICAL ANNEX	24

Tables

1.	Expected signs of the tested drivers of real long-term interest rates	9
A1.	Selected estimates of neutral interest rates	24
A2.	Definition of variables	25
A3.	Augmented Dickey-Fuller tests	26
A4.	Definitions of shocks to illustrate elasticities of estimated models in the tables below	26
A5.	Simplified estimation results of 2-stage ECM models for Canada	27
A6.	Simplified estimation results of 2-stage ECM models for France	28
A7.	Simplified estimation results of 2-stage ECM models for Germany	29
A8.	Simplified estimation results of 2-stage ECM models for Italy	30
A9.	Simplified estimation results of 2-stage ECM models for Japan	31
A10.	Simplified estimation results of 2-stage ECM models for the United Kingdom	32
A11.	Simplified estimation results of 2-stage ECM models for the United States	33
A12.	Estimation results of 2-stage ECM models for real policy rates in the United States	34

Figures

1.	Real government bond yields in advanced economies have fallen to low levels	5
2.	Real interest rates based on realised and expected inflation co-move closely	8
3.	Demographic transition in advanced economies	10
4.	Demographic transition and household saving in selected advanced economies	11
5.	Household holdings of US government bonds have varied over time	12
6.	Gross government debt has been on the rise in many advanced economies	13
7.	EMEs have accumulated large foreign exchange reserves	13

THE FALL IN REAL LONG-TERM GOVERNMENT BOND YIELDS: DISENTANGLING DIFFERENT DRIVERS

By

Łukasz Rawdanowicz, Mohamed Hammouch and Makoto Kasai¹

Introduction and main findings

Real long-term government bond yields have declined in the main advanced economies (AEs) from their peaks in the 1980s and the early 1990s (Figure 1). In the aftermath of the global financial crisis, they have reached very low levels, last seen in the 1960s and 1970s. In contrast to the 1960s and 1970s, when inflation was generally higher than in recent years, the current low real interest rates reflect primarily low nominal rates. The decline in real yields was unexpected, with consensus projections persistently over-predicting the yields over the past two decades (Council of Economic Advisers, 2015). Corporate bond yields and bank lending rates in AEs have followed the same trend. Estimated (unobservable) neutral interest rates, which ensure price stability in the absence of economic shocks, have also declined over the recent decades, in some cases to negative levels (Table A1 in Annex).

Figure 1. Real government bond yields in advanced economies have fallen to low levels

Note: Real yields are calculated as a difference between nominal 10-year benchmark government bond yields and contemporary year-on-year core inflation rates. Core inflation excludes prices of food and energy.

Source: OECD Economic Outlook No. 100 database; and authors' calculations.

1. The authors work at the OECD Economics Department; Mohamed Hammouch was an intern at the OECD at the time of writing the paper. We would like to thank OECD Economics Department colleagues, Sveinbjörn Blöndal, Boris Cournède, Robert Ford, Catherine L. Mann, Elena Rusticelli, Jean-Luc Schneider and Douglas Sutherland for their useful comments. We are grateful to Ane Kathrine Christensen and Seung-Hee Koh for statistical help and to Isabelle Fakih (all from the OECD Economics Department) for final document preparation.

The fall in real interest rates to very low levels in many countries around the world has stimulated research and policy discussions about causes and implications of this phenomenon (among others Bouis et al. (2014), IMF (2014); Bean et al. (2015), Council of Economic Advisers (2015), Rachel and Smith (2015), Hamilton et al. (2016), Nakaso (2016), Draghi (2016) and Fischer (2016a,b)). Persistently low real rates have far reaching implications for the conduct of monetary and fiscal policies, business models of financial institutions and more broadly households and businesses. Thus, it is essential for policymakers to understand how real interest rates are determined and to identify factors that have driven them down. Three broad explanations have been put forward, emphasising (1) the imbalance between desired saving and investment, being significantly affected by demographic changes; (2) the imbalance between supply of and demand for safe assets; and (3) the role of monetary policy at home and abroad.

While many of these explanations are based on theoretical arguments, stylised facts or calibrated models, there has been little empirical testing of their joint relevance in a unified econometric framework. For instance, Rachel and Smith (2015) come up with back-on-the-envelope calculations based on a rough calibration of the desired global saving and investment curves and an eclectic set of secular factors affecting desired saving and investment that would require changes in the equilibrium global real interest rate.² Several papers use calibrated overlapping-generation models to demonstrate that the decline in the equilibrium real interest rates over the past two decades can be explained to a large extent by demographic shifts (Ikeda et al., 2014; Gagnon et al., 2016; Carvalho et al., 2016; Lisack et al., 2017). For instance, Gagnon et al. (2016) show that the observed changes in US population, family composition, life expectancy and labour market efficiency account for a 1¼-percentage point decline in real GDP growth and the equilibrium real interest rate since 1980, i.e. essentially all of the permanent fall in these variables based on some estimates. These findings are not surprising given that these models do not account for other factors.

Several studies tested the role of fundamentals in driving real government bond yields in the (panel) cointegration framework for AEs. For instance, Orr et al. (1995) investigated long-term relationship with foreign real interest rates, returns on capital, a measure of bond portfolio risks, inflation, and current account and government budget balances. In the short run, real rates were regressed on changes in long-term determinants and in real short-term interest rates, structural deficits and exchange rates. They estimated a system of error correction models for 17 OECD countries, imposing homogenous long-run elasticities but letting short-run elasticities to vary across countries. They adopted a general-to-specific approach. Similarly, Poghosyan (2014) tested potential growth and government debt as long-term determinants, and changes in debt, inflation, real short-term interest rates, output growth and a primary balance in the error correction framework for a panel of 22 OECD countries between 1980 and 2010. Ciocyte et al. (2016) also estimated a panel for 20 OECD economies over the sample 1990-2013, but with nominal government bond yields as the dependent variable, and with potential GDP growth, inflation, inflation volatility, government gross debt, the share of population 20-39 in total population as explanatory variables. While Poghosyan (2014) found that bond yields are positively related to the government debt-to-GDP ratio and the potential growth rate, Ciocyte et al. (2016) (for nominal yields) found the opposite. Orr et al. (1995) found a positive role for foreign long-term interest rates and short-term interest rates, the latter was also corroborated by Poghosyan (2014). Ciocyte et al. (2016) found that the tested demographic variable affected, as expected, government bond yields.

2. Out of the estimated decline in the global real interest by 450 basis points (bps), Rachel and Smith (2015) attribute 300 bps to: demographic forces (90 bps), rise in inequality (45 bps), EMEs' saving glut (25 bps), falling relative prices of capital goods (50 bps), lower public investment (20 bps) and rise in the spread between the risk free rate and the rate of return on capital (70 bps); and further 100 bps to the expected decline in future global growth that lowered desired investment.

This paper contributes to the empirical literature by applying econometric time-series analysis to test jointly several determinants of long-term real government bond yields that have been suggested in support of the three different hypotheses. The analysis covers seven major AEs for a sample starting in most cases in 1972. The following conclusions can be drawn based on estimated country-specific 2-stage error-correction models:

Saving-investment imbalances: Demographics

- For most countries, falling dependency ratios, especially the one based on people not in employment, tend to reduce real government bond yields. For some countries, also the rising share of the high-saving population (aged 40-64 years) in total population tends to lower real yields. The role of life expectancy is difficult to establish. Surprisingly, demographic trends are rarely consistent with the evolution of household saving, which turn out not to have the expected long-term relationship with real government bond yields.

Supply of and demand for safe assets

- Rising government debt in relation to GDP rarely increases real government bond yields in the long run. The sign and significance of this explanatory variable vary across countries and model specifications. The negative impact of rising foreign exchange reserves in emerging market economies (EMEs) and oil-exporting countries is not supported by the data with the exception of the United States.

Monetary policy

- Real long-term government bond yields are closely linked with real policy interest rates both in the short and long term. This finding is robust to various model specifications and samples. The estimations do not explain to what extent policy rates responded to inflation, GDP and financial conditions. However, there is little evidence that real policy interest rates followed secular declines in real potential GDP growth – a proxy of neutral interest rates – as it would be implied by a Taylor rule with a time-varying neutral interest rate. Moreover, in many countries, potential GDP growth is either not cointegrated with real policy interest rates or is negatively related with them.
- In the United States, central bank holdings of government bonds are negatively correlated with real bond yields.
- Domestic real long-term interest rates are closely associated with foreign rates. This likely indicates the importance of financial market and monetary-policy spillovers, with increasing financial openness, and common global trends that affect nominal interest rates and inflation.

The remainder of the paper, first, outlines estimation strategy in terms of selecting the dependent variable, regressors and estimation approach and, then, discusses estimation results along with robustness checks. The final section draws conclusions for future research.

Estimation strategy

This paper jointly tests several drivers of long-term real interest rates from the three broad categories discussed in the literature for G7 economies (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States).

Many explanations of the decline in real interest rates refer to unobserved equilibrium rates, the estimates of which are highly uncertain and likely to be biased downwards.³ Since this complicates econometric testing and limits country coverage, real 10-year government bond yields are used as the dependent variable. Due to the lack of sufficiently long time series of long-term inflation expectations, real rates are calculated based on realised core inflation. The comparison of the real interest rates based on long-term inflation expectations (where available) and the real interest rates as defined in this paper indicates that both rates tend to co-move closely, justifying the simplified assumption (Figure 2).

Figure 2. Real interest rates based on realised and expected inflation co-move closely

Note: Real interest rates based on expected inflation refer to: in the United States, 10-year government bond yields deflated with 10-year ahead expected inflation from the Survey of Professional Forecasters by the Federal Reserve Bank of Philadelphia; in the United Kingdom, 3-year government bond yields deflated with 3-year ahead expected inflation from the Monetary Policy Committee's projected probability distributions based on market expectations for the annual rate of CPI inflation published by the Bank of England in the Inflation Report; and, in Germany and France, 5-year government bond yields deflated with 5-year ahead expected inflation for the euro area from the Survey of Professional Forecasters by the ECB. Real interest rates based on realised inflation refer to government bond yields (of maturity indicated above) deflated with core inflation.

Source: OECD Economic Outlook No. 100 database; Bank of England; ECB; Federal Reserve Bank of Philadelphia; and authors' calculations.

3. For instance, for the baseline model in Bouis et al. (2013) based on the Mésonnier and Renne (2007) methodology, the 95% confidence intervals around the estimated unobservable rate are between 3 and 4 percentage points. The neutral real interest rate estimates can also change by up to 4 percentage points with alternative assumptions of the risk aversion coefficient. Similarly, the average standard error of the neutral interest rate estimates in Laubach and Williams (2013) reaches 2 percentage points. The estimates differ up to 0.5 percentage point depending on whether a one or two-sided Kalman filter is applied. Moreover, the estimates of neutral rates obtained by standard methods are likely to be biased downwards. This stems from the failure to account for financial factors that affect the long-term equilibrium conditions (Juselius et al., 2016) and for credit rationing (Cukierman, 2016).

Table 1. Expected signs of the tested drivers of real long-term interest rates

	Saving-investment imbalances: demographics	Supply of and demand for safe assets	Monetary policy and international spillovers
Dependency ratio	+		
Share of 40-64 population in total population	-		
Life expectancy	-		
Household saving	-		
Government debt		+	
EMEs foreign exchange reserves		-	-
Economic policy uncertainty index		-	
Real central bank policy rate			+
Central bank holdings of government bonds			-
Foreign real long-term interest rate			+
Real potential GDP growth	+		+

Source: Authors' compilation.

The remainder of this section provides an overview of the different drivers suggested in the literature. Table 1 lists the selected explanatory variables and their expected signs.

Saving-investment imbalances: Demographics

Low global real interest rates are seen to stem from high desired saving in relation to desired investment, where this imbalance is mostly driven by secular factors (IMF, 2014; Bean et al., 2015; Rachel and Smith, 2015; Fischer, 2016b).

On the saving side, equilibrium rates are considered to be affected by three important demographic transitions taking place in many AEs (Figure 3; Ikeda and Saito., 2014; Gagnon et al., 2016; Carvalho et al., 2016; Lisack et al., 2017). First, the labour force participation of the post-war baby boomers, together with falling fertility rates, has reduced the dependency ratio, i.e. the number of dependants (children and elderly people) to working age population. This is expected to increase desired savings and put downward pressure on real interest rates. A similar impact should come from the increase in the share of the middle-aged population as this group has a high propensity to save as stressed by the life-cycle hypothesis (Bean et al., 2015). Second, expected longevity has been rising and encouraged asset accumulation to finance consumption during longer retirement. Third, falling fertility rates and increasing longevity in AEs have worked to slow population growth and raise the share of older people in the total population, reversing the previous trends in dependency ratios and hence reducing saving.

On the investment side, many studies have pointed to secular and cyclical factors that have reduced investment over recent decades, including the increase in capital-labour ratios due to demographic changes (Carvalho et al., 2016),⁴ falling relative prices of investment goods (Sajedi and Thwaites, 2016), heightened risk aversion (OECD, 2015; Bean et al., 2015), and expectations of lower productivity and demographically-driven global output growth (OECD, 2015; Council of Economic Advisers, 2015; Fischer, 2016b).

4. Falling population growth raises capital per worker and thus reduces the marginal return on capital and discourages investment.

Figure 3. Demographic transition in advanced economies

1. The dependency ratio refers to the ratio of the population of less than 20 years old and of more than 64 years old to population between 20 and 64 years old.

Source: OECD Population statistics database; OECD Economic Outlook No. 100 database; and authors' calculations.

The saving-investment imbalance hypothesis is appropriate for the world real interest rates (i.e. for a closed economy). Given the focus on country-specific estimations for mostly open economies, it is not tested in this paper. Omitting investment-related factors may be justified in view that investment demand may not have a strong impact on government bond yields. Total domestic investment is dominated by private investment. Business investment is financed only partly by corporate bonds, especially in Europe.⁵ Thus, changes in total investment may have a limited impact on the supply and yields of corporate bonds and in turn on government bond yields. This is in contrast with equilibrium rates in theoretical models without financial assets and the government sector where investment affects demand for funding and interest rates directly. In contrast, demographic variables can affect household saving and in turn demand for government bonds. Thus, the following variables are tested (Table A2 in Annex): dependency ratio (young and elderly population over working age population), effective dependency ratio (calculated as a share of population not in employment to total employment), the share of population 40-64 years old in total population, and life expectancy at age of 15 and 60. Real interest rates should be positively related to dependency ratios and negatively related to life expectancy and the share of population with high saving propensity.

There are two caveats about the role of dependency ratios in explaining real long-term government bond yields. First, in several countries, household saving in relation to GDP has declined since the mid-1980s or the early-1990s, even though the dependency ratio has continued to fall or stabilised (Figure 4). A similar puzzle arises for the rising life expectancy. This suggests that other factors than demographics have been affecting saving and in turn real interest rates. Rising wealth due to a rapid increase in asset prices, which reduces the need to save, may be one explanation. Also, financial liberalisation could have reduced

5. In the United States, on average between 1989 and 2006, only around 16% of total investment by US firms was financed by debt issuance, with nearly 60% covered by cashflow (Elsas et al., 2014). Similarly, in the United Kingdom, between 1987 and 2015, internal funds accounted for 67% of the aggregate net acquisition of funds, equity 15%, bonds 7% and bank loans 3% (Bank of England, 2016).

Figure 4. Demographic transition and household saving in selected advanced economies

Note: Saving refers to gross household saving as a per cent of GDP. For Japan, the gross saving rate before 1980 is approximated based on net saving. The effective dependency ratio refers to the ratio of population not in employment to total employment.

Source: OECD Economic Outlook No. 100 database; OECD Population Statistics database; and authors' calculations.

Figure 5. Household holdings of US government bonds have varied over time

Note: Household holdings of government bonds include bonds held by households directly and indirectly via pension funds.

Source: Federal Reserve Flow of Funds; and authors' calculations.

financial constraints and in turn desire to save. Consequently, an additional model is estimated with gross household saving in relation to GDP instead of demographic variables. A higher saving ratio should be associated with lower real government bond yields. Second, in contrast to the assumption used in many calibrated theoretical models, households can invest their savings in various financial and non-financial assets. Thus, falling dependency ratios or rising saving may exert downward pressure on government bond yields only to a limited extent. For instance, in the United States, the (direct and indirect) ownership of government bonds by households has varied significantly over the past five decades (Figure 5).

Supply of and demand for safe assets

Low yields of government bonds could stem from rising demand for safe assets in excess of their supply. Government bonds frequently have the status of safe assets due to high liquidity, being seen as a reliable store of value and insurance against future crises.

On the supply side, other things being equal, a rising supply of government bonds should reduce their price and thus raise yields. This relation is likely to be non-linear. At high debt levels, growing debt raises the risk of default and thus risk premia and bond yields. In many AEs, government gross debt has been on the rise, especially since the beginning of the crisis, likely exerting an upward pressure on bond yields (Figure 6). To test the role of the supply of government bonds, gross general government debt as a per cent of GDP is used as a potential explanatory variable in the estimations below. The higher the debt-to-GDP ratio, other things being equal, the higher real interest rates are expected to be.

Figure 6. Gross government debt has been on the rise in many advanced economies

Source: OECD Economic Outlook No. 100 database.

Figure 7. EMEs have accumulated large foreign exchange reserves

Source: IMF Balance of Payments statistics; OECD Economic Outlook No. 100 database; and authors' calculations.

On the demand side, three factors are stressed in the literature:

- The build-up of foreign exchange reserves by EMEs and oil-exporting countries. This is related to the global saving glut hypothesis (Bernanke, 2005; Roubini and Setser, 2005), suggesting that excess saving, as measured by current account surpluses, contributed to the decline in real interest rates in advanced countries (see Desroches and Francis (2007) for empirical evidence). High saving relative to investment is attributable to precautionary saving given poorly developed public safety nets. However, current account balances reveal little about the role a country plays in international borrowing/lending (Borio and Disyatat, 2011). As net capital flows capture changes in net claims on a country stemming from trade in goods and services, they say little about purchases of foreign assets. Besides, current account surpluses of a country or a region do not indicate actual financing of a particular foreign country. Following the 1997 financial crisis, many EMEs accumulated large reserves to have buffers in case of capital outflows and, in some countries, to prevent the appreciation of their currencies (Figure 7). These reserves have been invested mostly in US safe assets, but in some cases also in safe assets of other AEs.⁶ In the

6. The role of the US dollar as a reserve currency has diminished over the past few decades, but the US dollar still accounts for around 60% of foreign exchange reserves of EMEs. The other two large currency areas, the euro area and Japan, recently accounted for around 20% and 3%, respectively. While the share of

empirical work reported below, foreign exchange reserves of central banks in EMEs and oil-exporting countries as a share of GDP of a given G7 economy is used as a regressor. The higher the share, the lower the real interest rate should be.

- Higher perceptions of risks can stimulate demand for government bonds (Miles et al., 2005; Barro, 2006). This may have been particularly relevant after the recent global crisis. Thus, a role of uncertainty measures to account for the flight to safety is investigated. Given data limitations, uncertainty as measured by the economic policy uncertainty index from Baker et al. (2016) is tested for a few countries with available long time series.⁷ Its increase should be associated with lower real interest rates.
- The supply of safe assets by the private sector. A provision of private safe assets, with perceived similar risk characteristics, is likely to affect demand for government bonds. For instance, in the aftermath of the crisis, private safe assets have shrunk massively, with certain private assets (such as mortgage-backed securities and other securitised instruments) losing investment-grade ratings (Caballero and Farhi, 2013). This should have boosted demand for government bonds. However, due to the lack of sufficient data on private safe assets, this hypothesis is not tested.

Monetary policy

Theoretical models typically assume that monetary policy cannot affect real equilibrium interest rates, which are linked to potential growth.⁸ However, monetary policy may in practice affect real long-term government bond yields. This reflects interactions of nominal interest rates, with monetary policy determining the short end of the yield curve and influencing medium and long-term rates through expectations of short rates and inflation. With little changes in inflation expectations (or when expectations are fully backward-looking as it is assumed in this paper – see above), movements in nominal rates should be reflected in real interest rates. Prolonged periods of asymmetric monetary policy could also have a persistent impact on long-term rates. For instance, the resolve of monetary authorities to reduce high inflation in the 1980s led to high real interest rates. In the subsequent decades, falling global inflation helped monetary authorities to maintain an accommodative stance. Moreover, Borio (2012, 2014) argues that the monetary policy stance was repeatedly eased in downturns by more than tightened during booms. In this context, a positive relationship between real policy rates and real long-term government bond yields is expected.

However, finding a positive relationship between policy and long-term real interest rates does not necessarily imply causation. For instance, policy rates could respond to secular factors that affect neutral interest rates, which in theory should guide policy rates. To test for this possibility, real policy interest rates are regressed on real potential output growth (as estimated by the OECD), as a proxy of neutral interest rate, to see if they are related in the long run. To further explore its role, potential growth is tested as a direct explanatory variable of real long-term interest rates instead of policy rates.

currencies of smaller European countries in foreign exchange reserves of EMEs is small, EMEs' assets in these currencies are still large in proportion to the GDP of these smaller European economies.

7. Alternatively, financial market-based uncertainty measures, like the equity market volatility index VIX, could be used. However, for many countries, time series of such indices are quite short. For instance, the US VIX based on the comparable methodology starts only in 2004.
8. In practice, monetary policy may affect potential output as – to some extent – it is endogenous to demand. For instance, a weakness in demand can lower potential growth via unemployment hysteresis effects and lower investment and productivity, and thus accommodative monetary policy can mitigate longer-term implications of the downturn on the economy's productive capacity (Reifschneider et al., 2015).

More recently, it has been argued that the decisions of the monetary authorities to buy assets on a large scale (quantitative easing – QE) and provide forward guidance have helped lower nominal government bond yields. Central banks' bond purchases should not only affect government bond yields directly but also indirectly by signalling an easy monetary policy stance in the future. However, the magnitude and durability of unconventional measures' effects, in particular QE, are debated.⁹ To explore the potential effects, the share of government bond holdings by central banks in total outstanding government bonds has been tested for countries where central banks implemented QE (Japan, the United Kingdom and the United States).¹⁰ The hypothesis is that a rising share should lower real interest rates.

Since the decline in real interest rates has been a common phenomenon across AEs and monetary policy in different countries has followed similar trends, foreign real long-term interest rates are tested. They are included to account for the possibility of international spillovers via capital flows and possible global trends affecting domestic real interest rates and inflation. Thus, domestic real long-term interest rates are expected to be positively related to foreign rates. To get sufficiently long time series, for a given country, an unweighted average of real long-term interest rates of foreign AEs is used.¹¹ While foreign interest rates are likely to improve the fit of the estimated equations, the limitation of this approach is that their inclusion does not help to identify the underlying factors driving global rates.

Estimation strategy

The econometric approach involves estimating country-specific reduced-form equations. Given that some dependent and explanatory variables are stationary and others are not (Table A3 in Annex), possibly resulting in spurious regressions, a cointegration framework is employed. Two-stage error-correction models (ECM) are estimated so as to distinguish long-term relationships (cointegrating vector) from short-term dynamics. At both stages, statistically insignificant variables are iteratively eliminated at the 95% confidence level from an initial general specification.

In the first stage, the long-term equation is estimated by fully modified OLS (FMOLS) (Phillips and Hansen, 1990).

$$rir_t = c + BX_t + \varepsilon_t$$

where rir_t is a real interest rate, X_t is a vector of explanatory variables and ε_t is an error term. The FMOLS attempts to address two forms of endogeneity – simultaneity and the failure of weak exogeneity. It uses a semi-parametric correction to eliminate problems caused by the long-run correlation between the cointegrating equation and stochastic regressors' innovations.

In the second stage, the following ECM is estimated:

-
9. Many empirical papers are based on event studies which try to capture flow effects and thus can indicate little about the durability of the effects. This problem is addressed by studies based on structural models of demand for government bonds. For instance, Kaminska and Zinna (2014) find that the 2009-12 QE measures in the United States lowered real 10-year US government bond yields by around 140 basis points. Similarly, in the United Kingdom, QE in 2009 is estimated to have pushed down real long-term interest rates by about 80 basis points (Meaning and Zhu, 2011; Hofmann and Zhu, 2013).
 10. QE was also undertaken by the ECB. However, due to the difficulty with obtaining long time series with central bank holdings of government debt, this variable was not tested for France, Germany and Italy.
 11. Foreign countries include G7 countries, excluding the country in question, as well as Belgium, the Netherlands, Spain, Sweden and Switzerland.

$$\Delta rir_t = \lambda(rir_{t-1} - \hat{c} - \hat{B}X_{t-1}) + \sum_{i=1}^8 \gamma_i \Delta rir_{t-i} + \sum_{j=0}^8 \alpha_j \Delta X_{t-j} + \vartheta_t$$

where λ is the speed of the adjustment, $\hat{c}$ and $\hat{B}$ indicate the long-term coefficients estimated at the first stage, γ 's and α 's are short-term coefficients, and ϑ_t is an error term. For some specifications, there are fewer explanatory variables entering the long-run relationship than variables in first differences. This general specification is estimated with 8 (quarterly) lags of the differenced dependent variable and current and 8 lags of differenced explanatory variables. Both in the first and second stage, statistically insignificant variables are iteratively eliminated at the 95% confidence level to get a parsimonious specification.

The estimation sample generally starts in 1972, depending on data availability. A similar sample is set for the first stage and the second stage. Series are at quarterly frequency. OLS estimations with Newey-West standard errors are used in the second stage to account for possible serial correlation and the heteroscedasticity of residuals.

Estimation results

Below are main findings based on country-specific estimations reported in Tables A5-A11 in Annex.

Demographics

In the long run, real bond yields are – as expected – positively related to the effective dependency ratio (DRET) in all countries but Italy. A similar relationship is evident in the short run. Thus, a rising dependency ratio seems to reduce the saving capacity of households and in turn demand for government bonds, increasing their yields. These findings generally hold true independently of whether real policy rates are included or excluded.

Regarding the dependency ratio based purely on demographic characteristics of population (TDRWA), it is generally positively related to real bond yields, but results are less consistent across model specifications and countries. There are cases where the dependency ratio is not significant or wrongly signed, in particular for France, Italy and Japan.

Mixed results are also obtained for the share of population 40-64 years old in total population (POPS4064). In Canada, Germany and the United Kingdom, it is mostly negatively – i.e. as expected – related to real bond yields, implying that a rising population of high savers pushes prices of government bonds up and thus lowers their yields. In the remaining countries, this variable is not always significant and correctly signed.

Life expectancy at age of 60 and 15, interpolated based on UN population statistics, proved significant and correctly signed in the long term only in Canada, Germany and France. In other countries there were problems with establishing long-term relationships. This probably reflects the fact that these variables resemble time trends. More problems were encountered for life expectancy at age 15. Given these problems, the results are not reported in Annex but available from the authors on request.

The role of demographic variables is not corroborated by estimations with household saving (SAVHGQ). In most cases, the saving rate in the long-run relationship is either not significant or incorrectly signed. Only for Italy and Japan, in equations with potential output growth instead of real policy rates, is the saving rate negatively correlated with real government bond yields. This is puzzling and suggests that the demographic shifts work via other mechanisms than saving and household saving has no impact on demand for government bonds.

Supply of and demand for safe assets

Evidence on the role of the supply of government bonds is not consistent and robust. In some specifications, rising government debt in relation to GDP (GGFLQ) tends to be associated with an increase in real interest rates but it rarely has a long-term relationship with real long-term interest rates. Moreover, significance and signs differ across model specifications, with instances of a negative relationship. The lack of a robust link between real government bond yields and government debt may reflect a non-linear relationship between the two or problems in accounting for other important drivers of real rates, for instance QE – see below, which have been exerting downward pressure on long-term rates when public debt was rising.

Estimations for the countries for which economic policy uncertainty indices (EUPI) are available, necessitating significantly shorter samples, did not render robust results and thus are not reported in the paper. The only exception is Japan, where – as expected – the index is negatively related to real government bond yields in the short run, suggesting increased demand for safe assets during periods of uncertainty (Table A9 in Annex).

Similarly, no robust results were found for the role of foreign exchange reserves of EMEs and oil-exporting countries (FXQ2), and results are not reported with the exception of the United States. In the latter case, rising reserves in relation to US GDP seem to boost demand for US government bonds in the short term and thus lower their yields (Table A11 in Annex).

Monetary policy and international spillovers

The most robust result across different model specifications and countries is that real policy interest rates are positively correlated with long-term interest rates both in the short run and, in most cases, in the long run. As discussed in the previous section, the long-term correlation may reflect a decline in potential growth, which could be driving both short-term and long-term interest rates. However, estimations do not support this hypothesis in most cases. Only in the United States, do policy rates turn out to be cointegrated with estimated potential GDP growth (Table A12 in Annex),¹² suggesting that the monetary authority has been partly reacting to secular trends. No such long-term relationships are detected in the other countries. The tenuous direct link between long-term bond yields and potential growth is further underscored by a cointegration analysis of these two variables. In most cases, real potential GDP growth is either not cointegrated with real long-term government bond yields or is cointegrated with a negative coefficient. This is difficult to explain from the theoretical point of view. The only exceptions is France and, in some specifications, the United States and Canada. In Canada and France, equations with real potential GDP growth instead of real policy rates have lower explanatory power though, suggesting a role for policy rates beyond potential growth.

12. The cointegration between real policy interest rates and real potential GDP growth is tested in the same 2-stage error correction framework as equations for the real government bond yields. The estimated long-term model is equivalent to the Taylor rule (without a constant) with real potential GDP growth (approximating the time-varying neutral interest rates), an output gap and a year-on-year core inflation rate.

In the United States, the rising share of the Federal Reserve's holdings of government bonds in the total stock of bonds (PII3) is – as expected – negatively correlated with real interest rates in the short term.¹³ In Japan and the United Kingdom, the variable proved to be not significant or incorrectly signed and results are not reported in Annex. This may stem from the fact that even if QE lowered nominal bond yields, these measures took place when inflation was falling and real bond yields did not change much.

Domestic real long-term interest rates are significantly related to moves in foreign long-term rates. This is particularly the case for short-term dynamics but also long-term cointegration in most countries and specifications (with notable exception of the Italy and the United Kingdom, and to a lesser extent Japan). This finding is likely to capture both increasing financial openness, with ensuing spillovers via financial markets and monetary policy, and common global trends affecting real interest rates as well as inflation. Indeed, additional estimations, not reported in the paper, found support for the role of both global nominal long-term government bond yields as well as global core inflation rates.

Robustness checks

While estimations over a long sample are desirable to test the role of slow-moving variables (like demographic indicators) and to ensure robust inferences thanks to more observations, long samples have a drawback of including possible structural breaks. In the case of this study they could relate in particular to changes in monetary policy framework (including the creation of a currency union in the euro area), liberalisation of international capital flows and financial market development. Thus, as a robustness check, the models presented in Annex were re-estimated for a shorter sample, starting in 1990.

The estimations over the shorter sample, not reported in Annex but available from the authors on request, confirm the positive correlation between real long-term government bond yields and real policy interest rates as well as foreign real long-term yields. Regarding other variables, results are mixed. On the one hand, for Canada, France and Italy, there is more evidence about a positive correlation with the potential GDP growth rate when it replaces the real policy rate in the regressions. The role of government gross debt is again mixed, with mostly positive signs for Germany and France and mostly negative signs for Canada and the United Kingdom. Evidence for the role of demographic variables does not change much, with more supportive evidence in line with the expectations for Italy but less for Japan. For the United Kingdom, there were problems with establishing cointegration relationships for most models. This relates to volatility at the beginning of the sample, i.e. in the aftermath of the United Kingdom's exit from the European Exchange Rate Mechanism in 1992.

Another robustness check involves testing differences between old and young dependency ratios (i.e. where dependants in the numerator are defined either as people older than 65 or people younger than 20). The old and young dependency ratios tends to work similarly to the total dependency ratio but results were less consistent across countries and model specifications, with more cases of not significant or incorrectly signed variables in the long-term equations. Thus, the results are not reported in Annex but available from the authors on request.

13. Given that the Federal Reserve's QE policy has gained importance only after the crisis, this variable is not included in the cointegration vector but only in short-term dynamics.

Conclusions

The results reported in this paper support the expected relationship between real long-term government bond yields and several demographic variables. However, the lack of robust evidence on household saving raises questions about the transmission mechanisms of demography. Further research is needed to check if there is causality between demographic shifts and real rates or just correlation. Similarly, in view of the clear link between real policy rates and real long-term government bond yields, further investigation on the nature of this relationship would be desirable, possibly by estimating system equations to better deal with the issue of potential residual endogeneity. Finally, with robust evidence about sizeable spillover effects, it would be warranted to explore the underlying causes both on the nominal and inflation side.

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ANNEX 1. STATISTICAL ANNEX

Table A1. Selected estimates of neutral interest rates

Study	Method and sample	Approximate estimates, in %	
		around 2000	latest available
United States			
Lubik and Matthes (2016)	TVP VAR, 1966-2016	2	0
Holston et al. (2016)	LW, 1990-2015	3	0
Laubach and Williams (2015)	LW, 1980-2015	3	0
Pescatori and Turunen (2015)	LW, 1983-2015	2	1
Hamilton et al. (2015)	Long-term ex-post real rates, 1858-2015	4	-2
Cúrdia et al. (2015)	DSGE model, 1987-2015	5	-3
Del Negro et al. (2015)	DSGE model, 2007-2015	5 ¹	0
Bouis et al. (2013) ²	MR, 1990-2013	2	0
Euro area			
Holston et al. (2016)	LW, 1990-2015	2	-1
Bouis et al. (2013) ²	MR, 1990-2013	2	-1
Fries et al. (2016), for France	MR, 2000-2015	5	-1
Fries et al. (2016), for Germany	MR, 2000-2015	5	-1
Fries et al. (2016), for Spain	MR, 2000-2015	4	-1
Fries et al. (2016), for Italy	MR, 2000-2015	5	-1
Japan			
Imakubo et al. (2015)	LW method augmented by natural yield curve, 1992-2014	1	0
Bouis et al. (2013) ²	MR, 1990-2013	-2	-2
Canada			
Holston et al. (2016)	LW, 1990-2015	3	1
Berger and Kempa (2014)	LW, 1978-2010	4	-1
United Kingdom			
Holston et al. (2016)	LW, 1990-2015	3	1
Goldby et al. (2015)	DSGE/BoE COMPASS model, 1997-2015	2	0
Bouis et al. (2013) ²	MR, 1990-2013	4	-1

1. In 2007.

2. Bouis et al. (2013) refer to the updated estimates presented in Rawdanowicz et al. (2014).

Note: LW stands for Laubach-Williams methodology; MR stands for Mésonnier and Renne methodology; TVP VAR stands for time-varying parameter vector autoregressive model.

Source: Authors' compilation.

Table A2. Definition of variables

Acronym	Description	Source
RIRCB2	Real central bank policy rate deflated by year-on-year core inflation	Central banks and OECD
F1RIRL2	Unweighted average of foreign real long-term government bond yields deflated with year-on-year core inflation (G7 countries, excluding the country in question, Belgium, the Netherlands, Spain, Sweden and Switzerland)	OECD
GDPVTRY	Year-on-year real potential GDP growth	OECD
GGFLQ	Gross general government financial liabilities, % of GDP	OECD
DRET	Effective dependency ratio: population not in employment per total employment	OECD and UN population statistics
TDRWA	Total dependency ratio: population less than 20 years old and more than 64 years old per population between 20 and 64 years old	OECD and UN population statistics
POPS4064	Share of population between 40 and 64 years old in total population	OECD and UN population statistics
LE15/LE60	Life expectancy at age of 15/60 years	Intrapolated quarterly series from the UN population statistics
SAVHGQ	Gross household saving, % of GDP	OECD
PII3	Share of government bond holdings by a central bank in total gross government debt	Central banks
EPUI	Economic Policy Uncertainty Index	Baker et al. (2016) - www.policyuncertainty.com
FXQ2	Foreign exchange reserves of selected EMEs and oil exporting countries, % of the analysed country's GDP	IMF and OECD
PCOREY	Year-on-year core inflation	OECD
GAP	Output gap	OECD

Source: Authors.

Table A3. Augmented Dickey-Fuller tests

	Canada 1972	France 1972	Germany 1972	Italy 1972	Japan 1972	United Kingdom 1972	United States 1972
<i>level</i>							
RIRL2	-1.88	-2.49	-2.09	-2.04	-2.47	-3.49***	-2.81*
RIRCB2	-2.54	-3.04**	-2.88**	-2.31	-2.28	-3.43**	-2.11
F1RIRL2	-1.26	-1.30	-1.31	-2.27	-2.45	-1.26	-1.25
GDPVTRY	-1.64	-1.83	-1.03	-1.18	-0.37	-1.91	0.09
GGFLQ	-0.92	0.49	-1.09	-0.52	0.55	-0.29	-0.43
DRET	-2.96**	-1.95	-0.14	-3.33**	-1.90	-2.08	-2.76*
TDRWA	-3.00**	-2.36	-3.78***	-2.96**	0.42	-2.44	-3.14**
POPS4064	-2.73*	-2.55	-1.72	0.50	-2.25	-2.30	-4.01***
SAVHGQ	-0.90	-1.61	-2.30	-0.34	-1.33	-2.78*	-1.77
PII3					-1.25	-0.70	-2.36
EPUI	-4.43***	-1.67	-4.90***		-6.93***	-2.33	-3.62***
FXQ2	2.95**	1.22	0.54	1.35	1.18	-2.04	-0.03
PCOREY	-0.98	-1.99	-2.28	-1.40	-1.57	-1.81	-1.23
GAP	-3.06**	-2.64*	-3.74***	-2.33	-2.15	-3.44**	-2.91**
<i>first difference</i>							
RIRL2	-10.96***	-9.10***	-10.92***	-6.11***	-8.10***	-10.08***	-8.68***
RIRCB2	-11.26***	-9.89***	-6.41***	-8.55***	-8.27***	-9.98***	-6.93***
F1RIRL2	-8.66***	-8.53***	-8.36***	-8.15***	-8.67***	-8.41***	-8.44***
GDPVTRY	-4.50***	-4.38***	-3.10**	-4.73***	-3.68***	-3.91***	-4.05***
GGFLQ	-4.58***	-2.78*	-3.30**	-4.44***	-4.10***	-3.73***	-3.01**
DRET	-3.10**	-3.17**	-3.31**	-3.49***	-2.39	-4.48***	-3.95***
TDRWA	-0.87	-1.00	-1.08	-1.51	-1.63	-1.85	-0.41
POPS4064	-0.55	-1.00	-2.56	-1.94	-1.92	-1.42	-0.63
SAVHGQ	-3.34**	-5.47***	-4.51***	-3.12**	-3.34**	-4.74***	-3.32**
PII3					-0.59	-8.74***	-2.80*
EPUI	-12.04***	-17.02***	-8.59***		-12.31***	-7.38***	-10.69***
FXQ2	-9.65***	-2.44	-2.46	-2.39	-4.44***	-3.12**	-5.46***
PCOREY	-5.47***	-4.45***	-3.97***	-3.58***	-9.20***	-5.07***	-7.82***
GAP	-7.10***	-7.37***	-10.58***	-7.94***	-11.18***	-8.12***	-6.43***

Note: ***, ** and * denote the rejection of the null hypothesis of a unit root at 1%, 5% and 10% significance level, respectively. Years under the country names indicate the start of the sample for unit root test for most of the series (some series are shorter).

Source: Authors' calculation.

Table A4. Definitions of shocks to illustrate elasticities of estimated models in the tables below

Explanatory variable	Type of shock	Scale of shock	
DRET	multiplicative	1	%
TDRWA	multiplicative	1	%
POPS4064	multiplicative	1	%
SAVHGQ	additive	1	% pts
GGFLQ	additive	10	% pts
RIRCB2	additive	0.25	% pts
GDPVTRY	additive	1	% pts
F1RIRL2	additive	0.25	% pts
PII3	multiplicative	1	%
FXQ2	additive	10	% pts
EPUI	multiplicative	100	%
PCOREY	additive	1	% pts
GAP	additive	0.5	% pts

Source: Authors.

Table A5. Simplified estimation results of 2-stage ECM models for Canada

	_eq_1		_eq_2		_eq_3		_eq_4		_eq_5		_eq_6		_eq_7		_eq_8	
D(CAN_RIRL2)	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y
DRET	0.01	0.02							0.02	0.03						
TDRWA			0.02	0.04							0.02	0.00				
POPS4064					-0.02	-0.04							-0.02	-0.04		
SAVHGQ							0.02	0.05							0.00	0.03
GGFLQ	0.00	-0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.00	-0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RIRCB2	0.05	0.04	0.04	0.00	0.04	0.00	0.07	0.06								
GDPVTRY									0.10	-0.01	0.42	-0.01	0.15	-0.01	0.47	0.59
F1RIRL2	0.22	0.27	0.24	0.35	0.22	0.30	0.18	0.21	0.29	0.33	0.30	0.35	0.27	0.30	0.29	0.34
Adj. R2	0.605		0.578		0.578		0.578		0.510		0.487		0.484		0.508	
Sample:	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4
	EC:	-0.21	EC:	-0.16	EC:	-0.16	EC:	-0.16	EC:	-0.22	EC:	-0.21	EC:	-0.20	EC:	-0.20
	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00
	RIRCB2	0.17	F1RIRL2	1.38	F1RIRL2	1.17	RIRCB2	0.25	F1RIRL2	1.31	F1RIRL2	1.38	F1RIRL2	1.17	F1RIRL2	1.35
	F1RIRL2	1.08	TDRWA	6.86	POPS4064	-0.11	F1RIRL2	0.83	DRET	2.89	TDRWA	6.86	POPS4064	-0.11	GDPVTRY	0.59
	DRET	1.90	C	-5.05	C	3.20	SAVHGQ	0.05	C	-3.71	C	-5.05	C	3.20	C	-2.08
	C	-2.34														

Note: To simplify presentation of estimation results and to facilitate interpretation of estimated elasticities (many variables have numerous lags), the table shows the response of the long-term real interest (RIRL2) level to a stylised shock to statistically significant explanatory variables (see Table A4). The response accounts for both the long and short-term elasticities. Reported responses indicate that a given explanatory variable is statistically significant (with the maximum p-value of 0.05). "n.s." indicates that a variable was eliminated from the equation (i.e. it had the p-value above 0.05). An empty cell indicates that a particular variable was not used in estimation. "EC term" stands for the error correction term. See Table A2 for definitions of variables.

Source: Authors' calculation.

Table A6. Simplified estimation results of 2-stage ECM models for France

	_eq_1		_eq_2		_eq_3		_eq_4		_eq_5		_eq_6		_eq_7		_eq_8	
D(FRA_RIRL2)	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y
DRET	0.01	0.01							0.11	0.09						
TDRWA			1.37	0.05							-0.01	-0.02				
POPS4064					0.00	-0.07							0.00	-0.40		
SAVHGQ							0.00	0.01							n.s.	n.s.
GGFLQ	0.00	0.13	0.00	-0.02	0.00	0.02	0.00	0.14	0.00	0.27	0.09	0.52	0.00	0.34	0.00	0.38
RIRCB2	0.07	0.07	0.09	0.08	0.07	0.08	0.08	0.08								
GDPVTRY									-0.73	0.47	0.02	0.85	-0.33	0.25	-0.25	0.20
F1RIRL2	0.18	0.18	0.16	0.17	0.17	0.17	0.17	0.17	0.21	0.22	0.20	0.25	0.19	0.26	0.20	0.26
Adj. R2	0.599		0.617		0.609		0.611		0.558		0.540		0.563		0.548	
Sample:	1973Q2	2015Q4	1973Q2	2015Q4	1973Q2	2015Q4	1973Q2	2015Q4	1974Q1	2015Q4	1974Q1	2015Q4	1974Q1	2015Q4	1974Q1	2015Q4
	EC:	-0.27	EC:	-0.32	EC:	-0.26	EC:	-0.29	EC:	-0.40	EC:	-0.29	EC:	-0.29	EC:	-0.29
	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00
	RIRCB2	0.30	RIRCB2	0.31	RIRCB2	0.31	RIRCB2	0.31	F1RIRL2	0.93	F1RIRL2	0.99	F1RIRL2	1.04	F1RIRL2	1.04
	F1RIRL2	0.70	F1RIRL2	0.66	F1RIRL2	0.69	F1RIRL2	0.69	DRET	7.51	GGFLQ	0.01	GDPVTRY	0.19	GDPVTRY	0.19
	DRET	0.53	TDRWA	1.13	C	0.72	C	0.72	GDPVTRY	0.39	TDRWA	-2.18				
									C	-10.65	GDPVTRY	0.72				

Note: To simplify presentation of estimation results and to facilitate interpretation of estimated elasticities (many variables have numerous lags), the table shows the response of the long-term real interest (RIRL2) level to a stylised shock to statistically significant explanatory variables (see Table A4). The response accounts for both the long and short-term elasticities. Reported responses indicate that a given explanatory variable is statistically significant (with the maximum p-value of 0.05). "n.s." indicates that a variable was eliminated from the equation (i.e. it had the p-value above 0.05). An empty cell indicates that a particular variable was not used in estimation. "EC term" stands for the error correction term. See Table A2 for definitions of variables.

Source: Authors' calculation.

Table A7. Simplified estimation results of 2-stage ECM models for Germany

	_eq_1		_eq_2		_eq_3		_eq_4		_eq_5		_eq_6		_eq_7		_eq_8	
D(DEU_RIRL2)	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y
DRET	0.04	0.08							0.20	0.09						
TDRWA			0.01	0.03							n.s.	n.s.				
POPS4064					-1.22	-0.11							-0.53	-0.07		
SAVHGQ							n.s.	n.s.							n.s.	n.s.
GGFLQ	0.00	0.01	0.53	-0.30	0.89	-0.01	0.58	-0.62	0.00	0.04	-0.43	-1.00	n.s.	n.s.	-0.43	-1.00
RIRCB2	0.13	0.09	0.14	0.14	0.15	0.12	0.20	0.14								
GDPVTRY									n.s.	n.s.	-0.70	-1.64	n.s.	n.s.	-0.70	-1.64
F1RIRL2	0.08	0.09	0.08	0.08	0.09	0.06	0.09	-0.01	0.13	0.15	0.16	0.14	0.20	0.25	0.16	0.14
Adj. R2	0.654		0.629		0.645		0.720		0.583		0.461		0.437		0.461	
Sample:	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1983Q1	2015Q4	1983Q2	2015Q4	1983Q2	2015Q4	1983Q2	2015Q4	1983Q2	2015Q4
	EC:	-0.17	EC:	-0.12	EC:	-0.13	EC:	-0.10	EC:	-0.19	EC:	-0.12	EC:	n.s.	EC:	-0.12
	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00			RIRL2	-1.00
	RIRCB2	0.38	RIRCB2	0.55	RIRCB2	0.48	RIRCB2	0.61	F1RIRL2	0.61	F1RIRL2	0.52			F1RIRL2	0.52
	F1RIRL2	0.36	F1RIRL2	0.32	F1RIRL2	0.25	GGFLQ	-0.05	DRET	8.76	GGFLQ	-0.11			GGFLQ	-0.11
	DRET	7.63	GGFLQ	-0.03	POPS4064	-0.32	C	5.22	C	-9.93	GDPVTRY	-1.74			GDPVTRY	-1.74
	C	-8.14	TDRWA	5.02	C	12.39					C	10.56			C	10.56

Note: To simplify presentation of estimation results and to facilitate interpretation of estimated elasticities (many variables have numerous lags), the table shows the response of the long-term real interest (RIRL2) level to a stylised shock to statistically significant explanatory variables (see Table A4). The response accounts for both the long and short-term elasticities. Reported responses indicate that a given explanatory variable is statistically significant (with the maximum p-value of 0.05). "n.s." indicates that a variable was eliminated from the equation (i.e. it had the p-value above 0.05). An empty cell indicates that a particular variable was not used in estimation. "EC term" stands for the error correction term. See Table A2 for definitions of variables.

Source: Authors' calculation.

Table A8. Simplified estimation results of 2-stage ECM models for Italy

	_eq_1		_eq_2		_eq_3		_eq_4		_eq_5		_eq_6		_eq_7		_eq_8	
D(ITA_RIRL2)	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y
DRET	0.26	0.01							0.33	0.00						
TDRWA			-1.05	0.01							-2.30	-0.01				
POPS4064					0.05	0.21							0.13	0.48		
SAVHGQ							0.00	-0.06							0.09	-0.25
GGFLQ	-0.65	0.13	-0.23	0.06	-0.40	-0.01	0.05	0.13	-0.35	0.15	0.38	-0.09	1.22	0.11	-0.05	0.29
RIRCB2	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20								
GDPVTRY									-0.59	-1.33	-0.32	-1.18	n.s.	n.s.	-0.02	0.02
F1RIRL2	0.06	0.00	n.s.	n.s.	0.08	0.00	n.s.	n.s.	0.38	0.40	0.33	0.39	0.46	0.46	0.34	0.49
Adj. R2	0.777		0.762		0.756		0.733		0.500		0.502		0.524		0.548	
Sample:	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1973Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1973Q1	2015Q4
	EC:	-0.16	EC:	-0.10	EC:	-0.13	EC:	-0.11	EC:	-0.12	EC:	-0.09	EC:	-0.14	EC:	-0.09
	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00
	RIRCB2	0.82	RIRCB2	0.82	RIRCB2	0.80	RIRCB2	0.82	F1RIRL2	1.63	F1RIRL2	1.63	F1RIRL2	1.84	F1RIRL2	2.03
	GGFLQ	0.01	GGFLQ	0.01	POPS4064	0.32	GGFLQ	0.01	GDPVTRY	-1.34	GDPVTRY	-1.34	POPS4064	0.77	SAVHGQ	-0.23
					C	-8.54							C	-27.09		

Note: To simplify presentation of estimation results and to facilitate interpretation of estimated elasticities (many variables have numerous lags), the table shows the response of the long-term real interest (RIRL2) level to a stylised shock to statistically significant explanatory variables (see Table A4). The response accounts for both the long and short-term elasticities. Reported responses indicate that a given explanatory variable is statistically significant (with the maximum p-value of 0.05). "n.s." indicates that a variable was eliminated from the equation (i.e. it had the p-value above 0.05). An empty cell indicates that a particular variable was not used in estimation. "EC term" stands for the error correction term. See Table A2 for definitions of variables.

Source: Authors' calculation.

Table A9. Simplified estimation results of 2-stage ECM models for Japan

	_eq_1		_eq_2		_eq_3		_eq_4		_eq_5		_eq_6		_eq_7		_eq_8		_eq_9		_eq_10	
D(JPN_RIRL2)	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y
DRET	0.02	0.02							0.13	0.17							0.19	0.00	0.55	-0.02
TDRWA			n.s.	n.s.							-0.02	-0.04								
POPS4064					n.s.	n.s.							-0.02	-0.09						
SAVHGQ							-0.19	0.00							-0.46	-0.15				
GGFLQ	-0.05	-0.06	-0.06	-0.07	-0.06	-0.07	-0.06	-0.07	2.09	0.29	2.09	0.25	1.73	0.29	1.45	0.03	0.00	-0.04	0.98	-0.19
RIRCB2	0.27	0.29	0.28	0.29	0.28	0.29	0.26	0.29									0.22	0.20		
GDPVTRY									5.31	-0.15	7.77	-0.07	7.97	-0.16	5.60	-0.06			4.85	-0.05
F1RIRL2	0.06	0.00	0.05	0.00	0.05	0.00	0.05	0.00	0.31	0.38	0.38	0.29	0.29	0.33	0.31	0.26	0.09	0.11	0.04	0.01
EPUI																	-1.02	0.00	-0.37	-0.01
Adj. R2	0.869		0.864		0.864		0.883		0.614		0.559		0.540		0.600		0.866		0.427	
Sample:	1973Q1	2015Q4	1973Q1	2015Q4	1973Q1	2015Q4	1973Q1	2015Q4	1973Q2	2015Q4	1973Q2	2015Q4	1973Q2	2015Q4	1973Q2	2015Q4	1990Q3	2015Q4	1990Q3	2015Q4
	EC:	-0.26	EC:	-0.28	EC:	-0.28	EC:	-0.32	EC:	-0.16	EC:	-0.15	EC:	-0.14	EC:	-0.15	EC:	-0.16	EC:	-0.09
	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00
	RIRCB2	1.18	RIRCB2	1.15	RIRCB2	1.15	RIRCB2	1.15	F1RIRL2	1.63	F1RIRL2	1.20	F1RIRL2	1.34	F1RIRL2	1.06	RIRCB2	0.78	GGFLQ	-0.02
	GGFLQ	-0.01	GGFLQ	-0.01	GGFLQ	-0.01	GGFLQ	-0.01	GGFLQ	0.03	GGFLQ	0.01	GGFLQ	0.02	SAVHGQ	-0.15	F1RIRL2	0.38	DRET	4.74
	DRET	2.14	C	2.30	C	2.30	C	2.30	DRET	21.17	TDRWA	-5.21	POPS4064	-0.13			DRET	0.34		

Note: To simplify presentation of estimation results and to facilitate interpretation of estimated elasticities (many variables have numerous lags), the table shows the response of the long-term real interest (RIRL2) level to a stylised shock to statistically significant explanatory variables (see Table A4). The response accounts for both the long and short-term elasticities. Reported responses indicate that a given explanatory variable is statistically significant (with the maximum p-value of 0.05). "n.s." indicates that a variable was eliminated from the equation (i.e. it had the p-value above 0.05). An empty cell indicates that a particular variable was not used in estimation. "EC term" stands for the error correction term. See Table A2 for definitions of variables.

Source: Authors' calculation.

Table A10. Simplified estimation results of 2-stage ECM models for the United Kingdom

	_eq_1		_eq_2		_eq_3		_eq_4		_eq_5		_eq_6		_eq_7		_eq_8	
D(GBR_RIRL2)	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y
DRET	0.18	0.08							0.04	0.07						
TDRWA			0.14	0.04							0.91	0.08				
POPS4064					-0.06	-0.13							-0.79	-0.17		
SAVHGQ							0.44	0.35							0.28	0.47
GGFLQ	n.s.	n.s.	0.46	0.03	0.52	0.01	-0.10	0.01	-0.84	-0.69	-0.42	-0.60	-0.31	-0.45	-0.80	-0.56
RIRCB2	0.14	0.12	0.14	0.15	0.12	0.11	0.12	0.12								
GDPVTRY									0.78	0.00	1.24	0.00	1.20	0.00	0.39	-0.01
F1RIRL2	0.06	0.00	0.09	0.00	0.08	0.00	0.09	0.00	0.10	0.00	0.15	0.07	0.08	0.00	0.10	0.00
Adj. R2	0.723		0.698		0.700		0.725		0.417		0.448		0.421		0.474	
Sample:	1973Q2	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1974Q1	2015Q4	1974Q1	2015Q4	1974Q1	2015Q4	1974Q1	2015Q4
	EC:	-0.17	EC:	-0.14	EC:	-0.17	EC:	-0.14	EC:	-0.19	EC:	-0.26	EC:	-0.25	EC:	-0.22
	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00
	RIRCB2	0.50	RIRCB2	0.61	RIRCB2	0.45	RIRCB2	0.48	GGFLQ	-0.07	F1RIRL2	0.30	GGFLQ	-0.05	GGFLQ	-0.05
	DRET	7.11	TDRWA	2.86	POPS4064	-0.37	SAVHGQ	0.35	DRET	6.43	GGFLQ	-0.06	POPS4064	-0.56	SAVHGQ	0.45
	C	-6.12			C	13.59					TDRWA	9.00	C	23.20	C	3.83

Note: To simplify presentation of estimation results and to facilitate interpretation of estimated elasticities (many variables have numerous lags), the table shows the response of the long-term real interest (RIRL2) level to a stylised shock to statistically significant explanatory variables (see Table A4). The response accounts for both the long and short-term elasticities. Reported responses indicate that a given explanatory variable is statistically significant (with the maximum p-value of 0.05). "n.s." indicates that a variable was eliminated from the equation (i.e. it had the p-value above 0.05). An empty cell indicates that a particular variable was not used in estimation. "EC term" stands for the error correction term. See Table A2 for definitions of variables.

Source: Authors' calculation.

Table A11. Simplified estimation results of 2-stage ECM models for the United States

	_eq_1		_eq_2		_eq_3		_eq_4		_eq_5		_eq_6		_eq_7		_eq_8		_eq_9		_eq_10	
D(USA_RIRL2)	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y	1Y	5Y
DRET	0.00	0.03							0.15	0.05							0.01	0.03	0.11	0.02
TDRWA			0.83	0.08							n.s.	n.s.								
POPS4064					n.s.	n.s.							0.00	0.11						
SAVHGQ							0.02	0.09							0.05	0.18				
GGFLQ	-0.79	0.01	n.s.	n.s.	-0.34	-0.01	0.03	0.00	-0.97	-0.44	-0.07	-0.13	-0.32	-0.19	-0.35	-0.25	0.01	0.00	-0.21	-0.25
RIRCB2	0.06	0.10	0.07	0.10	0.04	0.11	0.07	0.09									0.07	0.09		
GDPVTRY									-0.18	0.43	-1.07	1.14	-1.23	1.02	-1.44	0.40			-0.63	0.34
F1RIRL2	0.15	0.15	0.14	0.13	0.16	0.13	0.14	0.13	0.19	0.22	0.18	0.19	0.18	0.19	0.19	0.22	0.16	0.14	0.20	0.22
PII3	-0.02	-0.01	0.00	-0.01	-0.01	-0.01	-0.02	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01				
FXQ2																	n.s.	n.s.	-0.89	0.14
Adj. R2	0.659		0.553		0.583		0.557		0.627		0.605		0.610		0.599		0.572		0.609	
Sample:	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4	1972Q1	2015Q4
	EC:	-0.19	EC:	-0.10	EC:	-0.17	EC:	-0.11	EC:	-0.09	EC:	-0.09	EC:	-0.09	EC:	-0.09	EC:	-0.11	EC:	-0.09
	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00	RIRL2	-1.00
	RIRCB2	0.40	RIRCB2	0.44	RIRCB2	0.44	RIRCB2	0.40	F1RIRL2	0.90	F1RIRL2	0.71	F1RIRL2	0.71	F1RIRL2	0.86	RIRCB2	0.40	F1RIRL2	0.90
	F1RIRL2	0.59	F1RIRL2	0.53	F1RIRL2	0.51	F1RIRL2	0.56	GGFLQ	-0.03	GGFLQ	-0.01	GGFLQ	-0.01	GGFLQ	-0.02	F1RIRL2	0.59	GGFLQ	-0.03
	DRET	0.55	TDRWA	1.15	C	0.88	SAVHGQ	0.08	DRET	1.82	GDPVTRY	0.73	GDPVTRY	0.73	SAVHGQ	0.21	DRET	0.55	DRET	1.82

Note: To simplify presentation of estimation results and to facilitate interpretation of estimated elasticities (many variables have numerous lags), the table shows the response of the long-term real interest (RIRL2) level to a stylised shock to statistically significant explanatory variables (see Table A4). The response accounts for both the long and short-term elasticities. Reported responses indicate that a given explanatory variable is statistically significant (with the maximum p-value of 0.05). "n.s." indicates that a variable was eliminated from the equation (i.e. it had the p-value above 0.05). An empty cell indicates that a particular variable was not used in estimation. "EC term" stands for the error correction term. See Table A2 for definitions of variables.

Source: Authors' calculation.

Table A12. Estimation results of 2-stage ECM models for real policy rates in the United States

D(USA_RIRCB2)	1Y	5Y
GDPVTRY	2.02	0.87
GAP	0.28	0.22
PCOREY	-0.27	0.15
Adj. R2	0.618	
Sample:	1982Q2	2015Q4
	EC:	-0.07
	RIRCB2	-1.00
	GDPVTRY	0.76
	GAP	0.49
	PCOREY	0.13

Note: To simplify presentation of estimation results and to facilitate interpretation of estimated elasticities (many variables have numerous lags), the table shows the response of the real central bank policy interest rate (RIRCB2) level to a stylised shock to statistically significant explanatory variables (see Table A4). The response accounts for both the long and short-term elasticities. Reported responses indicate that a given explanatory variable is statistically significant (with the maximum p-value of 0.05). “n.s.” indicates that a variable was eliminated from the equation (i.e. it had the p-value above 0.05). An empty cell indicates that a particular variable was not used in estimation. “EC term” stands for the error correction term. See Table A2 for definitions of variables.

Source: Authors' calculation.