Norges Bank Investment Management

#1 | 2024

Discussion note

Investor demand and government bond pricing

We study how investor demand and composition affect government bond yields. We estimate how investors adjust their holdings when debt levels increase, and how sensitive their demand is to a change in prices. We also show that quantitative tightening by central banks can have a significant impact on yields when investors are price-inelastic.

Date 01/02/2024

The Discussion Note series provides analysis which may form relevant background for Norges Bank Investment Management's investment strategy and advice to the asset owner. Any views expressed in the Discussion Notes are not necessarily held by our organisation. The series is written by employees, and is informed by our investment research and our experience as a large, long-term asset manager.

dn@nbim.no
www.nbim.no

Summary

- Central banks have started to reverse a decade of government bond purchases while sovereign debt is currently projected to remain high across most advanced economies. This raises the question of how different investor groups will respond to an increase in debt supply, and what the implications are for long-term yields. To answer this, we use data on investor holdings of sovereign debt to investigate how investor demand and composition affect government bond yields in advanced economies.
- We start by documenting differences in investor composition across government bond markets. We then study how debt supply is typically distributed across investors. We identify who the marginal buyers of government debt are by estimating the marginal responses of investor holdings to changes in government debt. We find that non-banks (such as investment funds) increase their holdings at a faster rate than banks. Investor marginal responses also show marked differences across countries.
- Using a demand system for government bonds that directly relates investor holdings to bond prices, we estimate the price elasticity of demand for each investor group. We find that foreign non-banks are by far the most elastic investor while domestic banks tend to be quite inelastic.
- We combine our estimates of marginal response and demand elasticity by investor group to quantify the yield impact of an increase in government debt. All else equal, a 10 percent increase in government debt increases ten-year bond yields by approximately 60 basis points on average. Using differences in investor composition, we also quantify the yield impact across countries. For the US, we estimate a yield impact of approximately 100 basis points.
- We use our demand system approach to evaluate the role of quantitative easing in explaining the gap between long-term real yields and long-term growth expectations over the past decade. We also investigate the implications of its reversal, known as quantitative tightening, for long-term yields. We find that the effects of quantitative tightening on yields can be meaningful, especially with the prevalence of price-inelastic investors. For instance, we estimate that if the US Federal Reserve were to sell an amount of bonds equal to 50 percent of the size of its purchases during the Covid-19 pandemic, yields could increase by about 80 basis points.

1. Introduction

In the past few decades, government debt has soared across most advanced economies, hitting a record high during the Covid-19 pandemic. Despite these large debt build-ups, long-term government bond yields have been steadily declining, at least until the end of 2020. As discussed in NBIM (2023), most of the decline prior to the global financial crisis (GFC), can be attributed to a fall in macro trends, defined as the sum of long-term growth and inflation expectations. However, following the GFC, long-term yields have deviated from these macro trends, resulting in a persistent gap. This period of increasing gap coincided with a decade of large-scale asset purchases by central banks, commonly known as quantitative easing (QE), which reduced the amount of government debt that private investors had to absorb.

The effectiveness of QE in lowering long-term yields is likely to depend on the composition of investors in government bond markets and their responses to such asset purchases. Central banks have now started to unwind these government bond purchases, while sovereign debt is projected to remain high across most advanced economies. Here too, the impact on long-term yields will depend on how different investor groups respond to the increase in debt supply. Based on these considerations, we use data on investor holdings of sovereign debt for the period 2004 to 2022 to study how investor demand and composition affect government bond yields in advanced economies.

We start by describing differences in investor composition across several government bond markets and their evolution over time. We identify who are the marginal buyers of government debt by estimating the marginal responses of investor holdings to changes in government debt. The aim is to understand how an increase in government debt is typically distributed across different investor groups. We find that, on average, for each additional unit of debt supplied, 45 percent is absorbed by private domestic investors and 43 percent by private foreign investors, while the remaining 12 percent is typically covered by central banks and the official sector. Foreign non-banks (which include pension funds, insurance companies, and investment funds) tend to be the most responsive investor, absorbing on average 36 percent of an increase in debt. Investor marginal responses also differ across countries. For example, private domestic investors tend to absorb most of the additional debt in Japan and the US, while domestic and foreign non-banks play a more important role in the UK. Changes in debt are more evenly distributed across investors in the euro area.

We then quantify the price elasticity of demand for each investor group, which indicates by how much each investor's government bond holdings would change in response to a change in price. To this end, we estimate a demand system for government bonds that directly relates investor holdings to bond prices. Our empirical model is built upon a new strand of research which recognises the important role of quantities and investor demand in driving asset prices.

We find that foreign non-banks are by far the most elastic investor, while domestic banks tend to be quite inelastic. We combine these estimates of demand elasticity with the estimated marginal responses to quantify the impact of an increase in government debt on government bond yields. We find that, all else equal, a 10 percent increase in government debt would increase long-term yields by approximately 60 basis points (bps) on average.

We use differences in investor marginal responses across countries to estimate the impact of rising government debt on yields for selected regions. We show that the yield impact of a 10 percent increase in government debt is higher in Japan and the US at 126 and 99 bps, respectively, and lower in the euro area and the UK at 65 and 62 bps, respectively. The difference is due to the prevalence of more price-inelastic investors in Japan and the US, where domestic banks and non-banks tend to absorb most of the increase in debt, while foreign non-banks, which also have the highest demand elasticity, play a more important role in the euro area and the UK.

Finally, we use our demand system to investigate the role of QE and its reversal (known as quantitative tightening, QT) in driving long-term yields, while emphasising the importance of investor composition. First, we provide some indicative evidence, by means of counterfactuals, that the increasing gap between nominal yields and macro trends since the GFC can only in part be explained by QE. Our counterfactual analysis indicates that advanced economies' yields would have been 73 bps higher on average without QE. Our results show that QE is more effective in the presence of price-inelastic investors.

To quantify the effects of QT on yields, we perform a scenario analysis. We consider the hypothetical scenario where central banks sell an amount of government bonds equal to 50 percent of the amount purchased since the beginning of the Covid-19 pandemic. We show how this new debt supply might be distributed across investors and quantify the potential yield impact across selected countries. Focusing on the US, we find that non-central-bank investors would have to absorb an additional 7 percent of government debt relative to their existing holdings, resulting in a yield impact of about 80 bps. In the euro area and the UK, a 50 percent reduction of the amount of debt purchased during the pandemic, would imply an increase in private investor holdings of 5 and 14 percent, respectively, which in turns implies a yield impact of approximately 40 bps in the euro area and 90 bps in the UK. On average we estimate that, all else equal, advanced economies' yields would be about 70 bps higher under our QT scenario.

The note proceeds as follows. In the next section, we present our dataset, and analyse investor composition in government bond markets across countries and over time. In Section 3, we provide estimates of marginal responses by investor group. In Section 4, we describe our empirical demand system for government bonds and discuss the main estimation results. In Section 5, we use our demand system to evaluate the role of QE and QT in driving long-term yields. Section 6 concludes.

2. Ownership structure in advanced economies' government bond markets

In this section, we describe the dataset and the investor group classification used in our analysis. We then document differences in investor composition across several advanced economies' government bond markets and their evolution over time.

Data

We use quarterly data on investor holdings of general government debt in advanced economies, compiled by Arslanalp and Tsuda (2014), covering the period Q1 2004 to Q4 2022. Within this dataset, the investor base for government bonds is classified into foreign (For) and domestic (Dom) investors. Each class is further divided into three categories: (i) private banks (BK), (ii) other private investors, labelled as non-banks (NB), i.e. non-financial corporations, pension and insurance companies, households, and other financial institutions (mainly investment funds), and (iii) official creditors (CB), e.g., central banks and international organizations such as the World Bank. We augment this dataset with data on real GDP and inflation forecasts from Consensus Economics, zero-coupon nominal government bond yields from ICE Indices, and other country-specific macroeconomic variables from the IMF.

Our sample includes 17 advanced economies, namely Australia, Austria, Belgium, Canada, Finland, France, Germany, Greece, Italy, Japan, Netherlands, New Zealand, Portugal, Spain, Switzerland, the UK, and the US. We exclude Korea and Slovenia because of missing data in some explanatory variables. We also remove Czech Republic, Denmark, Ireland, Norway, and Sweden because of zero holdings by domestic central banks in some periods. The countries excluded represent only 3 percent of total government debt outstanding at the end of Q4 2022.

Recent trends in sovereign debt investor holdings

Here, we analyse differences in investor composition across selected government bond markets and how these have evolved over time. For brevity, we focus on four main regions: Japan, the UK, the US, and the euro area (which we define as the four largest economies in the area, namely France, Germany, Italy, and Spain). At the end of Q4 2022, the total debt of these regions constituted about 90 percent of the total debt outstanding in our sample.[1]

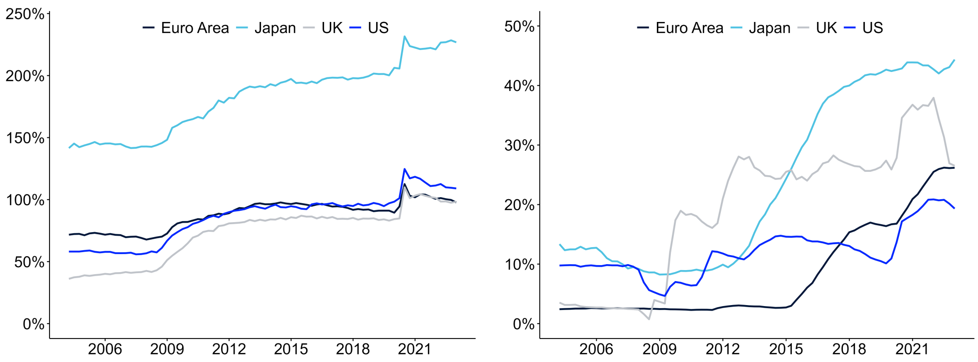
Panel (A) of Figure 1 displays the evolution of general government debt-to-GDP ratios across the four regions since 2004. At the beginning of our sample, both the UK and the US had low debt-to-GDP ratios at 36 and 58 percent respectively. Japan's debt level was already quite high at 142 percent of GDP, while the euro area's debt sat in the middle at about 72 percent of GDP. Since then, government debt has been on an upward trajectory across all regions, with most of the

[1]These regions represent approximately 85 percent of the GPFG's fixed income benchmark as of Q4 2022.

increase occurring during the GFC and the Covid-19 pandemic. At the end of Q4 2022, the debt-to-GDP ratio was nearly 98 percent for both the euro area and the UK, and around 109 percent for the US. In Japan, government debt reached 227 percent of GDP.

FIGURE 1 Government debt-to-GDP ratios and central bank holding shares across selected regions

(A) Government debt-to-GDP ratios **(B)** Share of central bank holdings



NOTE: The figure shows the evolution of general government debt-to-GDP ratios and the share of domestic central bank holdings of government debt from Q1 2004 to Q4 2022.

Despite these large debt build-ups, government bond yields have been steadily decreasing in our sample. Several explanations on this secular decline in interest rates have been put forward in the literature, including slowdown in productivity growth, excess savings, and demographic factors.[2] Here, we highlight the role of QE by central banks, which reduced net debt supply through large-scale purchases of government bonds.

Panel (B) of Figure 1 shows the share of government debt held over time by domestic central banks across the four regions of interest. Before the onset of the GFC, central banks owned a minimal share of government debt. Since the GFC, central banks have rapidly expanded their balance sheets by purchasing large amounts of government bonds as part of QE. The recent Covid-19 pandemic has also led to a large amount of stimulus. As a result, central banks have become some of the largest investors in sovereign debt. For example, the Bank of Japan owned approximately 44 percent of the government debt outstanding at the end of Q4 2022, the end of our sample period.

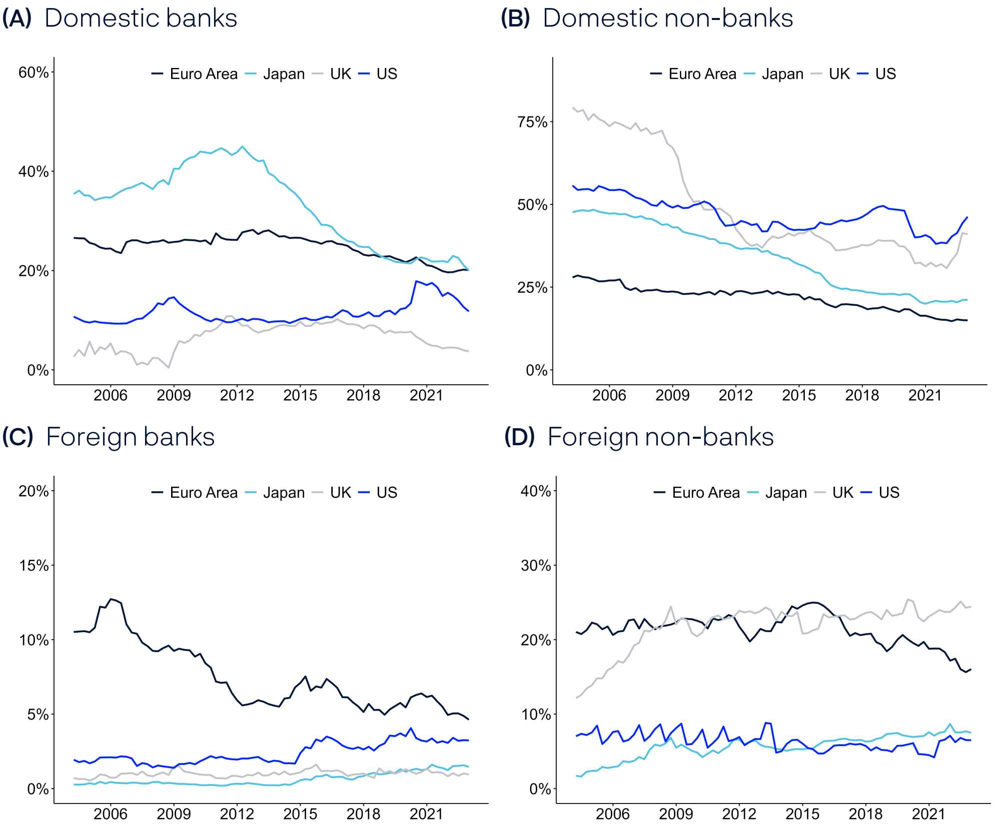
Despite having introduced QE only in 2015, the European Central Bank (ECB) expanded its balance sheet rapidly. At the end of our sample, the share of central bank holdings in the euro area was around 26 percent of outstanding government debt, exceeding the Federal Reserve's holdings of 19 percent. The Bank of England introduced QE soon after the Federal Reserve and held 27 percent of government debt at the end of Q4 2022.

The fact that central banks have become major investors in government bonds

[2]See for example Del Negro, Giannoni, Giannone, and Tambalotti (2017), and Rachel and Summers (2019) for studies on the drivers of the secular decline in interest rates.

suggests that some other investors may have reduced their exposures in relative terms in spite of rising debt levels. Figure 2 shows the evolution of the holding shares of different types of private investors across the four regions under study.[3] As can be seen, investors across all countries have reduced their holdings as a share of outstanding debt, albeit with variations between both investor groups and countries. We highlight some of these variations below.

FIGURE 2 Private investor holding shares of government debt across selected regions



NOTE: The figure shows the evolution of sovereign debt holding shares by investor group from Q1 2004 to Q4 2022.

In Japan, both domestic banks and non-banks largely reduced their holding shares, while foreign investors continued to play a marginal role despite having slightly increased their shares. In the euro area, all private investors saw some decline in their holding shares, with the largest drop in percentage terms registered by foreign banks.[4] In the UK, domestic non-banks halved their holding shares, from approximately 79 percent at the beginning of 2004 to 41 percent at the end of Q4 2022. In fact, insurance companies and pension funds shifted their portfolios away from government bonds towards corporate bonds (Joyce, Liu, and Tonks, 2017). Instead, foreign non-banks doubled their share to 24 percent

[3] See also Figure 7 in Appendix A for additional information.
[4] This is in line with the findings of Koijen, Koulischer, Nguyen, and Yogo (2021), who show that foreign investors accommodated a large portion of the Eurosystem's purchases.

although most of the increase occurred before the GFC.[5] Changes in investor compositions were less pronounced in the US.

With government debt projected to increase across most advanced economies, and with central banks now unwinding decade of large-scale purchases of sovereign debt, it is possible that some of the trends in investor holdings described above will reverse, potentially with significant pricing implications. The impact of any additional debt supply on yields is likely to depend on the composition of investors in a given bond market. To quantify this yield impact, we will in the following sections identify the marginal buyers of government debt and quantify the investors' elasticity of demand.

3. Marginal holders of sovereign debt

In this section, we evaluate how an increase in government debt is typically distributed across different investors. To this end, for each investor group, we regress the changes in government bond holdings on the change in government debt and estimate how investors adjust their holdings on average in response to an increase in government debt.

Let $H_{n,t}^{(i)}$ be the total face value of country n's sovereign debt held by investor group i at time t. For each country n, market clearing requires that demand for government bonds is equal to supply. Hence, at each point in time, the total amount of investor holdings must be equal to the total amount of government debt outstanding, $D_{n,t}$. A similar identity holds in terms of flows since debt issuance must be offset by investors' net purchases. As shown in Appendix B, starting from this identity, we can estimate the marginal holding response of each investor group to an increase in government debt. In particular, for each investor group i and for each country n, we regress the changes in holdings (scaled by lagged debt outstanding) on the rate of growth of government debt:

$$\frac{\triangle H_{n,t}^{(i)}}{D_{n,t-1}} = \alpha_n^{(i)} + \lambda_n^{(i)} \frac{\triangle D_{n,t}}{D_{n,t-1}} + u_{n,t}^{(i)}, \tag{1}$$

where $\triangle D_{n,t}$ and $\triangle H_{n,t}^{(i)}$ denote the change in debt outstanding and the change in the face value of investor group i's holdings from time $t-1$ to t, respectively.

By construction, $\sum_{i=1}^{I} \lambda_n^{(i)} = 1$ for each country n. The intuition is that all additional debt supply must be absorbed by some investors within a country. Each coefficient $\lambda_n^{(i)}$ can therefore be thought of as the marginal holding response of investor group i to changes in country n's government debt. We allow these marginal holding responses to differ not only across investor groups but also across countries, given that these differ in terms of institutional setting, size of government debt, and financial market development, amongst other factors.

It is also important to note that both debt issuance and investor demand may be driven by common unobserved factors, which may influence both changes in investor holdings and government debt issuance decisions. As an example, during

[5] See OBR (2023) and OMFIF's article of 31 July 2023 for discussion on the role of foreign investors in the UK gilt market.

the GFC and the more recent Covid-19 crisis, both government debt supply and investor demand for safe assets increased at the same time. Therefore, to mitigate endogeneity concerns, we allow the error terms to follow a multi-factor structure. To this end, we estimate the $\lambda_n^{(i)}$ by using the common correlated effects (CCE) method proposed by Pesaran (2006). The investor-specific coefficients can be obtained by using the so-called mean group (MG) approach which consists of taking a simple average of their respective country-specific CCE estimates.[6]

Results from these regressions are reported in Table 1. Panel A reports the estimated marginal holding responses by investor group, averaged across countries. The first two columns show that, on average, for each additional unit of debt supplied, 53 percent is absorbed by domestic investors, while the remaining 47 percent is typically covered by foreign investors. Among domestic investors, non-banks play the biggest role, absorbing about 27 percent of the additional supply of debt, on average. Foreign non-banks are even more responsive, taking up on average 36 percent of new issuance. Domestic banks tend to play a more important role than their foreign counterparts, with an estimated marginal response of 18 percent.

We also find that there is a high degree of heterogeneity in the marginal responses of each investor group across countries.[7] In Panel B of Table 1, we report the estimated marginal responses by investor group across the four main regions of interest. We describe the main differences below, as these investor responses will be used to compute the yield impacts of government debt at the country level.

In Japan, on average, domestic investors absorb most of the changes in government debt, while less than 10 percent is taken up by foreign investors. Domestic banks show a slightly larger response of 37 percent than domestic non-banks at 34 percent. In both the UK and the US, domestic investors are also more responsive than foreign ones. In both countries, domestic non-banks absorbed a large portion of debt supply, 44 percent in the UK and 34 percent in the US. The second-biggest players in the UK are foreign non-banks, which, as we saw in the previous section, have increased their exposure to UK gilts in our sample. At the same time, the response of both domestic and foreign banks is rather muted. Conversely, in the US, domestic banks are the largest absorber of debt among private investors. Foreign non-banks' response is lower in the US than in the UK, albeit still sizeable. Finally, results for the euro area are more aligned with the average responses described in Panel A. The marginal response is larger for domestic investors than for foreign investors at 61 and 39 percent, respectively. Foreign non-banks display the largest marginal response of 35 percent, followed by domestic banks and domestic non-banks at 33 and 23 percent, respectively.

[6] See Appendix B for technical details.

[7] See Figure 8 in Appendix B for a graphical depiction of the distribution of investor marginal responses across countries.

TABLE 1 Marginal responses and average holding shares of sovereign debt by investor group

	Dom	For	DomBK	DomNB	DomCB	ForBK	ForNB	ForCB
				Panel A: Average marginal responses				
AE	0.53*	0.47*	0.18*	0.27*	0.08*	0.07*	0.36*	0.04*
	(0.07)	(0.07)	(0.04)	(0.07)	(0.02)	(0.02)	(0.06)	(0.02)
				Panel B: Region-specific marginal responses				
EA	0.61	0.39	0.33	0.23	0.05	0.04	0.35	0.00
JPN	0.91	0.09	0.37	0.34	0.20	0.01	0.07	0.01
UK	0.69	0.31	0.04	0.44	0.21	0.00	0.30	0.01
US	0.80	0.20	0.36	0.34	0.12	0.01	0.14	0.03
				Panel C: Average holding shares				
AE	0.56	0.44	0.19	0.27	0.09	0.07	0.20	0.17
EA	0.55	0.45	0.25	0.21	0.09	0.08	0.22	0.16
JPN	0.90	0.10	0.33	0.34	0.24	0.01	0.06	0.03
UK	0.75	0.25	0.07	0.49	0.20	0.01	0.22	0.02
US	0.70	0.30	0.11	0.47	0.12	0.02	0.06	0.21

NOTE: Panel A reports the CCEMG estimates of the marginal responses by investor group, obtained by averaging the CCE estimates of $\lambda_n^{(i)}$ described in equation (1), across 17 advanced economies (AE). Panel B displays CCE estimates of marginal responses for selected countries or areas. For the euro area (EA), we average marginal responses across France, Germany, Italy, and Spain. The sum of estimated marginal responses across investors may not sum up to one due to rounding. Panel C reports the average holding shares by investor groups across selected countries. Dom and For stand for domestic and foreign investors, respectively. BK stands for private banks, NB denotes non-banks, while CB indicates central banks. * indicates statistical significance at or below the 5 percent level.

Our estimates of investor marginal responses are generally consistent with the average holding shares for each investor, which we report in Panel C of Table 1. These are obtained by averaging investor holding shares across countries and over time. Notably, foreign non-banks' marginal responses are typically higher than their average shares. This suggests that while these investors may expand their holdings more quickly in response to an additional debt supply relative to other investor groups, they also tend to offset these purchases over time.

4. Demand system for sovereign bonds

Since the seminal work of Koijen and Yogo (2019), the use of asset demand systems has increased rapidly helped by greater availability of portfolio holdings data. The premise of this new strand of research is that market equilibrium requires that investors' demand for a particular asset must be equal to its supply. It therefore recognises the important role of quantities and investor demand in driving asset prices.

In this section, we employ a demand system for government bonds that directly relates investor holdings to bond prices, and estimate the price elasticity of demand by investor group. We then combine these estimates of demand elasticity with the estimated marginal responses from the previous section to quantify the yield impact of government debt supply and investigate the implications of rising government debt for bond yields.

Investor demand for sovereign debt

Our empirical approach is motivated by Koijen and Yogo (2019) who show that an investor's portfolio weights can be expressed as a logit function of observable asset characteristics and unobserved latent demand.[8]

We apply this framework in the context of government bond markets in advanced economies.[9] We express investor group i's demand for government bonds of country n as a function of the bond price and a vector of country-specific characteristics:

$$h_{n,t}^{(i)} = \alpha_n^{(i)} + \phi_n^{(i)} h_{n,t-1}^{(i)} + \beta_n^{(i)} p_{n,t} + \boldsymbol{\varphi}_n^{(i)\prime} \mathbf{x}_{n,t} + u_{n,t}^{(i)}, \tag{2}$$

where $h_{n,t}^{(i)}$ is the natural logarithm of $H_{n,t}^{(i)}$, the nominal amount of country n's government debt held by investor group i, while $p_{n,t}$ is the log of $P_{n,t}$, the price of country n's ten-year zero-coupon bond.[10]

In line with previous studies, the vector of country-specific characteristics, $\mathbf{x}_{n,t}$, includes several indicators of macroeconomic conditions which may influence investor demand, namely the log of real GDP per capita, one-year-ahead GDP and inflation forecasts, and the real effective exchange rate. In addition, we include a one-quarter-lagged dependent variable among the regressors in light of the fact that investor holdings tend to be quite persistent.[11]

The latent demand, $u_{n,t}^{(i)}$, captures additional drivers of investor i's demand for country n's government bonds that are not explained by prices and observed characteristics, such as investors' beliefs about expected returns and risk. As in the previous section, we allow these error terms to be a function of unobserved common factors. Intuitively, these common factors can be thought of as global economic and financial shocks which jointly affect all countries, albeit with different magnitudes. The GFC and the Covid-19 pandemic, which are both

[8] This requires three key assumptions: (i) the optimal portfolio is a mean-variance portfolio, (ii) returns have a factor structure, and (iii) both expected returns and factor loadings depend on an asset's own prices and characteristics. Koijen and Yogo (2019) focus on asset demand for individual stocks which depends on observed characteristics such as market equity, profitability, dividends, and market beta. We describe asset characteristics and unobserved demand in the context of our analysis later on in this section.

[9] A similar empirical approach is used in Koijen, Koulischer, Nguyen, and Yogo (2021), who study the portfolio rebalancing in the euro area during the ECB's quantitative easing programme from 2015 to 2017. See also Fang, Hardy, and Lewis (2023), whose main focus is on emerging markets.

[10] For clarity of exposition, we write $P_{n,t} = P_{n,t}(\tau)$ to denote the price of a zero-coupon government bond paying one currency unit at maturity τ. We set τ equal to ten years across all countries for reasons of both data availability and convenience, given that the ten-year yield can be used as a proxy for the level of the yield curve.

[11] The intuition is that, at any given time, investor holdings of government bonds depend on the previous period's holdings, and hence it is assumed that investors adjust their holdings gradually over time as opposed to making sudden changes.

covered in our sample, are clear examples of such shocks. This modelling choice can be seen as a generalisation of Koijen, Koulischer, Nguyen, and Yogo (2021) who use the ten-year US Treasury yield as a proxy for investment opportunities outside the euro area.

Our empirical framework thus extends the modelling approach of Koijen, Koulischer, Nguyen, and Yogo (2021) and Fang, Hardy, and Lewis (2023) by accounting for persistence in investor holdings, and by allowing for unobserved common factors.[12] Two other aspects set our empirical model apart. First, as it can be seen in equation (2), we allow investor responses to differ across countries. Second, our regression includes the log of bond prices instead of yields among the regressors. This choice has the advantage of giving a direct measure of demand elasticity, given by the negative of $\beta_n^{(i)}$, which does not depend on the unknown investor portfolio weights on outside investment opportunities.[13]

In order to estimate equation (2), we follow the literature and assume that the country-specific characteristics included in $\mathbf{x}_{n,t}$ are exogenous to latent demand. However, we cannot consistently estimate the demand elasticity coefficients, $\beta_n^{(i)}$, by least squares (OLS) because bond prices are likely to be correlated with latent demand. This is because both prices and quantities are determined in equilibrium. In other words, a positive demand shock to an investor group can also increase bond prices.

To overcome this endogeneity problem, we use an instrumental variable (IV) approach. Following Fang, Hardy, and Lewis (2023), we construct an instrument for bond prices by exploiting the fact that, in equilibrium, investor demand is equal to debt supply. To obtain this instrument, we first regress the market value of holdings for each investor-country combination on a set of country-specific characteristics given by $\mathbf{x}_{n,t}$. We then use the predicted values from these regressions and solve for the hypothetical prices that would clear the market.[14] We use these pseudo-prices as an instrument for the actual prices when estimating the investor demand equation.

The validity of this instrument depends on the assumption that a country's macroeconomic conditions (which enter in the reduced form regression for market value of holdings) and debt-to-GDP ratio (which enters in the market clearing condition) are exogenous to investor demand. As argued in Fang, Hardy, and Lewis (2023), the implicit assumption is that a country's current macroeconomic conditions are driven by fundamentals rather than investor demand. Similarly, debt-to-GDP is the result of government policy decisions (e.g., satisfying government's cash requirements) rather than being driven by investor demand.

With this instrument in hand, we can estimate the coefficients of equation (2) for

[12] The literature on demand systems is evolving rapidly. Most of the studies so far rely on cross-sectional estimation or static specifications. However, as we shall see, investor demand tends to be quite persistent, which needs to be accounted for. An alternative approach would be to follow van der Beck (2022) and focus on changes in portfolio holdings instead of levels. This approach, however, requires an external instrument variable.

[13] See Appendix C.6 for details.

[14] See Appendix C.1 for technical details.

each country-investor combination using the method proposed by Neal (2015) which extends the CCE approach to the case of endogenous regressors. This method replaces the common OLS with a two-stage least squares procedure. For brevity, we refer to these estimates as CCEIV. The average effects by investor (CCEIV-MG) are obtained by averaging the country-specific CCEIV estimates across countries.[15]

Demand elasticity and yield impact by investor group

Table 2 reports the CCEIV-MG estimates of selected coefficients of demand, shown in equation (2), by investor group.[16] We find that investor demand tends to be quite persistent. The estimated autoregressive coefficients are all significant in both economic and statistical terms. More importantly, in line with the fact that demand is typically downward sloping with respect to price, all investor groups have a negative coefficient on prices.

TABLE 2 Estimated government bond demand by investor group

	DomBK	DomNB	DomCB	ForBK	ForNB	ForCB
Lag dep. var.	0.77^{*}	0.69^{*}	0.90^{*}	0.77^{*}	0.76^{*}	0.75^{*}
	(0.03)	(0.06)	(0.04)	(0.05)	(0.04)	(0.05)
Log price	-0.46	-0.68^{*}	-0.44	-1.07	-3.16^{*}	-0.15
	(0.28)	(0.22)	(0.27)	(0.58)	(1.25)	(0.29)

NOTE: CCEIV-MG estimates of the main coefficients of investor demand for government bonds described in equation (2). The dependent variable is the natural log of the nominal amount of government debt held by a particular investor within each country. The sample consists of a balanced panel of 17 advanced economies observed at a quarterly frequency over the period Q1 2004 to Q4 2022. The total number of country-time observations is $1,275$. * indicates statistical significance at or below the 5 percent level.

Our estimation results also show a high degree of heterogeneity in demand elasticity, given by the negative of $\beta^{(i)}$ (the coefficient associated with price), across investor groups. The estimated elasticities are highly statistically significant for both domestic and foreign non-banks but are not significant for central banks, which hold government bonds for policy intervention rather than for investment reasons. The demand elasticity of domestic banks is also not statistically significant, possibly due to balance sheet constraints as documented in Favara, Infante, and Rezende (2022), among others. Instead, the estimated elasticity of foreign banks is statistically significant at the 10 percent level.

More generally, banks (both domestic and foreign) have much less elastic demand relative to non-banks. Among private institutions, we also find that domestic

[15] The main focus of the note is on investor-specific elasticities averaged across countries. We allow the coefficients of the demand system described in equation (2) to vary across countries, because when the model is dynamic, pooling and aggregating may give potentially misleading estimates of the average effects (Pesaran and Smith, 1995).

[16] Full estimation results are provided in Appendix C.2.

investors tend to be more price-inelastic than their foreign counterparts. In line with Koijen, Koulischer, Nguyen, and Yogo (2021), our results show that demand from foreign non-banks is the most price-elastic.

Using these elasticities, we can now compute the yield impact of an additional supply of debt for each investor group.[17] The estimated yield impacts and associated demand elasticities for each investor group are shown in Table 3.[18] As the yield impact is inversely proportional to demand elasticity, the higher the average demand elasticity across investor groups, the lower the yield impact of an increase in government debt. Thus, low-demand elasticities may represent a challenge in an environment of rising government debt, as inelastic investors would require a higher premium (hence lower prices) in order to increase their bond holdings.

TABLE 3 Demand elasticity and yield impact across investor groups, excluding central banks

	DomBK	DomNB	ForBK	ForNB
Elasticity	0.46	0.68	1.07	3.16
Yield impact	2.18	1.47	0.94	0.32
Ave hold. share	0.26	0.37	0.10	0.27
Marginal response	0.21	0.30	0.08	0.41

NOTE: Yield impact is computed as the inverse of demand elasticity. Average holding shares and marginal responses are re-scaled to sum up to one across non-central-bank investors. Dom and For stand for domestic and foreign investors, respectively. BK stands for private banks, while NB denotes non-banks.

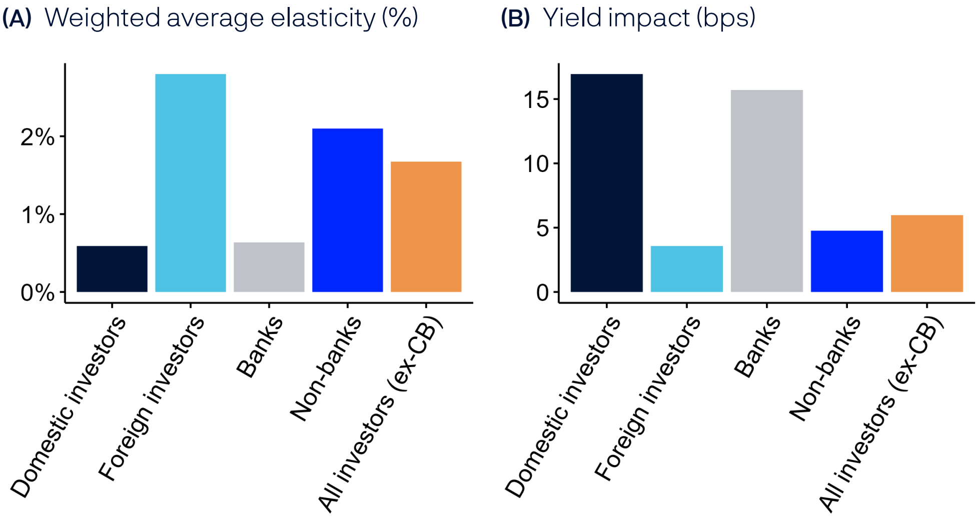
Among investors, foreign non-banks have the highest demand elasticity at 3.16, and hence the lowest yield impact. Assuming an average duration of ten years, this means that yields would have to increase by only 3 bps for a 1 percent increase in the supply of government bonds to be absorbed solely by these investors. At the other end of the scale, domestic banks tend to have the lowest elasticity at 0.46. As a result, a 1 percent increase in sovereign debt would require a 22 bps increase in bond yields to be absorbed entirely by these investors.

These results clearly show that the yield impact of government bond supply depends on how the new debt is distributed across investors and on their demand elasticity. To get a better sense of the impact of investor demand on bond yields, we perform some counterfactuals. Our aim is to quantify the yield impact of a 1 percent increase in debt outstanding under the hypothesis that this new debt is taken up only by some investor groups. Results are shown in Figure 3.

[17] Our measure of yield impact is described in greater detail in Appendix C.3.

[18] Henceforth, we focus on the elasticity of non-central-bank investors, as our interest is in the response of private investors to an increase in debt supply. This is particularly important when studying the effects of QT on yields, as QT requires non-central-bank investors to absorb the additional government bond supply issued by central banks.

FIGURE 3 Demand elasticity and yield impact by investor group



NOTE: The average demand elasticity is computed using investor marginal responses as weights. The corresponding yield impact is based on an increase in debt supply equal to 1 percent of debt outstanding, and an average duration of ten years, assuming the new debt is distributed only among some groups of investors (excluding central banks).

To estimate the yield impacts, we combine our estimates of marginal response and demand elasticity by investor group. For each counterfactual scenario, we set the marginal responses for the excluded investor groups equal to zero, and re-scale the marginal responses of the investor groups of interest so that they sum up to one. We then compute the demand elasticity as a weighted average of the investor-specific elasticities, with weights given by their marginal responses. The basic idea is to give higher weights to those investors who tend to absorb a larger portion of an increase in sovereign debt. The resulting weighted average demand elasticity (WAE) is then used to quantify the yield impact.[19] For example, in a market where the vast majority of marginal buyers have high demand elasticity, the yield impact of an additional debt supply should be relatively muted. Conversely, in the presence of a high proportion of price-inelastic marginal buyers, the yield impact is likely to be higher.

We find that the yield impact is lowest at 4 bps if the additional 1 percent increase in debt is absorbed by private foreign investors, which have the largest elasticity, and highest at 17 bps for private domestic investors. Among domestic investors, banks would require a much higher increase in yields to absorb the additional debt than non-banks, possibly due to binding balance sheet constraints following new regulations (such as the Basel III leverage ratio rule and the U.S. supplementary leverage ratio, e.g., Duffie (2017)). Overall, these findings demonstrate that investor composition and demand play an important role in determining bond prices. They also suggest that attracting foreign investors (or any other investor group with a high demand elasticity) can be beneficial to reduce the exposure of a country's borrowing costs to rising sovereign debt.

[19] Henceforth, for brevity, we will use the terms WAE and elasticity interchangeably.

In practice, any additional debt supply is typically absorbed by all investors at the same time, albeit with different degrees of absorption. For this reason, we compute the WAE for non-central-bank investors by setting the marginal share of central banks to zero and re-scaling the remaining marginal responses so that they sum up to one.[20] Using these marginal responses as weights, we obtain an average elasticity across non-central-bank investors of 1.67. For an average duration of ten years, our elasticity implies, all else equal, a yield impact of approximately 60 bps for a 10 percent increase in government debt.

Demand elasticity and yield impact by region

Our empirical approach allows the investor marginal responses to an increase in sovereign debt to vary across countries. We use this feature of our model to investigate how much the yield impacts of rising government debt differ across selected advanced economies.

Because it is difficult to precisely estimate elasticities at the country level, for the purpose of this analysis, we use the investor-specific estimates of demand elasticity averaged across countries, reported in Table 3, which provide a more reliable estimate of the elasticity.[21] This means that the heterogeneity in the country-specific yield impacts is solely driven by differences in investor weights, i.e. in investor marginal responses across countries. We prefer this weighting scheme as it assigns more importance to investors with a higher propensity to absorb new debt supply.[22]

Estimation results are provided in Table 4, where we report both the marginal responses by non-central-bank investors (re-scaled to sum up to one) and the corresponding WAEs and yield impacts across countries. Among the regions considered, the UK has the highest elasticity and lowest yield impact at 1.62 and 62 bps, respectively. These results are in line with the average estimates across all advanced economies discussed in the previous section.

To estimate the yield impact in the euro area, we first average the investor marginal responses across France, Germany, Italy, and Spain to then re-scale them after setting the responses of central banks equal to zero. Our results for the euro area are not too different from those for the UK: the estimated elasticity is slightly lower, and the yield impact slightly higher.[23]

Japan has the lowest elasticity, at 0.79. This is due to the fact that, outside the Bank of Japan, which owned 44 percent of government debt outstanding at the end of Q4 2022, private domestic institutions are by far the largest taker of additional debt supply. However, as we have previously seen, these investors also have the lowest demand elasticity. In the absence of further QE, an additional 10 percent increase in debt outstanding would imply, all else equal, a yield impact of about 126 bps,

[20] For completeness, the re-scaled marginal responses can be found in Table 3, where we also report the re-scaled average holding shares by investor group.

[21] See, for example, Maddala, Trost, Hongyi, and Joutz (1997) on the difficulties of estimating state-specific demand elasticities using time series data.

[22] In Appendix C.5, we also report estimates of yield impacts by country obtained by using additional sets of weights, based on investor holding shares at different points in time. These various weighting schemes lead to similar conclusions.

[23] Results for each euro area country are reported in Appendix C.4.

which is twice the estimated yield impact for the UK.

TABLE 4 Country-specific estimates of demand elasticity and yield impact

	Marginal responses				Yield impact	
	DomBK	DomNB	ForBK	ForNB	WAE	△Yield
EA	0.35	0.24	0.05	0.37	1.54	65
JPN	0.47	0.44	0.01	0.09	0.79	126
UK	0.05	0.56	0.00	0.38	1.62	62
US	0.42	0.40	0.01	0.17	1.01	99

NOTE: The first four columns report the marginal responses of non-central-bank investor groups to an increase in government debt (re-scaled to sum up to one). WAE denotes the weighted average demand elasticity, with weights given by the marginal responses. △Yield is the corresponding yield impact in basis points for an increase in debt supply equal to 10 percent of debt outstanding, and an average duration of ten years.

Similarly, in the US, domestic investors tend to absorb a large portion of debt supply despite being quite inelastic. As a result, we obtain an elasticity of around 1 for the US. Hence, an additional debt supply equal to 10 percent of the debt outstanding would result in an increase in ten-year bond yields of 99 bps. These results are in line with the findings of Eren, Schrimpf, and Xia (2023), who show that US long-term bond yields would have to increase by 1 percentage point in order to increase demand from non-central-bank investors by 11.4 percent.

5. The impact of central bank balance sheet policies on government bond yields

As discussed in NBIM (2023), most of the decline in long-term government bond yields in recent decades can be explained by the decline in long-term inflation and growth expectations, referred to as macro trends. However, since the GFC, real rates have deviated from long-term growth expectations. In this section, we describe this "real rate gap" and provide some indications, by means of counterfactuals, of whether part of this gap can be attributed to QE. We also evaluate the implications of unwinding QE for long-term government bond yields.

Trends in government bond real yields

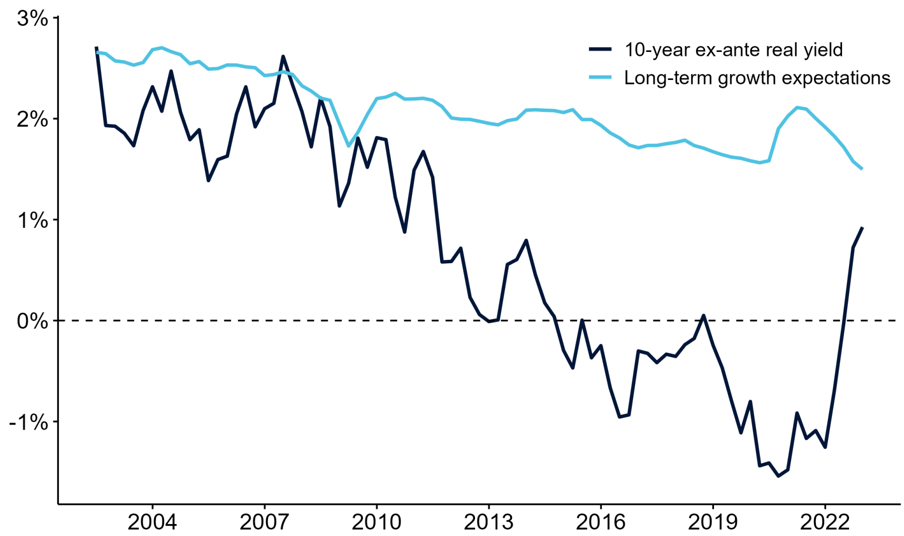
As shown in NBIM (2021), the yield on an n-period nominal government bond, $y_t^{(n)}$, can be decomposed as the sum of the long-term expected nominal rate, i_t^*, and a transitory component, $\gamma_t^{(n)}$, which includes the term premium. The long-term expected nominal rate consists in turn of two trend components: the long-term or "equilibrium" real rate, r_t^*, and long-term inflation expectations, π_t^*.[24] Theoretical

[24] The long-term expected nominal rate can be thought of as the long-term expectation of future nominal short-term interest rates. The equilibrium real rate is related to the concept of the natural rate of interest, i.e. the rate that brings output in line with its potential level in the absence of transitory shocks.

and empirical evidence suggests that the equilibrium rate is closely related to long-term growth expectations (NBIM, 2023). In fact, there was a high degree of co-movement between the two variables at least until the GFC.

Since the GFC, real rates have drifted away from long-term growth expectations. This can be seen in Figure 4, which shows the evolution over time of the ten-year ex-ante real yield and ten-year expectations of real GDP growth, both computed as a GDP-weighted average across all advanced economies in our sample.[25] This "real rate gap" between ex-ante real yields and long-term growth expectations has increased over time, reaching a peak of 350 bps in Q4 2020. A similar picture emerges when comparing ten-year nominal yields with the sum of long-term inflation and growth expectations.

FIGURE 4 Trends in advanced economies' long-term ex-ante real yield and expected real GDP growth



NOTE: Long-term growth expectations are obtained as a weighted average of ten-year expectations of real GDP growth across advanced economies, with weights given by real GDP. The ten-year ex-ante real yield is a GDP-weighted average of ex-ante real yields. For each country, the ten-year ex-ante real yield is computed by subtracting ten-year expectations of inflation from the ten-year nominal zero-coupon yield. Both growth and inflation forecasts are obtained from Consensus Economics.

This period of increasing real rate gap coincided with a decade of expansion in central bank balance sheets.[26] This raises two related questions. First, how much higher would government bond yields have been without QE? Second, since reaching its peak in Q4 2020, the gap between ex-ante real yields and growth expectations has shrunk. Will unwinding QE put further downward pressure on bond prices? We answer these questions by means of counterfactual and

[25] Based on the yield decomposition described above, the ex-ante real yield can be thought of as the sum of the equilibrium real rate, r_t^*, and the transitory component, $\gamma_t^{(n)}$.

[26] The literature has identified several potential drivers of the secular decline in the natural rate of interest, including demographic and technological factors (Eggertsson, Mehrotra, and Robbins, 2019) and rising premiums for the safety and liquidity of government bonds (Del Negro, Giannoni, Giannone, and Tambalotti, 2017). Demographics and productivity factors are less likely to drive the real rate gap, as they should affect both the level of interest rates and growth expectations. The focus of this section is on the role of QE.

scenario analyses.

Yield impact of quantitative easing: a counterfactual analysis

To quantify the potential increase in yields that would have occurred in the absence of QE, we perform a counterfactual analysis. We ask by how much yields would have increased if private investors had had to absorb the amount of new debt that was purchased by central banks. Thus, the main exercise consists of redistributing this debt across investors, giving higher weights to investors with higher holding shares before each policy intervention. The counterfactual yield impact will depend on the elasticity of such investors, with lower elasticities implying higher counterfactual yields. Hence, the effectiveness of QE in reducing bond yields is higher when investors are price-inelastic.

In line with Kiley (2020), who emphasises that the source of the decline in yields is global, we focus on the average yield impact across all advanced economies. To do so, we first aggregate investor holdings across countries in our sample. We infer the total amount of government bonds purchased from changes in total domestic central bank holdings. We then create a chronology of the main central bank balance sheet expansions, where each expansion is the period from trough to trough in central bank purchases.[27] For each of these expansion periods, we redistribute the amount of government bonds purchased by central banks across non-central-bank investors based on their holding shares in the quarter preceding each balance sheet expansion. We combine these holding shares with the estimated elasticity by investor group described in Table 3, to quantify the counterfactual yield impact of each QE episode.

The additional amount of debt that investors would have had to absorb in each QE episode identified varies between 3 and 18 percent, with the largest balance sheet expansion occurring during the Covid-19 pandemic. Because our measure of yield impact is proportional to the amount being redistributed, we find that the impacts on ten-year yields vary between 26 and 176 bps. Taken together, our findings suggest that "global" yields would have been 73 bps higher on average in the absence of QE.

Yield impact of quantitative tightening: a scenario analysis

Several central banks have already started to unwind QE, either by not reinvesting the principal when bonds mature (as in the case of the Federal Reserve and the ECB) or by actively selling government bonds (like the Bank of England).[28] Using our demand system, we perform a scenario analysis to quantify the potential impact of such a reduction in central bank balance sheets, typically referred to as

[27] More details on the QE periods identified can be found in Appendix C.7.

[28] For example, in June 2022, the Federal Reserve started to reinvest only principal payments in excess of a cap of 30 billion dollars per month, rising to 60 billion dollars per month after three months. In September 2022, the Bank of England voted to begin sales of UK government bonds with the aim of reducing the stock of gilts purchased by 80 billion pounds over the following 12 months. In September 2023, the Bank voted to reduce the stock of gilst by a further 100 billion pounds between October 2023 and September 2024. The ECB concluded its net purchases of government bonds in June 2022 and stopped reinvesting redemptions under the asset purchase programme (APP) from July 2023.

QT, on government bond yields.[29] We focus on a hypothetical scenario which sees central banks actively selling part of the government debt acquired during the Covid-19 pandemic.

The pandemic period is of particular interest given that it has led to a large increase in sovereign debt, accompanied by a large amount of stimulus from central banks. For example, general government debt in the US amounted to 21.3 trillion dollars at the end of Q4 2019, equivalent to 98 percent of GDP, and increased by 30 percent to 27.7 trillion dollars, or about 110 percent of GDP, by the end of Q2 2022.[30] Similarly, over the same period, government debt increased by 11 percent in the euro area and 17 percent in the UK.[31] In contrast, Japan saw a decline in nominal debt outstanding, from 10.4 to 9.3 trillion dollars, although the debt-to-GDP ratio increased from 206 to 227 percent over the same period. Total government debt across all countries in our sample increased by 16 percent from 47.7 trillion dollars (102 percent of total GDP) to 55.5 trillion dollars (111 percent of GDP). However, the amount of new debt that investors had to absorb was much lower thanks to the large-scale purchases of government bonds by domestic central banks. For example, the Federal Reserve purchased a nominal amount of government bonds equal to 2.8 trillion dollars between Q1 2020 and Q2 2021, thus absorbing approximately 44 percent of the increase in government debt over the same period.

We consider a hypothetical scenario where central banks sell an amount of government bonds equal to 50 percent of the amount purchased since the beginning of the Covid-19 pandemic.[32] We assume that this additional debt supply is distributed across non-central-bank investors based on their holding shares at the end of Q4 2019, before the start of the Covid-19 pandemic. Results are shown in Figure 5, where we report the additional amount in billions of dollars that each investor group would have to absorb, all else equal, across selected regions. We also show by how much their holdings would have to increase in percentage terms relative to the amount held at the end of Q4 2022. The overall percentage increase in the holdings of private investors and the corresponding yield impacts across regions are reported in Figure 6.

Starting with the US, a reduction of the Federal Reserve's balance sheet equal to 50 percent of the amount purchased from Q1 2020 implies that private investors would have to absorb 1.4 trillion dollars of additional debt. This means that, according to our weighting strategy, domestic banks and non-banks would need to increase their holdings by approximately 7 percent (relative to their holdings at the end of Q4 2022). Foreign investors (both banks and non-banks) would absorb only 189 billion dollars, or 14 percent of this additional supply, which corresponds to an increase in their total holdings of 7 percent. In total, this 1.4 trillion dollar

[29] This aspect has received considerable media attention recently. See, for example, Bloomberg (16 May 2023) and Financial Times (23 July 2023).

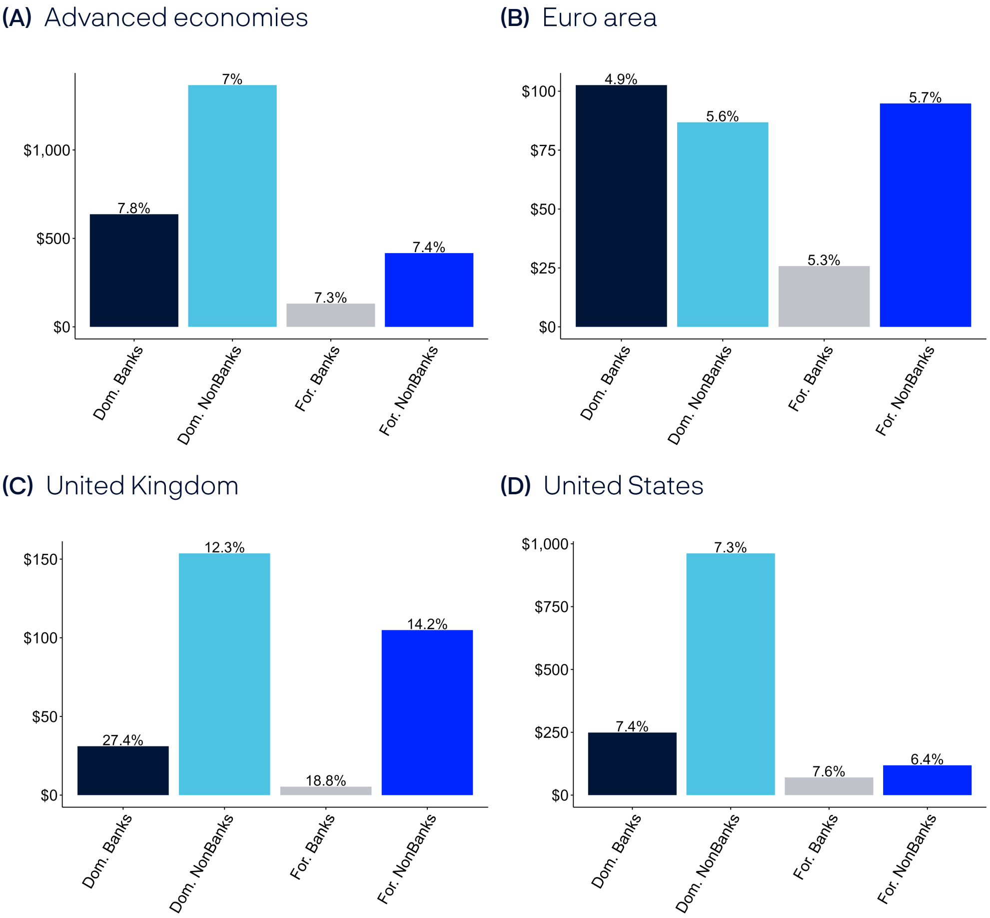
[30] For this analysis, we focus on Q2 2022 as the end period because it coincides with the ECB ending its government bond purchases, and with the Bank of England and the Federal Reserve planning a reduction in the size of their balance sheets. The latter two banks terminated their purchases of government bonds in Q4 2021 and Q2 2021, respectively.

[31] For the euro area, computations are based on total holdings across France, Germany, Italy, and Spain.

[32] This results in an amount of bond sales roughly in line with current central bank plans for reducing the size of their balance sheets in the next few years. Our focus is on the impact of active sales.

supply implies an increase in non-central-bank investor holdings of 7 percent and translates into an average yield impact of 83 bps.[33]

FIGURE 5 Additional debt supply (billions of dollars) to be absorbed by private investors for a reduction in central bank balance sheets equal to half the size of quantitative easing during the Covid-19 pandemic



NOTE: Additional amount in billions of dollars that non-central-bank investors would have to absorb for a reduction in central bank balance sheets equal to 50 percent of the amount of government debt purchased between Q1 2020 and Q2 2022. This additional debt supply is distributed among investor groups according to their pre-Covid holding shares (at the end of Q4 2019). On top of each bar, we report the percentage increase in each investor group's holdings relative to the amount held at the end of Q4 2022. The euro area comprises France, Germany, Italy, and Spain. For advanced economies, we sum holdings across all countries in our sample, while central bank purchases are inferred from changes in total domestic central bank holdings. *Dom* and *For* stand for domestic and foreign investors, respectively.

In the UK, according to our scenario, the amount to be absorbed by private investors is equal to 295 billion dollars, corresponding to an increase in non-central-bank holdings of 14 percent and implying a yield impact of about 90 bps. It should be noted that the Bank of England voted in September 2022 to reduce the stock of purchased UK government bonds over the subsequent 12-month period by 80 billion pounds. Using our empirical approach, we estimate

[33] This is roughly in line with the findings of Eren, Schrimpf, and Xia (2023) who estimate that a quantitative tightening of 1.8 trillion dollars by the Federal Reserve would lead to an increase of 1 percentage point in the eight-year bond yields.

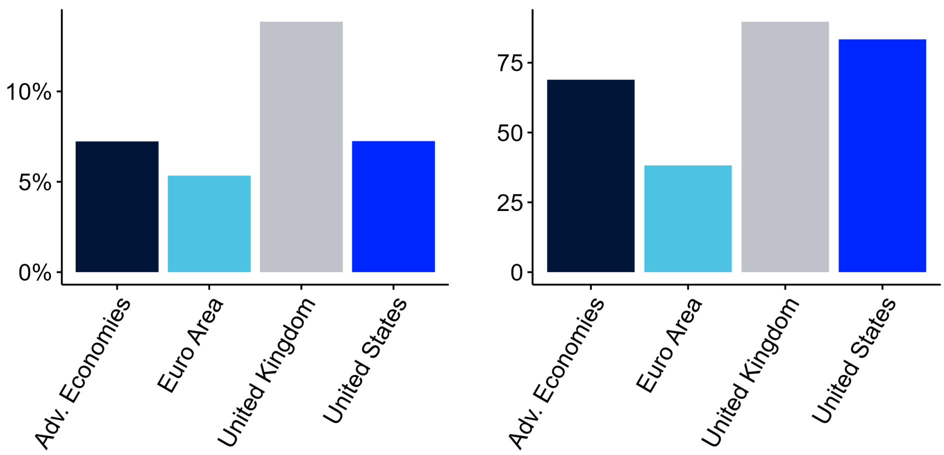
that the impact of these gilt sales on yields should be modest, at about 29 bps.

In the euro area, a 50 percent reduction of the amount of debt purchased by the ECB during the pandemic, estimated to be approximately 310 billion dollars, would imply an increase in private investor holdings of 5 percent, which would be distributed almost uniformly (in percentage terms) across each group. In absolute terms, the lowest amount would be absorbed by foreign banks. This amount of QT would in turn translate, ceteris paribus, into a yield impact of about 38 bps.

Finally, the estimated average yield impact across advanced economies indicates that, all else equal, global yields would be 69 bps higher under our QT scenario.

FIGURE 6 Yield impact of quantitative tightening for a reduction in central bank balance sheets equal to half the size of purchases during the Covid-19 pandemic

(A) Additional debt supply (%) **(B)** Yield impact (bps)



NOTE: The left panel shows the percentage increases in private investor holdings, relative to the amount held at the end of Q4 2022, following a reduction in central bank balance sheets equal to 50 percent of the amount of government debt purchased between Q1 2020 and Q2 2022. The right panel displays the corresponding yield impacts in basis points across regions.

These counterfactuals show that the potential impact of QT on bond prices is likely to depend on the composition of investors and their demand elasticity. At the time of writing, yields across several advanced economies have reached their highest levels in a decade, due to inflationary shocks and monetary tightening. All else equal, government bond sales by central banks could add additional pressure on yields when the majority of marginal buyers are price-inelastic.

6. Summary

We use a dataset of investor holdings of sovereign debt to study the role of investor demand and composition in government bond markets across advanced economies, and investigate their implications for government bond yields.

We start by highlighting some differences in investor composition across selected government bond markets. We then estimate how investors adjust their holdings in response to changes in government debt to provide some insight into how additional debt supply is typically distributed across investor groups.

We estimate a demand system for government bonds to relate investor holdings to bond prices. We obtain estimates of demand elasticity by investor group and find that foreign non-banks are by far the most elastic investor while domestic banks tend to be quite inelastic. We then combine our estimates of marginal response and demand elasticity by investor group to quantify the yield impact of an increase in sovereign debt. For an average duration of ten years, we find that, all else equal, a 10 percent increase in government debt would increase bond yields by approximately 60 basis points.

We also provide suggestive evidence, by means of counterfactuals, that only part of the decline in advanced economies' yields relative to macro trends can be explained by QE, and that its effectiveness is related to the presence of price-inelastic investors. Finally, we evaluate the effects of a reduction in central bank balance sheets by means of government bond sales, and document that the yield impact can be particularly meaningful with a prevalence of price-inelastic investors, such as domestic banks, or in the absence of price-elastic investors such as foreign non-banks.

References

Arslanalp, S. and T. Tsuda (2014). Tracking global demand for advanced economy sovereign debt. *IMF Economic Review 62*(3), 430–464.

Del Negro, M., M. Giannoni, D. Giannone, and A. Tambalotti (2017). Safety, liquidity, and the natural rate of interest. *Brookings Papers on Economic Activity*, 235–316.

Duffie, D. (2017). Post-crisis bank regulations and financial market liquidity. Working paper, Banca d'Italia.

Eggertsson, G. B., N. R. Mehrotra, and J. A. Robbins (2019). A model of secular stagnation: Theory and quantitative evaluation. *American Economic Journal: Macroeconomics 11*(1), 1–48.

Eren, E., A. Schrimpf, and F. D. Xia (2023). The demand for government debt. BIS Working Paper No 1105.

Fang, X., B. Hardy, and K. Lewis (2023). Who Holds Sovereign Debt and Why It Matters? NBER working paper.

Favara, G., S. Infante, and M. Rezende (2022). Leverage regulations and treasury market participation: Evidence from credit line drawdowns. Working Paper (SSRN).

Joyce, M., Z. Liu, and I. Tonks (2017). Institutional investors and the QE portfolio balance channel. *Journal of Money, Credit and Banking 49*, 1225–1246.

Kiley, M. T. (2020). The global equilibrium real interest rate: Concepts, estimates, and challenges. *Annual Review of Financial Economics 12*, 305–326.

Koijen, R., F. Koulischer, B. Nguyen, and M. Yogo (2021). Inspecting the mechanism of quantitative easing in the euro area. *Journal of Financial Economics 140*(1), 1–20.

Koijen, R. and M. Yogo (2019). A demand system approach to asset pricing. *Journal of Political Economy 127*(4).

Maddala, G., R. Trost, H. L. Hongyi, and F. Joutz (1997). Estimation of short-run and long-run elasticities of energy demand from panel data using shrinkage estimators. *Journal of Business & Economic Statistics 15*(1), 90–100.

NBIM (2021). Fundamental drivers of asset returns. *NBIM Discussion Note* (#2-2021).

NBIM (2023). Macro trends and long-horizon returns. *NBIM Discussion Note* (#1-2023).

Neal, T. (2015). Estimating heterogeneous coefficients in panel data models with endogenous regressors and common factors. University of New South Wales Working Paper.

OBR (2023, July). Fiscal risks and sustainability report.

Pesaran, H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica 74*(4), 967–1012.

Pesaran, H. and R. Smith (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of econometrics 68*(1), 79–113.

Rachel, L. and L. Summers (2019). On falling neutral real rates, fiscal policy, and the risk of secular stagnation. *Brookings Papers on Economic Activity Spring 2019*.

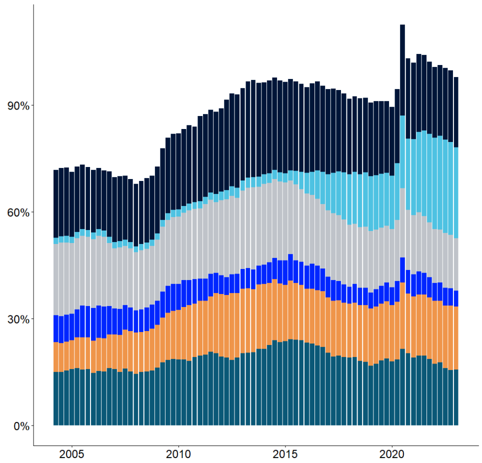
van der Beck, P. (2022). On the estimation of demand-based asset pricing models. Swiss Finance Institute Research Paper Series N22-67.

Appendix A: Data

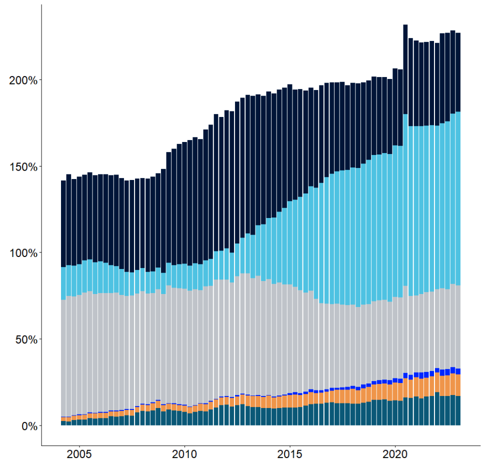
Figure 7 displays the evolution of general government debt-to-GDP ratios across the euro area, Japan, the UK and the US since Q1 2004, decomposed by investor ownership. For the euro area, we sum investor holdings across France, Germany, Italy, and Spain.

FIGURE 7 Sovereign debt-to-GDP dynamics across selected regions

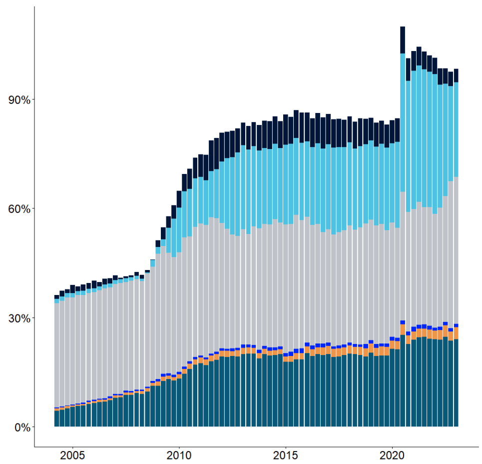
(A) Euro area



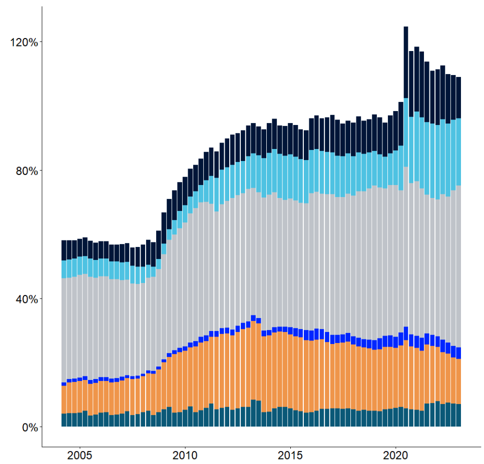
(B) Japan



(C) United Kingdom



(D) United States



NOTE: Bars show the amount of government debt as a share of GDP held by a particular investor group over the period Q1 2004 to Q4 2022. The euro area comprises France, Germany, Italy, and Spain.

Appendix B: Marginal responses by investor group

Let $H_{n,t}^{(i)}$ be the total face value of country n's sovereign debt held by investor group i at time t, for $n = 1, 2, ..., N$, $i = 1, 2, ..., I$, and $t = 1, 2, ..., T$. For each country n, market clearing requires that demand for government bonds is equal to supply. Hence, at each point in time, the total amount of investor holdings, $\sum_{i=1}^{I} H_{n,t}^{(i)}$, must be equal to the total amount of government debt outstanding, $D_{n,t}$. A similar identity holds in terms of flows, since debt issuance must be offset by all domestic and foreign investors' net purchases:

$$\frac{\triangle D_{n,t}}{D_{n,t-1}} = \sum_{i=1}^{I} \frac{\triangle H_{n,t}^{(i)}}{D_{n,t-1}}, \tag{3}$$

where $\triangle D_{n,t} = D_{n,t} - D_{n,t-1}$ and $\triangle H_{n,t}^{(i)} = H_{n,t}^{(i)} - H_{n,t-1}^{(i)}$.

Equation (3) allows us to perform a variance decomposition, partitioning the total variance in changes in debt outstanding into variation in holdings across investors:

$$var\left(\frac{\triangle D_{n,t}}{D_{n,t-1}}\right) = \sum_{i=1}^{I} cov\left(\frac{\triangle D_{n,t}}{D_{n,t-1}}, \frac{\triangle H_{n,t}^{(i)}}{D_{n,t-1}}\right). \tag{4}$$

This variance decomposition is equivalent to estimating the following regressions for each investor group i:

$$\frac{\triangle H_{n,t}^{(i)}}{D_{n,t-1}} = \alpha_n^{(i)} + \lambda_n^{(i)} \frac{\triangle D_{n,t}}{D_{n,t-1}} + u_{n,t}^{(i)}, \tag{5}$$

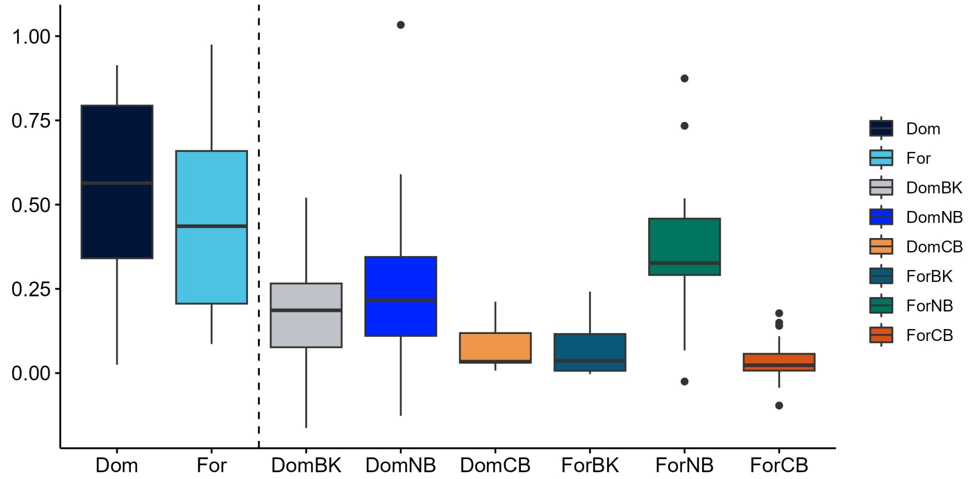
where, by construction, $\sum_{i=1}^{I} \lambda_n^{(i)} = 1$, for each country n.

We allow the error terms in equation (5) to follow a multi-factor structure, and estimate the $\lambda_n^{(i)}$ by using the common correlated effects (CCE) method proposed by Pesaran (2006). This estimation procedure involves estimating by least squares an auxiliary regression where the observed regressors in equation (5) are augmented with cross-sectional averages of both the dependent variable and the explanatory variables to account for the common factors.

We estimate equation (5) separately for each country to allow investor marginal responses to differ across countries. Figure 8 shows the distribution of marginal responses across countries for each investor group. The investor-specific coefficients can be obtained by using the so-called mean group (MG) approach, which involves taking a simple average of their respective country-specific CCE estimates:

$$\hat{\lambda}_{MG}^{(i)} = \frac{1}{N} \sum_{n=1}^{N} \hat{\lambda}_n^{(i)}. \tag{6}$$

FIGURE 8 Investor marginal responses across countries



NOTE: Box plots of the CCE estimates of $\lambda_n^{(i)}$ in equation (1) across 17 advanced economies for each investor group. Dom and For stand for domestic and foreign investors, respectively. BK stands for private banks, NB denotes non-banks, while CB indicates central banks.

For completeness, the average holding shares for each investor displayed in Table 1 are obtained by averaging holding shares across countries and over time:

$$AveHolding(i) = \frac{1}{NT}\sum_{t=1}^{T}\sum_{n=1}^{N} hs_{n,t}^{(i)}, \quad (7)$$

where $hs_{n,t}^{(i)} = H_{n,t}^{(i)}/D_{n,t}$ is the holding share of investor i in country n at time t.

Comparing different estimation methods. CCE estimation requires both the time series (T) and cross-section dimension (N) to be large. While T is quite large, our sample only contains $N = 17$ distinct countries. Hence, for some countries, $\sum_{i=1}^{I}\hat{\lambda}_n^{(i)}$ is very close but not exactly equal to one. As a result, we re-scale the estimated coefficients so that they sum up exactly to one.

As a robustness check, we also consider some special cases of the CCE approach, and re-estimate equation (5) by either allowing for standard fixed and time effects (FE-TE) or using the mean group (MG) approach of Pesaran and Smith (1995), which does not account for unobserved common factors. In these two cases, for each country n, $\sum_{i=1}^{I}\hat{\lambda}_n^{(i)}$ is exactly equal to one.

The estimated marginal responses by investor group for each method are reported in Table 5. It can be seen that the estimates in this analysis do not differ widely across methods.

TABLE 5 Variance decomposition: marginal responses by investor groups

	Dom	For	DomBK	DomNB	DomCB	ForBK	ForNB	ForCB
CCEMG	0.53*	0.47*	0.18*	0.27*	0.08*	0.07*	0.36*	0.04*
	(0.07)	(0.07)	(0.04)	(0.07)	(0.02)	(0.02)	(0.06)	(0.02)
FE-TE	0.53*	0.47*	0.17*	0.23*	0.12*	0.06*	0.36*	0.06*
	(0.06)	(0.06)	(0.03)	(0.04)	(0.04)	(0.02)	(0.05)	(0.02)
MG	0.57*	0.43*	0.19*	0.26*	0.11*	0.07*	0.26*	0.11*
	(0.06)	(0.06)	(0.03)	(0.05)	(0.02)	(0.02)	(0.04)	(0.02)
Num. obs.	1275	1275	1275	1275	1275	1275	1275	1275

NOTE: CCEMG estimates are rescaled to sum up exactly to one. Dom and For stand for domestic and foreign investors, respectively. BK stands for private banks, NB denotes non-banks, while CB indicates central banks. * indicates statistical significance at or below the 5 percent level.

Appendix C: Demand system estimation

Appendix C.1 Instrumental variable approach

Following Fang, Hardy, and Lewis (2023), we construct an instrument variable based on the market equilibrium ($D_{n,t} = \sum_{i=1}^{I} H_{n,t}^{(i)}$). By multiplying both sides of this equation by the government bond price, $P_{n,t}$, and dividing both sides by nominal GDP, $\Upsilon_{n,t}$, we obtain:

$$\frac{P_{n,t}D_{n,t}}{\Upsilon_{n,t}} = \sum_{i=1}^{I} \frac{H_{n,t}^{(m,i)}}{\Upsilon_{n,t}}, \tag{8}$$

where $H_{n,t}^{(m,i)} = P_{n,t}H_{n,t}^{(i)}$ denotes the market value of country n's debt held by investor i. The instrument for $P_{n,t}$ is the hypothetical price, $\tilde{P}_{n,t}$, that solves the market clearing condition:

$$\tilde{P}_{n,t} = \frac{\Upsilon_{n,t}}{D_{n,t}} \sum_{i=1}^{I} exp\left(\widehat{h_{n,t}^{(m,i)}}\right), \tag{9}$$

where $h_{n,t}^{(m,i)} = \log\left(H_{n,t}^{(m,i)}/\Upsilon_{n,t}\right)$. The predicted holding as a share of GDP, $\widehat{h_{n,t}^{(m,i)}}$, is obtained by estimating the following reduced-form regression (using the CCE approach):

$$h_{n,t}^{(m,i)} = \alpha_n^{(i)} + \phi_n^{(i)} h_{n,t-1}^{(m,i)} + \boldsymbol{\varphi}_n^{(i)\prime} \mathbf{x}_{n,t} + u_{n,t}^{(i)}, \tag{10}$$

where $\mathbf{x}_{n,t}$ is a vector of country-specific observed characteristics: the log of real GDP per capita, one-year-ahead GDP and inflation forecasts, and the real effective exchange rate.

The average effects by investor (CCEMG), obtained by averaging the CCE estimates of the coefficients of equation (10) across countries, are reported in Table 6.

TABLE 6 CCEMG estimates for reduced-form regression

	DomBK	DomNB	DomCB	ForBK	ForNB	ForCB
Lag dep. var.	0.830*	0.770*	0.890*	0.760*	0.823*	0.765*
	(0.024)	(0.049)	(0.024)	(0.039)	(0.030)	(0.041)
RGDPcap	-0.285*	-0.178	-0.108	-0.061	0.715*	-0.151
	(0.145)	(0.258)	(0.178)	(0.250)	(0.363)	(0.209)
GDP fcst	0.007	-0.002	0.008	0.016	-0.011	0.008
	(0.006)	(0.009)	(0.015)	(0.013)	(0.020)	(0.009)
Infl. fcst	0.018	0.003	0.004	0.021	-0.021	-0.029
	(0.013)	(0.029)	(0.016)	(0.020)	(0.020)	(0.024)
Real eff. FX	0.000	0.000	0.002	0.000	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
Num. obs.	1275	1275	1275	1275	1275	1275

NOTE: CCEMG estimates of the coefficients of equation (10). The dependent variable is the log of market value of holdings to GDP by investor group. RGDPcap denotes the log of real GDP per capita. GDP fcst and Infl. fcst indicate the one-year-ahead GDP and inflation forecasts, respectively. Real eff. FX is the real effective exchange rate. Dom and For stand for domestic and foreign investors, respectively. BK stands for private banks, NB denotes non-banks, while CB indicates central banks. * indicates statistical significance at or below the 5 percent level.

Appendix C.2 IV estimation results

Table 7 reports the CCEIV-MG estimates of the coefficients of equation (2) by investor group, obtained by averaging the country-specific CCEIV estimates across countries. As discussed in the paper, the estimation method used is based on Pesaran (2006) and Neal (2015).

In line with previous studies, we find that the estimates of the coefficients associated with the observed macro characteristics have high standard errors and are not statistically significant. Adding a one-quarter-lagged dependent variable greatly increases the predictive power of the model. The estimates of the autoregressive coefficients are highly significant in both economic and statistical terms, corroborating the hypothesis that investor holdings tend to be persistent.

TABLE 7 Estimated government bond demand by investor group

	DomBK	DomNB	DomCB	ForBK	ForNB	ForCB
Lag dep. var.	0.774*	0.692*	0.899*	0.768*	0.759*	0.752*
	(0.032)	(0.057)	(0.035)	(0.053)	(0.043)	(0.052)
log price	-0.459	-0.679*	-0.437	-1.068	-3.160*	-0.153
	(0.282)	(0.218)	(0.270)	(0.576)	(1.255)	(0.294)
RGDPcap	-0.031	0.159	0.048	-1.171	-0.305	-0.202
	(0.226)	(0.202)	(0.397)	(0.974)	(1.526)	(0.309)
GDP fcst	0.001	0.011	0.003	0.035*	-0.028	-0.003
	(0.012)	(0.016)	(0.015)	(0.015)	(0.028)	(0.009)
Infl. fcst	-0.003	-0.017	-0.019	0.018	0.009	-0.031
	(0.012)	(0.036)	(0.021)	(0.026)	(0.038)	(0.020)
Real eff. FX	0.002	0.004	0.002	0.003	-0.000	0.002
	(0.001)	(0.003)	(0.001)	(0.002)	(0.003)	(0.001)
Num. obs.	1275	1275	1275	1275	1275	1275

NOTE: CCEIV-MG estimates of the coefficients of the demand system equation described in equation (2). The estimation method is based on Pesaran (2006) and Neal (2015). The dependent variable is the log of nominal holdings for each investor group. The number of time periods (T) is 75, and the number of countries (N) is 17. * indicates statistical significance at or below the 5 percent level.

Appendix C.3 Relating demand elasticity to yield impact

To relate the demand elasticities to the yield impact, we follow Koijen, Koulischer, Nguyen, and Yogo (2021). First, we note that the modified duration (MD) of a bond is related to the approximate percentage change in price for a given change in yield:

$$MD = -\frac{1}{P}\frac{dP}{dy}. \tag{11}$$

The price elasticity of demand is defined as the percentage change in quantity demanded, Q, when the price, P, increases by 1 percent:

$$\eta = -\frac{dQ}{dP}\frac{P}{Q}. \tag{12}$$

Using (11) and (12), we obtain the yield impact of an increase in government debt as

$$dy = \frac{1}{MD}\frac{dQ/Q}{\eta}, \tag{13}$$

noting that for a zero-coupon bond, the modified duration is exactly equal to its time to maturity. It can be seen from equation (13) that, for an average duration of one year, the yield impact of a 1 percentage increase in the quantity supplied is exactly equal to the inverse of the elasticity.

In our demand system, we allow the elasticities, η_i, to differ across investors. The average elasticity, η, is obtained as a weighted average of the η_i's:

$$\eta = \sum_{i=1}^{I} w_i \eta_i, \tag{14}$$

where the weights, w_i, are either the investor marginal responses estimated in Section 3 or alternatively, the investor holding shares at a given point in time.

Appendix C.4 Demand elasticity and yield impact in the euro area

In Table 8 we report the estimated elasticity and corresponding yield impact for a 10 percent increase in debt outstanding across the four largest euro area countries, namely France, Germany, Italy and Spain.

We find a higher yield impact in Italy and Spain at 69 and 74 bps, respectively. The yield impact is lowest in France at 54 bps, followed by Germany at 65 bps. Because we use low-frequency data, our results may not capture episodes of stress in market conditions where, for example, investor demand shifts towards German government bonds in a flight to safety. Instead, differences across countries are solely driven by differences in investor marginal responses. In France and Germany, foreign non-banks, which have the most elastic demand, tend to absorb a larger portion of new debt than in Italy and Spain.

TABLE 8 Country-specific estimates of demand elasticity and yield impact within the euro area

	Marginal responses				Yield impact	
	DomBK	DomNB	ForBK	ForNB	WAE	$\triangle$Yield
France	0.23	0.24	0.05	0.48	1.85	54
Germany	0.64	-0.04	0.00	0.40	1.53	65
Italy	0.33	0.23	0.12	0.32	1.45	69
Spain	0.24	0.46	0.01	0.29	1.35	74

NOTE: The first four columns report the marginal responses of non-central-bank investor groups to an increase in government debt (re-scaled to sum up to one). WAE denotes the weighted average demand elasticity, with weights given by the marginal responses. $\triangle$Yield is the corresponding yield impact in basis points for an increase in debt supply equal to 10 percent of debt outstanding, and an average duration of ten years.

Appendix C.5 Yield impacts under different weighting schemes

Our estimated yield impacts reported in Section 4, depend on our measure of demand elasticity, obtained by averaging investor-specific demand elasticities with weights given by their respective marginal responses. This weighting scheme assigns more importance to investors with a higher propensity to absorb new debt supply. In this section, we investigate how the yield impacts would differ when using different sets of weights. We use three additional weighting schemes: (i) investor holding shares averaged over the entire sample period, (ii) investor holding shares at the end of Q4 2007 before the onset of the GFC, and (iii) investor holding shares at the end of Q4 2019 before the start of the Covid-19 pandemic. The resulting yield impacts are shown in Table 9. We report results for both the entire sample of advanced economies and selected regions.

TABLE 9 Yield impacts of an increase in government debt outstanding using different investor group weights

	Mar. Resp.	Ave Hold. Shar.	Q4-07 Hold. Shar.	Q4-19 Hold. Shar.
AE	60	75	72	77
EA	65	74	76	70
JPN	126	129	132	108
UK	62	74	81	65
US	99	112	108	115

NOTE: Yield impacts in basis points for an increase in debt supply equal to 10 percent of government debt outstanding, and an average duration of ten years. Results in each column are based on different measures of weighted average demand elasticity, with weights given by marginal responses, average holding shares, holding shares at the end of Q4 2007, and holding shares at the end of Q4 2019. EA denotes the euro area, which in our case comprises France, Germany, Italy, and Spain. AE and JPN refer to advanced economies and Japan, respectively.

Appendix C.6 Alternative derivation of demand elasticity

Koijen, Koulischer, Nguyen, and Yogo (2021) estimate the following government bond demand equation by investor group in the euro area:

$$\log\left(H_{n,t}^{(m,i)}\right) = \alpha_n^{(i)} + \beta_0^{(i)} y_{n,t} + \boldsymbol{\beta}_1^{(i)\prime} \mathbf{x}_{n,t} + \beta_3^{(i)} y_{\$,t} + u_{n,t}^{(i)}, \tag{15}$$

where $H_{n,t}^{(m,i)}$ is the market value of country n's debt held by investor i, $y_{n,t}$ is the government bond yield of country n, and $y_{\$,t}$ is the ten-year US Treasury yield.

Investor i's demand elasticity for country n's government bonds is defined as

$$-\frac{\partial log(Q_{n,t}^{(i)})}{\partial log(P_{n,t}^{(i)})} = 1 + 100\frac{\beta_0^{(i)}}{m_{n,t}}(1 - w_{n,t}^{(i)}), \tag{16}$$

where $m_{n,t}$ is the weighted average maturity of country n's government debt outstanding.

The drawback of this measure is that it requires knowledge of the outside asset through the portfolio weight, $w_{n,t}^{(i)}$. Taking advantage of their dataset, they assume that the outside asset is the portfolio of corporate bonds, asset-backed securities, and covered bonds. Instead, as our dataset does not include information on outside assets, we regress the face value of holdings on prices (both in logarithm) to obtain a direct measure of elasticity.

Appendix C.7 Quantitative easing counterfactuals

Table 10 reports the additional amount of debt that investors would have had to absorb in each identified QE episode together with the corresponding counterfactual yield impacts.

TABLE 10 Counterfactual yield increases in the absence of quantitative easing

QE episode	△ debt supply (%)	Yield impact (bps)
2009:Q2 - 2009:Q4	2.7	26
2010:Q2 - 2012:Q3	6.0	58
2013:Q1 - 2014:Q2	5.0	48
2014:Q4 - 2016:Q3	8.7	82
2017:Q1 - 2018:Q1	5.0	48
2020:Q1 - 2021:Q4	18.5	176

NOTE: Counterfactual increase in advanced economies' yields in the absence of central bank balance sheet expansions, for an average duration of ten years. △ debt supply denotes the additional debt supply in percentage terms that investors would have to absorb without QE. We infer the total amount of government bonds purchased across advanced economies from changes in total domestic central bank holdings. Each QE episode is identified as the period from trough to through in total central bank purchases.