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A GLOBAL MONETARY POLICY FACTOR IN SOVEREIGN BOND YIELDS

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Abstract

We document the existence of a global monetary policy factor in sovereign bond yields, related to the size of the aggregate balance sheet of nine major central banks of developed economies that have implemented programs of large-scale asset purchases. Balance sheet policies of these central banks reduced the net supply of safe assets in the global economy, triggering a decline in global yields as investors rebalanced their portfolios towards more risky assets. We find that central banks' large-scale asset purchases have contributed to significant and *permanent* declines in long-term yields globally, ranging from around 330 bps for AAA-rated sovereigns to 800 bps for non-investment grade sovereigns. The stronger decline in yields of high-risk sovereigns can be partly attributed to the decline in the foreign exchange risk premium as their currencies appreciated. Global central bank asset purchases during the Covid-19 crisis have more than counterbalanced the effects of expanding fiscal deficits on global bond yields, driving them to even lower levels. Our findings have important policy implications: normalizing monetary policy by scaling down central bank balance sheets to pre-crisis levels may lead to sharp increases in sovereign bond yields globally, widening spreads and currency depreciations of vulnerable sovereigns with severe consequences for financial stability and the global economy.

Keywords: quantitative easing; central bank balance sheet policies; sovereign risk; interest rates; panel cointegration.

JEL-classifications: E42; E43; G12; G15

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1. Introduction

In the aftermath of the Global Financial Crisis of 2008-2009, major central banks of developed economies resorted to Quantitative Easing (QE) measures such as large-scale asset purchases and ample liquidity provision to commercial banks, as short-term interest rates had hit the zero lower bound (ZLB). The purpose of these measures was to improve the transmission of monetary policy and to lower long-term interest rates, thus supporting the real economy and avoiding a deflationary downward spiral.

As a result of QE, central banks ended up with large balance sheets. Figure 1 shows that the size of the aggregate balance sheet of the nine major central banks of developed economies which implemented QE strategies nearly quadrupled from USD 8 trillion in 2009 to USD 29 trillion in early 2021.[1] This is equivalent to 70% of the aggregate GDP of the nine countries/economic areas, up from about 20% of aggregate GDP in 2009. Interestingly, most of the increase in the aggregate balance sheet is due to central banks other than the Fed, which by early 2021 accounted for around three quarters of the aggregate balance sheet. Among those central banks, the European Central Bank and the Bank of Japan on their own account for about 60% of the aggregate balance sheet by early 2021.

[Insert Figure 1 around here]

The graphical evidence in Figure 1 is also supported by variance decompositions, which suggest that 59% of the variance of the aggregate balance sheet is due to other central banks' balance sheet policies whereas Fed policies account directly for 12% of the variance and indirectly (through the covariance term) for 29% of the variance of the aggregate balance sheet.

Numerous empirical papers have examined the effects of QE on financial market variables such as bond yields, equity returns and exchange rates at the national level.[2] There is indeed strong empirical evidence that the US Federal Reserve's Large-Scale Asset Purchase programme lowered US bond yields significantly.[3] Similar results have

[1] The nine central banks are: Federal Reserve System, European Central Bank, Bank of Japan, Bank of England, Swiss National Bank, Bank of Canada, Reserve Bank of Australia, Sveriges Riksbank and Danmarks Nationalbank.
[2] For two surveys of the empirical literature on the effects of QE on financial prices and macroeconomic variables see e.g., Bhattarai and Neely (2018) and Joyce et al. (2012).
[3] See, e.g., Gagnon et al. (2011), D'Amico et al. (2012), D'Amico and King (2013), Wright (2012), Krishnamurthy and Vissing-Jorgensen (2011) and Li and Wei (2013).

been obtained for the U.K., the euro area and Japan.[4] Moreover, QE has likely affected sovereign bond yields globally as investors rebalanced their portfolios towards higher-yielding sovereign bonds and other assets outside the borders of the countries which employed these policies. In fact, a number of studies examine international spillover effects of QE.[5]

In this paper, we evaluate the effects of central banks' balance sheet policies on global bond yields both in the short term and in the long term. We document the existence of a global monetary policy factor in sovereign bond yields in a panel consisting of both developed and emerging economies. This global factor is related to the size of the aggregate balance sheet of nine major central banks of developed economies which implemented QE strategies. We use a panel cointegration framework that accounts for the interaction between the level of sovereign risk, proxied by the probability of a sovereign default, and the size of the aggregate balance sheet of the nine major central banks. As a result, the effects of global QE differ across sovereigns with different credit ratings.

We find that, in the long run, sovereign bond yields are related to both sovereign credit risk and the size of the aggregate balance sheet of the nine major central banks, implying that QE is a global driver of bond yields. In terms of economic significance, our findings suggest that global balance sheet policies of central banks over the period 2009-2021 have contributed to a permanent decline in sovereign bond yields, ranging from 330 basis points (bps) for AAA rated sovereigns to 800 bps for non-investment grade sovereigns. Thus, the long-run effect of such asset purchases is to lower the yield spread between safe assets and risky assets by inducing agents to take more risk ("portfolio rebalancing" effect).

Our paper contributes to the empirical literature on the effects of QE. In contrast to previous papers in this strand of literature, which focus on balance sheet policies of a single central bank, we look at QE as a global phenomenon. By aggregating monetary policy measures across major central banks, we take the view that QE has acted as a global factor in sovereign bond markets, affecting their valuations. We provide

[4] For the U.K., see, e.g., Joyce et al. (2011), Breedon et al (2012), Christensen and Rudebusch (2012), McLaren et al. (2014) and Steeley (2015). For the euro area, see, e.g. Falagiarda and Reitz (2015), De Santis (2020) and Altavilla et al. (2021). For a review of the empirical literature on the effects of QE in the euro area, the UK and Japan see Dell'Ariccia et al. (2018).

[5] See, e,g., Neely (2015), Moore et al. (2013), Bowman et.al. (2015), Rogers et al. (2018), Belke et al. (2017), MacDonald (2017), Fratzscher et al. (2012, 2018), Ca'Zorzi et al. (2020).

extensive empirical evidence in support of this view, including a battery of robustness tests, such as controlling for short-term interest rates, forward guidance, fiscal policy, foreign exchange risk and global economic conditions.

Our paper is closely related to a recent theoretical literature, which emphasizes the role of investors' preferences ("preferred habitats"), frictions in financial intermediation and market segmentation (Vayanos and Vila 2021, Hamilton and Wu 2012, Greenwood and Vayanos 2014, Greenwood et al. 2015, Greenwood et al. 2020, Gourinchas et al. 2022). In preferred habitat models of the term structure, central bank purchases of long-term bonds reduce the effective supply of bonds available to private investors and lead, for a given demand, to declines in long-term bond yields. This is because by lowering the net supply of bonds, central banks reduce the total amount of interest rate risk borne by investors. In a two-country version of this model (Greenwood et al. 2020, Gourinchas et al. 2022), asset purchases of the domestic or the foreign central bank lead to a fall in long-term bond yields in both countries. In the Gourinchas et al. (2022) model, QE shocks are transmitted almost one-to-one across countries provided that short-term interest rates are sufficiently positively correlated and foreign currency traders' demand is sufficiently price elastic. In the Greenwood et al. (2020) model, bond yields in both countries are driven by the *aggregate* net supply of bonds of both countries if short-term interest rates are perfectly correlated (which is the case, e.g., when short-term rates are at the ZLB).[6] In this case, what matters for the determination of long-term bond yields is the size of the *aggregate balance sheet* of the central banks. The intuition behind this result is that when short-term interest rates are perfectly correlated, domestic and foreign investors face the same interest rate risk. As a result, term premia of domestic and foreign bonds move one-to-one, independently of which central bank makes asset purchases.

Hence, our paper can be viewed as a first attempt to empirically test the predictions of the two-country preferred-habitat model during a period of increased correlation between short-term interest rates. We believe that this case is representative of the sample period we study. Following the Global Financial Crisis, short-term interest rates converged uniformly to zero or negative levels in all economies providing

[6] See Proposition 1 of Greenwood et al. (2020) for the base case that net asset supplies are deterministic, e.g. when central banks pre-announce the path of asset purchases. This result also holds in the case of stochastic net supplies of bonds, provided that short-term interest rates are perfectly correlated, see Sections A.5.1 and A.5.3 of the Online Appendix of Greenwood et al. (2020) for a proof.

safe assets. With increasing correlation between short-term interest rates, the expectations hypothesis implies that term premia of long-term bonds are in the limit perfectly correlated. As a result, purchases of safe assets by any central bank reduce the total amount of interest rate risk borne by financial intermediaries, leading to a uniform decline in safe asset yields. In other words, the size of the aggregate balance sheet of central banks becomes a driving factor of safe asset yields. As investors rebalance their portfolios to high-risk assets, the decline in the net supply of safe assets has spillover effects on yields of lower-rated sovereign bonds through the standard portfolio balance channel (Tobin 1958, 1969).

Our paper is also related to the safe asset scarcity literature (Caballero et al. 2016, 2017, 2021, Caballero and Farhi 2017). Caballero and Farhi (2017) include safe assets in a general equilibrium model and analyze the macroeconomic effects of safe asset shortages in the closed economy.[7] Caballero et al. (2016, 2021) show that, in a two-country model with integrated financial markets, safe asset shortages spill over from one country to the other, affecting bond yields. Increased purchases of safe assets by the central bank of one country decrease the global supply of safe assets available to private investors, lowering the equilibrium return on safe assets. If the safe assets of the two countries are perfect substitutes, the return of the safe asset declines in both countries independently of which central bank purchases the safe asset.

Finally, our paper is related to the literature on the role of global factors in international bond yields. Pan and Singleton (2008) and Longstaff et al. (2011) provide evidence that sovereign yield spreads are related to global factors. Malliaropulos and Migiakis (2018) show that most of the re-pricing of sovereign risk in global bond markets following the Global Financial Crisis is related to a common risk factor, which is driven by global variables such as investor confidence, volatility risk, the Fed's monetary base and the position and the slope of the Treasury yield curve in the U.S. Rey (2013) and Miranda-Agrippino and Rey (2020, 2021) document the existence of a global financial cycle in asset prices which is largely driven by U.S. monetary policy variables and aggregate risk aversion. Kinateder and Wagner (2017) find that sovereign yield spreads in the euro area are driven by three unobservable common factors, which explain about 70% of their variation over time. Abbritti et al. (2018) find that global

[7] Empirical evidence on the effects of QE on bond yields through the safe asset channel is provided by Krishnamurthy and Vissing-Jorgensen (2011) and Van den End (2019).

factors explain more than 80% of term premia in a sample of advanced countries' bond yields.

Last but not least, in terms of econometric methodology our paper differs from the vast majority of empirical studies on the effects of QE, which use event-type methodologies. Typically, event studies examine the effects of policy announcements (news) on asset prices in a small window around the date of announcement (usually hours or days). The use of a narrow time window, however, implies that one cannot estimate the long-run effects of QE. Hence, event studies cannot answer the question whether QE has permanent or only temporary effects. In fact, some researchers have argued that QE announcements have only transient effects on bond yields, mostly disappearing within a six-month period, e.g. see Wright (2012). In contrast to event studies, our empirical framework allows distinguishing between permanent and temporary effects of balance sheet policies of central banks on government bond yields. This is an important issue from a policy perspective: if balance sheet policies have led to a permanent decline in global bond yields, as we actually find, then reducing the stock of assets in central banks' portfolios through Quantitative Tightening could lead to significant increases in long-term interest rates worldwide with severe consequences on public debt sustainability of weak sovereigns, global economic activity and financial stability.

The rest of the paper is structured as follows: Section 2 briefly reviews the principal modeling frameworks to study the effects of central bank balance sheet policies on bond yields, provided by the economic literature. Section 3 outlines the empirical model and describes our dataset. Section 4 presents the main findings of the empirical analysis. Section 5 presents a battery of robustness tests and section 6 concludes.

2. Explaining the impact of QE policies on sovereign bond yields: theory and evidence

In standard dynamic stochastic general equilibrium (DSGE) models, QE has no effect on long-term bond yields as long as markets are not segmented and there are no arbitrage opportunities.[8] The principal modeling frameworks to study the effects of central bank balance sheet policies on bond yields in a closed economy are the preferred habitat model of Vayanos and Vila (2021) and DSGE models with financial market frictions, such as Gertler and Karadi (2011, 2013) and Gertler and Kiyotaki (2010).[9]

Preferred habitat models of the term structure assume that some investors have preferences for bonds of specific maturities. In this case, bond markets are partially segmented and bond yields are determined by the interaction of demand and supply factors. Central bank purchases of long-term bonds reduce the effective supply of bonds available to private investors and lead, for a given demand, to declines in long-term bond yields. Vayanos and Vila (2021) propose a preferred-habitat model of the term structure in which risk-averse arbitrageurs absorb shocks to the demand and supply of bonds at different maturities. The model predicts that an increase in the supply of bonds raises bond yields and this effect is stronger for longer-maturity bonds. Hamilton and Wu (2012), Greenwood and Vayanos (2014) and Greenwood et al. (2015) quantify the effects of QE operations on the term structure and find that purchases of long-term Treasuries by the Fed reduce long-term yields in line with the predictions of the theory. In independent work, Greenwood et al. (2020) and Gourinchas et al. (2022) develop two-country models with specialized financial intermediaries/preferred habitats, where bond yields and the exchange rate are driven by shocks to demand and supply of domestic and foreign bonds. A reduction in the net supply of long-term bonds – such as QE of the domestic or the foreign central bank – leads to a fall in long-term bond yields in both countries because it reduces the total amount of interest rate risk borne by specialized financial intermediaries. Costain et al. (2021) extend the two-country preferred habitat model to a Core-Periphery model where the Core issues default-free sovereign bonds and the Periphery issues defaultable bonds in order to examine the effects of the ECB's Pandemic Emergency Purchase Program (PEPP) on German and Italian bond yields. They find that the PEPP announcement caused a large decline in Italian bond yields due to a reduction in the credit risk premium.

In the framework of DSGE models, one needs to model financial frictions that lead to leverage constraints or exogenous participation constraints in order to explain

[8] Wallace (1981) first showed this "irrelevance result" of central bank balance sheet policies.

[9] For a comprehensive overview of the role of unconventional monetary policy in DSGE models, see Bhattarai and Neely (2018).

effects of QE on long-term bond yields. Gertler and Karadi (2011, 2013) and Gertler and Kiyotaki (2010) study the effects of central bank asset purchases in a DSGE model with financial frictions in form of binding leverage constraints on private financial intermediaries. They find that, to the extent that financial market frictions give rise to an extranormal term premium in the government bond market, there is scope for large-scale asset purchases of the central bank to reduce long-term yields.

Wu and Xia (2016) use a shadow rate term structure model to measure the effect of unconventional monetary policy (UMP) at the ZLB. They find that large-scale asset purchases and forward guidance of the Fed in the period 2009-2014 has reduced the shadow rate 2 percentage points below the ZLB. Sims and Wu (2020) find that doubling the central bank's balance sheet is equivalent to a 3 per cent interest rate cut by the central bank. Finally, Sims and Wu (2021) study the effects of QE, forward guidance and negative interest rates in a DSGE model and find that an increase in the Fed's balance sheet by about 10% of U.S. GDP provides stimulus which is equivalent to a decline in the policy rate by 1 percentage point, in line with the findings of Wu and Xia (2016).

International spillovers of QE have been studied in the context of two-country, open economy DSGE models. Wu and Zhang (2019) study the effects of UMP in a two-country New Keynesian DSGE model with price rigidities. Alpanda and Kabaca (2020) propose a two-country, large-open-economy model with real and nominal rigidities and portfolio balance effects due to imperfect substitution between assets. They compare the spillover effects of a QE shock and a conventional interest rate shock in the U.S. (the home country) on the rest of the world economy. Both policies lead to qualitatively similar spillover effects on foreign bond yields. However, the portfolio balance effect on foreign long-term yields is stronger in the case of QE, compared to conventional monetary policy. This suggests that co-movements of global long-term interest rates are stronger when major central banks use balance sheet policies. In particular, QE shocks in the U.S. lead to a decline in the foreign term premium due to portfolio rebalancing, in contrast to conventional monetary policy shocks where this effect is not present. Finally, Kolasa and Wesolowski (2020) discuss the effects of QE in a two-country DSGE model comprising of a large and a small economy where agents can trade long- and short-term government bonds. Because of market segmentation between long- and short-term bonds, changes in the supply of bonds in the large country trigger portfolio adjustments that affect yields and economic activity in both countries.

3. Data and empirical model

3.1 Data

Our data consist of monthly observations of ten-year, zero-coupon, sovereign bond yields for 45 economies from Refinitiv (Datastream), covering the period from 2009:1 to 2021:1.

Our empirical analysis accounts for country-specific drivers of sovereign bond yields, such as sovereign default risk. This is important in order to disentangle the impact of QE on global bond yields from idiosyncratic factors affecting sovereign risk premia. Previous literature has used sovereign credit ratings to proxy sovereign default risk.[10] However, the use of numeric ratings as a continuous variable in regression analysis might be problematic because it inherently assumes that a one notch change has the same effect on yields across the rating spectrum. In order to account for nonlinearities, particularly around the cutoff point between investment-grade and speculative-grade bonds, we proceeded in two steps: First, we collected sovereign ratings of the three major credit rating agencies (Moody's, Standard and Poor's and Fitch) from Bloomberg for the same period. We used the 'second best rating' regulatory principle in order to mark ratings changes over time, meaning that we change the rating of a sovereign only if at least two rating agencies have changed their rating in the same direction. Second, for each rating category we assigned a probability of default (PD) equal to the historical default frequency of sovereigns belonging to this category over a ten-year horizon from S&P.[11]

Figure 2 illustrates the default frequencies of sovereigns across the rating spectrum over the next ten years, computed as the average frequency over the period 1975-2020.

[Insert Figure 2 about here]

[10] See, among others, Bhatia (2002), Sy (2002), Afonso et al. (2012), Correa et al. (2014), Aizenmann et al. (2013), Acharya et al. (2014) and Malliaropulos and Migiakis (2018).

[11] See, Table 62 from S&P's (2021) 'Sovereign default and transition study 1975-2020'.

As shown in Figure 2, historical default frequencies per rating follow a non-linear, exponential, pattern, suggesting that a downgrade within the non-IG category (particularly below BB) should lead to a much more pronounced increase in the yield than a downgrade within the IG category.

We use monthly balance sheet data on QE measures of the nine major central banks, collected from their websites. By aggregating their balance sheets (all denominated in U.S. dollars), we construct the variable "*total assets*", which measures the size of the combined balance sheets of the nine central banks as a ratio to the combined annual GDP of the nine countries/economic areas in U.S. dollars. Note that central banks' balance sheet data are reported at book value, implying that changes in bond yields do not mechanically affect the size of central banks' asset holdings through changes in their market value, other things being equal. [12]

In order to account for the short-run dynamics of sovereign bond yields, we use monthly changes of short-term interest rates, term spreads and measures of risk aversion such as the S&P500 implied volatility (VIX), which have been found significant drivers of changes in long-term yields in previous studies (Longstaff et al. 2011, Rey 2013, Malliaropulos and Migiakis 2018, Miranda-Agrippino and Rey 2020, 2021). We use both country-specific measures of short-term interest rates and term spreads in order to account for the effects of conventional monetary policy measures on bond yields. Finally, we use global proxies for short-term interest rates, computed as the first principal component of country-specific variables, in order to account for global factors of conventional monetary policy. A detailed description of our data is provided in Table A.1 of the Appendix.

3.2 Empirical model

In standard models of pricing sovereign debt with a non-negligible default risk – e.g. Duffie and Singleton (1999, 2012) – the yield to maturity of an n-period defaultable bond reflects the expected path of short-term interest rates (expectations hypothesis), the uncertainty around that path (term premium) and a default premium over the life of the bond.

[12] See, e.g. the "Sources and Methodology" of the section "Factors Affecting Reserve Balances of Depository Institutions and Condition Statement of Federal Reserve Banks--H.4.1" (https://www.federalreserve.gov/releases/h41/perfeval2015.htm, retrieved 20 June 2019), as well as ECB's press release on 22 January 2012 "ECB announces expanded asset purchase programme" (https://www.ecb.europa.eu/press/pr/date/2015/html/pr150122_1.en.html, retrieved 20 June 2019).

Following Greenwood et al. (2020), the term premium is driven by net bond supplies, i.e. depends negatively on central banks' asset purchases. The intuition behind this result is that by reducing the net supply of government bonds, central banks contribute to lower the term premium, as investors have to bear a lower amount of interest rate risk. In the limiting case of perfectly correlated short-term interest rates (e.g., when short-term interest rates hit the ZLB) asset purchases of either the domestic or the foreign central bank have the same negative impact on the domestic bond yield. In other words, in a multi-country framework, what matters for bond yields is the *aggregate* balance sheet of central banks.

Following Costain et al. (2021), central bank purchases of lower-quality government bonds may also reduce sovereign risk premia, as a lower net supply reduces the probability of default of the sovereign. The intuition behind this result is that with a smaller share of bonds held by private investors, the sovereign has a smaller incentive to default. Hence, we estimate the following model:

$$r_{it}^{n} = \alpha_i + \beta_1 PD_{it} + \beta_2 \left(\frac{total\ assets}{GDP}\right)_t + \beta_3 \left(\frac{total\ assets}{GDP}\right)_t \times PD_{it} + e_{it} \qquad (2)$$

where r_{it}^{n} is the yield to maturity of an n-period defaultable bond of sovereign i, $\left(\frac{total\ assets}{GDP}\right)_t$ is the size of the aggregate balance sheet of the nine central banks as a ratio of aggregate GDP, PD_{it} is the probability of default of the sovereign, and ε_{it} is the error term of the estimated equation.

Equation (2) specifies sovereign bond yields as a function of the probability of default of the sovereign, reflecting country-specific fundamentals, and a global monetary policy variable, proxied by the size of the balance sheet of the nine major central banks. The interaction term $\left(\frac{total\ assets}{GDP}\right)_t \times PD_{it}$ is included in order to capture heterogeneity of QE effects across sovereigns with different exposures to credit risk.

Since high-rated government bonds have zero probability of default (safe assets), β_2 captures the effect of central banks' purchases of high-rated government bonds on their yields (net supply effect). The coefficient of the interaction term, β_3, captures two effects: First, when central banks expand their balance sheet, lowering safe asset yields, investors rebalance their portfolios towards risky assets, bidding their yields down (portfolio rebalancing effect). Since yields of low-rated government bonds are increasing in the probability of default, we assume that the effect of portfolio rebalancing on yields of low-rated bonds is directly related to the probability of default of the sovereign.

Second, central banks have purchased substantial amounts of risky assets, either in form of lower-rated government bonds (e.g. ECB's purchases of peripheral countries' government bonds) or purchases of risky private debt (e.g. Fed's purchases of GSEs and MBSs during Q1 or ECB's purchases of private bonds). Hence, to the extent that the expansion of the central banks' balance sheet reflects purchases of risky assets, it reduces their yields directly. We assume that this effect is also proportional to the probability of default of the sovereign.

Overall, an increase in $\left(\frac{total\ assets}{GDP}\right)_t$ by one percentage point reduces yields of high-rated government bonds by β_2 and yields of low-rated government bonds by $\beta_2 + \beta_3 \times PD_{it}$.

4. Empirical estimates

4.1. Long-run effects of QE on sovereign bond yields

First, we test the null of no cointegration between sovereign yields, probabilities of default and total assets-to-GDP with the use of the Pedroni (1999, 2000) tests, which are suitable for heterogeneous panel datasets.[13] The results suggest that both probabilities of default and central banks' total assets as well their interaction term belong to the cointegration space (see Appendix, Table A.3).

[Insert Table 1 around here]

Table 1, Panel A, presents DOLS estimates of the cointegration relationship between sovereign yields, probabilities of default and total assets-to-GDP, eq. (2). All estimates have the expected sign and are statistically significant at the 1% level. In terms of economic significance, our estimates suggest that yields of AAA rated sovereign bonds declined by 6.5 bps for every one percentage point rise of the total

[13] We first test for unit roots, see Appendix, Table A.2.

assets-to-GDP ratio, while, for comparison, B rated sovereign bond yields (which are on average significantly higher than yields of AAA rated bonds) declined by 17 bps. Our estimates for the effect of QE on AAA rated bonds are in line with the literature. Williams (2014) summarizes a number of QE studies on the U.S. suggesting that bond purchases by the Fed corresponding to 10% of GDP reduce the 10-year yield by 35-65 bps. Gourinchas et al. (2022) estimate the effects of QE in a two-country model of the U.S. and the euro area. They find that asset purchases by either central bank equal to 10% of GDP reduce intermediate maturity bond yields by about 50 bps.

[Insert Figure 3 around here]

Figure 3 visualizes the cumulative effect of QE policies between 2009 and 2021 on sovereign bond yields across the rating spectrum. Given that total assets of the nine central banks as a ratio of the combined GDP of their economies rose by about 50 percentage points (from 20% in January 2009 to 70% in January 2021), our estimates suggest that global QE has contributed to a permanent decline in sovereign bond yields, ranging from 330 bps for AAA rated bonds to 800 bps for non-Investment grade bonds (i.e. a reduction of about 650 bps for BB-rated sovereigns and 850 bps for B-rated ones). The Figure also reports a decomposition of the total effect of QE on bond yields for each rating category into three sub-samples: the period January 2009- December 2014 (Fed's QE1-QE3), the period January 2015-February 2020 (Fed's taper) and the period March 2020-January 2021 (Covid-19). Reflecting the evolution of the central banks' aggregate balance sheet over time, nearly half of the decline in bond yields took place during the Covid-19 period, when central banks expanded their balance sheet by about 25% of aggregate GDP in less than one year, roughly equal to the expansion of their balance sheet over the previous decade.

4.2. Does the Fed dominate global monetary policy effects?

Next, we ask whether the reduction effects on yields are indeed due to global monetary policies rather than being dominated by policies of individual central banks, predominantly by the Fed. Previous papers, such as Miranda-Agrippino and Rey (2018) and Brusa et al. (2020), have shown that the Fed exerts a unique role in global financial markets and leads other central banks in setting monetary policy. To this end, we run two sets of tests: First, we replace our measure of the global monetary policy factor with a common factor extracted from the central banks' balance sheets. A common factor, such as the 1st principal component of central banks' balance sheets, may be a better measure of global monetary policy than the aggregate balance sheet because it may assign different weights rather than equal weights to each central bank. Table 1, Panel B, reports estimation results of equation (3) where we have replaced our measure of $\left(\frac{total\ assets}{GDP}\right)_t$ with the first principal component extracted from the central banks' balance sheets, which is highly correlated with our measure of the global monetary policy factor (92%). The results are very similar to the ones reported in the baseline model of Table 1, Panel A.

Second, we split our global monetary policy factor, $\left(\frac{total\ assets}{GDP}\right)_t$, in two parts: the size of the Fed's balance sheet and the orthogonal component of the other central banks' balance sheet, computed as the residual, u_t, of the following regression:

$$\left(\frac{Other\ central\ banks'assets}{GDP}\right)_t = a + b\left(\frac{Fed's\ assets}{GDP}\right)_t + u_t$$

We then estimate the regression:

$$r_{it}^n = \alpha_i + \beta_1 PD_{it} + \beta_2\left(\frac{Fed's\ assets}{GDP}\right)_t + \beta_3\left(\frac{Fed's\ assets}{GDP}\right)_t \times PD_{it} \qquad (3)$$

$$+\beta_4 u_t + \beta_5 u_t \times PD_{it} + e_{it}$$

Since u_t is orthogonal to the Fed's balance sheet, estimates of β_4 and β_5 capture the effects of other central banks' balance sheet policies on global yields independently of the Fed. Table 1, Panel C, reports the results of regression (3).

Our estimates of β_2 and β_4 suggest that an increase in the size of the Fed's balance sheet by 10 percent of aggregate GDP is related to a decline of global bond yields in the investment-grade category by 100 bps, whereas a similar increase of all other central banks' balance sheet is related to a decline of global bond yields in the same category by 56 bps. These estimates support the view that balance sheet policies of other major central banks have significantly contributed to the decline in global yields despite the leading role of the Fed in setting global monetary policy conditions.[14] Our results are in line with Miranda-Agrippino and Nenova (2022), who provide evidence that

[14] We have also estimated eq. (1) using the assets-to-GDP ratio of individual central banks (see Appendix, Table A4). Our results suggest that all three major central banks (Fed, ECB, BoJ) on their own have contributed significantly to the decline in global yields. Corroborating our findings in Table 1, Panel C, these estimates also suggest that global yields are more responsive to the size of the Fed's balance sheet.

unconventional monetary policies of the ECB have led to significant international spillovers in a similar manner as Fed policies, albeit to a somewhat more moderate degree.

Figure 4 presents a decomposition of the total effect on global yields per rating category over the period January 2009 to January 2021 in the share explained by balance sheet policies of the Fed and the share explained by the (orthogonal component of the) balance sheet policies of other central banks, respectively, based on the estimates of Table 1, Panel C. Our estimates suggest that the Fed on its own accounts on average for about half of the decline in sovereign bond yields globally in the post-GFC period. However, the effects differ significantly across rating categories. In particular, the Fed's balance sheet explains less than 40% of the total decline in AAA and AA yields, about 50% of the total decline in A and BBB yields and more than 65% of the decline in BB and B yields, indicating that the spillover effects of Fed's balance sheet policies are particularly strong in the non-investment grade category. This is in line with findings of the literature that Fed's QE had significant spillover effects on emerging markets -- Bhattarai et al. (2021).

[Figure 4 about here]

4.3. Do effects differ across types of balance sheet policies?

In order to address the concern that the effects of balance sheet policies may differ across types of policy measures (e.g. Krishnamurthy and Vissing-Jorgensen, 2011), we decompose the total assets-to-GDP ratio of the nine central banks into three basic categories: (i) purchases of government bonds, (ii) purchases of private sector debt and (iii) liquidity provision.

We construct the following variables (all denominated in U.S. dollars as a ratio of aggregate GDP):

(a) "*GvtBonds*", which measures the aggregate value of sovereign bonds in central banks' balance sheets;

(b) "*Private*", which measures the aggregate value of private debt in central banks' balance sheet;[15] and

[15] Note that this variable is dominated by the purchases of MBSs and GSE debt by the Fed.

(c) "*Liquidity*", which measures liquidity provision to the banking sector by the central banks. [16]

Figure 5 illustrates this decomposition. Purchases of government bonds are by far the largest component of balance sheet policies, followed by liquidity provision and purchases of private paper. As an illustration, from January 2009 to January 2021, government bond holdings of central banks increased from USD 930 bn (1.6% of GDP) to USD 15 trn (30% of GDP). Liquidity provision and private paper holdings were much lower in magnitude, accounting for 5% and 9% of GDP, respectively, in January 2021. Notably, liquidity provision has been gradually declining over time, with the exception of two spikes in 2011-2012 (euro area crisis) and in 2020 (Covid-19 crisis).

[Insert Figure 5 around here]

Next, we test for unit roots of the three series using the min-ADF test of Zivot and Andrews (1992), which accounts for structural breaks. Our results suggest that liquidity provision is stationary with a structural break in the mean in 2012, whereas the outstanding stock of government bonds and private sector debt in central banks' balance sheets are unit root processes. In terms of modelling strategy, this result implies that liquidity provision has no long-run effects on sovereign yields and should be included in the dynamic adjustment of bond yields to their long-run equilibrium. Consequently, we decompose $\left(\frac{total\ assets}{GDP}\right)_t$ in equation (3) in its two components, $\left(\frac{GovBonds}{GDP}\right)_t$ and the orthogonal component of $\left(\frac{Private}{GDP}\right)_t$ and re-estimate the long-run regression. Table 1, Panel D, reports the results.

The results suggest that both types of asset purchases lead to a decline in AAA bond yields by 10 bps for every one percentage point of GDP increase in central banks' asset purchases. Interestingly, however, we find that one unit of central banks' purchases of private debt lead to stronger declines in yields of lower-rated bonds than one unit of purchases of government debt. This is likely because private debt is a closer substitute of risky sovereign debt, implying that central bank purchases of private debt induce stronger portfolio rebalancing effects towards risky government bonds. This result is also in line with existing theory and empirical evidence. Caballero and Farhi

[16] We proxy liquidity provision of central banks by the sum of the Fed's Term Auction Facility, Primary Dealer Credit Facility, Securities Lending Facility and the discount window, ECB's MROs, LTROs and TLTROs.

(2017) show that when short-term interest rates hit the ZLB, the most powerful policies are those that help the private sector substitute some of their risky assets with safe ones.[17] An example of such policies is the Large-Scale Asset Purchase programme of the Fed (QE1), which concentrated on purchases of private debt such as GSE debt, agency debt and mortgage-backed securities. In fact, a number of empirical papers found that QE1 had stronger effects on yields compared to QE2 and QE3 (see, for example, Bauer and Neely, 2014 and De los Rios and Shamloo, 2017).

4.4. Short-run adjustment of sovereign bond yields

Next, we examine the dynamic adjustment of bond yields to their long-run equilibrium, along with a set of control variables driving their short-term dynamics. The set of control variables includes monthly changes of the probability of default implied by ratings downgrades of one notch and monthly changes of the assets-to-GDP ratio as well as monthly changes of the three main components of the assets-to-GDP ratio, namely government bonds, private paper and liquidity. Furthermore, in order to account for the effects of changes in global risk aversion, we use implied volatility of the S&P500 index (VIX). We also account for changes in the global term premium (Δterm), computed as the difference in the first principal components of ten-year and two-year bond yields from the countries in our sample. Finally, we account for changes in global short-term interest rates, using the three-month Fed Funds and EONIA futures rates.[18]

[Insert Table 2 around here]

The estimation results of the short-run model are reported in Table 2. In all specifications, the error-correction term is statistically significant with the expected negative sign. Changes in bond yields are positively related to changes in the probability of default implied by ratings downgrades and negatively related to changes in the assets-to-GDP ratio (Column 1).

The short-term effects of different forms of QE are reported in Column 2. Purchases of government bonds and liquidity provision both lead to lower yields in the short term. In line with the long-term effects, purchases of government bonds are related to stronger declines in yields of lower-rated sovereigns as suggested by the estimates

[17] This result holds more generally in DSGE models, independently of whether short-term interest rates are constrained or not, e.g. see Gertler and Karadi (2013) and Sims and Wu (2021).

[18] In unreported results (available on request), we replaced the Fed Funds and the EONIA futures rates with the first principal component of the two-year interest rates of the countries in our sample. The results are qualitatively similar to the baseline specification.

of the interaction term of government bonds with the probability of default. In contrast, changes in liquidity provision affect predominantly bond yields of higher-rated sovereigns, suggesting that the policies of ample liquidity provision of central banks has led to a substitution in investors' portfolios from lower-rated towards higher-rated sovereign bonds. This substitution effect may be related to incentives of commercial banks for holding highly rated bonds and pledge them as collateral in bilateral repos, as this reduces the total cost of two-way credit risk (Ewerhart and Tapking 2008). It may also be related to collateral frameworks of central banks.[19] For example, the ECB and the BoE implement investment-grade rating thresholds for accepting collateral in their monetary policy operations and market values of bonds pledged as collateral are subject to haircuts that relate to their ratings.

Estimation results reported in Columns 3-5 suggest that changes in bond yields are positively related to increases in implied volatility, increases in global term premia and increases in short term interest rates. Estimates of the interaction terms of these variables with the ratings-implied probability of default suggest that changes in these variables are associated in the short-term with stronger increases in yields of lower-rated sovereigns relative to higher-rated ones. Interestingly, including the global term premium increases the adjusted R^2 of the regression substantially, from around 6% (Column 3) to around 22% (Column 4), indicating that markets' expectations about the evolution of short-term interest rates, reflected in the global term premium, are a powerful driver of long-term sovereign yields' dynamics. Adding short-term interest rates such as the Federal Funds futures rate or the EONIA futures rate in Column 5 increases the adjusted R^2 of the regression only marginally, suggesting that current short-term interest rates do not add substantial information over and above the global term premium. Finally, Column 6 reports estimation results of the same regression of Column 5, with the only difference that we use the error correction term of the long-run model which distinguishes between purchases of government bonds and purchases of private paper (Table 1, Panel D). The results suggest that our estimates are robust to this specification.

[19] For an analysis of the impact of central bank collateral frameworks on financial markets see Nyborg (2017).

5. Robustness checks and refinements

5.1. Controlling for the effects of conventional monetary policy

Our analysis so far focuses on the sample period following the Global Financial Crisis of 2008-2009 in order to isolate the effects of central bank asset purchases on global yields. However, it is important to keep in mind that in most of this time, the Fed and other major central banks have kept short-term interest rates at near zero levels. Therefore, the question that arises is whether balance sheet policies of global central banks were a significant driver of sovereign bond yields – though, likely, of lower economic significance -- even prior to the Global Financial Crisis, when central banks used short-term interest rates as their main policy tool. In order to investigate this, we expand the sample to January 2001 – January 2021 and estimate our long-run equation (2) controlling for short-term interest rates. We use the two-year bond yield in each country as a proxy of the current and expected path of short-term interest rates. Table 3, Panel A, reports the results for the extended sample.

[Insert Table 3 around here]

Our estimates suggest that extending the sample and controlling for short-term interest rates does not affect the statistical significance of central banks' balance sheet policies in global bond yields. In terms of economic significance, both the coefficient of assets-to-GDP and its interaction term with the probability of default decline compared to our baseline specification in Table 1, Panel A. This result is in line with predictions of theory that QE is more effective when conventional monetary policy is constrained by the ZLB, e.g. see Sims and Wu (2021).

Although short-term interest rates were near the ZLB in major advanced economies most of the time after 2008, central banks in a considerable number of countries in our sample continued to use short-term interest rates in setting monetary policy. Hence, it is important to show that global QE continues to drive bond yields controlling for short-term interest rates in the post-2009 sample. In Panel B of Table 3, we report estimates of the same regression over the 2009:1 – 2021:1 sample. The coefficient of assets-to-GDP and its interaction term with the probability of default increase compared to the extended sample (Panel A) but are still lower than in our baseline specification of Table 1, Panel A. Indicatively, an increase in the central banks' balance sheet by one percent of aggregate GDP is related to a decline of AAA yields by 3 bps and a decline of B yields by 13 bps, compared to 7 and 25 bps, respectively, in our baseline specification. Overall, however, our results suggest that global QE remains a significant driver of sovereign bond yields even after controlling for short-term interest rates.

5.2. Controlling for the effects of forward guidance

Our model focuses on the effects of balance sheet policies of global central banks. However, unconventional monetary policy has also affected bond yields through forward guidance (e.g. Wu and Xia 2016, Wu and Zhang 2019, Sims and Wu 2021). Wu and Zhang (2019) estimate a shadow rate, which can be thought as a summary statistic of both conventional and unconventional monetary policy. The shadow rate is equal to the central bank policy rate when the ZLB is not binding and negative otherwise. Wu and Zhang (2019) show that in the case of the U.S., the shadow rate is highly correlated with the size of the Fed's balance sheet. Furthermore, the shadow rate also reflects the effect of forward guidance, in particular during periods of intensive central bank communication with the public about the future of QE, such as the time of the taper tantrum in May 2013 and the time of the lift off following the end of QE3 in December 2014.

In order to proxy for the effect of forward guidance, we use Wu and Zhang's (2019) estimates of the shadow rate for the Fed and the ECB.[20] We subtract from the Fed's shadow rate the current effective fed funds rate at time t and from the ECB's shadow rate the current deposit facility rate, hence removing the effect of conventional monetary policy of the two central banks. Then, by means of a simple regression of the shadow rates on the size of the balance sheet of the two central banks, we remove from the shadow rates the direct effects of balance sheet policies. The residuals of these regressions capture the effects of forward guidance of the two major central banks. Finally, we compute the average of the two residuals and use this as a proxy of forward guidance. We include this proxy in our long-run regression (2). Table 4, presents the results.

[Insert Table 4 around here]

Our estimates suggest that both the direct effect of the size of the global balance sheet and its interaction term with the probability of default remain highly significant. In terms of economic significance, our estimates suggest that yields of AAA rated sovereign bonds decline by 7 bps for every one percentage point rise of the total assets-

[20] We are grateful to Jing Cynthia Wu for making their data available in her website, https://sites.google.com/view/jingcynthiawu/shadow-rates (retrieved 16 April 2022).

to-GDP ratio, while, for comparison, B rated sovereign bond yields decline by 16 bps. The effects of forward guidance are also significant. A decline in the shadow rate by one percentage point due to forward guidance reduces yields of AAA rated bonds by 32 bps and yields of B rated bonds by 36.5 bps. In order to get a sense of the economic magnitude of these effects, Sims and Wu (2020) estimate that a decline of the shadow rate by one percentage point is equivalent to an increase in the Fed's balance sheet by 12.5%. Using this estimate suggests that forward guidance equivalent to an increase of the banks' balance sheet by one percent of GDP is related to a decline in global AAA yields by 2.5 bps. This is about one third of the effect of outright asset purchases equivalent to one percent of GDP (7 bps).

5.3. Do effects differ across types of countries?

The effects of global balance sheet policies on sovereign bond yields may have been stronger for countries whose bonds had been included in the asset purchase programmes of central banks compared to other countries, whose bond yields were affected only through spillover effects. For example, German Bunds may have benefitted from both direct asset purchases of the ECB and, indirectly, through spillover effects of purchases of U.S. Treasuries by the Fed, as investors rebalanced their portfolios towards German Bunds. In contrast, Norwegian government bonds, for example, are likely to have benefitted less from global balance sheet policies as they have been affected only by spillover effects. In order to address this concern, we split our sample in two groups, one group of countries whose bonds were in the list of assets purchased by any of the nine central banks, and, hence, were affected by both direct and spillover effects of global balance sheet policies (Group A); and a second group, consisting of countries whose bonds were not directly affected by central bank purchases (Group B). Group A consists of nineteen countries (U.S., U.K., JP, eleven Eurozone countries, Sweden, Denmark, Australia, Switzerland and Canada) whereas group B consists of the remaining twenty six countries in our sample.[21]

[Insert Table 5 around here]

Estimation results of equation (3) for the two groups of countries are presented in Table 5. Our estimates in Panel A suggest that global balance sheet policies had stronger effects on sovereign yields of countries belonging to group A, compared to countries

[21] Note that, we include Greece in the first group (Panel A) after March 2020, when the ECB decided to include Greek government bonds in the Pandemic Emergency Purchase Program. For the preceding period we include Greece in the second group of countries (Panel B), because Greek government bonds were not eligible for the APP.

belonging to group B. In particular, the cumulated effect of global balance sheet policies over the period 2009 to 2021 on bond yields of countries of group A ranges from -390 bps for AAA rated bonds to -600 bps for A rated bonds and -840 bps for BBB rated bonds. In contrast, spillover effects of global balance sheet policies on bond yields of countries of group B (Panel B) are estimated at -210 bps on average for all sovereigns, independent of their credit rating. Overall, our results suggest that global balance sheet policies have mostly benefitted countries which were directly affected by central banks' asset purchase programmes, with the effect being particularly strong for countries in this group with relatively low credit ratings. The latter group of countries consists of Eurozone members, such as Italy, Portugal, Ireland and Spain, which have been mostly affected by the sovereign credit crisis.

5.4. Controlling for fiscal policy effects

The decline in long-term yields of vulnerable countries -- particularly in the euro area, e.g. Greece -- cannot only be credited to asset purchases of central banks, not least because bonds of vulnerable countries were not always eligible for asset purchases.[22] Fiscal austerity measures which were part of EU/IMF programs have also contributed to the decline in long-term yields in a number of countries, notably Greece. Hence, in a complementary set of robustness checks we have asked how much of the reduction in yields is due to fiscal consolidation. Table 6 reports results of our long-run regression (2) controlling for primary budget deficits of the countries as a share of GDP.

[Table 6, around here]

Our estimates suggest that increasing the assets-to-GDP ratio by one percentage point reduces AAA bond yields by 7.9 bps, slightly more than a reduction of the primary deficit by one percent of GDP. In other words, central bank asset purchases can fully neutralize the effect of rising budget deficits on bond yields. The effects are stronger for yields of lower rated sovereigns. In particular, we find that lowering primary budget deficits between 2009 and 2019 has contributed to a decline in bond yields of 25 bps for AAA rated sovereigns and 110 bps for B rated ones on average. Of course, the effects differ significantly across countries, depending on the fiscal consolidation effort undertaken. For example, for Greece, a country which has reduced primary fiscal deficits by about 15 percent of GDP between 2010 and 2019, the effect of fiscal

[22] For example, Greek government bonds were not accepted as eligible collateral in ECB operations over extended periods of time, e.g. February 2015 to March 2020.

consolidation on sovereign yields is about -110 bps on top of the spillover effect of the global monetary policy factor on Greek yields (-250 bps).

Second, our results can shed light on the effects of monetary and fiscal policy coordination on sovereign bond yields during the recent Covid-19 crisis. In order to support the economy during the Covid-19 crisis, governments have increased spending aggressively, leading to sharp widening of budget deficits and higher debt. In order to absorb the higher net supply of debt, investors required a higher yield. However, central banks stepped in, absorbing large volumes of government debt. In fact, the increase in global central banks' balance sheet during the Covid-19 crisis was bigger than the aggregate primary deficit of the respective governments, driving sovereign yields to lower levels. In particular, in 2020, the primary deficit in the nine countries/currency areas we consider as the main issuers of safe assets increased by 9.6% of GDP on average, whereas central banks increased their balance sheet by 18% of aggregate GDP in the same year, effectively absorbing all new debt issuance, including rollover needs due to redemptions of old government debt.

[Figure 6, around here]

In Figure 6, we decompose the total effect on bond yields during the Covid-19 crisis period into its fiscal and monetary policy component. The effect of the widening primary deficits after March 2020 on bond yields is positive, amounting to 45-60 bps across rating classes. In contrast, the effect of global central banks' expansion of the balance sheet is negative, ranging between -140 and -430 bps across rating classes. Hence, the net effect of expansionary fiscal and monetary policy during this period on bond yields is negative, ranging from -90 bps for AAA to -360 bps for B rated sovereigns.

5.5. Controlling for exchange rate effects

Our analysis uses local-currency-denominated bonds. Hence, if agents engage in currency carry trades, i.e. borrow-domestic to lend-foreign trades, then local bond yields should reflect a foreign exchange risk premium. As a result, changes in foreign exchange rates could act as a confounding factor in documenting the effects of balance sheet policies of central banks across the rating spectrum. For example, an increase in asset purchases of central banks may trigger a portfolio rebalancing from safe bonds to bonds of risky sovereigns. Capital inflows in high-risk countries may lead to an appreciation of their currencies vis-a-vis the currencies of safe asset countries. In this case, the yields of local-currency-denominated bonds of high-risk countries will reflect a foreign exchange risk premium, i.e. bond yields of risky sovereigns will decline more than bond yields of safe sovereigns because they reflect expectations of an appreciation of the risky countries' currencies. Gilchrist et al. (2019) find that during the unconventional monetary policy regime, an unanticipated easing of U.S. monetary policy leads to significant appreciation for countries with both investment-grade and speculative-grade sovereign bonds. Hence, it is important to control for the effects of exchange rates vis-a-vis the U.S. dollar.

In order to account for exchange rate effects on local-currency-denominated bond yields, we estimate the following regression:

$$r_{it}^{n} = \alpha_i + \beta_1 PD_{it} + \beta_2 \left(\frac{total\ assets}{GDP}\right)_t + \beta_3 \left(\frac{total\ assets}{GDP}\right)_t \times PD_{it} + \beta_4 FX_{i,t} + \beta_5 FX_{i,t} \times \left(\frac{total\ assets}{GDP}\right)_t \times PD_{it} + e_{it} \quad (4)$$

where $FX_{i,t}$ is the log of country's i exchange rate vis-a-vis the U.S. dollar. Exchange rates are quoted as units of local currency per U.S. dollar, hence, an increase in $FX_{i,t}$ is a depreciation of the local currency against the U.S. dollar.

We are particularly interested in the estimate of β_5, the coefficient of the triple-interaction term $FX_{i,t} \times \left(\frac{total\ assets}{GDP}\right)_t \times PD_{it}$. This coefficient captures the effect of global balance sheet policies on sovereign bond yields through their effect on exchange rates, i.e. the foreign currency risk premium component of bond yields. A priori, we expect the foreign currency risk premium effect to be positive and particularly strong in bond yields of high-risk sovereigns whose currencies appreciated vis-à-vis the U.S. dollar. In fact, we find that, in the period 2009-2021, currencies of investment-grade sovereigns depreciated by 15% on average, whereas currencies of non-investment-grade sovereigns appreciated by 160% on average vis-à-vis the U.S. dollar.

Table 7 reports the results of our long-run regression (4), controlling for countries' exchange rates vis-a-vis the U.S. dollar.

[Table 7, around here]

Both the total assets-to-GDP ratio and its interaction term with the probability of default remain statistically highly significant and robust to the inclusion of exchange rates in the regression. The estimate of β_4 is statistically insignificant, likely suggesting that the effect of the exchange rate is largely captured by the country fixed effects. The estimate of β_5 is positive and highly significant, suggesting that asset purchases of central banks have reduced bond yields of high-risk countries with appreciating currencies relative to bond yields of low-risk countries with depreciating currencies. In economic terms, the estimate of the triple-interaction term implies that, over the period 2009-2021, bond yields of non-investment-grade countries declined by 210 basis points, reflecting the reduction of the foreign currency risk premium due to the appreciation of their currencies as major central banks expanded their balance sheet, triggering capital inflows towards high-risk countries.

5.6. Global monetary policy factor vs. global economic conditions

Monetary policy decisions are based on the prevailing economic conditions and inflation developments. As economic activity in each country is affected by the global business cycle, this endogeneity of monetary policy implies that the global monetary policy factor may reflect the effect of global economic conditions. In order to distinguish the effect of the global monetary policy factor from the effect of the global business cycle on sovereign bond yields, we expand our baseline specification (2) with control variables that reflect global economic conditions and inflation.

We use the *global industrial production* index of Baumeister and Hamilton (2019) to control for global economic conditions. This index is constructed based on the industrial production indicators of the OECD countries with the addition of China, Brazil, India, Indonesia, Russia and South Africa.[23] We also used the *global economic conditions indicator* of Baumeister et al. (2020) as a broader control variable in the long-run regression. Baumeister et al. (2020) constructed this variable to forecast energy demand using 16 indicators, covering real economic activity, financial indicators, expectations formation, uncertainty, commodity prices and others. The indicator tracks known episodes of global contractions and expansions well. Finally, we control for global inflation, using the first principal component of annual inflation in the core countries which are the main suppliers of safe assets for the global economy.[24]

[Insert Table 8, around here]

Table 8 presents our estimation results of the long-run regression. *Global industrial production* is negatively related to sovereign bond yields (Panel A), likely because higher growth improves debt sustainability, hence, reducing sovereign risk

[23] Monthly data from January 2009 to January 2021 have been downloaded from Baumeister's website (retrieved on 15 April 2022, from sites.google.com/site/cjsbaumeister/research).

[24] We use the year-on-year percentage changes of the CPI indices for the U.S., euro area, U.K. and Japan. Data are monthly from 1/1/2008 to 1/1/2021 from Refinitiv.

premia. The *global economic conditions* indicator is not significant in explaining global bond yields over and above ratings and the global monetary policy factor (Panel B). The inflation factor is positively related to sovereign bond yields, as expected (Panel C). Finally, in all three specifications, the global monetary policy factor continues to exercise significant reduction effects on global sovereign bond yields, which are stronger for lower-rated sovereigns.

6. Concluding remarks

We examine the effects of balance sheet policies of nine major central banks of developed economies which implemented QE strategies in a panel data set of ten-year sovereign bond yields from a sample that includes both emerging markets and developed economies. We employ cointegration techniques for heterogeneous panels in order to account for both permanent and temporary effects on sovereign bond yieldsOur analysis provides support for the hypothesis that the size of the aggregate balance sheet of the major central banks is a global factor in sovereign bond markets in line with predictions of the recent theoretical literature which emphasizes the role of preferred habitats and frictions in financial intermediation (e.g. Greenwood et al. 2020, Gourinchas et al. 2022). We find that the increase in the size of central banks' balance sheet over the period 2009 to 2021 is related to a significant and permanent decline in global sovereign yields, ranging between 330 bps for AAA rated sovereign bonds and 800 bps for non-investment grade sovereign bonds. Weak Eurozone countries (such as Italy, Portugal, Ireland and Spain) have benefitted the most from global balance sheet policies, with their yields declining by between 620 and 860 bps. These effects are both statistically and economically significant.

Our results are robust to a number of model specifications. We show that our global monetary policy factor is not dominated by QE policies of individual central banks such as the Fed. Asset purchases by the Fed account for about half of the decline in sovereign bond yields globally in the post-GFC period across all rating classes. However, the expansion of the Fed's balance sheet explains more than 65% of the decline in bond yields in the non-investment grade category, indicating that Fed policies exert stronger spillover effects on yields of high-risk sovereigns.

We find that apart from the size, also the composition of global central banks' balance sheet matters. Purchases of private debt lead to stronger declines in yields of high-risk sovereigns relative to purchases of government debt, suggesting stronger portfolio rebalancing effects between risky private and risky government debt.

Our results shed light on the effects of monetary and fiscal policy coordination on sovereign bond yields during the recent Covid-19 crisis. We show that the increase in global central banks' balance sheet during the Covid-19 crisis was significantly bigger than the increase in the aggregate primary deficit of the respective governments, driving global sovereign yields to lower levels.

Our estimates are robust to controls for the effects of conventional monetary policy. Extending the sample to the period prior to the GFC and controlling for country-specific short-term interest rates lowers the economic significance of the global monetary policy factor but does not change our qualitative results. Our results are also robust to controls for the effects of forward guidance.

Finally, we control for the effects of foreign exchange risk premia in local-currency-denominated bond yields. We find that an economically significant part of the larger decline in bond yields of high-risk countries relative to bond yields of low-risk countries reflects the reduction of the foreign exchange risk premium due to the appreciation of their currencies as major central banks expanded their balance sheet, triggering capital inflows towards high-risk countries.

Our findings have important policy implications: First, if balance sheet policies on aggregate had sizeable and permanent effects on global bond yields, scaling down the size of central banks' balance sheets (Quantitative Tightening) is likely to lead to significant increases in sovereign bond yields, particularly for lower-rated sovereigns, capital outflows from Emerging Markets and depreciation of their currencies, with significant implications for the global economy and financial stability. Second, closer coordination of fiscal and monetary policy can help to contain the effects of Quantitative Tightening on sovereign bond yields. For example, unwinding central banks' balance sheets at a similar pace as reducing fiscal deficits after the Covid-19 crisis will likely mitigate the effects of Quantitative Tightening on global bond yields, as the effect of the combined withdrawal of monetary and fiscal stimulus leaves the net supply of government debt unchanged.

References

Abbritti, M., Dell'Erba, S., Moreno, A., Solab, S., 2018. Global factors and the term structure of interest rates. *International Journal of Central Banking,* vol. 14(2), 301-339.

Acharya, V., Drescher, I., Schnabl, P., 2014. A Pyrrhic victory? Bank bailouts and sovereign credit risk. *Journal of Finance*, vol. 69(6), 2689-2739.

Afonso, A., Furceri, D. Gomes, P., 2012. Sovereign credit ratings and financial markets linkages: application to European data. *Journal of International Money and Finance,* vol. 31, 606-638.

Aizenmann, J., Hutchinson, M., Jinjarak, Y., 2013. What is the risk of European sovereign defaults? Fiscal space, CDS spreads and market pricing of risk. *Journal of International Money and Finance*, vol. 34, 37-59.

Alpanda, S. and Kabaca, S., 2020. International spillovers of large-scale asset purchases. *Journal of the European Economic Association*, vol. 18(1), 342-391.

Altavilla, C., Giannone, D., Lenza, M., 2021. The financial and macroeconomic effects of the OMT announcements. *International Journal of Central Banking*, vol. 17, 1-48.

Baumeister, C. and Hamilton, J.D., 2019. Structural interpretation of vector autoregressions with incomplete identification: revisiting the role of oil supply and demand shocks. *American Economic Review*, vol. 109(5), 1873-1910.

Baumeister, C., Korobilis, D., Lee, T., 2020. Energy markets and global economic conditions. National Bureau of Economic Research working paper No. 27001.

Bauer, M.D., Neely, C.J., 2014. International channels of the Fed's unconventional monetary policy. *Journal of International Money and Finance*, vol. 44, 24-46.

Belke, A., Gros, D., Osowski, T., 2017. The effectiveness of the Fed's quantitative easing policy: new evidence on international interest rate differentials. *Journal of International Money and Finance*, vol. 73, 335-349.

Bhatia, A.V., 2002. Sovereign credit ratings methodology: an evaluation. International Monetary Fund working paper No. 02/170.

Bhattarai, S. and Neely C.J., 2018. An analysis of the literature on international unconventional monetary policy. Federal Reserve Bank of St. Louis working paper No. 2016-021C.

Bhattarai, S., Chatterjee, A. and Park, W.Y. (2021). Effects of quantitative easing on emerging market economies. *Journal of Economic Dynamics & Control*, vol. 122, 1-22.

Bowman, D., Londono, J.M. and Sapriza, H., 2015. U.S. unconventional monetary policy and transmission to emerging market economies. *Journal of International Money and Finance*, vol. 55, 27-59.

Breedon, F., Chadha, J.S., Waters, A., 2012. The financial market impact of UK quantitative easing. *Oxford Review of Economic Papers*, vol. 28(4), 702-728.

Brusa, F., Savol, P., Wilson, M., 2020. One central bank to rule them all. *Review of Finance*, vol. 24(2), 263-304.

Caballero, R.J. and Fahri, E., 2017. The safety trap. *Review of Economic Studies*, vol. 85(1), 223-274.

Caballero, R.J., Farhi, E. and Gourinchas, P.-O., 2016. Safe asset scarcity and aggregate demand. *American Economic Review: Papers & Proceedings*, vol. 106(5), 513-518.

Caballero, R.J., Farhi, E. and Gourinchas, P.-O., 2017. The safe asset shortage conundrum. *Journal of Economic Perspectives*, vol. 31(3), 29-46.

Caballero, R.J., Farhi, E. and Gourinchas, P.-O., 2021. Global imbalances and currency wars at the zero lower bound. *Review of Economic Studies*, vol. 88(6), 2570-2621.

Ca'Zorzi, M., Dedola, L, Georgiadis, G., Jarocinski, M., Stracca, L., Strasser, G., 2020. Monetary policy and its transmission in a globalized world. European Central Bank Working Paper No. 2407.

Choi, I., 2001. Unit root tests for panel data. *Journal of International Money and Finance*, vol. 20, 249–272.

Christensen, J.H.E., Rudesbusch, G., 2012. The response of interest rates to US and the UK quantitative easing. *Economic Journal,* vol. 122(564) F385-F414.

Costain, J., Nuno, G., Thomas, C., 2021. The term structure of interest rates in a heterogenous monetary union. Discussion Paper, Banco de Espana.

Correa, R., Lee K.H., Sapriza, H., Gustavo, S., 2014. Sovereign credit risk, banks' government support, and bank stock returns around the world. *Journal of Money, Credit and Banking*, vol. 46(1), 93-121.

D'Amico, S. and King, T.B., 2013. Flow and stock effects of large-scale treasury purchases: evidence on the importance of local supply. *Journal of Financial Economics*, vol. 108(2), 425-448.

D'Amico, S., English, W., Lopez-Saido, D., Nelson, E., 2012. The Federal Reserve's Large-Scale Asset Purchase Programs: rationale and effects. Federal Reserve Board Finance and Economics Discussion Series paper No. 2012-85.

De Santis, R., 2020. Impact of the asset purchase programme on euro area government bond yields using market news. *Economic Modelling*, vol. 86, 192-209.

Dell'Ariccia, G., Rabanal, P., Sandri, D., 2018. Unconventional monetary policies in the Euro Area, Japan, and the United Kingdom. *Journal of Economic Perspectives*, vol. 32(4), 147-172.

De los Rios, A.D., Shamloo, M., 2017. Quantitative easing and long-term yields in small open economies. IMF working paper 17/212.

Duffie, D. and Singleton, K., 1999. Modeling term structures of defaultable bonds. *Review of Financial Studies*, vol. 12(4), 687-720.

Duffie, D. and Singleton, K., 2012. Credit risk. Princeton University Press, Princeton, New Jersey.

Ewerhart, C. and Tapking, J., 2008. Repo markets, counterparty risk and the 2007/2008 crisis. European Central Bank, Working Paper No. 909.

Falagiarda, M. and Reitz, S., 2015. Announcements of ECB unconventional programs: Implications for the sovereign spreads of stressed euro area countries. *Journal of International Money and Finance*, vol. 53, 276-295.

Fratzscher, M., Lo Duca, M., Straub, R., 2012. A global monetary tsunami? On the spillovers of US quantitative easing. CEPR Discussion Paper No 9195, October 2012.

Fratzscher, M., Lo, Duca M., Straub, R., 2018. On the international spillovers of US Quantitative Easing. *Economic Journal*, vol. 128(608), 330-377.

Gagnon, J., Raskin, M., Remache, J., Sack, B., 2011. The financial market effects of the Federal Reserve's Large-Scale Asset Purchases. *International Journal of Central Banking*, vol. 7, 3-43.

Gertler, M. and Karadi, P., 2011. A model of unconventional monetary policy. *Journal of Monetary Economics*, vol. 58(1), 17-34.

Gertler, M. and Karadi, P., 2013. QE1 vs. 2 vs. 3…: A framework for analyzing large scale asset purchases as a monetary policy tool. *International Journal of Central Banking*, vol. 9(2), 6-53.

Gertler, M. and Kiyotaki, N. 2010. Financial intermediation and credit policy in business cycle analysis. In *Handbook of Monetary Economics*, *vol. 3*, edited by B.M. Friedman and M. Woodford, 547-599. San Diego and Amsterdam: Elsevier, North Holland.

Gilchrist, S., Yue, V., Zakrajšek, E., 2019. U.S. monetary policy and international bond markets. *Journal of Money, Credit and Banking*, vol. 51(51), 127-161.

Gourinchas, P.-O., Ray W.D., Vayanos D., 2022. A preferred-habitat model of term premia, exchange rates, and monetary policy spillovers. NBER working paper no. 29875.

Greenwood, R., Hanson S.G, Stein J.C., 2015. A comparative-advantage approach to government debt maturity. *Journal of Finance*, vol. 70(4), 1683-1772.

Greenwood, R., Hanson S.G, Sundream A., 2020. A quantity-driven theory of term premia and exchange rates. NBER working paper no. 27615.

Greenwood, R. and Vayanos, D., 2014. Bond supply and excess bond returns. *Review of Financial Studies*, vol. 27(3), 663-713.

Hadri, K., 2000. Testing for stationarity in heterogeneous panel data. *Econometrics Journal*, vol. 3m, 148-161.

Hamilton J.D. and Wu, J.C., 2012. The effectiveness of alternative monetary policy tools in a zero lower bound environment. *Journal of Money, Credit and Banking*, vol. 44(1), 3-46.

Im, K.S., Pesaran, M.H., Shin, Y. 2003. Testing for unit roots in heterogeneous panels. *Journal of Economics*, vol. 115, 53-74.

Joyce, M., Tong, M., Woods, R., 2011. The United Kingdom's quantitative easing policy: design, operation and impact. *Bank of England Quarterly Bulletin* 2011Q3.

Joyce, M., Miles, D., Scott, A., Vayanos, D., 2012. Quantitative easing and unconventional monetary policy – an introduction. *The Economic Journal*, vol. 122(564), F271-F288.

Kinateder, H. and Wagner, N., 2017. Quantitative easing and the pricing of EMU sovereign debt. *The Quarterly Review of Economics and Finance*, vol. 66, 1-12.

King, M.R., Ongena, S., Tarashev, N., 2017. Bank standalone credit ratings. Bank for International Settlements working paper No. 542.

Kolasa, M. and Wesolowski, G., 2020. International spillovers of quantitative easing. *Journal of International Economics*, vol. 126, 1-32.

Krishnamurthy, A. and Vissing-Jorgensen, A., 2011. The effects of quantitative easing on interest rates: channel and implications for policy. *Brookings Papers on Economic Activity* (Fall 2011), 215-287.

Levin, A., Lin, C.-F., Chu, J., 2002. Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Econometrics*, vol. 108(1), 1–24.

Li, C. and Wei, M., 2013. Term structure modeling with supply factors and the Federal Reserve's Large-Scale Asset purchase Programs. *International Journal of Central Banking*, vol. 9(1), 3-39.

Longstaff, F.A., Pan, J., Pedersen, L.H., Singleton, K.J., 2011. How Sovereign Is Sovereign Credit Risk? *American Economic Journal: Macroeconomics*, vol. 3(2), 75-103.

MacDonald, M., 2017. International capital market frictions and spillovers from quantitative easing. *Journal of International Money and Finance*, vol. 70, 135-156.

Malliaropulos, D. and Migiakis, P., 2018. The re-pricing of sovereign risks following the global financial crisis. *Journal of Empirical Finance*, vol. 49C, 39-56.

McLaren, N., Banerjee, R.N., Latto, D., 2014. Using changes in Auction Maturity Sectors to help identify the impact of QE on Gilt Yields. *The Economic Journal*, vol. 124(576), 453-479.

Miranda-Agrippino, S. and Nenova, T., 2022. A tale of two global monetary policies. *Journal of International Economics*, vol. 136(May 2022), 103606.

Miranda-Agrippino, S. and Rey, H., 2020. US monetary policy and the global financial cycle. *Review of Economic Studies*, vol. 87, 2754-2776.

Miranda-Agrippino, S. and Rey, H., 2021. The global financial cycle. National Bureau of Economic Research, working paper No. 29327.

Moore, J., Nam, S., Suh, M., Tepper, A., 2013. Estimating the impacts of U.S. LSAPs on emerging market economies' local currency bond markets. Federal Reserve Bank of New York, Staff Report No. 595.

Neely, C.J., 2015. Unconventional monetary policy had large international effects. *Journal of Banking and Finance*, vol. 52, 101-111.

Nyborg, K., 2017. Central bank collateral frameworks. *Journal of Banking and Finance*, vol. 76, 198-2014.

Pan, J. and Singleton, K.J., 2008. Default and recovery implicit in the term structure of sovereign CDS spreads. *Journal of Finance*, vol. 63(5), 2345-84.

Pedroni, P., 1999. Critical values for cointegration test in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, vol. 61, 653-670.

Pedroni, P., 2000. Fully modified OLS for heterogeneous cointegrated panels. *Advances in Econometrics*, vol. 15, 93-130.

Rey, H., 2013. Dilemma not trilemma: The global financial cycle and monetary policy independence. Proceedings - Economic Policy Symposium - Jackson Hole, Federal Reserve of Kansas City Economic Symposium, 285-333.

Rogers, J.H., Chiara, S., Wright, H., 2018. Unconventional monetary policy and international risk premia. *Journal of Money, Credit and Banking*, vol. 50(8), 1827-1850.

Sims, E. and Wu, J.C., 2020. Are QE and conventional monetary policy substitutable? *International Journal of Central Banking*, vol. 16(1), 195-230.

Sims, E. and Wu, J.C., 2021. Evaluating central banks' tool kit: past, present and future. *Journal of Monetary Economics*, vol. 118, 135-160.

Steeley, J.M., 2015. The side effects of quantitative easing: evidence from the UK bond market. *Journal of International Money and Finance*, vol. 51, 303-336.

Sy, A.N.R., 2002. Emerging market bond spreads and sovereign credit ratings: reconciling views with economic fundamentals. *Emerging Markets Review*, vol. 3, 380-408.

Tobin, J., 1958. Liquidity preference as behavior towards risk. *Review of Economic Studies*, vol. 25, 124-131.

Tobin, J., 1969. A general equilibrium approach to monetary theory. *Journal of Money, Credit, and Banking*, vol. 1, 15-29.

Vayanos, D. and Vila, J.-L., 2021. A preferred-habitat model of the term structure of interest rates. *Econometrica,* vol. 89(1), 77-112.

Van den End J.W., 2019. Effects of QE on sovereign bond spreads through the safe asset channel. De Nederlandsche Bank working paper no. 647.

Wallace, N. 1981. A Modigliani-Miller theorem for open-market operations. *American Economic Theory,* vol. 71(3), 267-274.

Wiliams, J. 2014. Monetary policy at the zero lower bound: Putting theory into practice. In: *Hutchins Center on Fiscal and Monetary Policy* (Brookings Institution).

Wright, J.H., 2012. What does monetary policy do to long-term interest rates at the zero lower bound? *The Economic Journal,* vol. 122(5), F447-F466.

Wu, J.C. and Xia, F.D., 2016. Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit and Banking,* vol. 48(2-3), 253-291.

Wu, J.C. and Zhang, J., 2019. Global effective lower bound and unconventional monetary policy. *Journal of International Economics*, vol. 118, 200-216.

Zivot, E. and Andrews, K., 1992. Further evidence on the great crash, the oil price shock and the unit root hypothesis. *Journal of Business and Economic Statistics*, vol. 10(10), 251-270.

Table 1 Estimates of long-run relationship

Panel A: Total assets-to-GDP

	PD	Total assets-to-GDP	Total assets-to-GDP x PD
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$
	0.002**	$-6.85x10^{-4}$**	$-3.92x10^{-5}$**
	$(1.90x10^{-4})$	$(1.69x10^{-5})$	$(4.67x10^{-6})$
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
79.98%	515,820.3	-11.227**	-12.779**
	[0.000]	[0.000]	[0.000]

Panel B: Common factor of central banks assets-to-GDP

	PD	1st PC of assets-to-GDP	1st PC of assets-to-GDP x PD
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$
	0.002**	$-7.95x10^{-4}$**	$-5.04x10^{-5}$**
	$(1.47x10^{-4})$	$(1.89x10^{-5})$	$(3.30x10^{-5})$
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
81.49%	207,452.4	-11.371**	-11.981**
	[0.000]	[0.000]	[0.000]

Panel C: Distinguishing between effects from the Fed and from all other central banks

PD	Fed's assets-to-GDP		Other CBs' (aggregate) assets-to-GDP	
$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$	$\boldsymbol{\beta_4}$	$\boldsymbol{\beta_5}$
0.002**	-0.001**	$-8.49x10^{-5}$*	$-5.58x10^{-4}$**	$9.26x10^{-6}$
$(1.82x10^{-4})$	$(1.27x10^{-4})$	$(3.51x10^{-5})$	$(3.68x10^{-5})$	$(1.06x10^{-6})$
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat	
80.83%	84,461.9	-11.793**	-12.344**	
	[0.000]	[0.000]	[0.000]	

Panel D: Specific asset categories

PD	GovtBonds	GovtBonds x PD	Private	Private x PD
$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$	$\boldsymbol{\beta_4}$	$\boldsymbol{\beta_5}$
0.002**	-0.001**	$-1.11x10^{-4}$**	$-9.94x10^{-4}$**	$-5.12x10^{-4}$**
$(1.02x10^{-4})$	$(5.59x10^{-5})$	$(8.01x10^{-6})$	$(3.23x10^{-4})$	$(8.25x10^{-6})$
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat	
84.43%	38,022.8	-13.698**	-15.044**	
	[0.000]	[0.000]	[0.000]	

Note: The table reports Dynamic Ordinary Least Squares (DOLS) estimates of the long-run relationship between yields, 10-year horizon probabilities of default, implied by ratings, and variables capturing balance sheet policies of global central banks (the US Federal Reserve, the European Central Bank, Bank of Canada, Bank of England, Bank of Japan, Bank of Sweden, Denmark's National Bank, the Reserve Bank of Australia and the Swiss National Bank). In panel A, the variable in question is the total assets-to-GDP ratio of the nine central banks. In Panel B, this variable is substituted by the first principal component of the total assets-to-GDP ratio of the nine central banks. In Panel C, we examine effects exercised by the total assets-to-GDP ratio of the Fed and the total assets-to-GDP ratio of all other central banks. Finally, in Panel D, we examine effects exercised by purchases of government bonds (GovBonds) and corporate bonds and MBSs (Private) as ratios to GDP. All specifications include country fixed effects; lags are selected based on the Akaike Information Criterion; finally, the estimation is adjusted for cross-section heterogeneity by employing sandwich techniques for heterogeneous variances. The null of the ADF test is the existence of individual unit roots in the residuals (see, Choi, 2001), while that of the LLC test is the existence of a common unit-root in the panel of residuals (see, Levin, Lin and Chu, 2002). Figures in parentheses (.) are standard errors, while figures in brackets [.] are p-values; asterisks (* & **) denote significance (at the 5% & 1% level, respectively).

Table 2 Short-run dynamics of sovereign bond yields

	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-1.93×10^{-4}**	-2.47×10^{-4}**	-6.03×10^{-4}**	-4.36×10^{-5}	-1.88×10^{-5}	-1.27×10^{-4}
	(5.06×10^{-5})	(5.24×10^{-5})	(1.21×10^{-4})	(1.14×10^{-4})	(1.36×10^{-4})	(1.37×10^{-4})
Error correction term $_{it-1}$	-0.052**	-0.056**	-0.057**	-0.041**	-0.043**	
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	
Error Correction Term$_{it-1}$ (specification Panel D, Table 1)						-0.043**
						(0.004)
Δ(Assets/GDP)$_{t-1}$	-1.29×10^{-4}**					
	(5.14×10^{-5})					
Δ(Assets/GDP)$_{t-1}$ *PD$_{it-1}$	9.16×10^{-8}					
	(5.55×10^{-8})					
Δ(Liquidity/GDP)$_{t-1}$		-8.42×10^{-4}**	-9.30×10^{-4}**	-7.15×10^{-4}**	-5.07×10^{-4}**	-4.78×10^{-4}**
		(1.17×10^{-4})	(1.13×10^{-4})	(1.11×10^{-4})	(1.21×10^{-4})	(1.22×10^{-4})
Δ(Liquidity/GDP)$_{it-1}$ *PD$_{t-1}$		1.49×10^{-4}**	1.44×10^{-4}**	5.65×10^{-5}**	5.03×10^{-5}**	4.88×10^{-5}
		(1.28×10^{-5})	(1.30×10^{-5})	(1.21×10^{-5})	(1.25×10^{-5})	(1.25×10^{-5})
Δ(GvtBonds/GDP)$_{t-1}$		0.024	0.021	0.011	0.012	0.022
		(0.020)	(0.020)	(0.018)	(0.021)	(0.021)
Δ(GvtBonds/GDP)$_{t-1}$ *PD$_{it-1}$		-0.005*	-0.005*	-0.005**	-0.009**	-0.007**
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Δ(Private/GDP)$_{t-1}$		4.77×10^{-5}	-6.19×10^{-5}	-5.45×10^{-5}	4.54×10^{-5}	-4.87×10^{-4}
		(7.19×10^{-4})	(7.20×10^{-4})	(0.001)	(7.42×10^{-4})	(7.45×10^{-4})
Δ(Private/GDP)$_{t-1}$ *PD$_{it-1}$		-9.00×10^{-6}	-3.77×10^{-5}	-1.18×10^{-4}	-7.04×10^{-7}	-1.14×10^{-5}
		(8.35×10^{-5})	(8.25×10^{-5})	(7.52×10^{-5})	(7.99×10^{-5})	(7.95×10^{-5})
Δ(PD)$_{it}$	2.59×10^{-4}**	2.50×10^{-4}**	2.40×10^{-4}**	1.99×10^{-4}**	2.02×10^{-4}**	2.02×10^{-4}**
	(3.67×10^{-5})	(3.68×10^{-5})	(3.67×10^{-5})	(3.34×10^{-5})	(3.33×10^{-5})	($3.34\text{x}0^{-5}$)
VIX$_t$			0.001**	-7.22×10^{-4}	-2.21×10^{-4}	-4.55×10^{-4}
			(4.82×10^{-4})	(4.53×10^{-4})	(5.79×10^{-4})	(5.81×10^{-4})
VIX$_t$*PD$_{it}$			3.96×10^{-5}	8.61×10^{-5}**	1.56×10^{-4}**	1.39×10^{-4}**
			(2.43×10^{-5})	(2.62×10^{-5})	(2.55×10^{-5})	(2.56×10^{-5})
Δ(term spread)$_{t-1}$				0.002**	0.002**	0.002**
				(3.63×10^{-4})	(3.95×10^{-4})	(3.96×10^{-4})
Δ(term spread)$_{t-1}$ *PD$_{it-1}$				1.05×10^{-4}**	0.001**	0.001**
				(3.37×10^{-4})	(3.47×10^{-5})	(3.48×10^{-5})
Δ(Fed funds future)$_t$					7.09×10^{-4}	5.24×10^{-4}
					(5.78×10^{-4})	(5.79×10^{-4})
Δ(Fed-funds future)$_t$ *PD$_{it}$					1.43×10^{-4}**	1.79×10^{-4}**
					(6.27×10^{-5})	(6.29×10^{-5})
Δ(EONIA future)$_t$					0.002**	0.002**
					(5.65×10^{-4})	(5.67×10^{-4})
Δ(EONIA future)$_t$ *PD$_{it}$					1.33×10^{-4}**	1.42×10^{-4}**
					(4.91×10^{-5})	(4.93×10^{-5})
Obs.	6458	6458	6458	6458	6458	6458
No. sections	45	45	45	45	45	45
Adj. R-squared	3.47%	5.11%	5.97%	21.58%	23.42%	23.09%
DW	1.982	2.071	2.069	2.167	2.206	2.200
Jarque-Berra	25,671,279**	19,425,454**	21,018,659**	50,935,538**	4,881,907**	4,833,280**
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]

Note: FGLS estimates with fixed effects and cross-section weights for heterogeneity. All models are estimated with country fixed effects; asterisks (*,**) denote significance (at the 5%, 1% level, respectively).

Table 3 Controlling for short-term interest rates

Panel A: 2001:1 to 2021:1			
PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**	**Short-term rates**
β_1	β_2	β_3	β_4
0.001**	-2.72×10^{-4}**	-4.43×10^{-5}*	0.006**
(1.75×10^{-5})	(8.83×10^{-4})	(9.65×10^{-6})	(6.45×10^{-4})
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
94.13%	2,948,895.7	-16.026**	-16.397**
	[0.000]	[0.000]	[0.000]
Panel B: 2009:1 to 2021:1			
PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**	**Short-term rates**
β_1	β_2	β_3	β_4
0.002**	-3.10×10^{-4}**	-2.91×10^{-5}**	0.007**
(1.94×10^{-4})	(1.33×10^{-5})	(4.88×10^{-6})	(0.001)
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
89.72%	1,580,504.7	-18.021**	-17.349**
	[0.000]	[0.000]	[0.000]

Note: The table reports Dynamic Ordinary Least Squares (DOLS) estimates of the long-run relationship between yields, 10-year horizon probabilities of default, implied by ratings, central banks' total assets as a ratio of total GDP and country-specific short-term interest rates. All specifications include an individual constant accounting for country fixed effects. Figures in parentheses (.) are standard errors, while figures in brackets [.] are p-values; asterisks (* & **) denote significance (at the 5% & 1% level, respectively). See also the note of Table 1.

Table 4 Controlling for the effects of forward guidance

PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**	**Forward guidance**	**Forward guidance x PD**
β_1	β_2	β_3	β_4	β_5
0.002**	-7.23×10^{-4}**	-2.43×10^{-5}**	0.320**	0.045**
(1.58×10^{-4})	(1.52×10^{-5})	(4.22×10^{-6})	(0.023)	(0.005)
Adj. R-squared	Jarque-Berra	ADF z-stat		LLC t-stat
82.52%	44,678.5	-13.991**		-14.901**
	[0.000]	[0.000]		[0.000]

Note: The table reports Dynamic Ordinary Least Squares (DOLS) estimates of the long-run relationship between yields, 10-year horizon probabilities of default, implied by ratings, central banks' total assets as a ratio of total GDP and a proxy of forward guidance derived from Wu and Xia's (2019) shadow rates for the U.S. and the euro area. All specifications include an individual constant accounting for country fixed effects. Figures in parentheses (.) are standard errors, while figures in brackets [.] are p-values; asterisks (* & **) denote significance (at the 5% & 1% level, respectively). See also note of Table 1.

Table 5 Disentangling direct from spillover effects of QE

Panel A: direct + spillover effects			
	PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$
	0.005**	-8.43x10^{-4}**	-1.26x10^{-4}**
	(7.99x10^{-4})	(1.46x10^{-5})	(1.84x10^{-5})
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
67.99%	11,196.3	-7.154**	-8.568**
	[0.000]	[0.000]	[0.000]
Panel B: spillover effects			
	PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$
	0.003**	-4.35x10^{-4}**	-5.14x10^{-5}
	(2.14x10^{-4})	(2.85x10^{-5})	(6.41x10^{-6})
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
77.94%	67,480.6	-10.544**	-11.726**
	[0.000]	[0.000]	[0.000]

Note: Panel A: Only countries whose sovereign bonds were in the list of assets purchased by any of the nine CBs have been included in the system. Panel B: Only countries whose sovereign bonds were not in the list of assets purchased by any of the nine CBs have been included in the system. The table reports Dynamic Ordinary Least Squares (DOLS) estimates of the long-run relationship between yields, 10-year horizon probabilities of default, implied by ratings and total assets of the central banks for those countries whose bonds were not included in an asset purchase program; Greece is included in this group since March 2020, when its government bonds were included in the pandemic emergency asset purchase program of the ECB (PEPP). All specifications include an individual constant accounting for country fixed effects. Figures in parentheses (.) are standard errors, while figures in brackets [.] are p-values; asterisks (* & **) denote significance (at the 5% & 1% level, respectively). See also note of Table 1.

Table 6 Controlling for fiscal effects

PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**	**Primary balance-to-GDP**
$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$	$\boldsymbol{\beta_4}$
0.003**	-7.90x10^{-4}**	-6.17x10^{-5}**	-7.04x10^{-4}**
(3.05x10^{-4})	(2.47x10^{-5})	(7.45x10^{-6})	(5.67x10^{-5})
	Jarque-Berra	ADF z-stat	LLC t-stat
Adj. R-squared	64,226.3	-10.451**	-10.918**
80.25%	[0.000]	[0.000]	[0.000]

Note: The table reports Dynamic Ordinary Least Squares (DOLS) estimates of the long-run relationship between yields, 10-year horizon probabilities of default, implied by ratings, central banks' total assets as a ratio of total GDP and the country-specific primary balance-to-GDP ratio. All specifications include an individual constant accounting for country fixed effects. Figures in parentheses (.) are standard errors, while figures in brackets [.] are p-values; asterisks (* & **) denote significance (at the 5% & 1% level, respectively). See also note of Table 1.

Table 7 Controlling for the effect of exchange rates

PD	Total assets-to-GDP	Total assets-to-GDP x PD	Exchange rate	Exchange rate x PD x Total assets-to-GDP
β_1	β_2	β_3	β_4	β_5
0.003**	-7.10x10^{-4}**	-5.91x10^{-5}**	-2.52x10^{-3}	1.13x10^{-5}**
(2.11x10^{-4})	(1.78x10^{-4})	(5.89x10^{-6})	(1.5x10^{-3})	(1.08x10^{-6})

Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
80937%	106,377.8	-14.365**	-15.161**
	[0.000]	[0.000]	[0.000]

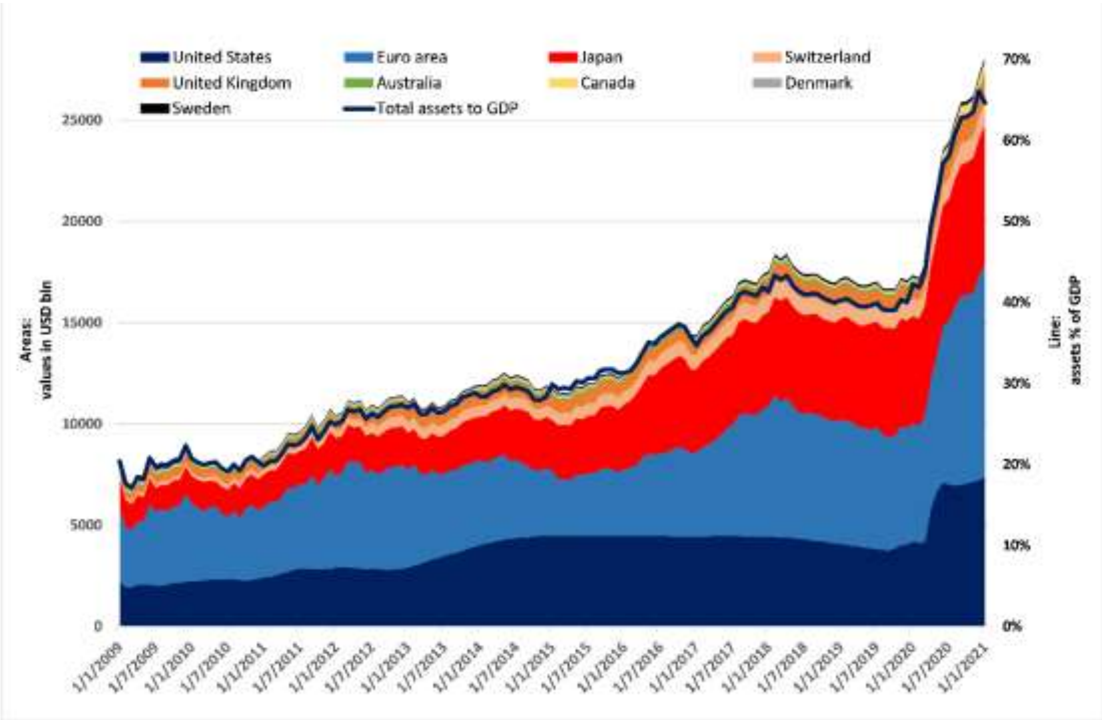
Note: The table reports Dynamic Ordinary Least Squares (DOLS) estimates of the long-run relationship between yields, 10-year horizon probabilities of default, implied by ratings, central banks' total assets as a ratio of total GDP and the exchange rate of the local currency vis-à-vis the US dollar (equation 4 in the text). All specifications include an individual constant accounting for country fixed effects. Figures in parentheses (.) are standard errors, while figures in brackets [.] are p-values; asterisks (* & **) denote significance (at the 5% & 1% level, respectively). See also note of Table 1.

Table 8 Controlling for global economic conditions

Panel A: Global industrial production				
	PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**	**Global Ind. Prod.**
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$	$\boldsymbol{\beta_4}$
	0.002**	-4.01x10^{-4}**	-4.05x10^{-5}**	-4.59x10^{-4}**
	(1.89x10^{-4})	(2.93x10^{-5})	(5.65x10^{-6})	(3.67x10^{-5})
Adj. R-squared	Jarque-Berra	ADF z-stat		LLC t-stat
80.54%	143,330.9	-12.819**		-13.825**
	[0.000]	[0.000]		[0.000]
Panel B: Global Economic Activity Conditions				
	PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**	**Global Econ. Cond.**
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$	$\boldsymbol{\beta_4}$
	0.002**	-6.84x10^{-4}**	-3.95x10^{-5}**	4.17x10^{-4}*
	(1.92x10^{-4})	(1.70x10^{-5})	(4.70x10^{-6})	(2.30x10^{-4})
Adj. R-squared	Jarque-Berra	ADF z-stat		LLC t-stat
80.08%	126,519.6	-11.665**		-13.416**
	[0.000]	[0.000]		[0.000]
Panel C: Common component of inflation rates				
	PD	**Total assets-to-GDP**	**Total assets-to-GDP x PD**	**1st PC Inflation rates**
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$	$\boldsymbol{\beta_4}$
	0.002**	-6.45x10^{-4}**	-3.66x10^{-5}*	0.002**
	(1.85x10^{-4})	(2.03x10^{-5})	(5.43x10^{-6})	(1.27x10^{-4})
Adj. R-squared	Jarque-Berra	ADF z-stat		LLC t-stat
80.64%	94,274.8	-12.651**		-13.288**
	[0.000]	[0.000]		[0.001]

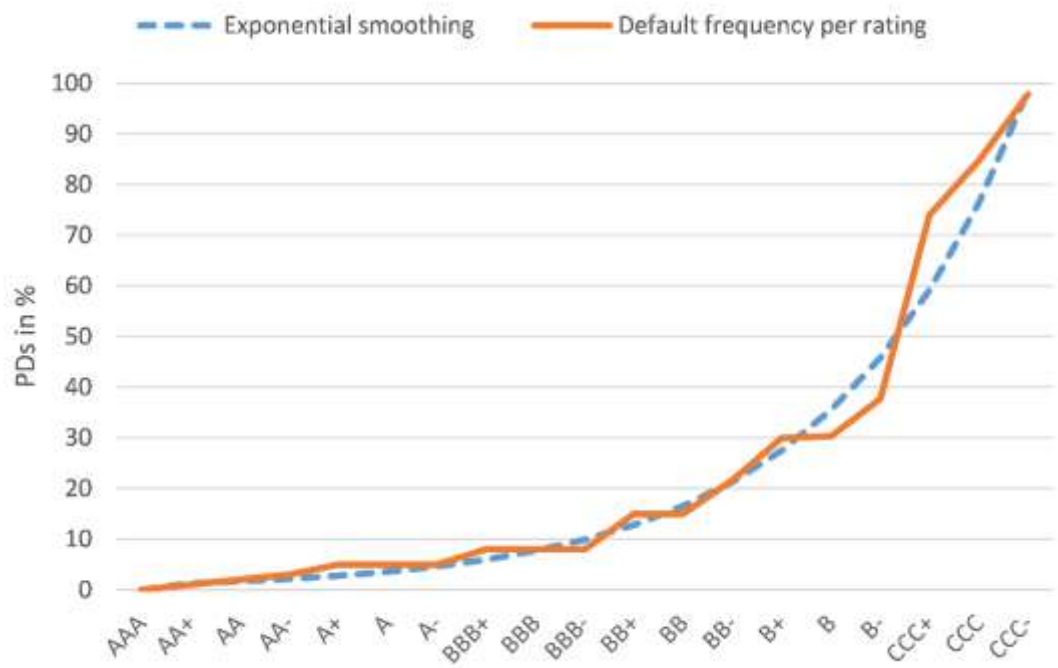
Note: The table reports Dynamic Ordinary Least Squares (DOLS) estimates of the long-run relationship between yields, 10-year horizon probabilities of default, implied by ratings, central banks' total assets as a ratio of total GDP and measures of global economic activity and inflation. In Panel A, we control for global industrial production in the OECD countries plus China, Brazil, Indonesia, India, Russia and South Africa, following Baumeister and Hamilton (2021). In Panel B, we control for global economic activity conditions of Baumeister et al. (2020). In Panel C, the control variable is the first principal component of CPI inflation in the US, euro area, UK and Japan. All specifications include an individual constant accounting for country fixed effects. Figures in parentheses (.) are standard errors, while figures in brackets [.] are p-values; asterisks (* & **) denote significance (at the 5% & 1% level, respectively). See also note of Table 1.

Figure 1: Central Banks' Total assets as a ratio to aggregate GDP



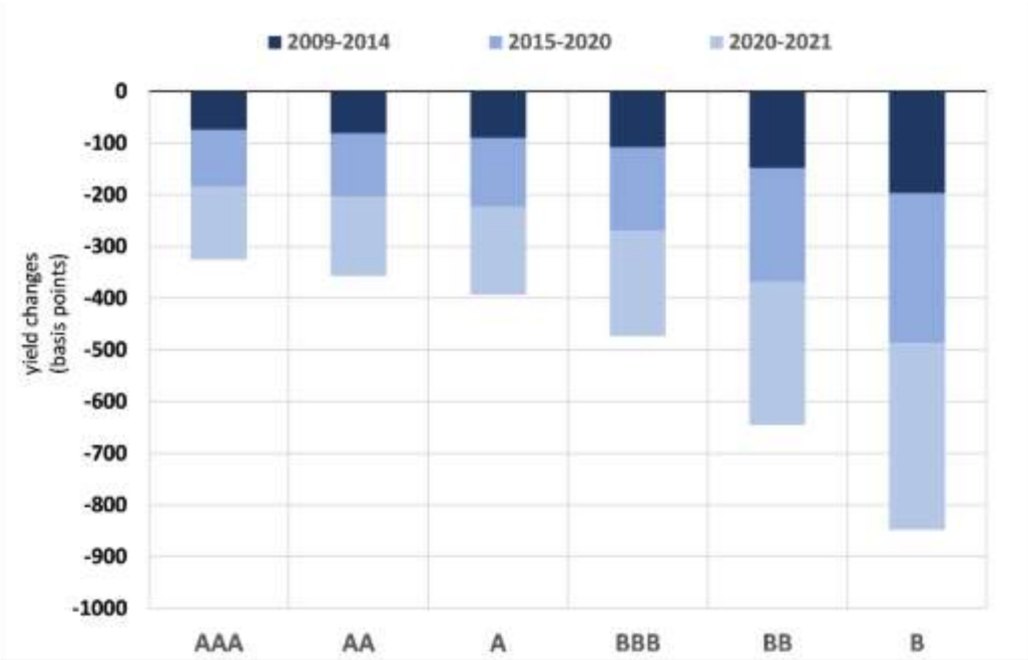
Note: The figure plots the size of the balance sheet of central banks that proceeded to asset purchase programs, in billion U.S. dollars (left-hand side axis). Total assets-to-GDP is the ratio of the aggregate balance sheet of the central banks as a ratio of the aggregate GDP of the respective economies in U.S. dollars (right-hand side axis).

Figure 2: Probability of default of sovereigns



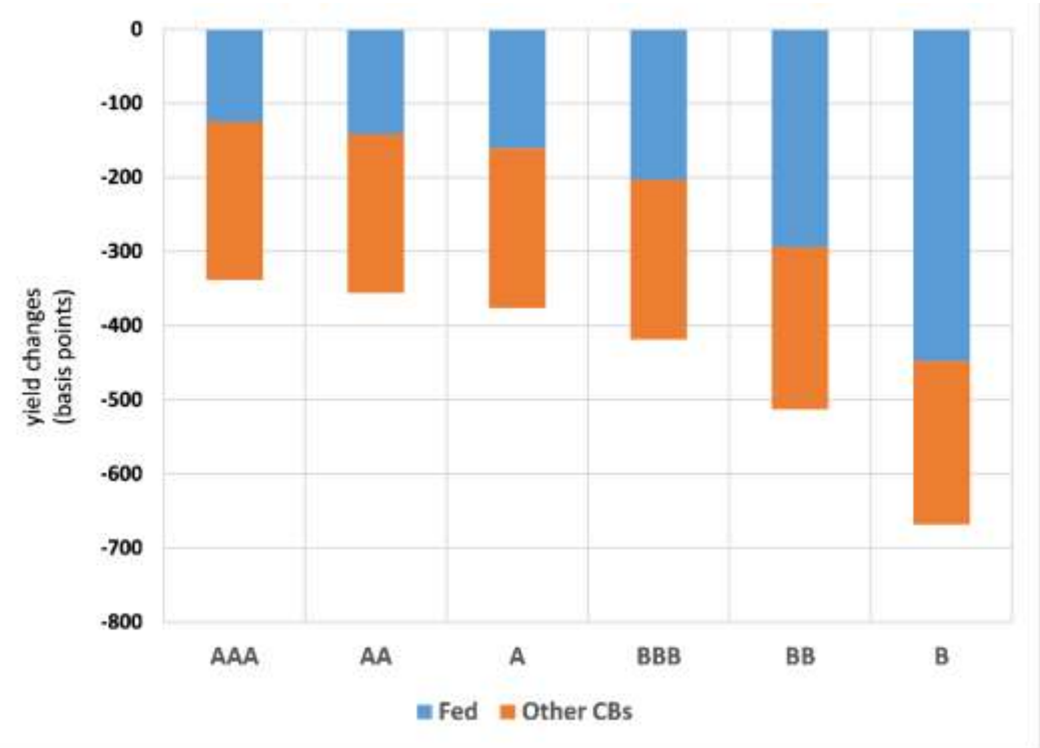
Note: The figure plots the observed 10-year default frequencies, per rating category (orange line) and an exponential smoothing interpolation (blue dotted line) of the observations. The default frequencies are those provided by rating agencies, according to the history of default in each rating category from 1975 to 2020.

Figure 3: Estimated effect of balance sheet expansion on global bond yields



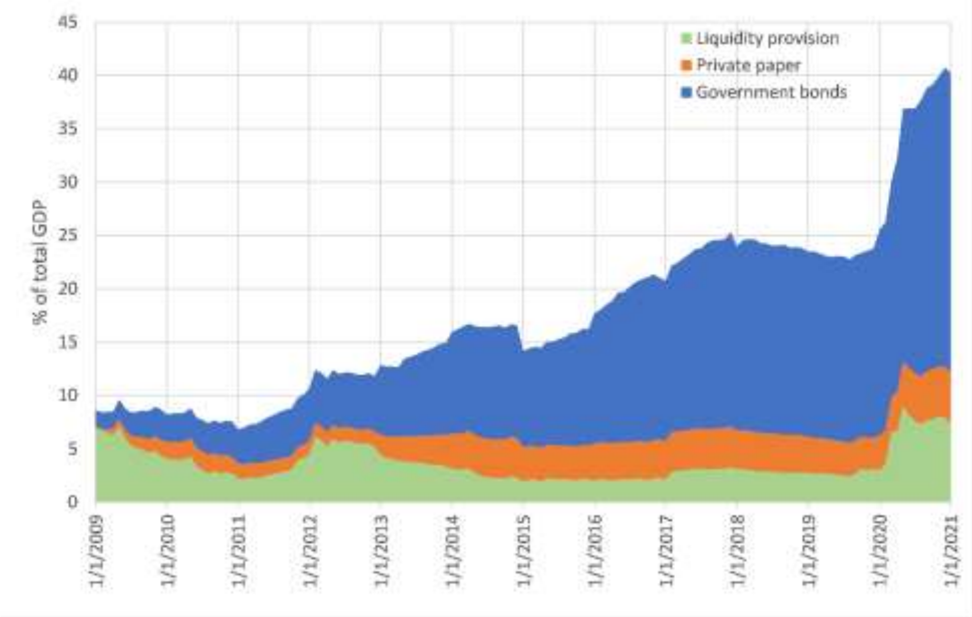
Note: The figure plots the estimated effect on sovereign bond yields from the increase of the nine central banks' aggregate balance sheet as a ratio of aggregate GDP, based on the estimates of Table 1, Panel A.

Figure 4: Effects of Fed and other central banks' QE on global bond yields



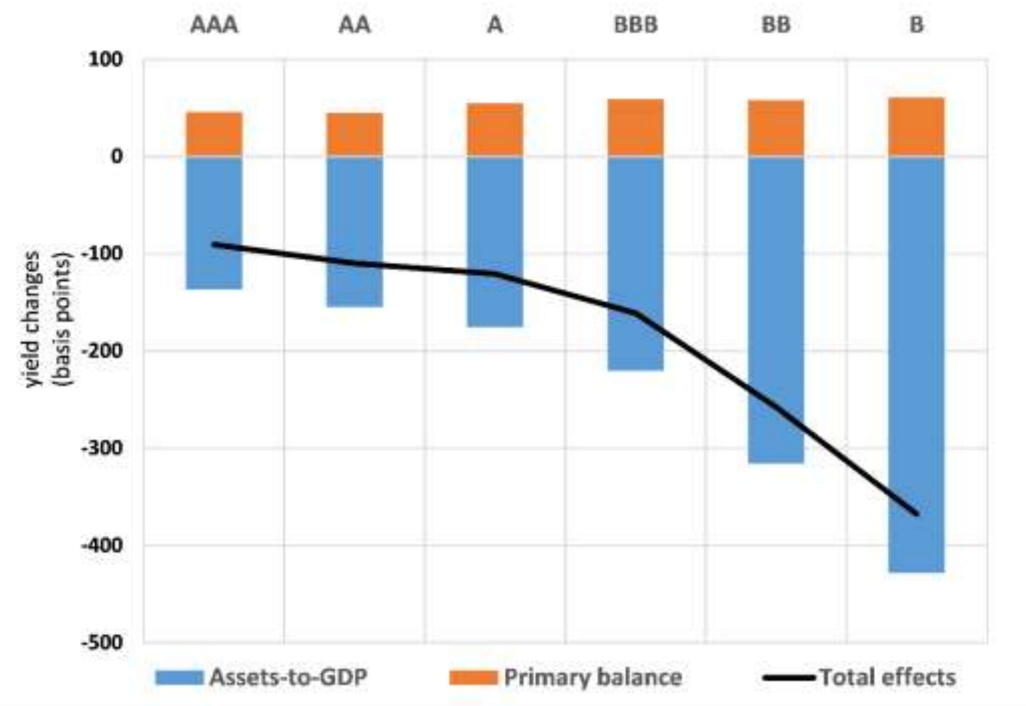
Note: The figure plots the estimated effects on sovereign bond yields from the increase of the Fed's balance sheet (blue bars) and all other central banks' balance sheets (orange bars), based on the estimates of Table 1, Panel C.

Figure 5: Components of total assets-to-GDP



Note: The figure plots the decomposition of the total assets-to-GDP ratio of the central banks in liquidity provision, purchases of government bonds and purchases of private paper.

Figure 6: Monetary and fiscal effects during the Covid-19 crisis



Note: The figure shows the effects on sovereign bond yields, per rating category, exercised by monetary and fiscal policies, after the shock of the pandemic, based on the estimates of Table 7. Blue bars show the contribution of the expansion of central banks' total assets as a percentage of total GDP, for the period April 2020 to January 2021 and the orange ones show the contribution of the fiscal expansion over the same period.

Appendix

Table A.1 Description of data set

Variable	Details of the data
Yields	**Definition:** Ten-year government bond yields; **Source:** Refinitiv; **Period:** 2009:1-2021:1; **Frequency:** monthly; **Economies:** Albania; Austria; Australia; Belgium; Brazil; Bulgaria; Canada; China; Colombia; Croatia; Czech Rep.; Denmark; Finland; France; Germany; Greece; Hong Kong, China; Hungary; Iceland; India; Indonesia; Ireland; Italy; Japan; Korea; Lithuania; Malaysia; Mexico; New Zealand; Netherlands; Norway; Philippines; Poland; Portugal; Russia; Singapore; Slovakia; Spain; South Africa; Sweden; Switzerland; Taiwan, China; Thailand; United Kingdom; United States.
Rating-implied probability of default	**Definition:** Historical default frequencies associated to the foreign currency long-term issuer credit ratings; **Source:** Refinitiv (ratings) and rating agencies' reports (default frequencies); Period: 2009:1-2021:1; **Frequency:** monthly; **Economies:** As above.
Total assets-to-gdp	**Definition:** Total assets of the balance sheets of the following nine central banks: US Federal Reserve System, the European Central Bank, Bank of England, Bank of Japan, Bank of Canada, Bank of Sweden, Switzerland's National Bank, Denmark's National Bank and the Reserve Bank of Australia; **Sources:** Refinitiv and central banks' websites; **Period:** 2009:1 to 2021:1; **Frequency:** monthly. Data have been transformed from local currency to US dollars. Then we calculate the ratio of aggregate liquidity provision to the aggregate GDP of the underlying economies.
Liquidity-to-GDP	**Definition:** Provision of liquidity to the banking sector from the US Federal Reserve System, the European Central Bank; **Sources:** Refinitiv, SDW-ECB, FRED, BoE and BoJ; **Period:** 2009:1 to 2021:1; **Frequency:** monthly; **Description:** Aggregate amounts of liquidity provided by the Fed and the ECB (including Fed's Term Auction Facility, Primary Dealer Credit Facility, Securities Lending Facility and the discount window, ECB's MROs and LTROs and TLTROs). We calculate the ratio of aggregate liquidity provision to the aggregate GDP of the underlying economies.
Government bond purchases-to-GDP	**Definition:** total holdings of domestic gvt-bonds as a ratio of the combined GDP of the nine central banks mentioned above; **Sources:** Refinitiv, SDW-ECB, FRED, BoE and BoJ; **Period:** 2009:1 to 2021:1; **Frequency:** monthly; **Description:** Data have been transformed from local currency to US dollars. We aggregate the amounts of domestic government bonds purchased by central banks and calculate the ratio of government bonds' held to the aggregate GDP of the underlying economies.
Private-to-GDP	**Definition:** Bonds issued by the private sector (corporate bonds and MBSs) held by the nine central banks mentioned above; **Sources:** Refinitiv, SDW-ECB, FRED; **Period:** 2009:1 to 2021:1; **Frequency:** monthly; **Description:** Data have been transformed from local currency to US dollars. We aggregate the amounts of domestic private-sector bonds purchased by central banks (adding also MBSs purchased by the Fed) and calculate the ratio of government bonds' held to the aggregate GDP of the underlying economies.
Short term yields	**Definition:** Yields on 2-year bonds (or bonds of similar maturity) for each economy in our sample; **Source:** Refinitiv; **Period:** 2009:1 to 2021:1; **Frequency:** monthly.
Short term yields (common component)	**Definition:** The first principal component of the yields on 2-year bonds (or bonds of similar maturity) for each country in our sample; **Source:** Refinitiv; **Period:** 2009:1 to 2021:1; **Frequency:** monthly.
Fed fund rates' futures	**Definition:** Futures contracts on the fed funds rate (implied rate) for various FOMC meetings ahead standardized to an horizon of 6 months ahead of the observation date; **Source:** Refinitiv; **Period:** 2009:1 to 2021:1; **Frequency:** monthly.
EONIA futures	**Definition:** Futures contracts on the euro overnight index average 3 months ahead of the observation date; **Source:** Refinitiv; **Period:** 2009:1 to 2021:1; **Frequency:** monthly.
Term spread	**Definition:** Difference between the 1st principal component (PC) of 10-year yields vis-à-vis the 1st PC of the 2-year yields of the 45 economies; **Source:** Refinitiv; **Period:** 2009:1 to 2021:1; **Frequency:** monthly;
Fiscal variable	**Definition:** Primary budget balance as a ratio to GDP; positive values of this variable denote primary fiscal surpluses and the negative ones primary fiscal deficits. **Source:** Refinitiv; **Period:** 2009:1 to 2021:1, **Frequency:** monthly
Volatility	**Definition:** VIX, i.e. the implied volatility of the S&P 500; **Sources:** Refinitiv; **Period:** 2009:1 to 2021:1 **Frequency:** monthly.

Table A.2 Tests for a common or individual unit root in yields

	Individual root IPS W-stat	Common root LLC t-stat	Hadri z-stat (null: stationarity)
Series with constant	-0.811	-1.115	49.579
	[0.209]	[0.132]	[0.000]
Series with intercept and trend	-2.290*	-1.229	32.507
	[0.035]	[0.109]	[0.000]

Note: The IPS W-stat stands for the W statistic of Im, Pesaran and Shin (2003) for testing for individual unit roots in panel data sets, while the LLC t-stat stands for the t-stat test of Levin, Li and Chu (2002) for a common unit root in panel data sets. Hadri z-stat stands for the Hadri (2000) test under the null of stationarity. Figures in brackets [.] are p-values.

Table A.3 Panel cointegration tests

	Panel PP-statistic within	Panel PP-statistic between	Panel ADF-statistic within	Panel ADF-statistic between
Panel A: Pairwise cointegration of yields with rating-implied PDs				
Specification 1:	-5.060**	-3.522**	-4.899**	-3.276**
No intercept or trend	[0.000]	[0.000]	[0.000]	[0.000]
Specification 2: individual	-2.669**	0.544	-2.944**	0.623
intercept	[0.000]	[0.707]	[0.000]	[0.733]
Specification 3: individual	-7.424**	-6.320**	-7.857**	-6.006*
intercept and individual trend	[0.000]	[0.000]	[0.000]	[0.000]
Panel B: Pairwise cointegration of yields with total assets-to-GDP				
Specification 1:	0.741	0.633	0.571	1.488
No intercept or trend	[0.771]	[0.795]	[0.716]	[0.865]
Specification 2: individual	-4.015**	-3.746**	-3.199**	-2.938*
intercept	[0.000]	[0.000]	[0.000]	[0.015]
Specification 3: individual	-2.407**	-4.244**	-0.519	-2.138**
intercept and individual trend	[0.008]	[0.000]	[0.302]	[0.016]
Panel C: Pairwise cointegration of yields with total assets-to-GDP*PDs				
Specification 1:	-2.719**	-1.148	-2.507**	-1.697*
No intercept or trend	[0.003]	[0.126]	[0.006]	[0.043]
Specification 2: individual	-4.489**	-3.893**	-4.024**	-3.291**
intercept	[0.000]	[0.000]	[0.000]	[0.000]
Specification 3: individual	-4.397**	-3.579**	-4.292**	-3.075**
intercept and individual trend	[0.000]	[0.000]	[0.000]	[0.000]

Note: The statistics reported correspond to the Pedroni test for the null of no cointegration in heterogenous panel data sets. Optimal specification of lags, bandwidth selection (Newey-West) and Bartlett kernel for spectral estimation has been used. Alternative specifications (e.g. pre-specified number of lags) have also been tested. Figures in brackets [.] are p-values. Asterisks (* & **) denote rejection of the null of no cointegration (at the 5% and 1% level, respectively).

Table A.4 Effects from individual central banks

	Federal Reserve		
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$
	0.006**	-0.003**	-1.69x10^{-4}**
	(4.79x10^{-4})	(1.17x10^{-4})	(2.73x10^{-5})
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
76.43%	991,575.1	-13.365**	-14.815**
	[0.000]	[0.000]	[0.000]
	European Central Bank		
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$
	0.004**	-0.002**	-4.53x10^{-5}*
	(4.29x10^{-4})	(1.35x10^{-5})	(2.65x10^{-5})
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
69.74%	515,820.3	-11.227**	-12.779**
	[0.000]	[0.000]	[0.000]
	Bank of Japan		
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$
	0.005**	-0.002**	-1.55x10^{-4}*
	(4.01x10^{-4})	(5.35x10^{-5})	(2.02x10^{-5})
Adj. R-squared	Jarque-Berra	ADF z-stat	LLC t-stat
78.06%	1,189,592	-11.169**	-12.703**
	[0.000]	[0.000]	[0.001]

Note: : The table reports Dynamic Ordinary Least Squares (DOLS) estimates of the long-run relationship between yields, 10-year horizon probabilities of default, implied by ratings, and the individual central banks' assets as a ratio of total GDP. $\boldsymbol{\beta_1}$ is the estimate of the probability of default; $\boldsymbol{\beta_2}$ is the estimate of the assets-to-GDP ratio; $\boldsymbol{\beta_3}$ is the estimate of the interaction term of the assets-to-GDP ratio with the probability of default. All specifications include an individual constant accounting for country fixed effects. Figures in parentheses (.) are standard errors, while figures in brackets [.] are p-values; asterisks (* & **) denote significance (at the 5% & 1% level, respectively).

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