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Central bank independence and risk-taking at the zero lower bound

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Abstract

Unprecedented balance sheet expansion in recent years has resulted in heightened financial risk for central banks, reflected initially in higher profits and subsequently in significant losses. Combining data on central bank balance sheets with market data on asset prices, we provide evidence on the evolution and determinants of financial risk-taking by 18 advanced economy central banks. Based on the estimated Value at Risk (VaR), we document that average central bank balance sheet risk increased to about 3 percent of GDP. Central banks took more risk in periods of low policy rates, less expansionary fiscal policies, and more favorable growth prospects. Less independent central banks were more risk averse than their more independent peers, contrary to the fiscal dominance view.

Keywords: Monetary policy, Central bank profitability, Central bank independence, Monetary-fiscal interactions
JEL Codes: E52, E58, E63, G32

Non-technical summary

Following the financial crisis, central banks across the world have increasingly employed "balance sheet policies" such as quantitative easing programmes or large-scale lending operations. Such balance sheet expansions – whether prompted by efforts to stimulate the economy at the effective lower bound on interest rates or by large foreign exchange interventions – have raised concerns about possible financial losses of central banks themselves, and their implications for monetary policy independence.

This paper analyses the dynamics and drivers of risk-taking by central banks in advanced economies. Focusing on 18 advanced-economy central banks from the mid-1990s to the mid-2010s, the paper investigates two questions. First, it asks how overall financial risk-taking on central bank balance sheets evolved over time in view of the greater deployment of the balance sheet as a monetary policy tool. Second, it explores how macroeconomic and institutional conditions affect the degree of financial risk taken by central banks.

To answer these questions, this paper employs a parametric Value at Risk (VaR) framework to quantify potential financial losses under adverse market conditions. Since central banks hold a mix of marketable assets (such as domestic government bonds, foreign exchange reserves, and gold) and non-marketable instruments (notably secured lending to commercial banks), their risk exposure stems from multiple channels, including movements in interest rates, sovereign credit risk, currency fluctuations, and the default risk of counterparty banks. The paper combines annual data from central bank financial statements with daily market price information, allowing a time-varying VaR estimate for each institution.

The paper shows that, on average, central banks have substantially increased their risk exposure over the course of three decades. The average VaR more than tripled from below 1% of GDP in the late 1990s and early 2000s to over 3% by 2015. This growth can partly be attributed to larger asset holdings, but also to riskier asset compositions, most visible during post-crisis quantitative easing operations and foreign exchange interventions. With respect to the drivers of these developments, the paper finds that risk-taking rises when interest rates are at or near the effective lower bound, suggesting that central banks deploy more aggressive balance-sheet measures when conventional policy tools have limited scope. There is also evidence that more independent central banks assume higher levels of risk, plausibly because they are in better position to focus solely on policy objectives rather than on profit and loss considerations which affect the dividends paid to governments. Finally, in countries where fiscal policy tightens, central banks tend to increase risk-taking on their own balance sheets, although this finding applies mainly to central banks with greater institutional independence.

In conclusion, the paper shows that both macroeconomic and institutional factors matter for understanding the financial vulnerabilities that central banks accept in the pursuit of their monetary policy objectives and, by extension, the monetary-fiscal interactions arising from using the central bank's balance sheet as a policy tool. Additional research could track how these dynamics evolved during the post-pandemic inflation surge.

1 Introduction

In recent years, central banks have begun contracting their balance sheets after unprecedentedly large expansions in the first decades of the 21st century. The post-Global Financial Crisis expansion of balance sheets had multiple drivers. In some cases it was the result of asset-purchase programs designed to provide monetary accommodation at or near the zero lower bound. In others, balance sheets expanded as central banks intervened in foreign exchange market to sterilize capital inflows, accumulating foreign reserves in the process.

The impact was dramatic. The Federal Reserve System's total assets rose from 6 percent of U.S. GDP at the end of 2007, prior to the onset of the Global Financial Crisis, to 33 percent at the end of 2022. The Eurosystem's balance sheet increased from 16 percent to 60 percent of euro area GDP between 2007 and 2022, that of the Bank of Japan from 21 percent to 126 percent. For comparison, note that the previous peak size of centrral banks' balance sheets was about 40 percent of GDP during World War II, when governments used central banks for war financing (Ferguson et al. 2023).

In addition to thesee changes in balance sheet *size*, there were changes in balance sheet *composition*. Central banks moved from holding mainly short-term securities and repos with commercial banks to holding long-term bonds, conducting longer-term refinancing operations, and accumulating foreign exchange reserves.

These changes in the size and composition of central bank balance sheets raised concerns about exposure to financial risk. Balance sheet policies conducted in the pursuit of monetary policy objectives left central banks exposed to the risk of losses on their asset positions in the event of increases in interest rates and depreciation of foreign currencies.[1] The Swiss National Bank posted a loss on foreign currency positions of CHF 131.5bn in 2022 (around 17% of GDP, Swiss National Bank, 2023), while the Fed has earmarked a deferred asset of about USD 133.3bn to account for the cumulative negative net income by end-2023 (around 0.5% of GDP, Federal Reserve, 2024). The ECB has warned that it expects to continue incurring losses as the result of the materialization of interest rate risk (European Central Bank, 2024).

Whether such losses affect the ability of central banks to set monetary policy in pursuit of their mandates, or tempt them to respond by increasing seigniorage and losing control of inflation, is disputed. In principle, central banks can operate with negative equity, such that even significant losses do not raise an immediate danger of technical insolvency. But there is no question that recurrent balance sheet losses put central banks in a difficult position. Falling profits may force them to curtail their remittances to the treasury, inviting scrutiny, criticism and questions of whether they are managing balance sheet risks appropriately. When central banks ask the fiscal authorities to replenish their capital, such questions intensify. As Sims

[1] For central banks applying a hold-to-maturity accounting approach, the financial risks materialised not through a revaluation of long-term bond holdings, but through the increasing cost of paying interest on reserves.

(2016) puts it, all this "invites political second-guessing, and reflects an increased fiscal impact of central bank decisions, thereby threatening independence."

To analyze balance sheet risk and its determinants, we apply the concept of Value at Risk (VaR) to central bank balance sheets. This is, to our knowledge, the first systematic empirical application of this concept to balance sheets for a significant international sample of central banks over an extended period, and specifically over the post-Global Financial Crisis period of quantitative easing when central bank balance sheets expanded dramatically.

VaR captures the return on an asset or portfolio that is expected in the worst α percent of outcomes, given assumptions about the return distribution of that asset or portfolio. We take a parametric approach to estimating the return distribution. For these purposes, we gather data for 18 central banks spanning the period 1995 to 2016. During this period, and specifically its later portion, balance sheet expansions were (mostly) a result of a battle against deflation risk in the context of "secular stagnation" and low equilibrium interest rates. The subsequent period of the Covid pandemic and war in Ukraine was different. It was dominated by a global health emergency giving rise to supply chain disruptions, geopolitical and energy shocks, and their associated large deficits. This is a different setting from the period of near zero interest rates, quantitative easing, and balance-sheet expansion whose implications for balance sheet risk we analyze in this paper. We therefore leave it outside the scope of this analysis.

The resulting measures of VaR vary over time and across central banks (Figure 1). For the Federal Reserve and the Bank of England, for example, VaR as a share of GDP increased by nearly a full order of magnitude (close to 10 times) across the threshold of the Global Financial Crisis. For other central banks, such as the Deutsche Bundesbank, the increase was more modest, on the order of 2 to 3 times. The highest risk exposures in our sample, however, arose from large foreign currency reserves, such as those of the SNB.

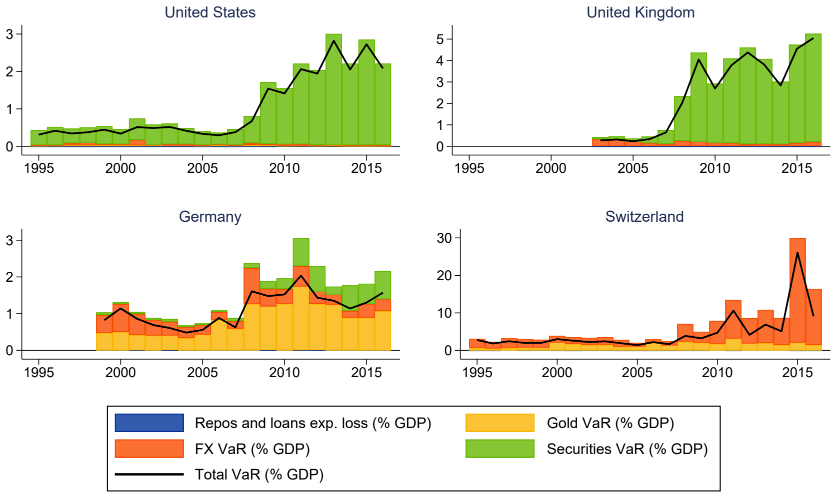
We show that VaR depends on more than the sheer size of the balance sheet. It depends also on the asset composition. While for the Federal Reserve and the Bank of England, VaR derives almost entirely from security holdings, for the Swiss National Bank it is dominated by the central bank's large foreign exchanges. For the Bundesbank, the largest single contributor is the central bank's extensive gold holdings.

Importantly, the total risk exposure of a central bank is smaller than the sum of risks due to its individual investments. This is due to diversification effects of holding less-than-perfectly correlated assets. Logically, diversification effects are more pronounced for central banks holding a wider variety of assets, such as the central banks of the euro area, compared to those whose exposures are more narrowly concentrated in individual market segments, such as the Fed.

Turning to drivers, we find that the VaR/GDP ratio is positively associated with the fiscal balance. When fiscal policy is less expansionary, central banks take more risk onto their balance sheets. Note that this is different from saying that the central bank tends to offset less

Figure 1: Central bank risk-taking over time

Chart shows the Value at Risk (VaR) of central bank assets by year (in % of GDP). Bars indicate the asset-level VaR, where as the black line indicates the total risk taking into account diversification effects among the tradeable assets as well as adding the expected losses from non-tradable assets.



expansionary fiscal policy with more expansionary monetary policy, since we control separately for the overall size of the balance sheet. Instead, central banks respond to a less expansionary fiscal policy with targeted interventions in markets for relatively risky assets, thereby shifting some of the risk that arises when fiscal policy is contractionary onto their balance sheets. Our data does not allow us to identify the direction of causality, and there are plausible hypotheses that would be consistent with a reverse causality. For example, a central bank that loads up more financial risk on its balance sheet might induce governments to run more prudent fiscal policies, if they are concerned about potential future losses. In either case, however, this result speaks against the view of fiscal dominance which predicts that central banks serve fiscal authorities. Instead, our results show a complementary role of monetary policy in taking up more risks during times of fiscal restraint and vice versa.

We also find that higher public debt ratios are associated with greater risk from domestic security holdings, while lower public debt ratios tend to correlate with higher risk from foreign reserve holdings. These results are in line with the observation that reserve currency countries issue more public debt, as they cater to foreign demand for their currency (Gourinchas and Rey, 2007; Farhi and Maggiori, 2018). Central banks of reserve currency countries hold few foreign currency reserves and are therefore relatively more exposed to domestic security risk compared to non-reserve currency countries. Nations which do not enjoy a "reserve currency-privilege" also tend to issue less debt, and hold more foreign reserves, which means that their central banks take on relatively more risk from holding foreign currency assets.

Positive projected GDP growth is associated with more risk-taking by central banks with large foreign exchange holdings. This likely captures the impact of currency appreciation due to increased capital inflows when growth prospects are favorable and efforts on the part of the central bank to lean against appreciation.

One of our most striking findings concerns the connection between central bank VaR and independence. A priori, one can imagine competing hypotheses about the relationship between central bank balance sheet risk and central bank independence. The fiscal dominance view suggests that the government may pressure the central bank to pursue risky policies; central bank independence then provides a bulwark against such pressure, making for a less risky balance sheet. On the other hand, more independent central banks may be inclined to pursue balance sheet policies with the sole pursuit of their objective in mind (expanding their balance sheets in response to the threat of deflation for example), disregarding the corollary impact on their ability to pay dividends to shareholders and repatriate profits to the government. In this case more independence should be associated with more balance sheet risk. We find that VaR tends to be greater for more independent central banks, which appear more willing to take on risk when doing so allows them to pursue their mandates – even when those risks may jeopardize their ability to pay out dividends to their shareholders, including the treasury. Thus, our results are more in line with the second hypothesis: we find that more independent central banks are more likely to take on financial risks than are their less independent peers. Our finding that the government's fiscal balance is positively associated with central bank risk-taking is also in line with this perspective.

The rest of the paper is organized as follows. Section 2 reviews related literature. In Section 3 we describe how we apply the Value at Risk measure to central bank balance sheets. Section 4 describes the data and econometric approach, Section 5 the findings. In concluding, Section 6 draws out some broader policy implications.

2 Related literature

Our paper is related to a number of literatures, starting with that asking why central bank balance sheets are important. Tanaka (2020) reviews work suggesting that a central bank with insufficient capital may pursue inflationary policies, since it may resort on seigniorage to cover its losses. Benigno and Nistiò (2020) analyze a model in which a central bank lacking treasury support and incurring balance sheet losses will seek to restore its solvency through inflation. Del Negro and Sims (2015), reasoning along similar lines, suggest that a central bank should have access to and ask for support from the fiscal authorities if it is to avoid such inflationary consequences. Buiter (2020) concludes, in contrast, that advanced-country central banks are able to absorb large losses without being forced into solvency-preserving monetary issuance on a scale that threatens their inflation targets.

The literature on optimal balance sheet policies (e.g. Karadi and Nakov, 2021; Carlstrom et al., 2017, among many others) does not deal with the financial risk implications for the central bank itself. An exception is Castillo-Martinez and Reis (2024), who discuss how central banks could adjust the risk composition of their assets to steer inflation.

Two empirical papers closely related to our analysis are Goncharov et al. (2023) and Caballero et al. (2020). Goncharov et al. (2023) show that central banks are reluctant to report negative profits, since these are correlated with adverse macroeconomics outcomes such as high inflation. While Goncharov et al. (2023) focus on realized (ex post) profits, we analyze the drivers of central banks' ex ante risk-taking. Caballero et al. (2020) consider the risk-taking of the Eurosystem during the euro area sovereign debt crisis. They show that large balance sheet expansions by central banks can reduce aggregate risk in the economy, giving rise to "risk endogeneity" on their balance sheets.

In addition, there is an empirical literature on the expansion of central bank balance sheets. Ferguson et al. (2023) study their evolution for 17 major economies over 400 years, showing that balance sheet size relative to GDP has varied, initially in response to the needs of war finance and then to financial crises. Filardo and Yetman (2012) compare the expansion of central bank balance sheets in Asia and other regions, showing that balance sheets in Japan, China and other Asian countries began expanding significantly already before the Global Financial Crisis (as Japan turned to unconventional monetary policies, while China and other Asian countries accumulated international reserves), whereas balance-sheet expansion in the U.S., UK and Euro Area took off only during the Global Financial Crisis. Subsequent work considered balance sheet composition as well as magnitude. Crowley (2015) notes that the foreign currency share of central bank assets increased significantly prior to the Global Financial Crisis. Pattipelohy (2016) examines balance sheet composition for 14 advanced countries and 20 emerging markets, documenting heterogeneity in balance sheet composition. He shows that this heterogeneity was particularly pronounced in the aftermath of the Global Financial Crisis, when some central banks engaged in large-scale purchases of domestic assets as a means of implementing monetary policy, whereas others accumulated foreign exchange reserves to limit currency appreciation.

Other studies turn from sources of balance sheet dynamics to their implications. Caruna (2012) argues that sustained balance sheet expansion renders the central bank's finances more exposed to market developments, such as a fall in the value of foreign assets or a rise in long-term interest rates. Filardo and Yetman (2012) conclude that the expansion of the foreign-currency component of balance sheets increased carrying costs for central banks and exposed them to revaluation risk when exchange rates and interest rates fluctuated. Humann et al. (2024) contrast the recent period of expansion with the period of tightening in the 1980s, finding relatively little effect on profits in this earlier episode . Relatedly, Gebauer et al. (2024) show that while larger central bank balance sheets lead to greater profit volatility for central banks, setting interest rates with a loss aversion objective in mind leads to higher inflation.

A related literature focuses on the efficacy and effects of central bank independence itself. Alesina and Summers (1993) showed that central bank independence is associated with relatively low and stable inflation, without a concomitant increase in output volatility. Unsal et al. (2022) confirm that more independent central banks are better able to anchor inflation expectations. Bonetti et al. (2024) analyze the strategic relationship between a central bank and its shareholders using an option-pricing framework. Recent contributions have also examined the association between central bank independence and fiscal dominance. Measuring fiscal dominance as the share of outstanding public debt backed by seigniorage revenue, Resende and Hoddenbagh (2023), for example, document a negative association between central bank independence and fiscal dominance.

A final literature focuses on the importance of central bank balance sheets for the conduct of monetary policy. Wallace (1981) is an influential statement that changes in balance sheet size and composition should have no equilibrium effects. Curdia and Woodford (2011) extend this analysis to a benchmark New Keynesian model, showing that balance sheet expansion has no equilibrium effects insofar as it is neutralized by offsetting adjustments by private agents. However, they then go on to show that targeted asset purchases can be effective when financial markets are disrupted. Iovino and Sergeyev (2018) relax the rational expectations assumption and show that central bank balance-sheet expansion regains its effectiveness in this more general setting. Durré and Pill (2012) consider a pair of disruptions, namely when the economic and financial system hits the zero lower bound and when the domestic financial system lacks the ability to intermediate large, foreign-currency-denominated financial flows. They show that aggregate and targeted balance-sheet expansions have equilibrium effects in this second-best setting.

Turning to the implications of loss making by central banks, Cecchetti and Hilscher (2024) argue that such losses should be balanced against the benefits of QE. They argue that losses are particularly large when the central bank implements QE by buying foreign assets, which results in a transfer to other countries, whereas losses in domestic asset positions lead to redistribution within the country.

3 Methodology

3.1 Risk estimate

We estimate central bank-risk taking using the "Value at Risk" (VaR) approach, which has been the most ubiquitous financial risk measure since the 1990s if not before (see e.g. Duffie and Pan, 1997, for an overview).

For tradable assets on which market prices can be observed (such as securities in domestic and foreign currency or gold), VaR represents the asset or portfolio return that can be expected in the worst α percent of outcomes, given assumptions about the return distribution. We apply a parametric approach to estimating the return distribution, assuming that (log) returns are normally distributed.[2] We compute each tradable asset i's daily log return $r_{i\tau}$ given observed market prices p on date τ, as well as its mean μ_{it} and variance σ^2_{it} over the number of business days T in year t:

$$r_{i\tau} = log\frac{p_{i\tau}}{p_{i\tau-1}} \ , \quad \mu_{it} = \frac{1}{T}\sum_{\tau}^{T} r_{i\tau} \ , \quad \sigma^2_{it} = \frac{1}{T}\sum_{\tau}^{T}(r_{i\tau} - \mu_{it})^2 \ .$$

Assuming that $r_{i\tau} \sim N(\mu_{it}, \sigma_{it})$ and given nominal holdings H_{it}, the VaR for marketable asset i in year t at the α percentile is thus given by

$$VaR^M_{it} = \sqrt{T} \times (1 - exp(\Phi^{-1}_{it}(\alpha))) \times H_{it} \tag{1}$$

where the daily VaR of asset i is scaled to an annual value by using the number of business days per calendar year, T. In our parameterization, we use the conventional 5%-confidence level for α.

Asset-level VaR measures the risk of any given asset. However, a portfolio composed of multiple assets offers diversification effects if returns are less than perfectly correlated with one another. We therefore compute for each central bank c a portfolio-level VaR. With total assets $TA_{ct} = \sum_i H_{it}$ and the relative weight of each asset $w_{it} = \frac{H_{it}}{TA_{ct}}$, the mean log return $\mathbf{M_{ct}}$ and variance $\mathbf{\Sigma_{ct}}$ of a central bank's total portfolio are derived as

$$\begin{aligned}
\mathbf{w_{ct}} &= \begin{pmatrix} w_{1t} & \dots & w_{it} \end{pmatrix}, \\
\mathbf{r_{c\tau}} &= \begin{pmatrix} r_{11} & \dots & r_{i1} \\ \vdots & \ddots & \vdots \\ r_{1T} & \dots & r_{iT} \end{pmatrix} \times \mathbf{w}^{\intercal}_{\mathbf{ct}}, \\
\mathbf{M_{ct}} &= \frac{1}{T}\mathbf{1}^{\intercal}_{T} \times \mathbf{r_{c\tau}}, \\
\mathbf{\Sigma_{ct}} &= \mathbf{w_{ct}} \times \begin{pmatrix} \sigma_{1t} & \dots & \sigma_{1it} \\ \vdots & \ddots & \vdots \\ \sigma_{i1t} & \dots & \sigma_{it} \end{pmatrix} \times \mathbf{w}^{\intercal}_{\mathbf{ct}}.
\end{aligned} \tag{2}$$

[2] Assuming a normal distribution for financial returns remains common in financial modelling despite a large literature criticizing the appropriateness of this assumption, see e.g. Longin (2005); at the same time, there is evidence that the realized volatility of returns over set intervals is well-captured by a log-normal distribution Andersen et al. (2001).

Assuming again that a central bank's total daily log returns are normally distributed, $r_{c\tau} \sim N(\mathbf{M_{ct}}, \mathbf{\Sigma_{ct}})$, this results in a the VaR for the central bank's total marketable assets TA_{ct}^M of

$$VaR_{ct}^M = \sqrt{T} \times (1 - exp(\Phi_{ct}^{-1}(\alpha))) \times TA_{ct}^M \tag{3}$$

Our approach has two important implications. First, our measure implies a "mark-to-market" (MtM) approach to valuing a central bank's holdings of marketable assets, which means that a change in the value of bonds and other assets is immediately reflected on the central bank's balance sheet. In practice, many central banks instead account for their asset holdings under a "hold-to-maturity" (HtM) approach. Under this approach, securities are revalued along the amortisation path from the purchase price to their par value, rather than in line with the prevailing market price.

These different accounting practices have an important implication for the channel through which a rise in short-term interest rates passes through to a central bank's financial strength. Under an HtM approach, rising interest rates do not directly affect the value of asset holdings; accordingly, the capital of the central bank is not immediately impacted. Likewise, however, the approach does not foresee a reassessment of the return on these holdings, since it is predetermined by the amortisation rate from the acquisition price back to par. The adverse impact of a rise in interest rates on the central bank's financial strength is therefore distributed over time, as the unchanged return on its assets is met by the increasing interest expenses on its liabilities (central bank reserves).

In contrast, under an MtM approach, the value of the assets falls immediately as interest rates rise, eating directly into the central bank's economic capital; however, this also implies a higher return on those assets in subsequent years, as the amortisation to par becomes more profitable, thus offsetting the higher interest expenses on the central bank's liabilities.

Second, our VaR_{ct}^M measure directly accounts for the credit risk of the issuer, to the extent that this is reflected in the market price of the asset. A decline in the creditworthiness of a sovereign issuer will lead to a rise in government bond spreads, as the market reassesses the probability of default, as well as the recovery value conditional on a default occurring. Changes in the credit risk of a central bank's marketable asset holdings are therefore captured in our estimated $\mathbf{r_{c\tau}}$, and we do not explicitly need model the default probability and recovery value on such marketable assets. assets.

Besides acquiring marketable assets, central banks also acquire non-marketable assets, notably when they engage in lending operations to commercial banks.[3] Since such loans are

[3]We are indebted to Alexandru Penciu for valuable discussions and suggestions on estimating risks from lending operations and how to aggregate them with the estimated risks from marketable assets.

not traded, their daily market value cannot be observed, and hence hence the empirical return distribution of these loans cannot be readily computed. In banking regulation, the credit risk from non-marketable assets such as loans is thus typically computed by estimating the credit loss in the α percent of worst cases, often referred to as the Vasicek model (Vasicek, 2002; Zimper, 2014). Under this approach, the "worst-case default rate" ($WCDR$) of a portfolio of loans in which the banks borrowing from central bank c in year t have an average default probability PD_{ct} is given by:

$$WCDR_{ct} = \Phi\left(\frac{\Phi^{-1}(PD_{ct}) + \sqrt{\rho}\Phi^{-1}(\alpha)}{\sqrt{1-\rho}}\right) \tag{4}$$

where ρ denotes the correlation between the borrowers in the loan portfolio, i.e. the commercial banks borrowing from the central bank. Since banks' borrowing from the central bank is anonymous, ρ cannot be observed. In our parameterization, we therefore apply a value of $\rho = 0.25$, in line with the value prescribed under the Basel banking regulation (BCBS, 2010).

Given the estimated $WCDR_{ct}$, the credit risk VaR^C_{ct} from central bank's total credit operations TA^C_{ct}, is the expected loss in the α worst percentile of cases:

$$VaR^C_{ct} = (1 - R) \times WCDR_{ct} \times TA^C_{ct} \tag{5}$$

where R is the expected recovery rate conditional on default. Central banks' loans are secured, meaning that commercial banks must pledge eligible assets as collateral in order to be able to draw liquidity. These collateral requirements mean that recovery rates can be close to 1, substantially limiting the risk from lending operations.[4] The precise composition of the assets pledged as collateral in central bank lending operations is not publicly available in a manner that is comparable across countries. In our parameterization, we set the recovery value to 95% (or equivalently, assume that a central bank's loss given default on a collateralised lending operation is 5%), broadly in line with the parameterization in the literature (see e.g. Caballero et al., 2020, for the Eurosystem).

Finally, we aggregate the risk from marketable assets, VaR^M_{ct}, and the risk from non-marketable lending operations, VaR^C_{ct}, using the widely applied variance-covariance approach:

$$Risk_{ct} = \sqrt{(VaR^M_{ct})^2 + (VaR^C_{ct})^2 + 2\rho \times VaR^M_{ct} \times VaR^C_{ct}} \tag{6}$$

[4]For instance, the German Bundesbank recovered its EUR 8.5bn claim from lending operations to Lehman Brothers in full after liquidating the collateral for EUR 7.4bn and covering the residual claim from the insolvency estate. See the press release "Bundesbank receives final payment from German Lehman insolvency proceedings", February 10, 2015.

This approach rests on the assumption that the risk from marketable assets and lending operations is multivariate normally distributed (Böcker and Hillebrand, 2008). While this assumption may not always hold in practice, the approach is widely used, including in banking regulation, such as the Basel Solvency II framework Paulusch (2017); Li et al. (2015).[5] In any case, due to the assumed near-perfect recovery rate, the implications of the risk from credit operations for the aggregate risk estimate is limited.

3.2 Empirical framework

Our empirical interest is uncovering systematic correlates of central bank risk-taking. We employ an agnostic approach to this end, starting from the following benchmark specification:

$$
\begin{aligned}
\frac{\text{Risk}}{\text{GDP}}_{ct} &= \beta_1 \text{Total assets/GDP}_{ct} + \beta_1 \text{Policy rate}_{ct} \qquad (7)\\
&+ \underbrace{\beta_3 \text{Output gap}_{ct} + \beta_4 \text{Proj. inflation dev. from target}_{ct} + \beta_5 \text{Projected GDP growth}_{ct}}_{\text{“Taylor rule”}}\\
&+ \underbrace{\beta_6 \text{Fiscal balance}_{ct} + \beta_7 \text{Debt/GDP}_{ct}}_{\text{Fiscal}}\\
&+ \underbrace{\beta_8 \text{Current account}_{ct} + \beta_9 \Delta \text{Exchange rate}_{ct}}_{\text{External balance}}\\
&+ \underbrace{\beta_{10} \text{CB Independence}_{ct}}_{\text{Institutional setting}}\\
&+ m_c + n_t + u_{ct}
\end{aligned}
$$

The rationale for this specification is threefold. First, we control for variables representing the stance of monetary policy. We include the total assets held by the central bank, as well as the level of the key policy rate. Since central banks are more likely to pursue balance sheet policies when interest rates are approaching their effective lower bound (ELB), we account for a potentially non-linear relationship between the policy rate and VaR.[6] This reflects that as long as interest rates are away from their ELB, central banks can vary their stance by adjusting rates without increasing asset holdings. Once policy rates are close to the ELB, however, changes in monetary policy stance are likely to be reflected in the balance sheet rather than the level of the policy rate. These considerations are consistent with a convex relationship beteeen the policy rate and risk-taking.

Second, we relate our estimate of financial risk-taking to variables traditionally considered in

[5] As above, we set $\rho = 0.25$ in line with the Basel regulatory guidelines.

[6] The potential non-linearity arises because we do not observe the “shadow interest rate” that the central bank would set below the ELB.

monetary policy rules. Similar to central banks' administered policy rates, their balance sheets are an expression of the monetary policy stance. An expansion of a central bank's asset holdings typically reflects an easing of the stance, whereas a balance sheet contraction corresponds to a tightening. Balance sheet policies comprise a broad set of different instruments, working through different transmission channels: for instance, large-scale asset purchase programmes, so-called quantitative easing policies, are aimed at lowering longer-term interest rates by incentivising portfolio rebalancing by the private sector. Direct lending operations to commercial banks can ease bank funding costs, on the other hand, thus focussing more on the bank lending channel. In any case, expansionary balance sheet policies tend to transfer risk from the private sector's balance sheet to the central bank, e.g. in the form of duration and credit risk in outright securities holdings and more loans to banks. This implies that central bank risk-taking may be governed by a "risk reaction function," akin to a Taylor rule for policy rates. We therefore include in our benchmark specification the (projected) deviation of inflation from inflation targets, (projected) GDP growth, and the estimated output gap.

Third, broader macroeconomic developments are likely to affect the riskiness of central banks' assets. A domestic government bond will be less risky if the fiscal trajectory is perceived as safe. We therefore consider the potential role of the government's fiscal balance and the debt/GDP ratio. Likewise, foreign reserves are typically held in the form of foreign government bonds, making their riskiness a function of the foreign issuer's creditworthiness and the country's external balance. We capture these factors through the current account balance and the annual change in the exchange rate vis-a-vis the USD.

We then turn to the role of central bank independence and include the corresponding index. We investigate whether greater independence affects the role of other variables on risk-taking by interacting the independence measure with other determinants in the regression.

In order to abstract from nominal effects, we express all variables in percent of GDP and control for country and year fixed effects.

4 Data and empirical results

4.1 Data sources

We use four categories of data in an annual panel for 18 countries. Table 1 contains summary statistics for the variables that enter our regressions. The data annex contains a detailed description of the sources and assumptions per country underlying the construction of the VaR.

Balance sheet data The primary source for computing balance sheet risk statistics is the annual reports released by central banks annually to inform the public about their activities. Overall, we collect 332 annual balance sheets reported by 18 central banks between 1995 and

Table 1: Summary statistics of key variables

	N	Mean	SD	P1	P50	P99
VaR (% GDP)	332	1.48	1.86	0.16	1.10	6.89
Gold VaR (% GDP)	332	0.49	0.59	0.00	0.27	2.30
FX VaR (% GDP)	332	0.83	2.00	0.00	0.45	8.83
Securities VaR (% GDP)	332	0.78	1.06	0.00	0.39	5.04
Repos and loans exp. loss (% GDP)	332	0.04	0.16	0.00	0.00	0.76
Total assets (% GDP)	332	19.79	17.05	3.45	15.30	93.70
LAC (% GDP)	332	3.05	2.63	0.00	2.74	13.66
LAC (% Total assets)	332	17.45	13.05	0.07	15.84	56.09
Policy rate (%)	332	1.88	1.89	-0.65	2.00	6.25
Output gap (% potential GDP)	332	-0.48	2.34	-7.55	-0.34	4.83
Inflation deviation from 2% (forecast t+1)	332	0.46	0.62	0.00	0.20	2.55
GDP growth (forecast t+1)	332	2.00	1.15	-1.01	1.97	5.26
Fiscal balance (% GDP)	332	-2.21	3.62	-11.40	-2.05	4.99
Gross government debt (% GDP)	332	71.91	38.65	11.75	64.48	228.40
Current account (% GDP)	332	0.86	4.81	-10.29	1.01	11.60
Delta FX (%, y-o-y)	332	0.16	10.10	-18.11	0.00	21.15
Central Bank independence index	332	0.74	0.22	0.32	0.90	0.93

2016. We focus on financial statements containing the asset and liability positions at year-end, and the accompanying commentary with additional detail on individual positions. The share of each position in the total assets leads to the portfolio weights $\mathbf{w_{ct}}$ in eq. (3.1).

We exploit the information in the annual reports to code the asset holdings at the most granular available level in terms of asset class, maturity, and currency composition.[7] For instance, we divide the Federal Reserve's US Treasury security holdings reported in the main reporting table (H.4.1) into five categories, assets with a residual maturity of up to 12 months, 1-5 years, 5-10 years, and above 10 years, and compute the risk from each category. The maturity composition has important implications for the VaR measure, as the value of Treasury securities with medium or long-term residual maturity tends to be more volatile than the price of short-run T-bills.

For the central banks of the euro area, we further account for asset-specific income and risk-sharing arrangements across national central banks (NCB) as well as the ECB. The ECB is owned by the NCBs of the European Union, meaning that the ECB's financial income is de facto shared by NCBs according to their stake in the ECB's capital. Thus, the income and risks related to QE purchases of private sector securities, bonds issued by supranational institutions, as well as bonds purchased under the Securities Markets Programme (SMP), an

[7] While some central banks release their consolidated annual financial statements in machine-readable form, the accompanying notes contain important details for the computation of financial risks. For instance, while the size of the Federal Reserve's SOMA portfolio can be downloaded from the Fed's website, information on individual maturity buckets is contained in the commentary on the annual financial statement.

earlier purchase programme conducted during the European sovereign debt crisis, are shared across all NCBs according to their subscription to the ECB's capital. In contrast, the income from the QE purchases of NCBs' domestic government bonds under the Public Sector Purchase Programme (PSPP) is reflected mainly on their own income statement.[8] We account for these arrangements by aggregating the holdings of risk-shared assets as well as the ECB's assets and re-allocate them to the individual NCBs according to their ECB capital key share.

Since liquidity provided by Eurosystem NCB's under the Emergency Liquidity Assistance (ELA) is not subject to income sharing, the risks reside with the NCB conducting the operation. In contrast, the risk entailed in the ECB's monetary policy refinancing operations, while generally subject to a risk-sharing arrangement across the NCBs, depends on the pledged collateral.[9] Since the pledged collateral is not publicly available at a sufficiently granular level, we assign the risk from monetary policy refinancing operations to the NCB conducting the lending operation, as we do for ELA operations. This overestimates the true financial risk associated with monetary policy repos for individual NCBs, while underestimating it for others that would be required to share losses associated with collateral pledged under the common risk control framework. However, since the estimated risk emanating from refinancing operations is small, it is inconsequential for our empirical estimates.

Market data To compute the market risk associated with each asset, we link each category with a corresponding financial time series of daily returns, corresponding to r_{it}. Overall, we collect around 330 separate financial time series. Most return data are based on representative asset prices or market indices downloaded from the market-data providers Bloomberg and Refinitiv. For example, we value the Federal Reserve's holdings of Treasury bonds with the quote price of the US Government Benchmark Bonds from Refinitiv; for the MBS holdings, we use the US MBS Total Return Value USD index from Bloomberg.

For the risk related to lending operations, we use the average CDS quotes for the major banks in each country to compute the market-implied average (risk-neutral) default probability PD in central banks' lending operations. Where bank CDS quotes are not available, we use Moody's probability of default ratings, for consistent scaling extrapolated into the corresponding CDS quotes based on the correlation in the overlapping sample.

The Annex provides a detailed summary of the data used to value each asset and the list of banks used to approximate the average default probability per country.

[8] NCBs share only "notional" income from national PSPP holdings at a reference rate. See Decision No. 2016/2248 of the ECB ("Decision on the allocation of monetary income of the national central banks of Member States whose currency is the euro").

[9] National central banks in the euro area can implement frameworks under which they accept "additional credit claims" as collateral, in order "to take into account specific conditions in their respective countries, such as the types of collateral available or special legal and operational circumstances" European Central Bank (2021). National central banks accepting such assets as collateral must set up national risk control frameworks, subject to a common minimum risk control framework approved by the ECB's Governing Council.

Macroeconomic data Since we are interested in economic determinants of central banks' profits and risk-taking, we match central bank balance sheet data with macroeconomic variables, both historical and projected. In order to ensure methodological consistency over time and across countries, we use the IMF's World Economic Outlook database to retrieve information on GDP growth, inflation, the output gap in percent of potential GDP,[10] the current account, fiscal balance, and gross government debt (the latter three all in percent of GDP).

Central bank independence The final component of our dataset is variables measuring the institutional independence of central banks. We employ the central bank independence index prepared by Romelli (2022). The index is based on datasets collected by Grilli et al. (1991) and Cukierman et al. (1992), but complements the measure with dimensions that are particularly relevant for central banks' risk-taking, such as financial independence and reporting and disclosure rules. While the central banks in our sample of advanced economies enjoy, on average, a comparatively high degree of independence (the independence in our regression sample has an average value of 0.74), there is still a notable variation across countries and over time. The cross-sectional dimension captures the range of institutional settings from the Bank of Japan, with a relatively low independence score, to the highly independent central banks of the euro area; the temporal dimension captures events such as the Sveriges Riksbank Act of 1999 or the Swiss National Bank Act of 2003, which granted the Swedish and Swiss central banks' greater autonomy.

4.2 Descriptive statistics

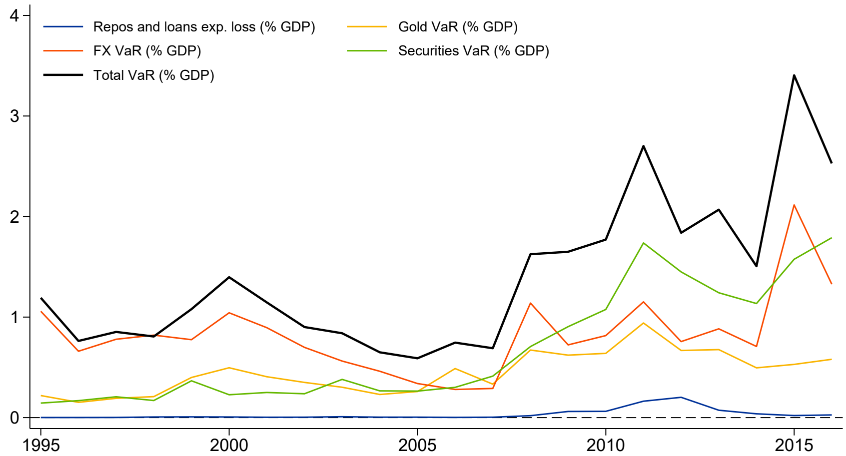
Our analysis reveals a significant increase in financial risk-taking by central banks over time (Figure 2). While the estimated Value-at-Risk (VaR) averaged 1.4% of GDP across our sample period, this figure conceals a pronounced upward trend. Specifically, the average VaR more than tripled from below 1% of GDP in the late 1990s and early 2000s to over 3% by 2015. This trend is largely attributable to a structural shift in the composition of central bank assets. Prior to the Global Financial Crisis (GFC) of 2007–2008, foreign currency reserves and gold were the predominant sources of balance sheet risk. However, in the aftermath of the crisis, large-scale asset purchase programs —-primarily involving domestic currency sovereign bonds —- became the dominant contributors to central bank financial risk.

The degree of risk-taking varies substantially across central banks and has become increasingly divergent. From 1995 to 2009, the cross-sectional standard deviation of VaR rarely exceeded 1%. However, since 2010, it has consistently remained above this threshold, reaching a peak of 5.7% in 2015. This growing divergence largely reflects differences in monetary policy frameworks, with some central banks primarily managing exchange rate stability while

[10]For Switzerland, we use the output gap estimate by the Swiss State Swiss Secretariat for Economic Affairs, as no IMF WEO estimate is available.

Figure 2: Average central bank balance sheet risk

Chart shows the Value at Risk (VaR) of central bank assets by year (in % of GDP).



others pursued balance sheet policies aimed at domestic inflation targeting. Figures 3 to 5 illustrate the annual VaR estimates across countries, grouping central banks according to their predominant risk exposures.

The balance sheets of the central banks of Australia, Switzerland, Denmark, and Sweden have remained dominated by foreign reserve holdings throughout the sample period. In these cases, fluctuations in VaR have primarily been driven by idiosyncratic factors, such as the Swiss Franc devaluation in 2015.

In contrast, financial risk exposure for the Federal Reserve, the Bank of England, and the Bank of Japan exhibits a marked structural break coinciding with the introduction of quantitative easing (QE) programs. For these institutions, risk is primarily driven by the expansion of nominal asset holdings rather than volatility in market valuations. The Bank of Canada represents an exception within this group. Despite holding a balance sheet dominated by domestic currency securities, it did not implement large-scale asset purchases in response to the GFC.[11]

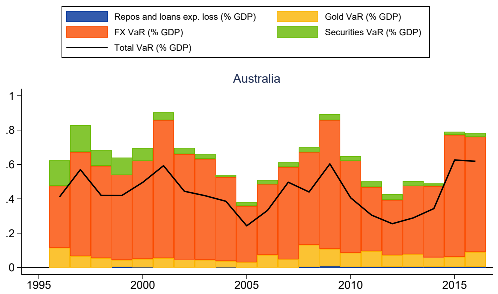
The national central banks of the euro area fall in between these categories, exhibiting moderate increases in financial risk due to domestic bond holdings, which remained limited in scale during our sample period. In these economies, fluctuations in gold and foreign reserve holdings contributed to changes in balance sheet risk. Notably, while the physical quantities of gold reserves in most advanced economies have remained largely stable, their valuation has been subject to market price fluctuations.[12]

[11]The Bank of Canada introduced a QE program ("Government of Canada Bond Purchase Program," GBPP) only in response to the COVID-19 pandemic, which falls outside our sample period.

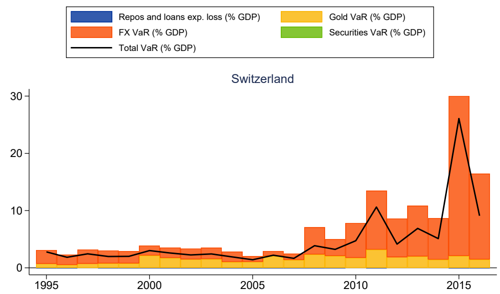
[12]For instance, the Bundesbank's gold reserves (measured in ounces) have remained largely unchanged since

Figure 3: FX-risk taking central banks

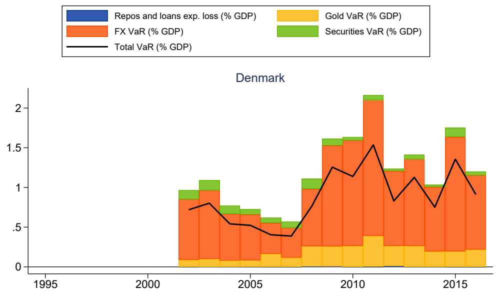
Chart shows the Value at Risk (VaR) of central bank assets by year (in % of GDP). Bars indicate the portfolio-specific VaR, wherewas black line indicates the total VaR taking into account diversification effects.



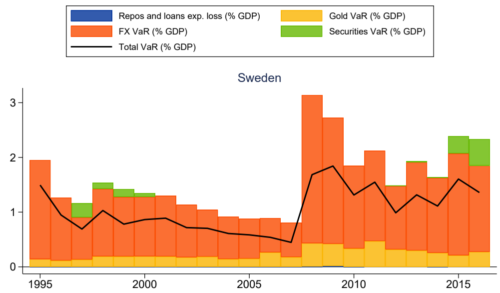
(a) Reserve Bank of Australia



(b) Swiss National Bank



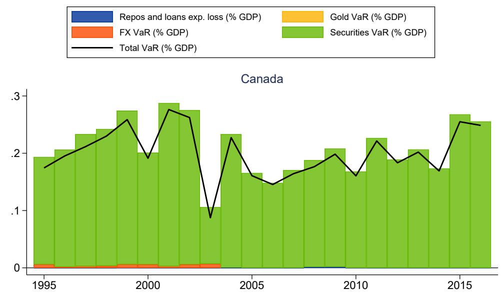
(c) Danish Nationalbank



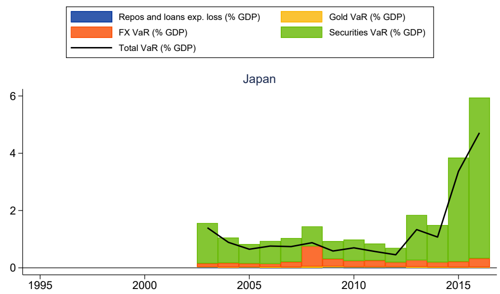
(d) Swedish Riksbank

Figure 4: Domestic-risk taking central banks

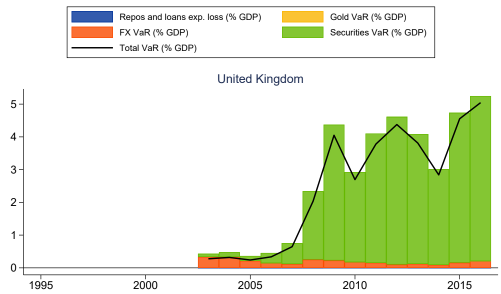
Chart shows the Value at Risk (VaR) of central bank assets by year (in % of GDP). Bars indicate the portfolio-specific VaR, whereas black line indicates the total VaR taking into account diversification effects.



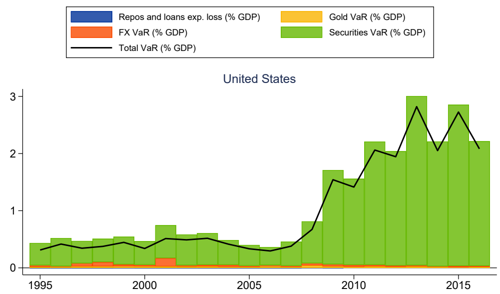
(a) Bank of Canada



(b) Bank of Japan



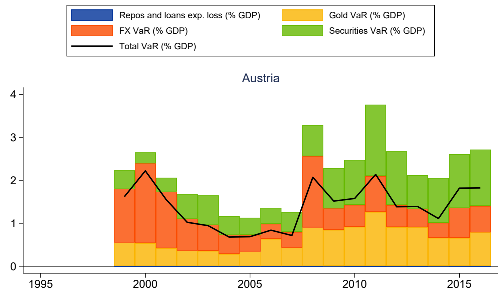
(c) Bank of England



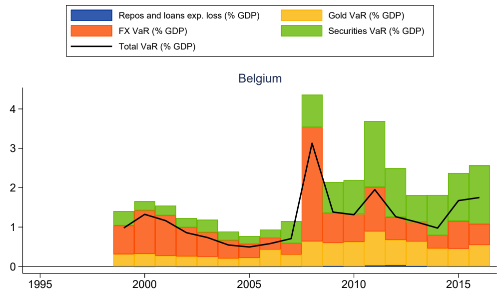
(d) Federal Reserve

Figure 5: Euro area central banks

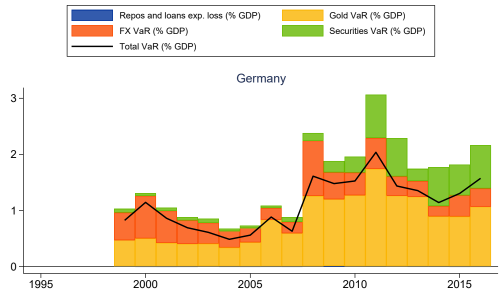
Chart shows the Value at Risk (VaR) of central bank assets by year (in % of GDP). Bars indicate the portfolio-specific VaR, whereas black line indicates the total VaR taking into account diversification effects.



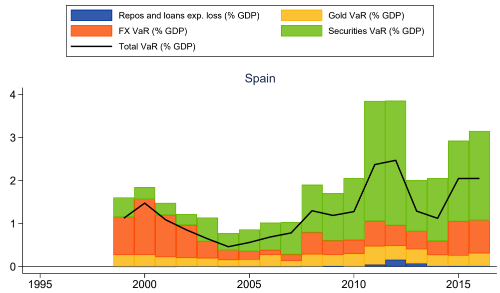
(a) Austrian National Bank



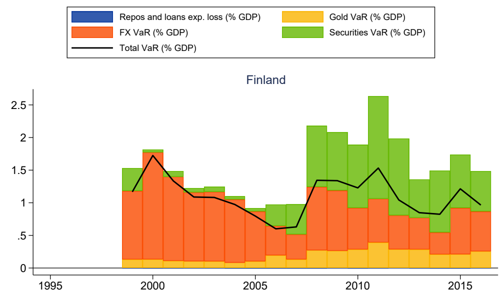
(b) National Bank of Belgium



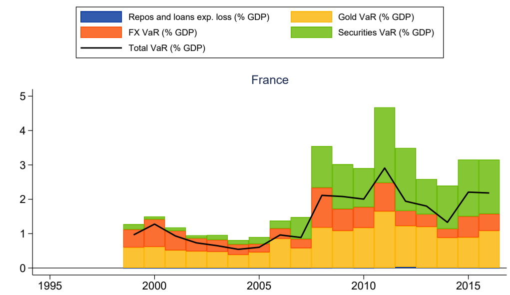
(c) German Bundesbank



(d) Bank of Spain



(e) Bank of Finland



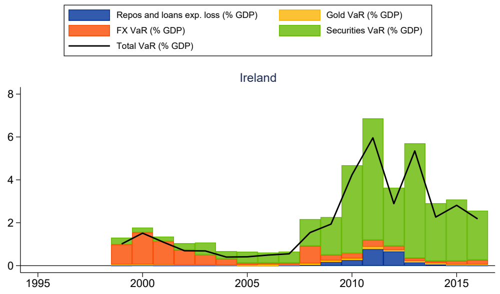
(f) Bank of France

Despite the euro area's reliance on commercial bank refinancing operations, our estimates do not indicate a significant contribution of these lending activities to overall financial risk. An exception is Ireland, whose banking system was perceived as relatively risky following the financial crisis.

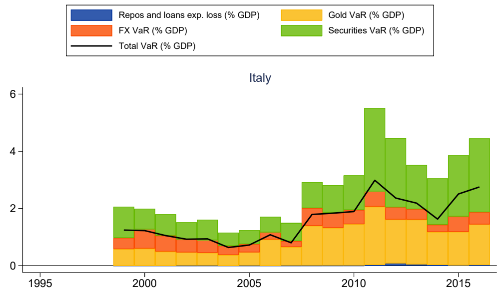
Alongside the rising financial risks in central banks' balance sheets, their ability to absorb losses has significantly improved over time. Loss-absorbing capacity (LAC) refers to the financial

the introduction of the euro in 1999; see Deutsche Bundesbank (2013).

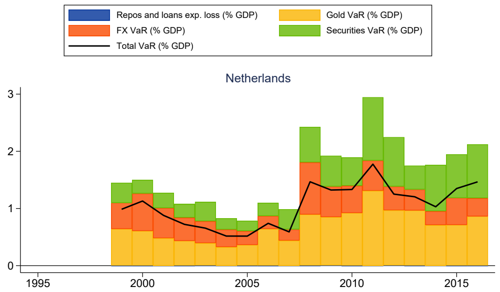
Figure 5: Euro area central banks (continued)



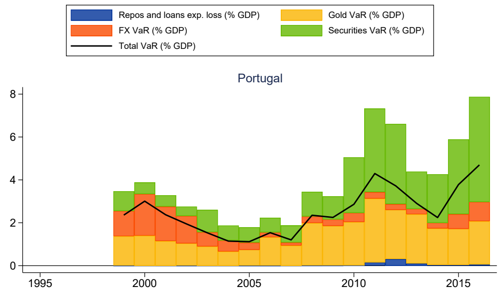
(g) Central Bank of Ireland



(h) Bank of Italy



(i) The Netherlands' Bank



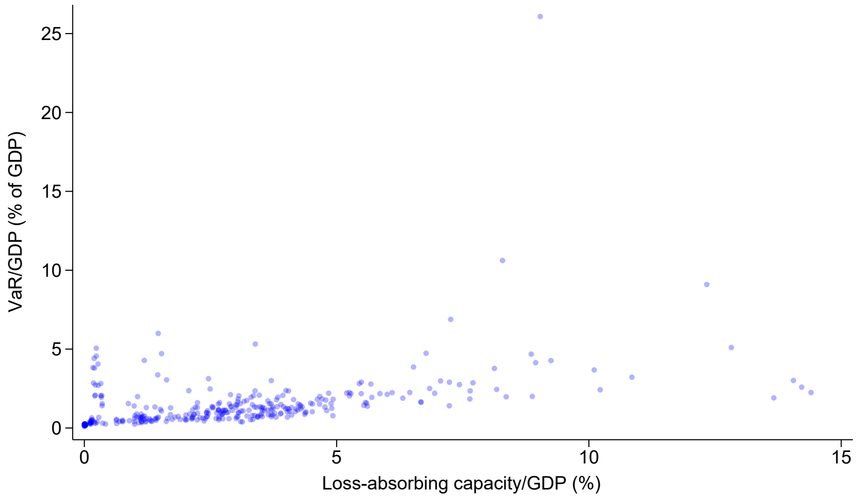
(j) Bank of Portugal

buffers that central banks hold to absorb potential losses arising from balance sheet risks. These buffers typically include equity, reserves, retained earnings, provisions, and revaluation accounts, which help ensure central banks' financial resilience despite fluctuations in asset values or income shortfalls. On average, the LAC of central banks in our sample increased from 2.4% of GDP in 1995 to almost 4.1% in 2016. Reserve currency central banks (Federal Reserve, Bank of England, Bank of Japan, and Bank of Canada) typically hold comparatively few buffers, but their LAC has also increased from 0.1% in 1995 to 0.5% by the end of our sample period. In contrast, central banks with higher foreign currency and gold exposure, such as the Swiss National Bank, Reserve Bank of Australia, the Danish Nationalbank and the Swedish Riksbank, tend to take stronger provisions averaging 4.4% in our sample period, with more notable variation ranging from 3.2% to 5.8% of GDP. The euro area central banks once again fall somewhere in between these groupd, with LAC rising from 2.6% to 5.2% of GDP over the same period, with national variations—e.g., the central banks of Italy and Portugal maintaining the highest LAC at 4.7% and 5.4% of GDP, respectively, while Spain and Ireland and Spain reported at 2.1% to 2.2%.

These differences highlight the evolving balance between financial risk and resilience. Prudent risk management would prescribe an increase in LAC as financial risk increases. Figure 6 confirms that this is generally indeed the case, albeit with some notable variation across

Figure 6: Risk and loss-absorption capacity

Chart shows the Value at Risk (VaR) of central bank assets by year against the prevailing loss-absorbing capacicites (both in % of GDP)).



countries, illustrating the heterogeneity in central bank risk management approaches.

4.3 Multivariate results

In this section we relate the estimated VaR to macroeconomic and institutional variables, using the benchmark specification in eq. (7). Table 2 presents the results for the total VaR in the full sample. Table 3 shows results for the different asset categories, thereby abstracting from cross-asset diversification effects. Table 4 divides the sample into regional and time subsets.

On average, central banks expanding their balance sheets by one percentage point of GDP take on 0.07 to 0.1% more risk (first row of Table 2). The positive sign of the coefficient is a mechanical consequence of balance sheet expansion: all else equal, a larger portfolio will expose the owner to a rise in the amount that can be lost, a reflection of the VaR positive homogeneity property.

When we condition on total assets in order to abstract from this nominal effect, we can draw conclusions about how the composition of the balance sheet affects overall risk. There is a significant relationship between balance sheet risk and conventional interest rate policies. As the level of short-term interest rates falls (rises), central banks take on more (less) risk (second and third row of Table 2). A fall in the policy rate from 5% to 0% more than doubles estimated risk-taking, from 0.8% of GDP to 2% of GDP (see Figure 7 showing the fitted values from the regression for different levels of the policy rate). This may be a reflection of QE programmes and other balance sheet policies becoming a more important when interest rates approach the effective lower bound. This result depends on including a quadratic term of the policy rate,

Table 2: Main results: Determinants of central bank risk-taking

Column (1) includes only the central bank's total assets. Column (2) adds the policy rate and "Taylor rule" variables for projected inflation, the output gap and growth. Column (3) adds a squared term for the policy rate. Column (4) includes as measures of the fiscal stance the fiscal balance and the government's gross debt-to-GDP ratio. Column (5) controls for the external balance by adding the current account and the exchange rate. Column (6) adds the central bank independence index. Column (7) shows the variables identified by the general-to-specific algorithm. All estimations include country and year fixed effects. Standard errors are robust to heterskedasticity and autocorrelation and clustered at the country level.

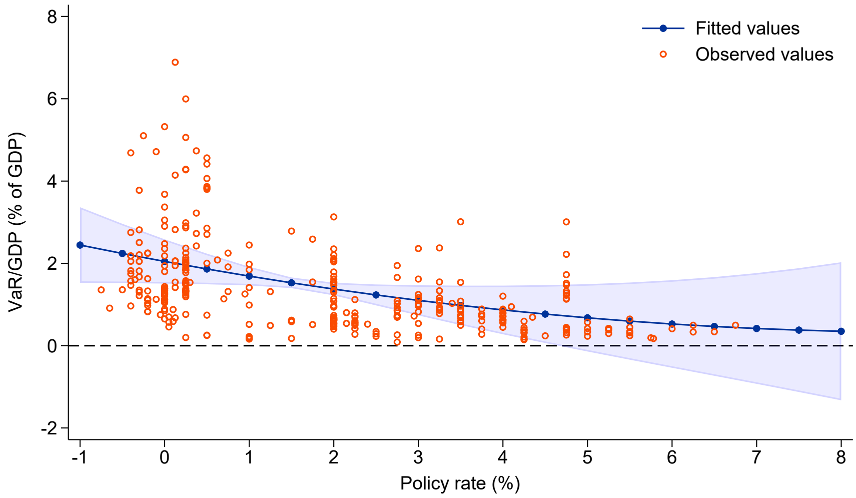
	(1) VaR (% GDP)	(2) VaR (% GDP)	(3) VaR (% GDP)	(4) VaR (% GDP)	(5) VaR (% GDP)	(6) VaR (% GDP)	(7) VaR (% GDP)
Total assets (% GDP)	0.073**	0.083***	0.083***	0.091***	0.092***	0.089***	0.090***
	(0.026)	(0.023)	(0.022)	(0.021)	(0.021)	(0.021)	(0.021)
Policy rate		-0.157	-0.356*	-0.291	-0.341*	-0.377*	-0.361
		(0.123)	(0.187)	(0.175)	(0.182)	(0.190)	(0.208)
Policy rate × Policy rate			0.031	0.018	0.019	0.021	0.020
			(0.021)	(0.020)	(0.020)	(0.020)	(0.022)
Inflation deviation (p.p., forecast t+1)		0.122	0.100	0.119	0.125	0.101	
		(0.188)	(0.173)	(0.136)	(0.129)	(0.119)	
GDP growth (%, forecast t+1)		0.292***	0.308***	0.195**	0.208**	0.208**	0.204**
		(0.085)	(0.091)	(0.075)	(0.074)	(0.077)	(0.074)
Output gap (% Potential GDP)		0.134*	0.141*	0.029	0.030	0.026	
		(0.071)	(0.073)	(0.035)	(0.031)	(0.029)	
Fiscal balance (% GDP)				0.111*	0.107*	0.099*	0.097*
				(0.055)	(0.053)	(0.051)	(0.050)
Gross government debt (% GDP)				-0.012	-0.012	-0.010	-0.013
				(0.014)	(0.014)	(0.014)	(0.014)
Current account (% GDP)					-0.007	-0.013	
					(0.017)	(0.017)	
Δ FX (%, y-o-y)					0.019*	0.021*	0.020
					(0.011)	(0.012)	(0.012)
Central Bank independence index						2.178**	2.176**
						(0.962)	(0.915)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of obs.	332	332	332	332	332	332	332
R-Squared	0.489	0.517	0.520	0.541	0.546	0.549	0.547

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 7: Risk-taking as a function of the level of interest rates

Chart shows the estimated VaR (red dots) and the fitted VaR (blue dots; area represents 95% confidence band) based on column 6 in Table 2, both conditional on the level of the short-term policy rate. Axes are limited to 8%, omitting outliers from the chart above that level for legibility, but including all values in the regression sample.



which suggests that the substitutability between balance sheet policies and policy rates is not linear (see columns 2 and 3) and points again to the potential importance of the zero lower bound for central bank VaR.

The standard inputs of central bank reaction functions–the deviation of inflation from target, the output gap, and GDP growth – are only weakly correlated with risk-taking. The only (positive) significant relation appears to be with projected GDP growth. While this may appear counterintuitive, it could be the consequence of FX-related risk-taking: a better performing economy attracts capital inflows, leading to currency appreciation and hence a fall in the value of the central bank's foreign reserve holdings (see Table 3 and below).

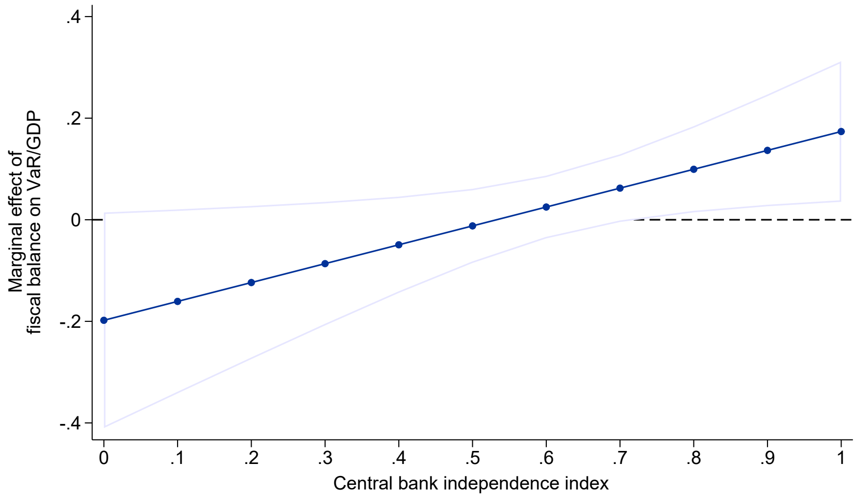
There is a robust relationship between central bank risk-taking and the fiscal policy stance: a contractionary fiscal policy, measured by an improvement in the fiscal balance, is associated with more risk-taking. This is not because monetary policy offsets fiscal policy with an expansion of the central bank balance sheet, since we are controlling separately here for total assets. Conditional on the overall size of the central bank's balance sheet, however, a less expansionary fiscal policy tends to be associated with an increase in the riskiness of the central bank's assets.[13] Conversely, this result suggests that central banks, on average, do not accommodate fiscal expansions by taking on more risks.

Our results also suggest that institutional independence plays a role in balance sheet

[13] In contrast, a country's external position does not appear to be correlated with risk-taking.

Figure 8: Marginal effect of fiscal balance on central bank risk-taking conditional on institutional independence

Chart shows the marginal effect of a one-percentage point increase in the fiscal balance on total VaR, conditional on different levels of the central bank independence index of Romelli (2022). Blue-shaded area represents the 95% confidence band around the estimated effect. Positive values imply that a fiscal contraction (expansion) is associated with less (more) risk on the balance sheet.



policies. In our sample, more independent central banks take on more risk, controlling for the macroeconomic correlates outlined above. A possible explanation for the positive coefficient is that independent central banks are more willing to deploy balance sheet policies in pursuit of their mandate, since concerns about dividend payments to their shareholders do not affect monetary policy-making. An alternative hypothesis that would lead one to expect a negative coefficient is that governments encourage less independent central banks to take on more risk, for instance to support more expansionary fiscal spending (this might be called the "fiscal dominance" hypothesis). Our results are more in line with the first hypothesis. This interpretation is also supported by our finding that central bank risk-taking does not rise in periods of fiscal expansion. We can further test this explanation by interacting the fiscal variables with the independence index. In line with our conjecture, we find that more independent central banks are driving the positive correlation: an improvement in the fiscal balance (a declining fiscal deficit) is significantly associated with an increase in risk-taking only for central banks with an independence index above 0.7 (Figure 8).[14]

Overall, the benchmark results suggest that central banks deploy their balance sheets as complementary instruments to other macroeconomic policies. They take on more risk when

[14]Analogously to this result, we also tested if the correlation of central bank risk-taking with the public debt/GDP ratio is conditional on central bank independence. We did not find a significant effect for any level of the independence index.

Table 3: Risk by asset category

Column (1) shows results for the VaR related to gold holdings, column (2) for FX holdings, and column (3) for domestic securities holdings. Column (4) shows estimates for the expected loss from lending operations. All estimations include country and year fixed effects. Standard errors are robust to heterskedasticity and autocorrelation and clustered at the country level.

	(1) Gold VaR (% GDP)	(2) FX VaR (% GDP)	(3) Securities VaR (% GDP)	(4) Credit Risk (% GDP)
Total assets (% GDP)	0.004**	0.090**	0.025**	0.005*
	(0.002)	(0.041)	(0.010)	(0.003)
Policy rate (%)	-0.097*	-0.091	-0.329***	-0.008
	(0.050)	(0.250)	(0.102)	(0.026)
Policy rate × Policy rate	0.017***	0.020	0.008	-0.001
	(0.004)	(0.033)	(0.012)	(0.002)
Inflation deviation (p.p., forecast t+1)	0.025	0.135	-0.050	0.024
	(0.034)	(0.155)	(0.047)	(0.014)
GDP growth (%, forecast t+1)	-0.046	0.356***	-0.054	-0.030*
	(0.036)	(0.109)	(0.072)	(0.015)
Fiscal balance (% GDP)	0.044***	0.116	0.018	-0.004
	(0.014)	(0.088)	(0.021)	(0.003)
Output gap (% Potential GDP)	0.027*	-0.102*	0.074**	-0.006
	(0.014)	(0.055)	(0.028)	(0.007)
Gross government debt (% GDP)	0.003	-0.054**	0.030***	0.003
	(0.003)	(0.023)	(0.007)	(0.002)
Current account (% GDP)	0.010	-0.017	-0.004	-0.000
	(0.006)	(0.023)	(0.020)	(0.005)
Δ FX (%, y-o-y)	-0.003	0.014	0.008	0.000
	(0.002)	(0.015)	(0.004)	(0.001)
Central Bank independence index	0.454*	4.361*	-1.137	-0.170
	(0.245)	(2.138)	(0.939)	(0.112)
Year FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Number of obs.	332	332	332	332
R-Squared	0.595	0.494	0.739	0.545

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

short-term interest rates – the standard monetary policy tool – approach the effective lower bound and when fiscal policy turns contractionary, potentially heightening other risks. Moreover, more independent central banks are more likely than their less independent counterparties to take on balance sheet risk.

These conclusions are confirmed by a purely data-driven approach. To narrow the full set of variables to a more parsimonious specification, we employ a General-To-Specific (GETS) algorithm of Hoover and Perez (1999) as described by Clarke (2014). The algorithm starts from the baseline specification in equation (7), ranks the estimated coefficients by their estimated t-statistics, and consecutively eliminates the variables with the lowest t-statistics until the reduced specification's F-statistic no longer indicates an improvement over the current specification. Column 7 presents the reduced specification. The algorithm selects the policy rate, fiscal variables, projected GDP growth, the change in the FX rate, and the institutional independence index as the main drivers of central bank risk-taking, controlling for the size of the balance sheet.

Breaking down risk by asset category reveals several results consistent with the conjectures

Table 4: Robustness checks

Column (1) shows results for the central banks of countries predominantly taking on FX risk (Australia, Denmark, Sweden, Switzerland). Column (2) shows results for all other countries. Column (3) restricts the sample to euro area countries (where the coefficient on the policy rate is captured by the year fixed effects), and column (4) to non-euro area countries. Column (5) is estimated over the the pre-2008 period and Column (6) over the post-2008 period. Column (7) excludes the outlier observations in Switzerland in 2015-16 from the sample. Column (8) adds the capital ratio of the domestic banking system (using data by Jordà et al. (2021)). All estimations include country and year fixed effects. Standard errors are robust to heteroskedasticity and autocorrelation and clustered at the country level.

	(1) VaR (% GDP)	(2) VaR (% GDP)	(3) VaR (% GDP)	(4) VaR (% GDP)	(5) VaR (% GDP)	(6) VaR (% GDP)	(7) VaR (% GDP)	(8) VaR (% GDP)
Total assets (% GDP)	0.120***	0.046***	0.040***	0.114***	0.033**	0.087***	0.056***	0.105***
	(0.009)	(0.007)	(0.007)	(0.015)	(0.012)	(0.023)	(0.006)	(0.018)
Policy rate	-0.075	-0.049		-0.346	0.074	-0.876	-0.244*	-0.337*
	(0.473)	(0.198)		(0.262)	(0.080)	(0.925)	(0.134)	(0.172)
Policy rate × Policy rate	-0.018	-0.055*		0.014	-0.007	0.111	0.008	0.009
	(0.027)	(0.029)		(0.021)	(0.011)	(0.156)	(0.014)	(0.014)
Inflation deviation (pp. forecast t+1)	1.143	0.017	-0.021	0.451*	-0.007	0.218	0.011	0.167
	(0.662)	(0.052)	(0.051)	(0.236)	(0.029)	(0.246)	(0.065)	(0.117)
GDP growth (forecast t+1)	-1.052	0.057	0.026	-0.083	0.120***	0.056	0.157**	0.146
	(1.030)	(0.051)	(0.051)	(0.345)	(0.038)	(0.142)	(0.055)	(0.102)
Output gap (% Potential GDP)	-0.191	0.083**	0.075	-0.017	-0.021	0.119	0.046	0.072*
	(0.339)	(0.038)	(0.049)	(0.072)	(0.032)	(0.091)	(0.030)	(0.035)
Fiscal balance (% GDP)	0.124	0.036**	0.036*	-0.020	-0.006	0.145**	0.062**	-0.015
	(0.110)	(0.014)	(0.017)	(0.055)	(0.020)	(0.066)	(0.022)	(0.035)
Gross government debt (% GDP)	-0.016	0.014	0.016	-0.019	-0.005	-0.016	0.007	-0.018
	(0.027)	(0.008)	(0.010)	(0.013)	(0.006)	(0.016)	(0.009)	(0.011)
Current account (% GDP)	0.034	0.014	0.010	-0.006	-0.001	0.041	-0.010	-0.004
	(0.061)	(0.016)	(0.014)	(0.036)	(0.012)	(0.034)	(0.018)	(0.021)
Δ FX (y-o-y)	0.048	0.012**	-0.040***	0.020	0.000	0.017	0.010***	0.022*
	(0.046)	(0.005)	(0.012)	(0.011)	(0.003)	(0.016)	(0.003)	(0.012)
Central bank independence Index	-1.569	-18.509*	-9.817	0.660	-0.396	-28.997*	1.262**	1.673*
	(1.443)	(9.481)	(13.263)	(1.122)	(0.268)	(14.687)	(0.569)	(0.800)
Bank capital ratio (%)								0.002
								(0.067)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of obs.	80	252	180	152	170	162	330	296
R-Squared	0.666	0.822	0.863	0.590	0.662	0.344	0.721	0.561

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

outlined above (Table 3). Consistent with the notion that the positive correlation between GDP growth and VaR may be related to expected capital inflows putting upward pressure on the exchange rate, we find that the correlation is only significantly positive with the VaR of FX reserves (column 2). For the other categories (columns 1, 3 and 4), the correlation is, if anything, negative, consistent with the idea that an economic downturn increases the risk of domestic exposures, such as domestic bond holdings and lending to the commercial banking system. Similarly, the negative correlation between the policy rate and financial risk is most pronounced for domestic securities (column 3), in line with the notion that central banks absorb more risk through QE when the standard interest rate tool approaches the effective lower bound.

Our results point to a negative association between the public debt ratio and foreign reserve risk (column 2) and a positive association between the public debt ratio and domestic security risk (column 3). These results could be explained by the tendency of reserve currency countries to issue larger quantities of public debt in order to satisfy global investors' demand (Gourinchas and Rey, 2007; Farhi and Maggiori, 2018). The "exorbitant privilege" granted to reserve currency countries, specifically their ability to issue debt in domestic currency with little price sensitivity among investors, increases the scope for the government to issue bonds and, consequently, for the central bank to take on risk in its domestic security portfolios.[15] Conversely, central banks in non-reserve currency countries will hold larger foreign reserve portfolios, and their governments more constrained in issuing (domestic currency-denominated) debt.

Results differ not only by asset cateogry but also across countries and periods (Table 4). Column 1 restricts the sample to central banks whose risk predominantly stems from their foreign reserve holdings. Besides overall balance sheet size, risk-taking appears largely uncorrelated with macroeconomic variables, presumably because it is driven predominantly by the exchange rate and thus to a large extent by external factors. Results for the remaining countries (column 2) are more clearly correlated with the determinants in the benchmark specification, as also evident from the better model fit in this sub-group.

Splitting the sample into euro area and non-euro area countries produces largely similar results, although for every unit of total assets, the risk increase is only about a third as large for euro area central banks compared to other central banks.[16]

In contrast, there appears to be a clear break following the financial crisis of 2007/08. First, risk per unit of balance sheet size has more than tripled, likely reflecting the build-up of bond portfolios and their associated market risk. Second, the positive correlation between projected

[15] In principle, the reverse causality is also conceivable: central banks that are willing to take on more risk through domestic securities may incentivise governments to issue more debt. However, the positive - albeit insignificant - coefficient on the fiscal balance speaks against this interpretation.

[16] Note that the variables common to all central banks of the euro area (the policy rate and the exchange rate) are absorbed by the year fixed effects.

GDP growth and risk-taking disappears after 2008, consistent with the notion that the latter is primarily related to FX risk, which became less important after the financial crisis. Third, the fiscal balance and institutional independence emerge as significant correlates mainly in the second part of the sample. Moreover, the conditional marginal effect documented in Figure 8 only appears in the post-2008 sample. This suggests that institutional independence has been particularly important for risk-taking in the more recent period, when central banks engaged in large-scale purchases of sovereign securities.

We also check for whether our results are driven by the Swiss National Bank (SNB), given its outsized estimated risk in 2015/16. Column (7) shows the results for the benchmark specification when excluding Switzerland in 2015/16 . These do not differ materially from the main results. We therefore conclude that the SNB is not a decisive driver of our estimates.

Another potential source of central bank risk-taking relates to the soundness of the domestic financial system. Central banks taking on more risk on their own balance sheet in response to a more vulnerable domestic banking system could be seen as an indication of "financial dominance" (Hellwig, 2014). We test this concern by including the capital ratio of the domestic banking system in our benchmark equation, using data by Jordà et al. (2021). Column (8) shows that there is no significant correlation between banks' capital ratio and the central bank's risk-taking, suggesting that there is no evidence for "financial dominance" in our sample period.[17]

Finally, we analyze the drivers and consequences of central bank leverage, measured by their precautionary loss-absorbing capacities. Table 5 reports the results. In line with greater risk-taking in the proximity of the effective lower bound, LAC declines with expanding balance sheets (column 1). That is, central banks tend to grow their risk buffers less than proportionately during balance sheet expansions. A higher domestic government debt-to-GDP ratio is associated with stronger risk buffers, suggesting that central banks tend to act more cautiously in environments with high public debt. Conversely, more independent central banks tend to operate with fewer risk absorption capacities, a result that aligns with the finding above indicating that more independent central banks are more likely to take on financial risks in pursuit of their monetary policy objectives.

The ratio of LAC over total assets can be interpreted as a measure of central bank leverage (similar to the capital ratio of commercial banks). Greater leverage as expressed in a lower LAC/assets ratio could in principle be related with greater propensity to take on risks. We check this conjecture in column (2), but we do not find any significant evidence of such risk-taking behavior by central banks.

[17] Including banks loan-to-deposit ratio instead of the capital ratio leads to similar results.

Table 5: Loss-absorbing capacities

Column (1) shows the results from regressing loss-absorbing capacities (in % of GDP) on the variables used in the baseline regression. The estimation includes country and year fixed effects. Standard errors are robust to heteroskedasticity and autocorrelation and clustered at the country level.

	(1) LAC (% GDP)	(2) VaR (% GDP)
Total assets (% GDP)	0.008	0.090***
	(0.011)	(0.021)
Policy rate	-0.538*	-0.376*
	(0.258)	(0.192)
Policy rate × Policy rate	0.101**	0.021
	(0.035)	(0.020)
Inflation deviation (pp, forecast t+1)	0.190	0.100
	(0.135)	(0.121)
GDP growth (%, forecast t+1)	-0.184	0.213**
	(0.149)	(0.076)
Output gap (% Potential GDP)	0.047	0.022
	(0.068)	(0.030)
Fiscal balance (% GDP)	0.167***	0.099*
	(0.055)	(0.051)
Gross government debt (% GDP)	0.028***	-0.011
	(0.008)	(0.014)
Current account (% GDP)	0.059	-0.015
	(0.036)	(0.017)
Δ FX (y-o-y)	-0.028**	0.021*
	(0.011)	(0.012)
Central bank independence Index	-6.584***	2.299**
	(1.917)	(0.942)
LAC (% total assets)		0.004
		(0.008)
Year FE	Yes	Yes
Country FE	Yes	Yes
Number of obs.	332	332
R-Squared	0.486	0.549

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5 Conclusion

The growth and changing composition of central bank balance sheets have raised concerns about the financial risks associated with balance sheet policies, leading some to argue that capital losses may undermine the conduct of monetary policy and endanger central bank independence. To date, however, the empirical literature has not systematically assessed the magnitude of those risks and their drivers across countries.

We do so by applying the concept of Value at Risk (VaR) to balance sheets for 18 central banks. We find that VaR increased significantly over the threshold of the Global Financial Crisis, approaching 3 percent of GDP. These changes in the size and composition of central bank balance sheets created the potential for significant capital losses. Some will say that potential losses are small compared to the risk of the crisis-related output losses that balance sheet policies were designed to avert. Others will object that the rewards did not justify the risks.[18]

We find that balance sheet risks vary with economic and financial circumstances and with the structure of central banks themselves. Central banks take more risk in periods of low policy rates, more contractionary fiscal policies, and more favorable growth prospects. More independent central banks are more likely to assume higher levels of risk, plausibly reflecting their greater capacity to pursue monetary policy objectives without fear of political objections and interference. This finding stands in contrast to the view the fiscal dominance that less independent central banks may be pressured into adopting riskier policies by the fiscal authorities. Our results suggest that independent central banks can take on more risk precisely because they are better insulated from political pressure, allowing them to focus on policy effectiveness rather than the fiscal implications of their actions.

This conclusion about the positive association of VaR and central bank independence, evident for the era of quantitative easing, could of course be different in the subsequent era of health emergencies, energy shocks and geopolitical crises, when higher interest rates raise the cost of financing budget deficits. Our focus in this paper is the earlier era of interest rates close to the zero-lower bound and the deployment of quantitative easing as an alternative policy tool. A comparison with the subsequent period would be interesting, but we leave this to future work.

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[18]We do not take a position in this paper on whether or not the policies exposing central banks to these risks were justified.

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Appendix: Data sources and assumptions

Table 6: Federal Reserve (US)

Asset class	Asset	Price	Price source	Weights source
Gold	Gold	Gold price	DLX Haver	Federal Reserve, Factors Affecting Federal Reserve Balances (H.4.1)
Foreign reserves	DE bond	1-3 Year Germany Total Return Index Value USD	Bloomberg	Treasury and Federal Reserve Foreign Exchange Operations: Quarterly Reports
Foreign reserves	FR bond	1-3 Year France Total Return Index Value USD	Bloomberg	Treasury and Federal Reserve Foreign Exchange Operations: Quarterly Reports
Foreign reserves	NL bond	Euro Aggregate Treasury Netherlands Total Return Index USD	Bloomberg	Treasury and Federal Reserve Foreign Exchange Operations: Quarterly Reports
Foreign reserves	JP bond	1-3 Year Japan Statistics Index Value USD	Bloomberg	Treasury and Federal Reserve Foreign Exchange Operations: Quarterly Reports
Foreign reserves	ÉUR cash	EUR/USD FX rate	Bloomberg	Treasury and Federal Reserve Foreign Exchange Operations: Quarterly Reports
Foreign reserves	JPY cash	JPY/USD exchange rate	Bloomberg	Treasury and Federal Reserve Foreign Exchange Operations: Quarterly Reports
Securities	MBS	US MBS Index Total Return Value USD	Bloomberg	Federal Reserve, Factors Affecting Federal Reserve Balances (H.4.1)
Securities	US Treasury 0-1y	US 1-month Government Benchmark bond	Refinitiv	Federal Reserve, Factors Affecting Federal Reserve Balances (H.4.1)
Securities	US Treasury 1-5y	US 5 Years Government Benchmark Bond	Refinitiv	Federal Reserve, Factors Affecting Federal Reserve Balances (H.4.1)
Securities	US Treasury 5-10y	US 10 Years Government Benchmark Bond	Refinitiv	Federal Reserve, Factors Affecting Federal Reserve Balances (H.4.1)
Securities	US Treasury above 10y	US 30 Years Government Benchmark Bond	Refinitiv	Federal Reserve, Factors Affecting Federal Reserve Balances (H.4.1)

Notes:

- Between 1995 and 2001, the asset composition is available only at an annual level. From 2002 onward, the asset composition is available at a weekly level.
- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:
  - American Express; Bank of America; Citigroup; Goldman Sachs; JP Morgan; Morgan Stanley; Lehman Brothers; Merrill Lynch

Table 7: Bank of Japan (JP)

Asset category	Asset	Price	Price source	Weights source
Gold	Gold	Gold price	DLX Haver	Bank of Japan Accounts, Financial Department, Bank of Japan
Foreign reserves	EUR bond	Euro Aggregate Treasury Total Return Index JPY (until 2010), Euro Treasury 3-5 Year Total Return Index JPY (from 2011)	Bloomberg	Principal Terms and Conditions for the Management of Foreign Currency Assets
Foreign reserves	US bond 5-10	US Treasury 5-10 Year Index JPY	Bloomberg	Principal Terms and Conditions for the Management of Foreign Currency Assets
Foreign reserves	UK bond 1-5	UK Gilt 1-5 Year Year Total Return Index JPY	Bloomberg	Principal Terms and Conditions for the Management of Foreign Currency Assets
Foreign reserves	EUR cash	EUR/JPY FX rate	Bloomberg	Principal Terms and Conditions for the Management of Foreign Currency Assets
Foreign reserves	USD cash	USD/JPY FX rate	Bloomberg	Principal Terms and Conditions for the Management of Foreign Currency Assets
Foreign reserves	GBP cash	GBP/JPY FX rate	Bloomberg	Principal Terms and Conditions for the Management of Foreign Currency Assets
Securities	Japanese T-bills	Japan 3 Month Government Benchmark bond	Refinitiv	Bank of Japan Accounts, Financial Department, Bank of Japan
Securities	JGBs up to 2y	Japan 2 Year Government Benchmark bond	Refinitiv	Bank of Japan Accounts, Financial Department, Bank of Japan
Securities	JGBs up to 5y	Japan 5 Year Government Benchmark Bond	Refinitiv	Bank of Japan Accounts, Financial Department, Bank of Japan
Securities	JGBs up to 10y	Japan 10 Year Government Benchmark Bond	Refinitiv	Bank of Japan Accounts, Financial Department, Bank of Japan
Securities	JGBs up to 20y	Japan 20 Year Government Benchmark Bond	Refinitiv	Bank of Japan Accounts, Financial Department, Bank of Japan
Securities	JGBs up to 30y	Japan 30 Year Government Benchmark Bond	Refinitiv	Bank of Japan Accounts, Financial Department, Bank of Japan
Securities	JGBs up to 40y	Japan 40 Year Government Benchmark Bond	Refinitiv	Bank of Japan Accounts, Financial Department, Bank of Japan

Notes:

- The currency and maturity breakdown of the Bank of Japan's foreign reserves holdings is not publicly available. The BoJ's "Principal Terms and Conditions for the Management of Foreign Currency Assets" foresee that foreign reserves are comprised of deposits and holdings of (government) bonds denominated in USD, EUR, and GBP with maturities of up to 5 years. We approximate the composition of the BoJ's foreign reserves therefore by applying the split between deposits and securities as reported in the annual reports and assuming an equal distribution across the three currencies within the two FX assets.
- The Euro Treasury Index in JPY for the 3-5y maturity segment is available only from 2011; prior to that, we employ the Euro Aggregate Treasury Index in JPY.
- The UK Gilt Index in JPY is available only from 2010; prior to that, we split the foreign reserves evenly across EUR and USD.

- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:
  - Bank of Tokyo-Mitsubishi; Sumitomo Mitsui Banking Corp; Resona Bank; Mizuho Corporate Bank; Norinchukin Bank; Nomura

Table 8: Riksbank (SE)

Asset category	Asset	Price	Price source	Weights source
Gold	Gold	Gold price	DLX Haver	Annual Report
Foreign reserves	EUR bonds	Germany 1/5/10y government benchmark bonds (before 2000); Euro Aggregate Sovereign 3-5 Year Total Return Index EUR (from 2000)	Refinitiv (before 2000), Bloomberg (from 2000)	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	USD bonds	US 1/5/10y Government Benchmark Bond	Refinitiv	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	JPY bonds	US 1/5/10y Government Benchmark Bond	Refinitiv	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	GBP bonds	US 1/5/10y Government Benchmark Bond	Refinitiv	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	AUD bonds	US 1/5/10y Government Benchmark Bond	Refinitiv	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	CAD bonds	US 1/5/10y Government Benchmark Bond	Refinitiv	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	EUR cash	EUR-SEK exchange rate (from 1999); DEM/SEK FX rate (until 1998)	Bloomberg	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	USD cash	USD/SEK exchange rate	Bloomberg	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	JPY cash	JPY/SEK exchange rate	Bloomberg	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	GBP cash	GBP/SEK exchange rate	Bloomberg	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	AUD cash	AUD/SEK exchange rate	Bloomberg	Annual Report; International Reserves and Foreign Currency Liquidity
Foreign reserves	CAD cash	CAD/SEK exchange rate	Bloomberg	Annual Report; International Reserves and Foreign Currency Liquidity
Securities	SGB up to 1y	Sweden 3 Month Government Benchmark bond	Refinitiv	Annual Report
Securities	SGB up to 2y	Sweden 2 Year Government Benchmark bond	Refinitiv	Annual Report
Securities	SGB up to 5y	Sweden 5 Year Government Benchmark Bond	Refinitiv	Annual Report
Securities	SGB up to 10y	Sweden 10 Year Government Benchmark Bond	Refinitiv	Annual Report

Notes:

- We only consider foreign reserve holdings denominated in USD, EUR, GBP, CAD, JPY, and AUD, capturing 98-100% of the overall foreign reserves. In individual years, the foreign reserves also contained other currencies, whose size never exceeds 2.5% in our sample period.
- Since the currency composition is only available from 1999 onward, we apply the 1999 split to the period 1995-98. Prior to 1999, we use DEM bond returns for the EUR holdings.
- The detailed maturity composition of the foreign reserves is only available from 2008 onward. Between 2003-07, a composition into deposits and securities is available; we split the securities holdings in that part according to the distribution in 2008. For the period 1995-2003, we assume the maturity composition as in 2003.
- We compute SEK returns for the foreign currency bond holdings by converting the foreign currency-denominated bond prices (return index values) into SEK using the the bilateral exchange rates.
- We assume that the maturity composition of domestic securities holdings in 1997-2000 follows the maturity composition in 2012, the earliest year for which data is available.
- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:
  - Nordea Bank; SEB; Svenska Handelsbanken; Swedbank

Table 9: Bank of England (UK)

Asset category	Asset	Price	Price source	Weights source
Foreign reserves	EUR bond	Euro Aggregate Treasury 1-5y Total Return Index GBP	Bloomberg	Bank of England Database (PQM-BABK), Annual Report 2016
Foreign reserves	JPY bond	Japan 1 Year Government Benchmark bond	Refinitiv	Bank of England Database (PQM-BABL), Annual Report 2016
Foreign reserves	EUR cash	GBP/EUR exchange rate	Bloomberg	Bank of England Database (PQM-BABK), Annual Report 2016
Foreign reserves	JPY cash	GBP/JPY exchange rate	Bloomberg	Bank of England Database (PQM-BABL), Annual Report 2016
Securities	Gilt up to 1y	United Kingdom 1 Year Government Benchmark bond	Refinitiv	Annual Report of the Asset Purchase Facility Fund
Securities	Gilt up to 5y	United Kingdom 5 Year Government Benchmark Bond	Refinitiv	Annual Report of the Asset Purchase Facility Fund
Securities	Gilt up to 10y	United Kingdom 10 Year Government Benchmark Bond	Refinitiv	Annual Report of the Asset Purchase Facility Fund
Securities	Gilt up to 30y	United Kingdom 30 Year Government Benchmark Bond	Refinitiv	Annual Report of the Asset Purchase Facility Fund

Notes:

- Bonds purchased under the Bank of England's (BoE) QE programme were held on the balance sheet of a dedicated vehicle, the "Asset Purchase Facility Fund Limited" (APF), rather than on the BoE's own balance sheet. The APF, in turn, was largely financed by a loan from the Bank of England. We consolidate the balance sheet of the BoE and the APF by replacing the BoE-APF loan with the APF's bond holdings.
- The maturity composition of the BoE/APF bond holdings under the QE programme are only available from 2017 onward. Prior to 2017, we assume the same maturity distribution as of the earliest available observation.
- The granularity of information on the maturity distribution of foreign currency-denominated securities holdings varies considerably over time. The most granular information in our sample period is available in 2016, which distinguishes between maturities of below 1m, 1-3m, 3-12m, 1-5y, and above 5y. We assume that this maturity distribution for the entire sample period. Moreover, we treat foreign reserve holdings with a maturity of below 1m as cash, and maturities above 1y as bonds.
- The currency composition of the BoE's foreign currency asset holdings is dominated by EUR and JPY holdings. We distribute the small share of "other" holdings (less than 3% on average during our sample period) equally to EUR and JPY holdings. We compute GBP returns for the JPY bond holdings by converting the JPY-denominated bond prices into GBP using the the bilateral exchange rate.

- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:
  - Barclays; HSBC; Lloyds; Royal Bank of Scotland; Standard Chartered; National Westminster Bank

Table 10: Bank of Canada (CA)

Asset category	Asset	Price	Price source	Weights source
Foreign reserves	USD cash	USD/CAD exchange rate	Bloomberg	Annual Report
Securities	GCB 1y	Government of Canada 1 Year Benchmark bond	Bloomberg	Annual Report
Securities	GCB 5y	Government of Canada 5 Year Benchmark bond	Bloomberg	Annual Report
Securities	GCB 10y	Government of Canada 10 Year Benchmark bond	Bloomberg	Annual Report

Notes:

- The reported maturity composition of GCB holdings changes from T-bills, bonds with maturity of <3y, 3-5y, 5-10y, and >10y until 2007 to T-bills, bonds with maturity 1-3m, 3-12m, 1-5y, >5y from 2008. In order to create consistent time series, we assign the holdings of <3y maturities to the GCB 5y category and the 3-5y, 5-10y, and >10y maturities to the GCB 10y category before 2008. From 2008 onwards, we combine the holdings of T-bills and the holdings of bonds with maturity 1-3m, 3-12m in the GCB 1y category.
- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:
  - Bank of Nova Scotia; Royal Bank of Canada; Bank Montreal; Toronto-Dominion Bank

Table 11: Reserve Bank of Australia (AU)

Asset category	Asset	Price	Price source	Weights source
Gold	Gold	Gold price	DLX Haver	Annual Report
Foreign reserves	USD cash	USD-AUD exchange rate	Bloomberg	Annual Report
Foreign reserves	EUR cash	EUR-AUD exchange rate	Bloomberg	Annual Report
Foreign reserves	JPY cash	JPY-AUD exchange rate	Bloomberg	Annual Report
Foreign reserves	GBP cash	GBP-AUD exchange rate	Bloomberg	Annual Report
Foreign reserves	CAD cash	CAD-AUD exchange rate	Bloomberg	Annual Report
Foreign reserves	CNY cash	CNY-AUD exchange rate	Bloomberg	Annual Report
Foreign reserves	KRW cash	KRW-AUD exchange rate	Bloomberg	Annual Report
Foreign reserves	USD bonds	US 5y Government Benchmark Bond (until 2007); US Treasury Total Return Index Unhedged AUD (from 2007)	Refinitiv, Bloomberg	Annual Report
Foreign reserves	EUR bonds	DE 5y Government Benchmark bond (until 1998); Euro Aggregate Treasury Germany Total Return Index AUD (from 1999)	Refinitiv, Bloomberg	Annual Report
Foreign reserves	JGB	Japan 5y Government Benchmark Bond (until 2000); Japan Treasury Statistics Index JPY (from 2001)	Refinitiv, Bloomberg	Annual Report
Foreign reserves	GBP bonds	Sterling Gilts Total Return Index AUD	Bloomberg	Annual Report
Foreign reserves	CAD bonds	Canada Aggregate Treasury Total Return Index CAD	Bloomberg	Annual Report
Foreign reserves	CNY bonds	China Treasury Total Return Index CNY	Bloomberg	Annual Report
Foreign reserves	KRW bonds	South Korea Total Return Index USD	Bloomberg	Annual Report
Securities	AU1y	Australia 1 Year Government Benchmark bond	Refinitiv	Annual Report
Securities	AU5y	Australia 5 Year Government Benchmark Bond	Refinitiv	Annual Report
Securities	AU10y	Australia 10 Year Government Benchmark Bond	Refinitiv	Annual Report

Notes:

- We use broad market indices for calculating the returns on foreign currency-denominated bond holdings. For USD, EUR and JPY-denominated bonds in the early part of our sample period, we use the returns on 5y benchmark bonds (converted into AUD) as an approximation. For the return indices which are not available in AUD, we convert the prices into AUD using the bilateral exchange rates.
- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:

– AMP Bank Ltd CDS; Australia and New Zealand Banking Group; Commonwealth Bank of Australia; Macquarie Bank; National Australia Bank; St George Bank

Table 12: Danmarks Nationalbank (DK)

Asset category	Asset	Price	Price source	Weights source
Gold	Gold	Gold price	DLX Haver	Annual Report
Foreign reserves	EUR cash	EUR-DKK exchange rate	Bloomberg	Annual Report
Foreign reserves	USD cash	USD-DKK exchange rate	Bloomberg	Annual Report
Foreign reserves	EUR bonds	Euro Aggregate Treasury Total Return Index DKK	Bloomberg	Annual Report
Foreign reserves	EUR corporate bond ETF	Euro Aggregate Corporates Total Return Index DKK	Bloomberg	Annual Report
Foreign reserves	USD bonds	US 5y Government Benchmark Bond	Refinitiv	Annual Report
Foreign reserves	GBP bonds	UK 5 Year Government Benchmark Bond	Refinitiv	Annual Report
Foreign reserves	JPY bonds	JP 5 Year Government Benchmark Bond	Refinitiv	Annual Report
Foreign reserves	DKK mortgage bond	Nykredit Danish Mortgage Bond Index	Bloomberg	Annual Report
Securities	DK5y	Denmark 5 Year Government Benchmark Bond	Refinitiv	Annual Report

Notes:

- The Annual Report publishes the composition of the foreign reserve assets in EUR, USD, GBP and JPY, as well as an additional "other" category. We distribute the holdings in "Other" equally over the four remaining currencies.
- We only consider foreign reserve assets held as deposits (cash), foreign currency-denominated bonds, ETFs, and repos. We do not account for other miscellaneous foreign-reserve assets (such as margin claims re futures or claims re two-way collateral in swap lines).
- DK swaps its foreign exchange exposure into EUR (and USD until 2010). We account for the post-swap exposure by converting the foreign cash holdings and the prices of foreign reserve security holdings into EUR (and USD until 2010) using the bilateral exchange rates.
- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:
  - Danske Bank

Table 13: Switzerland

Asset category	Asset	(1) Variable type	(3) Source	(4) Weights source
Gold	Gold	Gold price	DLX Haver	Annual Report
Foreign reserves	US Treasuries	US 2/5y Government Benchmark Bond	Refinitiv	SNB foreign currency investments – by currency; Foreign currency investments of the SNB – Investment categories and breakdown of fixed income assets
Foreign reserves	European government bonds	DE 2/5y Government Benchmark Bond (until 2000), EUR 3-5Y AAA index (from 2001)	Refinitiv, Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	Gilts	UK 1/5y Government Benchmark Bond	Refinitiv	SNB foreign currency investments – by currency/investment categories
Foreign reserves	JGBs	Japan 2/5y Government Benchmark Bond	Refinitiv	SNB foreign currency investments – by currency/investment categories
Foreign reserves	CGBs	Government of Canada 2/5y Benchmark Bond	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	USD covered bonds	iBoxxx $ Covered Bond index	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	EUR covered bonds	iBoxxx EUR Germany Covered Bond index	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	GBP covered bonds	iBoxxx EUR UK Covered Bond index	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	Canada covered bonds	iBoxxx $ Canada Covered Bond index	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	US equities	S&P 500 (SPX Index)	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	European equities	Euro Stoxx (SXXE Index)	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	UK equities	FTSE (UKX Index)	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	Japanese equities	Nikkei (NKY Index)	Bloomberg	SNB foreign currency investments – by currency/investment categories
Foreign reserves	Canadian equities	S&P/TSX (SPTSX Index)	Bloomberg	SNB foreign currency investments – by currency/investment categories

Notes:

- We model explicitly the foreign reserve assets denominated in USD, EUR, JPY, GBP, and CAD. Holdings of foreign assets denominated in other currencies account on average for 3% of the total foreign reserves during our sample period. We distribute the holdings of these other currencies equally over the five remaining currencies. The earliest observation for the currency composition is 1997; we assume the same distribution in 1995-1996.
- The foreign currency holdings are predominantly invested in government bonds, other bonds (such as covered bonds), and equity. In our sample period, these categories account on average for 92% of the total foreign currency reserves. We distribute the holdings of other foreign reserve assets equally over these three categories. The earliest observation for the asset class composition is 2010; we assume the same distribution in 1995-2009.

- Since we do not have a breakdown of asset classes per currency, we assume the same asset composition in each foreign currency.
- For European covered bonds, we use an index of German covered bonds to capture a consistent index over a large part of our sample. We do not observe a sufficient sample of covered bond returns for Japan; we therefore re-distribute the weight on JP covered bond holdings to government bonds and equities.
- The average duration of foreign security investments is 4 years during our sample period. Since we do not observe a more granular breakdown into maturity classes, we approximate the maturity of the foreign reserve assets with indices with similar duration or a weighted average of 2y and 5y benchmark bonds.
- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:
  - Credit Suisse AG; UBS AG

Table 14: Eurosystem Central Banks

Asset category	Asset	(1) Variable type	(3) Source	(4) Weights source
Gold	Gold	Gold price	DLX Haver	Annual Report
Foreign reserves	USD cash	USD-EUR exchange rate	Bloomberg	Annual Report, ECB Annual Account
Foreign reserves	JPY cash	JPY-EUR exchange rate	Bloomberg	Annual Report, ECB Annual Account
Securities	Covered bonds (CBPP1-3)	iBoxx EUR Covered Bond indices for France, Germany, Spain, Italy, Netherlands, Finland, and Austria	Bloomberg	Annual Report; ECB, "Breakdown of CBPP3 portfolio by rating and country of risk (semi-annual)"
Securities	Public sector bonds (SMP, PSPP)	1-10y; 15y government benchmark bonds	Refinitiv	Annual Report; ECB, "PSPP weighted average maturity"; capital key (rescaled); ECB, "SMP breakdown history"
Securities	Corporate sector bonds (CSPP)	iBoxx non-financial corporate bond market index for FR, DE, IT, ES, NL, BE	Bloomberg	Annual Report; ECB, "CSPP breakdown by sector, rating, country"

Notes:

- We apply the assumptions above to each of the 10 euro area central banks in our sample.
- Foreign reserves: We assume that the currency composition of national central banks' securities holdings follows the composition of the ECB's foreign reserves as published in the ECB's annual accounts. We apply the average share of USD and JPY holdings reported in the annual accounts during our sample period.
- Securities:
  - Covered bond purchase programmes (CBPP) 1-3: For the country composition under the CBPP1, 2 and 3, we employ the average shares of CBPP3 holdings by "country of risk" over 2019-21 for France, Germany, Spain, Italy, Netherlands, Finland, and Austria, which together account for 95% of the origin of covered bond holdings. We redistribute the remaining 5% proportionally over these countries. Source for country distribution: https://www.ecb.europa.eu/mopo/pdf/CBPP3_breakdown_by_rating_country.xlsx
  - Securities Markets Programme (SMP): We employ the year-end distribution of holdings by jurisdiction. For the holdings from each country, we compute the weighted average return using the average remaining maturity of the year-end holdings. Source for country distribution and remaining maturity: https://www.ecb.europa.eu/mopo/pdf/SMP_breakdown_history.csv
  - Public Sector Purchase Programme (PSPP):
    - Government bonds: We employ the year-end weighted average maturity of public sector bonds per jurisdiction (Source: https://www.ecb.europa.eu/mopo/pdf/PSPP_weighted_average_maturity.xlsx). For the national central banks' direct holdings of public sector bonds, we consider only bonds issued by the domestic government, in line with the implementation practice under the PSPP. For the ECB's holdings, we assume that the holdings follow the capital key distribution, rescaled to the 10 euro area countries in our sample; ECB holdings are then redistributed to the 10 NCBs, given that they own the ECB's capital.

    * Supranational bonds: We approximate the return of the supranational bonds with the return of a synthetic bond weighted by the rescaled capital key of the five largest euro area countries (DE, FR, IT, ES, NL). The NCBs' individual holdings of supranational bonds are redistributed to all NCBs according to the rescaled capital key, in line with the income sharing arrangement for these type of bonds.
  - Corporate Sector Purchase Programme (CSPP):
    * We assign country weights according to https://www.ecb.europa.eu/mopo/pdf/CSPP_breakdown_by_sector_rating_country.xlsx. We allocate the NCBs' individual holdings of corporate bonds to all euro area central banks in our sample, in line with the income sharing arrangement for these types of bonds.
  - Other securities holdings: For other securities holdings, which include, for instance, the NCBs' own investment portfolios, we assume that they are invested in the domestic government 10-year benchmark bond.

- We use the following banks' CDS quotes to compute the average risk-neutral market-implied default probability:
  - Austria: UniCredit Bank Austria AG
  - Belgium: BNP Paribas Fortis; Belfius Banque; KBC Bank
  - Finland: Nordea Bank; Nordic Investment Bank
  - France: BNP Paribas; BPCE; Banque Federative du Credit Mutuel; Caisse Federale du Credit Mutuel; Credit Agricole; Credit Lyonnais; Dexia credit local; HSBC France; NATIXIS; Societe Generale
  - Germany: Bayerische Landesbank; Commerzbank; DZ Bank; Deutsche Bank; Deutsche Postbank; HSH Nordbank; Landesbank Baden-Wuerttemberg; Landesbank Hessen-Thueringen; Norddeutsche Landesbank; UniCredit Bank
  - Greece: Alpha Bank; Bank of Greece; EFG Eurobank Ergasias; Piraeus Bank
  - Ireland: Allied Irish Banks; Bank of Ireland; DEPFA Bank
  - Italy: Banca IMI; Banca Monte dei Paschi di Siena; Banco Popolare; Banco BPM; Intesa Sanpaolo; UniCredit
  - Netherlands: ABN Amro Bank; Cooperatieve Rabobank; ING Bank
  - Portugal: Banco Comercial Portugues; Novo Banco; Banco BPI
  - Spain: Banco Bilbao Vizcaya Argentaria; Banco Popular Espanol; Banco Santander; Banco de Sabadell; Bankia; CaixaBank

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