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Jens H. E. Christensen
Federal Reserve Bank of San Francisco

Nikola Mirkov
ITAM

Xin Zhang
Sveriges Riksbank

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Quantitative Easing and Safe Asset Scarcity: Evidence from International Bond Safety Premia

Jens H. E. Christensen[†]

Nikola Mirkov[‡]

Xin Zhang[*]

Abstract

Through large-scale asset purchases, widely known as quantitative easing (QE), central banks around the world have reduced the available supply of safe assets. We examine the effects of the European Central Bank's asset purchases in the 2015-2021 period on an international panel of bond safety premia from four highly rated countries: Denmark, Germany, Sweden, and Switzerland. We find statistically significant negative effects for all four countries. This points to a novel and important international spillover channel of QE programs to bond safety premia that operates via changes in the perceived *relative* scarcity of safe assets across international bond markets.

JEL Classification: E43, E47, G12, G13

Keywords: term structure modeling, convenience yields, unconventional monetary policy, European Central Bank

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[†]Corresponding author: Federal Reserve Bank of San Francisco, 101 Market Street MS 1130, San Francisco, CA 94105, USA; phone: 1-415-974-3115; e-mail: jens.christensen@sf.frb.org.

[‡]Visiting researcher, ITAM; e-mail: nikola.mirkov@gmail.com.

[*]Sveriges Riksbank; e-mail: xin.zhang@riksbank.se.

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1 Introduction

When a central bank operates a large-scale asset purchase program, a policy commonly referred to as quantitative easing (QE), it effectively reduces the supply of safe assets available to the public.[1,2] In addition to the effects on domestic interest rates widely documented in the literature,[3] we argue that such purchases may have additional effects—domestically and internationally—by changing investors' perceptions about the relative scarcity of safe assets across international bond markets.[4]

To offer empirical evidence of this novel QE transmission mechanism, we exploit the fact that highly safe assets can trade at a so-called convenience or safety premium, i.e. at prices (yields) higher (lower) than otherwise, see Christensen and Mirkov (2022, henceforth CM) among many others.[5] We then explore whether the reduction in the supply of safe assets resulting from the operation of QE programs has any impact on such safety premia. Specifically, we examine the effects of the public sector purchase program (PSPP) operated by the European Central Bank (ECB) on an international panel of bond safety premia estimated for four highly rated countries: Denmark, Germany, Sweden, and Switzerland.

We selected these four countries for two notable reasons. First and foremost, all four countries are closely related to the euro area, but to varying degrees. Germany is one of the core members in the euro area. Denmark is not part of the euro area but maintains a long-established peg of the Danish krone to the euro. Although Sweden and Switzerland are both outside the euro area with floating exchange rates, they both have strong economic ties with the euro area through trade and their financial systems. Second and of practical relevance, all four countries have well-developed government bond markets, which provide the requisite high-quality bond price information needed for the estimation of our yield curve models. Furthermore, as the ECB's QE policy was designed and operated to affect economic conditions in the euro area, including in Germany, our study hence provides both a domestic and a cross-border perspective on the effects of QE on bond safety premia.

To estimate the safety premia in each bond market, we use an arbitrage-free dynamic term structure model augmented with a bond-specific risk factor. The identification of the bond-specific risk factor comes from its unique loading for each individual bond, as in Andreasen, Christensen, and Riddell (2021, henceforth ACR). Our analysis uses prices of individual bonds

[1] By law, most central banks are not allowed to buy and hold risky debt as part of their normal operations. For example, the U.S. Federal Reserve may only acquire U.S. Treasury securities or government-sponsored mortgage-backed securities outside of emergency contingencies.

[2] The central bank pays for the assets with reserves, which are overnight claims that only banks can hold.

[3] For U.S. evidence, see Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011), and Christensen and Rudebusch (2012), among many others. Similar evidence for U.K. and euro area interest rates can be found in Joyce et al. (2011) and Altavilla et al. (2021), respectively, among many others.

[4] The cross-border impact of QE asset purchases on foreign bond markets have received much less attention in the literature. One example is Christensen et al. (2023), who examine the effect of U.S. and U.K. QE announcements on Canadian government bond yields.

[5] See also Longstaff (2004) and Krishnamurthy and Vissing-Jorgensen (2012).

rather than the more usual input of yields from fitted synthetic curves. The underlying mechanism assumes that, over time, an increasing proportion of the outstanding inventory is locked up in portfolios of buy-and-hold investors. Given forward-looking investor behavior, this lock-up effect means that a particular bond's sensitivity to the market-wide bond-specific risk factor will vary depending on how seasoned the bond is and how close to maturity it is. In a careful study of nominal Treasuries, Fontaine and Garcia (2012) also find a pervasive bond-specific factor that affects all bond prices with loadings that vary with the maturity and age of each bond. By observing a cross section of bond prices over time—each with a different time since issuance and time to maturity—we can identify the overall bond-specific risk factor and each bond's loading on that factor.

While CM already used this approach to estimate safety premia for the Danish and Swiss government bond markets, we provide updated results for these two markets. More importantly, to the best of our knowledge, we are the first to provide estimates of such safety premia for the German and Swedish government bond markets. Furthermore, even though our four samples have different start dates determined by data availability or other practical considerations, they all run through the end of 2021. Hence, our analysis includes the recent COVID-19 pandemic period, during which numerous central banks, including the ECB, acquired significant volumes of safe assets.[6]

In all four markets, we find large and time-varying bond-specific premia. Given that these markets are significantly less liquid than U.S. Treasury markets, maybe with the exception of the German bund market, we follow CM and refer to these convenience premia as safety premia. The estimated average safety premium is 0.15 percent, 0.62 percent, 0.54 percent, and 0.66 percent in the Danish, German, Swedish, and Swiss markets, respectively. Hence, in light of the very low interest rate levels prevailing in all four countries at the time of the ECB's QE operations, the safety premium represents a non-negligible part of the yield earned by bond investors during this period.

To study the relationship between changes in our estimated safety premium series and the ECB's asset purchases, we rely on panel regressions with a range of relevant control variables to account for factors that matter for the safety premia independent of the operation of the QE program. We find that the ECB's asset holdings measured as a percentage of nominal GDP in the euro area has a statistically and economically significant negative impact on the safety premia in all four countries. In other words, the higher the asset purchases, the lower the safety premia, and therefore, the lower the prices and the higher the yields of those safe assets.

We explain these findings by introducing a novel QE transmission channel built on investors' perceptions about the relative scarcity of safe assets in and across the safest govern-

[6]For example, the U.S. Federal Reserve increased its asset holdings by about 4.5 trillion dollars between December 2019 and December 2021; see https://www.federalreserve.gov/releases/h41/default.htm.

ment bond markets in the euro area and its neighboring countries.[7,8] The ECB's cumulative asset purchases likely reduced the relative scarcity of Danish, Swedish, and Swiss bonds by increasing the absolute scarcity of the purchased bonds.[9] For Germany, the sign of the effect is unclear ex ante though, because it would depend on the *perceived* change in the available amount of German bonds relative to the *perceived* changes in the available amount of safe bonds in other major government bond markets in the euro area and neighboring countries.

In terms of magnitudes, we find that asset purchases by the ECB equivalent to 1 percent of nominal GDP in the euro area tends to lower the safety premia by about 0.35 basis points. Given that the ECB has increased its bond holdings by as much as 40 percent of GDP between early 2015 and the end of 2021, our results imply that this is likely to have reduced safety premia on net by 0.12 percent, a considerable number given the very low interest rate levels prevailing during this period. Next, we run time series regressions for each of the four countries' safety premia individually. The results confirm that the ECB QE programs reduced the safety premium in all four countries. Interestingly, the impact of the ECB QE asset purchases on the safety premia varies notably across countries, with estimates ranging from -0.29 basis points for Switzerland to -1.77 basis points for Sweden.

The remainder of the paper is structured as follows. Section 2 offers a brief summary of the related literature, while Section 3 contains the description of our international panel of government bond prices. Section 4 details the no-arbitrage term structure model we use and summarizes our estimation results. Section 5 describes the calculation of the safety premia and examines their determinants. Finally, Section 6 concludes the paper.

2 Related Literature and Other QE Channels

The analysis in this paper relates to several important strands of literature. Most directly, it speaks to the voluminous literature on the financial market effects of central bank large-scale asset purchases. Second, our results relate to research on financial market convenience and safety premia. Finally, the paper contributes to the rapidly growing literature about the economic consequences of the COVID-19 pandemic.

In the following, we briefly relate our analysis to the other main transmission channels emphasized in the literature about the financial effects of QE.

[7] Caballero et al. (2017) and references therein focus on the demand and supply of safe assets relative to other assets, while our study is about the relative pricing power across different safe assets as measured through the lens of our estimated safety premium series.

[8] The existence of the safety premia we examine may ultimately be rooted in the aggregate demand for safe assets to meet money-like convenience services; see Krishnamurthy and Vissing-Jorgensen (2012, 2015), Greenwood and Vayanos (2010), and Greenwood et al. (2015), among many others.

[9] The ECB asset purchases should arguably be the dominating factor underlying any major changes in the relative scarcity of bonds across the European markets during the 2015-2021 period. The only exception to this general statement is Sweden, where the Riksbank operated its own QE programs during much of this period. Therefore, in our analysis, we make sure to carefully control for the Swedish safe asset purchases flowing from these programs.

One key channel through which QE transmits to interest rates is known as the signaling channel emphasized by Christensen and Rudebusch (2012) and Bauer and Rudebusch (2014), whereby bond yields can decline because the introduction of a QE program is interpreted by investors as a signal that interest rates will be low for longer than already anticipated. Since this channel operates mainly through the expectations component of bond yields, it is unlikely to affect the safety premia we consider in this paper.

Another important transmission mechanism is the supply- and reserve-induced portfolio balance channel discussed at length in Christensen and Krogstrup (2019, 2022). This channel works by forcing investors to substitute their investments away from the safe assets purchased by the central bank and into riskier assets with either longer duration or greater credit and liquidity risks. Hence, the effects from this channel materialize through a lowering of the general term premium component of bond yields and therefore also falls outside of our analysis. A similar argument applies to the local supply effects stressed by D'Amico and King (2013). These effects materialize as flow effects at the time of the central bank purchases and also mainly affect the term premium component of bond yields.

Finally, the liquidity effects flowing from QE asset purchases highlighted by Christensen and Gillan (2022) are limited to the classes of assets targeted by the QE program and operate through a lowering of the liquidity premium component of bond yields caused by a tilt in the bargaining power away from buyers and towards sellers. Clearly, bonds in Denmark, Sweden, and Switzerland were not targeted by the ECB's QE purchases. Hence, by definition, they cannot have been affected through this liquidity channel and, even for the German bonds, they are already trading at a convenience premium. This suggests that the bargaining power in this market is already favorable to sellers, although some marginal effect through this channel cannot be ruled out.[10]

Beyond the frequently cited channels listed above, there are other potential mechanisms for QE to work. For example, Hattori et al. (2016) stress that central bank asset purchases have the potential to provide insurance against macroeconomic tail risks by limiting the downside risk to asset prices. However, these effects are economy-wide in nature and would impact all asset classes instantaneously upon announcement thanks to the forward-looking behavior of investors and hence should matter little for our safety premia. Also, it may affect the perception and pricing of risk, leading to a so-called "risk-taking channel," as discussed in Borio and Zhu (2012), which also would not apply to the safe assets considered in our bond safety premium series.

[10]Effects from the liquidity channel on German bond prices would boost the German safety premia and go against the negative effects we document. Hence, our estimated effects for Germany are likely to be lower bound estimates of the true effect.

3 The International Government Bond Data

A limited number of developed countries are so highly rated that their government debt can command a safety premium; among them are Denmark, Germany, Sweden, and Switzerland.[11] In this section, we describe the data from each of these four government bond markets that we use in our empirical analysis.

To estimate the factors in our yield curve model, we use the prices of standard fixed-coupon government bonds. These are all marketable, non-callable bonds denominated in the local currency that pay a fixed rate of interest annually. With the exception of the Swiss data, which have been kindly provided by staff at the Swiss National Bank, the remaining data has been downloaded from Bloomberg. Hence, the start date for the sample for each country is determined by the data availability from these two sources.

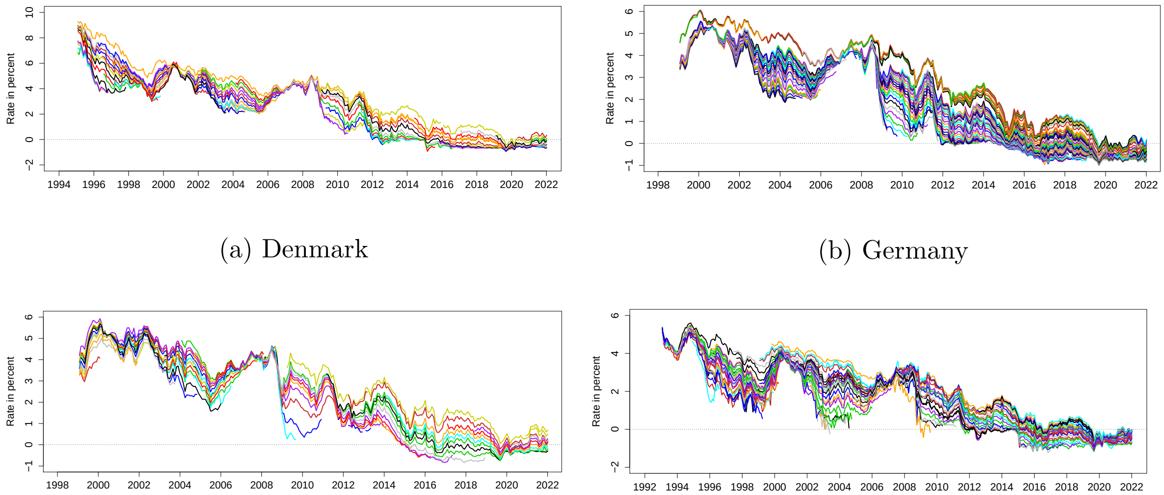
Figure 1a shows the yields to maturity series for all Danish government bonds in our sample, which runs from January 1995 through the end of December 2021. This represents an update of the Danish government bond price sample analyzed in CM. Figure 1b illustrates the yields to maturity for all German government bonds in our sample, which covers the period from January 1999 through the end of December 2021. Figure 1c shows the yields to maturity series for all Swedish government bonds in our sample from January 1999 to December 2021. We note that the start dates for these two markets were chosen to align with the launch of the euro in January 1999. In comparison to the other three markets, the Swiss government bond market is small, even relative to the Swiss economy. As of January 7, 2021, the total amount of outstanding Swiss government bonds was CHF67 billion, or less than 10 percent of Swiss nominal GDP in 2020. Thus, these bonds are among the safest in the world. Our Swiss government bond price data are collected daily by staff at the Swiss National Bank and are available back to the 1980s. However, we follow CM and start the data sample in January 1993, when the data appear to be systematically reliable across all available bonds.[12] Figure 1d shows the Swiss government bond prices converted into yield to maturity.

In general, yield levels in all four countries have trended lower the past 20-25 years and fell below zero by the end of our sample. Furthermore, business cycle variation in the shape of the yield curves is pronounced around the lower trends in all four markets. Note that these yield curves tend to flatten ahead of recessions and steepen during the initial phase of economic recoveries.

Regarding the important question of a lower bound on interest rates, the ECB kept its conventional policy rate well below zero for an extended period. Thanks to the high credit quality of the bonds we examine, their yields were frequently even lower. As a consequence, in most cases, short- and medium-term bond yields in our samples were significantly below

[11] During our period of analysis, all four countries held a triple-A rating with a stable outlook from all major rating agencies.

[12] Our sample represents an update of the Swiss bond data used by Christensen at al. (2022) and CM.



(a) Denmark

(b) Germany

(c) Sweden

(d) Switzerland

Figure 1: **Yield to Maturity of Government Bonds**
Illustration of Danish, German, Swedish, and Swiss government bond yields to maturity. The Danish sample starts in January 1995. The German and Swedish samples start in January 1999, while the Swiss sample starts in January 1993. All samples end in December 2021.

zero with no visible lower constraint. Thus, it is not clear that one would need to impose a lower bound to model these data. Empirically, it is challenging to determine whether an unconstrained Gaussian model approach is more appropriate than a model approach enforcing a lower bound in such cases; see Andreasen and Meldrum (2019) for a detailed discussion. Here, we choose to focus on models with Gaussian dynamics, which can easily handle negative interest rates.

4 Model Estimation and Results

In this section, we first detail the augmented arbitrage-free Nelson-Siegel model, referred to as the AFNS-R model, that serves as the benchmark in our analysis before we describe the restrictions imposed to achieve econometric identification of the model. We then report the estimation results for all four countries and compare the model fit.

4.1 The AFNS-R Model

To begin, let $X_t = (L_t, S_t, C_t, X_t^R)$ denote the state vector of the four-factor AFNS-R model also used by CM. Here, L_t denotes a level factor, while S_t and C_t represent slope and curvature factors. Finally, X_t^R is the added market-wide bond-specific risk factor.

The instantaneous risk-free rate is defined as

$$r_t = L_t + S_t. \tag{1}$$

The risk-neutral $\mathbb{Q}$-dynamics of the state variables used for pricing are given by

$$\begin{pmatrix} dL_t \\ dS_t \\ dC_t \\ dX_t^R \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & \lambda & -\lambda & 0 \\ 0 & 0 & \lambda & 0 \\ 0 & 0 & 0 & \kappa_R^{\mathbb{Q}} \end{pmatrix} \left[\begin{pmatrix} 0 \\ 0 \\ 0 \\ \theta_R^{\mathbb{Q}} \end{pmatrix} - \begin{pmatrix} L_t \\ S_t \\ C_t \\ X_t^R \end{pmatrix} \right] dt + \Sigma \begin{pmatrix} dW_t^{L,\mathbb{Q}} \\ dW_t^{S,\mathbb{Q}} \\ dW_t^{C,\mathbb{Q}} \\ dW_t^{R,\mathbb{Q}} \end{pmatrix},$$

where Σ is a lower-triangular matrix.

Based on the $\mathbb{Q}$-dynamics above, zero-coupon bond yields preserve a Nelson and Siegel (1987) factor loading structure

$$y_t(\tau) = L_t + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) S_t + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right) C_t - \frac{A(\tau)}{\tau}, \tag{2}$$

where $\frac{A(\tau)}{\tau}$ is a convexity term that adjusts the functional form in Nelson and Siegel (1987) to ensure absence of arbitrage (see Christensen et al. (2011)).

Importantly, due to bond-specific premia in our four government bond markets, individual bond prices are sensitive to the variation in the bond-specific risk factor X_t^R. As a consequence, the pricing of the bonds in each market is not performed with the standard discount function above, but rather with a discount function that accounts for the bond-specific risk:

$$\overline{r}_t^i = r_t + \beta^i (1 - e^{-\lambda^{R,i}(t - t_0^i)}) X_t^R, \tag{3}$$

where t_0^i denotes the date of issuance of the specific security and β^i is its sensitivity to the variation in the marketwide bond-specific risk factor. Furthermore, the decay parameter $\lambda^{R,i}$ is assumed to vary across securities as well.

As shown in Christensen and Rudebusch (2019), the net present value of one unit of currency paid by bond i at time $t + \tau$ has the following exponential-affine form

$$\begin{aligned} P_t^i(t_0^i, \tau) &= E^{\mathbb{Q}} \left[e^{-\int_t^{t+\tau} \overline{r}^i(s, t_0^i) ds} \right] \\ &= \exp\Big(B_1^i(\tau) L_t + B_2^i(\tau) S_t + B_3^i(\tau) C_t + B_4^i(t_0^i, t, \tau) X_t^R + A^i(t_0^i, t, \tau) \Big). \end{aligned}$$

This implies that the model belongs to the class of Gaussian affine term structure models. Note also that, by fixing $\beta^i = 0$ for all i, we recover the AFNS model.

Now, consider the whole value of the bond issued at time t_0^i with maturity at $t + \tau$ that pays a coupon C annually. Its price is given by[13]

$$P_t^i(t_0^i, \tau) = C(t_1 - t) E^{\mathbb{Q}} \left[e^{-\int_t^{t_1} \overline{r}^i(s, t_0^i) ds} \right] + \sum_{j=2}^{N} C E^{\mathbb{Q}} \left[e^{-\int_t^{t_j} \overline{r}^i(s, t_0^i) ds} \right] + E^{\mathbb{Q}} \left[e^{-\int_t^{t+\tau} \overline{r}^i(s, t_0^i) ds} \right]. \tag{4}$$

[13] This is the clean price that does not account for any accrued interest and that maps to our observed bond prices.

So far, the description of the AFNS-R model has relied solely on the dynamics of the state variables under the $\mathbb{Q}$-measure used for pricing. However, to complete the description of the model and to implement it empirically, we will need to specify the risk premia that connect these factor dynamics under the $\mathbb{Q}$-measure to the dynamics under the real-world (or physical) $\mathbb{P}$-measure. It is important to note that there are no restrictions on the dynamic drift components under the empirical $\mathbb{P}$-measure beyond the requirement of constant volatility. To facilitate empirical implementation, we use the essentially affine risk premium specification introduced in Duffee (2002). In the Gaussian framework, this specification implies that the risk premia Γ_t depend on the state variables; that is,

$$\Gamma_t = \gamma^0 + \gamma^1 X_t,$$

where $\gamma^0 \in \mathbf{R}^4$ and $\gamma^1 \in \mathbf{R}^{4\times 4}$ contain unrestricted parameters.

Thus, the resulting unrestricted four-factor AFNS-R model has $\mathbb{P}$-dynamics given by

$$\begin{pmatrix} dL_t \\ dS_t \\ dC_t \\ dX_t^R \end{pmatrix} = \begin{pmatrix} \kappa_{11}^{\mathbb{P}} & \kappa_{12}^{\mathbb{P}} & \kappa_{13}^{\mathbb{P}} & \kappa_{14}^{\mathbb{P}} \\ \kappa_{21}^{\mathbb{P}} & \kappa_{22}^{\mathbb{P}} & \kappa_{23}^{\mathbb{P}} & \kappa_{24}^{\mathbb{P}} \\ \kappa_{31}^{\mathbb{P}} & \kappa_{32}^{\mathbb{P}} & \kappa_{33}^{\mathbb{P}} & \kappa_{34}^{\mathbb{P}} \\ \kappa_{41}^{\mathbb{P}} & \kappa_{42}^{\mathbb{P}} & \kappa_{43}^{\mathbb{P}} & \kappa_{44}^{\mathbb{P}} \end{pmatrix} \left(\begin{pmatrix} \theta_1^{\mathbb{P}} \\ \theta_2^{\mathbb{P}} \\ \theta_3^{\mathbb{P}} \\ \theta_4^{\mathbb{P}} \end{pmatrix} - \begin{pmatrix} L_t \\ S_t \\ C_t \\ X_t^R \end{pmatrix} \right) dt + \Sigma \begin{pmatrix} dW_t^{L,\mathbb{P}} \\ dW_t^{S,\mathbb{P}} \\ dW_t^{C,\mathbb{P}} \\ dW_t^{R,\mathbb{P}} \end{pmatrix}.$$

This is the transition equation in the extended Kalman filter estimation of the AFNS-R model.

4.2 Model Estimation and Econometric Identification

Due to the nonlinear relationship between state variables and bond prices in equation (4), the model cannot be estimated with the standard Kalman filter. Instead, we use the extended Kalman filter as in Kim and Singleton (2012); see Christensen and Rudebusch (2019) for details. Furthermore, to make the fitted errors comparable across bonds of various maturities, we scale each bond price by its duration. Thus, the measurement equation for the bond prices takes the following form

$$\frac{P_t^i(t_0^i, \tau^i)}{D_t^i(t_0^i, \tau^i)} = \frac{\widehat{P}_t^i(t_0^i, \tau^i)}{D_t^i(t_0^i, \tau^i)} + \varepsilon_t^i.$$

Here, $\widehat{P}_t^i(t_0^i, \tau^i)$ is the model-implied price of bond i, $D_t^i(t_0^i, \tau^i)$ is its duration, which is calculated before estimation, and ε_t^i represents independent and Gaussian distributed measurement errors with mean zero and a common standard deviation σ_ε. See Andreasen et al. (2019) for evidence supporting this formulation of the measurement equation.

Furthermore, since the market-wide bond-specific risk factor is a latent factor that we do not observe, its level is not identified without additional restrictions. For the Danish market, we let the first 30-year bond issued on April 6, 1994, and maturing on November 10, 2024, with 7 percent coupon have a unit loading on this factor, that is, $\beta^i = 1$ for this bond. For the German market, we use the first 30-year bond issued on July 4, 1997, and maturing on July 4, 2027, with 6.5 percent coupon and let it have a unit loading on the bond-specific risk factor. For the Swedish market, we let the 12-year government bond issued on July 22, 1991, with maturity on May 5, 2003, and a coupon rate of 10.25 percent have a unit loading. Finally, for the Swiss market, we follow CM and let the first 30-year, 4 percent coupon Swiss Confederation bond, which was issued on April 8, 1998, and matures on April 8, 2028, have a unit loading on this factor. These choices imply that the β^i sensitivity parameters measure sensitivity to the bond-specific risk factor relative to that of the benchmark bond in each market.

Finally, we note that the $\lambda^{R,i}$ parameters can be hard to identify if their values are too large or too small. As a consequence, we impose the restriction that they fall within the range from 0.0001 to 10, which is without practical consequences. Also, for numerical stability during model optimization, we impose the restriction that the β^i parameters fall within the range from 0 to 250.

4.3 Estimation Results

In this section, we briefly summarize the estimation results of the AFNS-R model applied to the four government bond markets in our sample. In the interest of simplicity, we limit the focus to a version of the AFNS-R model where $K^{\mathbb{P}}$ and Σ are diagonal matrices. As shown in ACR, these restrictions have hardly any effects on the estimated bond-specific premia, because they are identified from the model's $\mathbb{Q}$-dynamics, which are independent of $K^{\mathbb{P}}$ and only display a weak link to Σ through the small convexity adjustment in yields.

Table 1 reports the estimated dynamic parameters. We do see differences across markets, which should be expected given that both the sample period and cross-sectional coverage vary from country to country. This affects the estimated persistence of the state variables as well as their estimated volatilities. It also impacts the value of λ, in particular given that this parameter determines the rate of decay in the yield factor loading of the slope factor in the model; a high value of λ implies a rapid decay of the slope factor loading and suggests that the estimated model puts more emphasis on fitting the short end of the yield curve.

Table 2 reports the summary statistics for the fit to all bonds in the sample from the four model estimations broken down into maturity buckets. Also reported are the number of fitted errors observed in each maturity bucket in each market. In general, we note the very strong fit of the AFNS-R model to the entire yield curve in each of the four government bond markets. This demonstrates that the model is able to produce a very accurate fit in all four markets.

Parameter	Denmark		Germany		Sweden		Switzerland	
	Est.	SE	Est.	SE	Est.	SE	Est.	SE
$\kappa_{11}^{\mathbb{P}}$	0.0028	0.0169	0.0258	0.0951	0.0295	0.0665	0.0066	0.0296
$\kappa_{22}^{\mathbb{P}}$	0.0032	0.0281	0.5112	0.2389	0.2288	0.2215	0.1700	0.1230
$\kappa_{33}^{\mathbb{P}}$	0.0130	0.0739	0.2213	0.1600	0.1582	0.1742	0.5393	0.2627
$\kappa_{44}^{\mathbb{P}}$	0.0863	0.1368	0.3854	0.2388	0.4118	0.2581	0.0067	0.0333
σ_{11}	0.0059	0.0002	0.0075	0.0003	0.0063	0.0002	0.0034	0.0001
σ_{22}	0.0122	0.0009	0.0172	0.0019	0.0131	0.0009	0.0085	0.0005
σ_{33}	0.0158	0.0010	0.0193	0.0011	0.0198	0.0010	0.0200	0.0014
σ_{44}	0.0058	0.0006	0.0133	0.0015	0.0051	0.0006	0.0099	0.0008
$\theta_{1}^{\mathbb{P}}$	0.1150	0.0298	0.0834	0.0246	0.0524	0.0308	0.0426	0.0162
$\theta_{2}^{\mathbb{P}}$	0.1122	0.0509	-0.0525	0.0187	-0.0111	0.0229	-0.0247	0.0108
$\theta_{3}^{\mathbb{P}}$	-0.0959	0.3655	-0.0309	0.0286	-0.0429	0.0341	0.0114	0.0111
$\theta_{4}^{\mathbb{P}}$	0.0131	0.0227	0.0052	0.0177	-0.0025	0.0042	0.1080	0.2710
λ	0.3111	0.0060	0.1774	0.0023	0.5884	0.0078	0.1838	0.0029
$\kappa_{R}^{\mathbb{Q}}$	1.8698	0.0902	0.8879	0.0289	1.5066	0.0617	2.5191	0.1110
$\theta_{R}^{\mathbb{Q}}$	-0.0021	0.0002	-0.0080	0.0006	-0.0021	0.0002	-0.0059	0.0004
σ_{ε}	0.0004	3.1×10^{-7}	0.0003	1.7×10^{-7}	0.0003	4.5×10^{-7}	0.0007	2.3×10^{-7}

Table 1: **Estimated Dynamic Parameters**

The table shows the estimated dynamic parameters for the international panel of AFNS-R models, each estimated with a diagonal specification of $K^{\mathbb{P}}$ and Σ.

Maturity bucket	Denmark			Germany			Sweden			Switzerland		
	Obs.	Mean	RMSE	Obs.	Mean	RMSE	Obs.	Mean	RMSE	Obs.	Mean	RMSE
0-2	771	0.43	8.77	937	-4.32	8.51	467	-0.96	6.49	848	0.06	9.34
2-4	688	0.57	5.46	1,200	1.09	3.88	506	1.03	5.29	984	0.36	5.89
4-6	512	0.33	6.29	1,305	3.06	5.09	472	-0.99	4.47	1000	-0.80	5.46
6-8	415	0.30	4.91	1,369	3.50	6.02	435	-0.41	3.07	906	0.41	4.49
8-10	372	0.61	5.63	1,385	3.85	6.23	415	-0.89	3.99	838	0.44	4.09
10-12	243	-0.58	5.50	193	1.98	4.66	241	0.24	4.12	650	0.40	3.79
12-14	24	3.38	5.39	146	-0.17	1.90	72	0.76	1.91	393	0.36	3.59
14-16	24	0.61	5.66	178	1.50	3.18	64	-0.08	2.46	252	0.83	4.86
16-18	26	0.96	2.05	174	2.46	4.23	45	0.32	2.98	222	0.71	4.70
18-20	48	0.10	1.14	210	4.56	7.41	46	-0.05	2.41	239	0.92	5.28
20-22	48	0.01	0.71	234	4.84	7.21	28	0.02	1.83	141	0.78	4.95
22-24	47	0.29	1.14	258	4.87	6.69	26	2.33	3.06	151	-1.43	4.33
24-26	48	0.46	1.69	281	6.57	8.53	35	0.15	2.69	131	-0.66	5.87
26-28	48	0.12	2.74	305	7.22	9.43	25	0.31	3.85	133	-2.73	6.52
28-30	46	3.00	10.21	301	6.71	8.86	24	0.13	5.48	111	-2.88	5.65
30<	33	0.19	3.79	207	5.31	7.78	2	n.a.	n.a.	443	0.30	5.65
All bonds	3,393	0.42	6.35	8,683	2.64	6.36	2,903	-0.26	4.59	7,442	0.08	5.64

Table 2: **Summary Statistics of Fitted Errors for Government Bond Yields**

This table reports the number of observations (Obs.), the mean pricing errors (Mean) and the root mean-squared pricing errors (RMSE) of government bond prices for the international panel of AFNS-R models, each estimated with a diagonal specification of $K^{\mathbb{P}}$ and Σ. The pricing errors are reported in basis points and computed as the difference between the implied yield on the coupon bond and the model-implied yield on this bond. Each data sample is monthly and described in Section 3.

5 The Government Bond Safety Premium

In this section, we analyze the government bond safety premia implied by the estimated AFNS-R models described in the previous section. First, we formally define the bond safety premia and study their historical evolution in each market. We then use regression analysis to examine their determinants and whether the ECB safe-asset purchases have affected them.

5.1 The Estimated Bond Safety Premium

We now use the estimated AFNS-R models to extract the safety premium in each government bond market. To compute this premium, we first use the estimated parameters and the filtered states $\{X_{t|t}\}_{t=1}^{T}$ to calculate the fitted bond prices $\left\{\hat{P}_t^i\right\}_{t=1}^{T}$ for all outstanding securities in a given market. These bond prices are then converted into yields to maturity $\left\{\hat{y}_t^{c,i}\right\}_{t=1}^{T}$ by solving the fixed-point problem

$$\begin{aligned}\hat{P}_t^i \quad &= \quad C(t_1 - t)\exp\left\{-(t_1 - t)\hat{y}_t^{c,i}\right\} + \sum_{k=2}^{n} C\exp\left\{-(t_k - t)\hat{y}_t^{c,i}\right\} \\ &\quad + \exp\left\{-(T - t)\hat{y}_t^{c,i}\right\},\end{aligned} \tag{5}$$

for $i = 1, 2, ..., n_t$, meaning that $\left\{\hat{y}_t^{c,i}\right\}_{t=1}^{T}$ is approximately the rate of return on the ith bond if held until maturity (see Sack and Elsasser 2004). To obtain the corresponding yields with correction for the safety premium, a new set of model-implied bond prices are computed from the estimated AFNS-R model but using only its frictionless part, i.e. with the constraints that $X_{t|t}^{R} = 0$ for all t, $\theta_R^{\mathbb{Q}} = 0$, and $\sigma_{44} = 0$. These prices are denoted $\left\{\tilde{P}_t^i\right\}_{t=1}^{T}$ and converted into yields to maturity $\tilde{y}_t^{c,i}$ by solving equation (5) in the same way as above. They represent estimates of the prices that would prevail in a world without any financial frictions or convenience premia. The safety premium for the ith bond is then defined as

$$\Psi_t^i \equiv \tilde{y}_t^{c,i} - \hat{y}_t^{c,i}, \tag{6}$$

where $\tilde{y}_t$ is the frictionless yield and $\hat{y}_t$ the fitted (observed) yield.

For each market we calculate the average of the estimated premia for each observation date, denoted $\overline{\Psi}_t^j$ for country j. These monthly averages of estimated safety premia for our four bond markets are shown in Figure 2.

As for magnitudes, Switzerland has the highest safety premium among our four series with an average of 0.66 percent, closely followed by Germany and Sweden with average safety premia of 0.62 percent and 0.54 percent, respectively, while Denmark has lower safety premia, which average 0.15 percent. This ranking seems reasonable given that Switzerland has a long history of being considered a safe haven country in times of crisis, while Germany has the most liquid government bond market in the euro area.

One notable difference between the German, Swedish, and Swiss safety premia on one hand and the Danish safety premia on the other is observed during the financial crisis, when key crisis events like the onset of the crisis itself in the summer of 2007 and the bankruptcy of

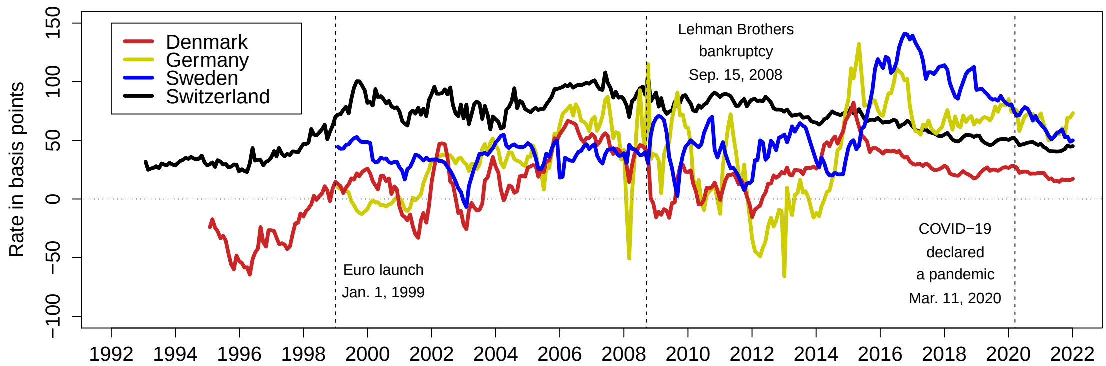


Figure 2: **Average Estimated Government Bond Safety Premia**
Illustration of the average estimated bond safety premium for each observation date implied by the AFNS-R model estimated with a diagonal specification of $K^{\mathbb{P}}$ and Σ using Danish, German, Swedish, and Swiss government bond prices. The German data is described in this paper and cover the period from January 31, 1999, to December 31, 2021. The Swedish data cover the same period, while the Danish and Swiss data follow the analysis of CM and start on January 31, 1995, and January 29, 1993, respectively. In all cases, the bond safety premia are measured as the estimated yield difference between the frictionless yield to maturity of individual bonds with the market risk factor turned off and the corresponding fitted yield to maturity.

Lehman Brothers in September 2008 coincided with spikes in the former safety premia, while they tend to be associated with declines in the Danish safety premium. We speculate that Denmark's peg to the euro was viewed by global investors as less of a safe haven during this period.

In the late 1990s, both Danish and Swiss safety premia increased notably. CM associate these increases with the launch of the euro on January 1, 1999.

Moreover, the German and Swedish safety premium series exhibit a unique behavior in the 2015-2017 period, which coincided with the asset purchase programs operated by the ECB and the Riksbank at the time; see Christensen and Zhang (2023) for details and analysis of the latter.

Lastly, the onset of the COVID-19 pandemic in spring 2020 left at most a short-lived mark on the safety premia in these four government bond markets.

5.2 Regression Analysis

We measure the average treatment effect of the ECB's QE asset purchases on the safety premia within a regression framework. In particular, we stack the four $\overline{\Psi}_t^j$ safety premium series into a single vector $\overline{\Psi}_t$ and run the following regression:

$$\bar{\Psi}_t = \alpha + \delta_{pspp} d_t^{pspp} + \delta_c D_t + \sum_{l=0}^{L} \delta_l X_{t-l} + \varepsilon_t, \quad (7)$$

where d_t^{pspp} is the stock of bonds acquired by the ECB through the PSPP, expressed as a percentage of nominal GDP in the euro area;[14] D_t and X_t are vectors of control dummies and continuous control variables, respectively; L is the number of lags included; and ε_t is a random residual. The estimate of δ_{pspp} measures the effect on the safety premia of a 1 percentage point change in the stock of bonds held by the ECB under the assumption that the confounding variables in the vector X_t are exogenous and that $E[\varepsilon_t|X_t] = 0$.

We control for a host of confounding factors. Specifically, we consider the CBOE Volatility Index (VIX), the TED spread, the 10-year on-the-run premium in U.S. Treasuries, and the spread between the Italian and each country's 10-year government bond yield to proxy for investors' risk aversion, financial market uncertainty, and related demand for safe-haven assets;[15] we use each country's debt-to-GDP ratio to control for effects tied to the supply of government bonds;[16] and the overnight interest rate in each country serves as a proxy for the opportunity cost of holding money and the associated liquidity premia of government bonds, as explained in Nagel (2016). For each country, we include the average government bond age and the one-month realized volatility of the 10-year government bond yield as additional proxies for bond liquidity following the work of Houweling et al. (2005). Inspired by the analysis of Hu et al. (2013), we include a noise measure of the government bond prices in each country to control for variation in the amount of arbitrage capital available in each market. We add the overnight federal funds rate to proxy for the U.S. safe-asset liquidity premium as in Nagel (2016), and we consider the MOVE volatility index to proxy for risk aversion in global bond markets. In addition, we include the domestic QE program in the case of Sweden because the Swedish QE program is highly correlated with the ECB purchases. Omitting the Swedish QE variable could lead to contaminated estimates for the ECB QE effect. Finally, we add a few dummy variables in D_t, including a dummy variable to control for the introduction of the euro in January 1999, a dummy variable to indicate whether the country under investigation is in a negative interest rate environment, and a dummy variable that takes the value of one in the period of minimum exchange rate control by the Swiss National Bank from September 2011 to January 2015 and zero otherwise.

Table 3 reports the results in which column (1) contains the outcomes without any controls,

[14]In principle, this measure should only include the truly safe assets acquired by the ECB and should exclude bonds issued by high-risk countries in the periphery of the euro area. However, in the absence of that granular data, we use the entire stock of purchased government-backed securities as a proxy for the amount of absorbed safe assets. Provided the ratio of truly safe assets in the ECB's portfolio is close to being constant, which is a reasonable assumption given the fixed distribution key for the purchases, there should be little bias in the estimated parameter. Please see Appendix B for detailed information on the ECB QE programs.

[15]See Grisse and Nitschka (2015).

[16]See Krishnamurthy and Vissing-Jorgensen (2012).

	1	2	3	4
α	87.150***	51.064***	61.555***	53.602***
	(3.053)	(12.136)	(11.583)	(9.682)
δ_{pspp}	-0.371***	-0.316***	-0.362***	-0.388***
	(0.045)	(0.048)	(0.054)	(0.038)
controls	No	Yes	Yes(Δ)	Yes(6 lags)
Country FE	YES	YES	YES	YES
No of obs	328	328	328	304
Adj. R^2	0.801	0.881	0.848	0.955

Table 3: **Average Treatment Effects of ECB Asset Purchases**
The table reports the coefficient estimates from regression (7) together with their respective robust standard errors. The first column reports the regression without controls, the second column reports the estimates with the core set of control variables, the third column contains the results including controls in first differences, and the last column contains controls with L set to six lags. The last three rows report the use of country fixed effects, the number of observations, and the adjusted R^2. The underlying safety premium sample starts in January 1995 for Denmark, in January 1999 for both Germany and Sweden, and in January 1993 for Switzerland. In all four cases, the samples end in December 2021. Note that we only run the regression for the period since January 2015 after the ECB had launched its first QE program.

while columns (2)-(4) report the regressions conducted by using the control variables in levels, the control variables in first differences, and the control variables with six lags, respectively. We note that the coefficient on the ECB QE purchase variable is negative and statically significantly so in all four regressions, in particular in the most conservative specification (4) with six lags included. Moreover, the sizes of the estimated coefficients are all similar and not statistically different from each other. Specifically, we find that an increase in the ECB QE bond purchases equal to 1 percentage point of nominal GDP in the euro area will lead to an average decline in the safety premium across the four countries between 0.32 basis point and 0.39 basis point, where the largest estimate for the safety premium decline comes from the most conservative regression with lagged control variables, reported in column (4). Importantly, the significance of these results are robust and hold up when we cluster the standard errors at the country level as documented in Appendix A. Finally, we stress that the sample used in these regressions starts in January 2015 after the ECB had launched its first actual QE program on January 22, 2015.

We further analyze the data using separate country-level regressions with Newey-West standard errors. These results are reported in Table 4. The findings are qualitatively similar to the panel regression results, but we can see that the effects of the ECB QE program vary across the countries in our sample. The Swiss safety premium is reduced by approximately 0.3 basis point for ECB QE purchases of additional bonds equivalent to 1 percent of euro area GDP, which is the smallest effect across the four countries in the sample. The largest impact on the safety premium is found in Sweden. In particular, Swedish bond safety premia are materially

	1	2	3	4	5	6	7	8
α	29.983***	30.476	53.908*	30.476	-54.109*	9.474	88.509***	2.898
	(10.779)	(22.125)	(31.403)	(22.125)	(31.052)	(34.089)	(9.139)	(30.754)
δ_{pspp}	-0.373***	-0.320***	-0.697***	-0.320***	-1.528***	-1.766***	-0.290***	-0.323***
	(0.064)	(0.062)	(0.233)	(0.062)	(0.383)	(0.211)	(0.028)	(0.057)
δ_{se}					5.379***	3.328***		
					(1.266)	(0.712)		
controls	Standard	6 lags	Standard	6 lags	Standard	6 lags	Standard	6 lags
Country	DEN	DEN	GER	GER	SWE	SWE	SWI	SWI
No of obs	82	76	82	76	82	76	82	76
Adj. R^2	0.886	0.936	0.540	0.936	0.847	0.968	0.929	0.926

Table 4: **Country-level Treatment Effects of ECB QE**
The table reports the coefficient estimates from regression (7) but run for each country separately. We use Newey-West standard errors with four monthly lags. The number of lags L in regressions (4) is set to six. The underlying safety premium sample starts in January 1995 for Denmark, in January 1999 for both Germany and Sweden, and in January 1993 for Switzerland. In all four cases, the samples end in December 2021. Note that we only run the regression for the period since January 2015 after the ECB had launched its first QE program.

affected by the ECB asset purchase program, as columns (5) and (6) in Table 4 suggest. An increase in the ECB bond purchases equal to 1 percent of euro area GDP will reduce the safety premium by between 1.53 basis points and 1.77 basis points. Interestingly, the domestic QE purchases by the Riksbank have the opposite effect with significant positive effects. Note that these positive coefficients are loadings on the Swedish QE purchases measured as a percentage of Swedish nominal GDP. Hence, they are not directly comparable to the results for the ECB QE purchases other than in terms of their interpretation. Importantly, all these results are economically significant. Hence, the country-specific results confirm that the ECB asset purchase program had important influences on the safety premium dynamics in Denmark, Germany, Sweden, and Switzerland.

5.2.1 Full Sample Results

For robustness we rerun the regressions using all available data from each country. In addition, we expand the measure of the ECB asset purchases to cover the period before their launch by simply inserting 0s for the earlier period.

First, we focus on the average estimated treatment effect using our full panel of data. These results are reported in Table 5. We note that the estimated average treatment effects are smaller when we use the full sample of data available for each country. Importantly, though, they remain negative and highly statistically significant for the empirically relevant cases where we include control variables. Furthermore, the adjusted R^2s all decline notably. This points to some instability over time in the empirical relationships between our dependent variables on one side and the control variables on the other. This makes us prefer the results from the 2015-2021 subsample that speaks most directly to the effects of the asset purchases

	1	2	3	4
α	45.144***	35.502***	30.329***	61.339***
	(0.846)	(6.191)	(4.544)	(8.045)
δ_{pspp}	0.245***	-0.135***	-0.137***	-0.118***
	(0.023)	(0.038)	(0.037)	(0.039)
controls	NO	YES	YES(Δ)	YES(6 lags)
Country FE	YES	YES	YES	YES
No of obs	1224	1224	1220	1200
Adj. R^2	0.409	0.608	0.576	0.611

Table 5: **Average Treatment Effects of ECB Asset Purchases: Full Sample**
The table reports the coefficient estimates from regression (7) together with their respective robust standard errors. The first column reports the regression without controls, the second column reports the estimates with the core set of control variables, the third column contains the results including controls in first differences, and the last column contains controls with L set to six lags. The last three rows report the use of country fixed effects, the number of observations, and the adjusted R^2. The safety premium sample starts in January 1995 for Denmark, in January 1999 for both Germany and Sweden, and in January 1993 for Switzerland. In all four cases, the samples end in December 2021.

	1	2	3	4	5	6	7	8
α	-24.687*	-6.618	-61.924***	-6.618	38.719**	44.230*	22.954***	21.784**
	(12.974)	(14.723)	(23.067)	(14.723)	(16.824)	(24.510)	(8.497)	(10.421)
δ_{pspp}	-0.422***	-0.426***	-0.438***	-0.426***	-1.914***	-1.737***	-0.540***	-0.509***
	(0.073)	(0.090)	(0.149)	(0.090)	(0.338)	(0.387)	(0.036)	(0.043)
δ_{se}					6.480***	5.984***		
					(1.088)	(1.291)		
controls	Standard	6 lags	Standard	6 lags	Standard	6 lags	Standard	6 lags
Country	DEN	DEN	GER	GER	SWE	SWE	SWI	SWI
No of obs	324	318	276	270	276	270	348	342
Adj. R^2	0.731	0.775	0.688	0.775	0.825	0.827	0.880	0.871

Table 6: **Country-level Treatment Effects of ECB Asset Purchases: Full Sample**
The table reports the coefficient estimates from regression (7) but run for each country separately. We use Newey-West standard errors with four monthly lags. The number of lags L in regressions (4) is set to six. The safety premium sample starts in January 1995 for Denmark, in January 1999 for both Germany and Sweden, and in January 1993 for Switzerland. In all four cases, the samples end in December 2021.

while they were ongoing.

Second, we repeat the exercise for the individual safety premium series. Table 6 shows that the safety premia for the four countries are significantly negatively correlated with the ECB QE purchases for the full sample as well. An increase in the ECB QE program equal to 1 percent of nominal euro area GDP lowers the safety premium extracted from the respective government bond yield curves to varying degrees with estimates ranging from 0.40 basis point to 1.74 basis points. Interestingly, the estimated effects are not smaller in this exercise. Rather, the results are qualitatively and quantitatively similar to those reported in Table 4.

Overall, we take these results to underscore the robustness of our findings.

6 Conclusion

In this paper, we examine the effects of the ECB's asset purchases from 2015 to 2021 on an international panel of bond safety premia from four highly rated countries.

Using panel regressions with an extensive list of control variables, we find that asset purchases by the ECB equivalent to 1 percent of nominal GDP in the euro area tends to lower the safety premia by about 0.35 basis points. Given that the ECB has increased its bond holdings by about 40 percent of GDP over the 2015-2021 period, our results imply that these QE purchases lowered the safety premia in these four countries by as much as 0.12 percent, which is a notable contribution given how low the overall interest rate level was during this period.

Importantly, a reduction in safety premia means a reduction in bond prices. Hence, the ECB QE purchases pushed *up* interest rate levels in these four countries. Whether this was offset by reductions in general term premia—the conventional way QE purchases are thought to affect bond markets—is not clear from our analysis, and we leave that question for future research.

Still, our results point to an important international transmission mechanism that works by affecting the perceptions about and the associated convenience premia tied to the *relative* scarcity of very safe government bonds. As a consequence, it would be interesting to explore whether our findings extend to other highly rated countries in Europe. However, we also leave that question for future research.

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A Appendix: Additional Results and Robustness Checks

	1	2	3	4
α	87.150***	51.064	61.555**	53.602*
	(1.069)	(29.499)	(10.722)	(18.343)
δ_{pspp}	-0.371***	-0.316**	-0.362***	-0.388***
	(0.018)	(0.069)	(0.057)	(0.064)
controls	NO	YES	YES(Δ)	YES(6 lags)
Country FE	YES	YES	YES	YES
No of obs	328	328	328	304
Adj. R^2	0.801	0.881	0.848	0.955
Std. Err.	Country	Country	Country	Country

Table A1: **Average Treatment Effects of ECB Asset Purchases: Clustered SE**
The table reports the coefficient estimates from regression (7) together with their respective clustered standard errors. The first column reports the regression without controls, the second column reports the estimates with the core set of control variables, the third column contains the results including controls in first differences, and the last column contains controls with L set to six lags. The last three rows report the use of country fixed effects, the number of observations, and the adjusted R^2. The underlying safety premium sample starts in January 1995 for Denmark, in January 1999 for both Germany and Sweden, and in January 1993 for Switzerland. In all four cases, the samples end in December 2021. Note that we only run the regression for the period since January 2015 after the ECB had launched its first QE program.

B Appendix: The ECB Quantitative Easing Programs

The QE programs implemented by the European Central Bank (ECB) starting in 2015 represented a monetary policy tool aimed at stimulating the economy and combatting deflationary pressures. The ECB's first outright QE program was officially announced in January 2015 and started operating in March 2015.[17] At its peak in 2022, the Eurosystem held assets totalling an amount equal to about 55% of euro area nominal GDP. The total stock of assets acquired under the QE program stood at €3,373 billion by the end of June 2023. The purchases were throughout allocated according to the Eurosystem national central banks' shares in the ECB's capital key, which reflect each country's share in the total population and gross domestic product (GDP) of the euro area.

ECB introduced a number of quantitative easing programs, under the overarching umbrella program known as the Asset Purchase Programs (APP). There are four major asset purchase programs included in the APP: The public sector purchase program (PSPP), the corporate sector purchase program (CSPP), the asset-backed securities purchase program (ABSPP),

[17] On 22 January 2015, the ECB introduced the Public Sector Purchase Program (PSPP), which would supplement the Asset-Backed Securities and Covered Bonds Purchase Programs (ABSPP and CBPP3) already in place.

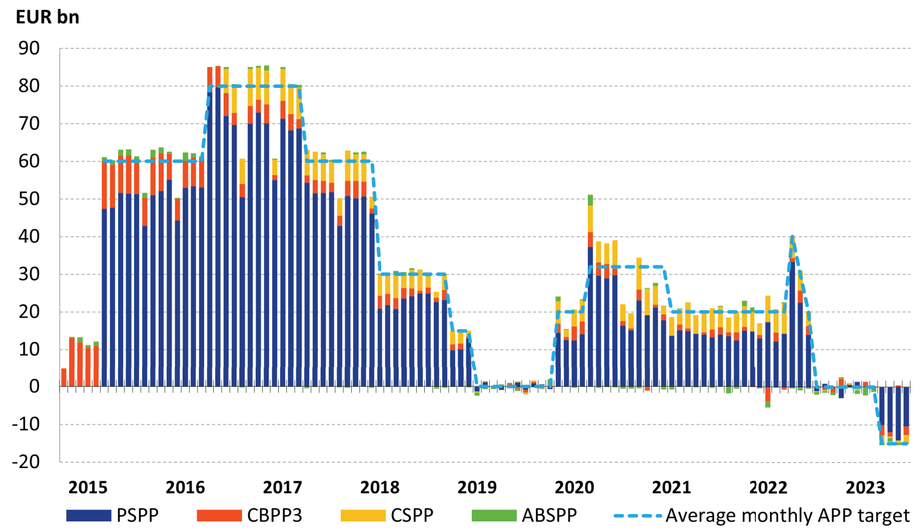

Figure B.1: **The ECB Asset Purchase Programs: Net Asset Purchases**
Illustration of the net asset purchases by different programmes under the asset purchase programmes. All numbers are in billions of euros. Source: the ECB official statistics.

and the third covered bond purchase program (CBPP3). Figure B.1 provides an overview of the net asset purchases made under these four programs. It is worth noticing that PSPP is by far the largest asset purchase program operated by the ECB. Furthermore, the other programs operated in assets such as corporate bonds that are not considered safe. This explains why we limit our focus to the PSPP program in the paper.

Under the PSPP the ECB actively purchased public sector securities in two periods: 1) March 2015–December 2018; 2) November 2019–June 2022. The principal payments from maturing securities were reinvested fully until February 2023, and only partially since then. The PSPP security holdings consist of nominal and inflation-indexed government bonds issued by euro area countries, and bonds issued by recognised agencies, regional and local governments, international organisations and multilateral development banks in the euro area. The majority of the securities held in the PSPP portfolio is in the form of government bonds and recognised agencies' bonds.

The primary goal of the ECB's QE programs was to bring the inflation rate to its 2% target and boost economic growth in the eurozone. Under the programs, the ECB purchased a substantial amount of government bonds and other eligible assets from eurozone countries. The ECB had certain selection criteria for the eligible assets. For instance, bonds had to be above a minimum credit rating and meet certain maturity requirements. This helped maintain the quality and safety of the assets acquired through the QE programs. These purchases have been shown to have direct impacts on financial markets, for examples see De Santis (2020); Koijen et al. (2021); Arrata et al. (2020); and to have substantial impacts on macroeconomic variables, see Gambetti and Musso (2017) and Hohberger et al. (2019), amongst many others.

After June 2022, ECB started to only partially reinvest principal payments from maturing securities in its portfolio of purchases assets. On March 1, 2023, the ECB switched to full-blown quantitative tightening (QT) after eight years of balance sheet expansion by committing to reducing its public sector bond holdings by €15 billion per month. This process of normalizing the ECB's balance sheet is anticipated to be very gradual and presumably will follow the Eurosystem capital key as well.