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Passive Quantitative Easing: Bond Supply Effects through a Halt to Debt Issuance

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&

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Abstract

This article presents empirical evidence of a supply-induced transmission channel to long-term interest rates caused by a halt to government debt issuance. This is conceptually equivalent to a central bank-operated asset purchase program, commonly known as quantitative easing (QE). However, as it involves neither asset purchases nor associated creation of central bank reserves, we refer to it as *passive* QE. For evidence, we analyze the response of Danish government bond risk premia to a temporary halt in government debt issuance announced by the Danish National Bank. The data suggest that declines in long-term yields during its enforcement reflected both reduced term premia, consistent with supply-induced portfolio balance effects, and increased safety premia, consistent with safe assets scarcity effects.

JEL Classification: E43, E47, G12, G13

Keywords: unconventional monetary policy, portfolio balance effects, safety premia

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1 Introduction

The literature on asset price effects arising from central bank large-scale asset purchases, commonly known as quantitative easing (QE), has identified two distinct portfolio balance effects tied to financial frictions. One is caused by imperfect asset substitutability derived from the reduced supply of the purchased assets; see Gagnon et al. (2011) and Krishnamurthy and Vissing-Jorgensen (2011), among many others. The other is due to the segmentation of the market for central bank reserves and works through banks' portfolio responses to associated reserves expansions; see Christensen and Krogstrup (2019, 2022). However, when a central bank operates a QE program, it is nearly impossible to distinguish between these two effects empirically as both transmission channels are operating simultaneously.

For separate identification of supply-induced portfolio balance effects—the main transmission channel emphasized in the literature—this paper argues that we need to focus on a halt to government debt issuance. This is so because such a policy is conceptually equivalent to a central bank-operated bond purchase program in that they both reduce the anticipated market supply of government bonds. However, there are two important differences that ensure the stated identification. First and most importantly, there is no creation of central bank reserves and hence no reserve-induced portfolio balance effects by definition. Second, without any active bond purchases by the central bank, there is also no change in the bargaining power between buyers and sellers in the market for government bonds and hence no reduction in bond liquidity risk premia; see Christensen and Gillan (2022). As a consequence, we refer to this unique policy as *passive* QE.

For empirical evidence on the financial market impact of passive QE, we focus on Denmark, where the government in January 2015 unexpectedly announced a halt to government debt issuance that lasted until October 2015 and, by our estimates, reduced the outstanding amount of Danish government bonds by 29.9 billion Danish krones (about 5 billion U.S. dollars). The shortfall in issuance was never made up, as the Danish government had sufficient funds in its general account with the Danish National Bank (DNB) for its operations during this period. As a result, this policy permanently lowered the trajectory for the outstanding amount of Danish government debt. Moreover, Denmark is a near-ideal place for examining the financial market effects of passive QE thanks to its very long-established peg to the euro.[1] This implies that the announcement of the halt to government debt issuance was unlikely to affect investors' expectations about future monetary policy. This effectively rules out the signaling channel as a relevant mechanism behind the price effects we document.[2]

To analyze potential remaining transmission channels in a unified framework, we use the preferred dynamic term structure model of Danish government bond prices identified by Chris-

[1] Before the launch of the euro in 1999, the Danish krone was pegged to the German mark for many years.

[2] For a discussion of, and evidence on, the signaling transmission channel of QE for U.S. data, see Christensen and Rudebusch (2012) and Bauer and Rudebusch (2014).

tensen and Hetland (2023, henceforth CH). In addition to providing estimates of standard term premia, this model also accounts for bond-specific safety premia as in Christensen and Mirkov (2022).

To examine the impact on Danish government bond risk premia from the announced debt halt, we regress Danish bond-specific safety and general term premium estimates on a dummy variable that is equal to one for the duration of the halt to debt issuance. Since both types of risk premia are likely to have been affected by the European Central Bank's (ECB) public sector bond purchase program (PSPP) ongoing at the time, we include two different measures of their size: one is the collateral scarcity premium of German government bonds, defined as the difference between the ECB deposit facility and the general collateral repo rate for German government bonds; the other is the ECB's holdings of government-backed securities acquired under the PSPP relative to nominal GDP in the euro area.[3] Beyond these main policy variables, we control for a variety of additional confounding factors with a total of 15 variables.

The results show that the average Danish safety premium was 16-21 basis points higher than could otherwise have been anticipated for the duration of the halt to debt issuance. At the same time, the Danish ten-year term premium was reduced 35-68 basis points. Given that the safety premium represents the extra yield investors forgo by holding the very safe Danish government bonds, a higher safety premium is equivalent to a lower absolute yield. Hence, the combined results suggest that Danish government bond yields were significantly lower than they otherwise would have been by between 51 basis points and as much as 89 basis points for the duration of the halt to debt issuance.

Based on these findings we conclude that passive QE works mainly by lowering standard term premia—a result consistent with standard supply-induced portfolio balance effects—but also by lifting bond safety premia, which would be consistent with the scarcity safety premium channel highlighted by Christensen et al. (2023). Furthermore, given that the size of our estimated effects is quantitatively similar to those reported in studies of QE programs in the United States and the United Kingdom,[4] our results suggest that passive QE may be about as effective at lowering long-term interest rates and easing financial market conditions as traditional active QE programs.

In light of the recent elevated level of inflation around the world, it is important for policymakers and investors alike to understand the effects of both QE and quantitative tightening (QT), that is, how central bank bond purchases and sales affect bond yields through different risk premia and over the term structure. Given that QT—where it has been implemented—in many ways can be viewed as a passive reversal of previous QE programs by simply letting

[3]Although the ECB also purchased other securities such as corporate bonds and asset-backed securities during this period, we focus on its holdings of government bonds as the relevant measure of substitutes for Danish government bonds.

[4]See Christensen and Rudebusch (2012) for an example.

bonds mature with at most partial reinvestment, we feel compelled to point out the differences and similarities between the passive QE analyzed in this paper and the passive QT alluded to above.

Under passive QT, when government bonds reach maturity, the government issues new long-term bonds to obtain the funds to pay off the holders of maturing bonds. This produces an upward push on bond yields through the supply-induced transmission mechanism identified in this paper. The central bank then receives its share of these funds and uses it to cancel a matching amount of outstanding reserves. As a result, the banking sector as a whole will see its assets and liabilities reduced by a magnitude equal to the amount of maturing bonds held by the central bank. In response to these exogenous changes to their balance sheets, banks are likely to rebalance their portfolios, which may produce additional reserve-induced portfolio balance effects, as described in Christensen and Krogstrup (2019, 2022). Moreover, if this is taking place in a government bond market like the Danish one in which the bonds can command a safety convenience premium, the added bond supply is likely to put downward pressure on the safety premium through the scarcity channel, as also documented in this paper. In summary, passive QT may raise interest rates through two separate portfolio balance channels in addition to the scarcity channel. As such, it has the potential to be even stronger and more contractionary for financial conditions than passive QE.[5,6]

The analysis in this paper relates to several important literatures. Most directly, it contributes 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 also speaks to the nascent literature about the economic consequences of QT when central banks scale back the size of their balance sheets.[7]

The remainder of the paper is organized as follows. Section 2 details the Danish halt to debt issuance, while Section 3 describes the estimated Danish bond risk premia used in the analysis. Section 4 examines the effects of the debt halt on the bond risk premia before Section 5 concludes the paper. Appendices available online contain details about the data and model used.

2 The Danish Halt to Debt Issuance in 2015

In early 2015, there was extreme market pressure for the Danish krone to appreciate. During the first two months of the year the DNB increased its foreign reserves by 275 billion krones,

[5]Note that, thanks to forward-looking behavior on the part of investors, a significant share of the increase in interest rates from passive QT is likely to materialize upon announcement and not when bonds held by the central bank actually mature.

[6]During the 2022-2023 monetary policy tightening cycle in the United States and elsewhere, passive QT coincided with large and rapid increases in conventional policy rates. This concurrence makes it almost impossible to isolate tightening effects on interest rates from QT during that episode.

[7]See Vissing-Jorgensen (2023) for a theoretical discussion of central bank balance sheet policies and the role of reserves.

or more than 40 billion U.S. dollars, an unprecedented amount in such a short period.[8]

The background for this immense pressure was that the Swiss National Bank had discontinued its minimum exchange rate to the euro on January 15, 2015, which resulted in an immediate and dramatic appreciation of the Swiss franc against the euro. In addition, the ECB had announced its first outright QE program on January 22, 2015. Importantly, in that market environment, speculation in favor of the Danish krone could be considered almost risk-free. Either the DNB would be forced to give up the peg to the euro, which would mean that the Danish krone would most likely appreciate strongly against the euro as the Swiss franc had in mid-January, or the peg would be maintained and investors would be able to freely convert their acquired Danish krones back into euros at the existing exchange rate.

Faced with this pressure, the DNB unexpectedly announced on January 30, 2015, that the Danish government had decided—following advice from the DNB—to halt debt issuance for the foreseeable future.[9] The announcement noted that the government expected to have sufficient funds for its operations at least through the end of 2015. Furthermore, it added that Danish long-term bond yields remained high despite a significant reduction in the DNB's key overnight policy rate to -0.50 percent and outsized purchases of foreign currency. The stated expectation was that the halt would help lower long-term bond yields, which were above their German counterparts, and thereby reduce the inflow of foreign currency.

During the ensuing spring and summer, financial market flows normalized. As a consequence, on August 26, the DNB was able to announce that debt issuance would be resumed as of October 1, 2015.[10] In practice, the halt ended with the issuance of a three-year bond on October 25, 2015.

The DNB serves as the debt manager of the Danish government. In this role, it aims to maintain liquidity in the secondary market for government bonds through frequent reopenings and about as frequent buyback auctions of existing bond series.[11] At the start of 2015, the stated target for government bond issuance for the 2015 calendar year was 75 billion Danish krones and with no details about the intended buyback strategy.[12] Furthermore, the target average duration of government debt was left unchanged at 12.5 years with admissible deviations of $\pm$ 1 year. Thus, investors are not likely to have anticipated any major changes to either the issuance pattern or the debt maturity profile at the time of the announcement. Therefore, to get an estimate of the missing volumes of issuance and buybacks during the eight-month period the debt issuance halt was in place, we compare the change in

[8] See p. 105 in Abildgren (2022).

[9] See https://www.nationalbanken.dk/da/viden-og-nyheder/presse/arkiv/2015/stop-for-salg-af-statsobligationer-30-01-2015

[10] See https://www.nationalbanken.dk/da/viden-og-nyheder/presse/arkiv/2015/genoptagelse-af-statsobligationssalg-og-nedsaettelse-af-foliorammer-26-08-2015

[11] The Danish National Bank also operates a security lending facility that is open to all primary dealers and applies to all government securities provided their notional amounts are above a certain minimum. No changes were made to the operation of this facility during the period under analysis. Further details can be found at: https://www.nationalbanken.dk/media/whfjr1zn/terms-for-securities-lending.pdf

[12] See p. 8 of Danish National Bank (2015).

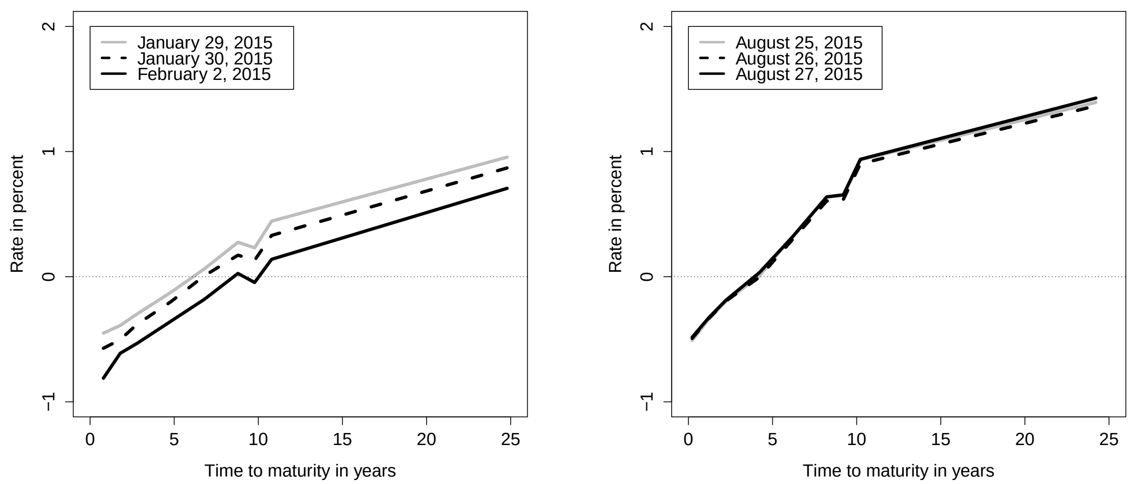
	New issuance		Buybacks		Net issuance	
	2015	Avg. 2016-2018	2015	Avg. 2016-2018	2015	Avg. 2016-2018
January	5,790	7,803	700	3,688	5,090	4,115
February	–	8,755	375	5,235	-375	3,520
March	–	6,953	200	2,928	-200	4,025
April	–	6,663	400	5,083	-400	1,580
May	2,000	7,317	3,550	6,153	-1,550	1,163
June	–	7,807	4,950	4,918	-4,950	2,888
July	2,500	4,388	3,340	4,765	-840	-377
August	–	6,607	5,150	3,148	-5,150	3,458
September	–	7,547	1,215	8,623	-1,215	-1,077
October	14,180	6,548	6,420	4,637	7,760	1,912
November	17,330	7,157	5,405	3,342	11,925	3,815
December	2,440	3,678	4,695	2,430	-2,255	1,248
Total, Feb.-Sep.	4,500	56,037	19,180	40,855	-14,680	15,182

Table 1: **Changes to the Outstanding Amount of Danish Government Bonds**
The table reports the monthly changes to the outstanding amount of Danish government bonds caused by issuance of new bonds and buybacks of existing bonds during 2015 along with the average of the corresponding changes in 2016, 2017, and 2018. The last line reports the net changes for the period from February to September both for 2015 and averaged for the years 2016, 2017, and 2018. All numbers are measured in millions of Danish krones.

the outstanding volume between February 1, 2015, and September 30, 2015, with the average change during the corresponding period in the years 2016, 2017, and 2018. These numbers are reported in Table 1.[13] We note that, in the February-September period of 2016-2018, the average net issuance amount was 15.2 billion Danish krones. In 2015, the corresponding number shows a net decline in the outstanding amount of bonds equal to 14.7 billion Danish krones as buybacks continued, albeit at lower volumes compared with the 2016-2018 period. Although uncertain, we take these numbers to suggest that the outstanding amount of Danish government bonds is likely to have been reduced by about 29.9 billion Danish krones thanks to the debt issuance halt. Furthermore, there is no evidence that the government tried to make up for this shortfall by subsequently increasing its debt issuance. As a result, this unique policy choice appears to have effectively lowered the trajectory for the outstanding amount of government debt permanently.

Because the announcement of the debt halt was unexpected and involved notable volumes, it would be reasonable to expect an immediate reaction from bond investors. To explore that conjecture, we examine the one- and two-day reactions of Danish government bond yields to the announcement for the set of bonds outstanding at the time. Figure 1(a) shows how the entire Danish government bond yield curve varied during the two-day event window. We note a moderate immediate reaction lower across the yield curve on January 30, 2015, which was

[13] The halt was not fully enforced as there were two small reopening auctions of a single bond in May and July 2015 to improve liquidity in the government bond market.



(a) January 30, 2015

(b) August 26, 2015

Figure 1: **Yield Responses to Debt Halt Announcements**
Panel (a) shows the one- and two-day responses of the outstanding Danish government bond yields to the announcement of the halt to debt issuance on January 30, 2015. Panel (b) shows the one- and two-day responses of the outstanding Danish government bond yields to the announcement of the resumption of debt issuance on August 26, 2015. The data are downloaded from Bloomberg.

likely tempered because it happened on a Friday. By Monday's close on February 2, 2015, though, we see the full market reaction, which reveals a forceful movement lower in the entire yield curve of about 25 basis points. Crucially, given how low interest rates were already, the forceful immediate reaction to the announcement of the debt halt can be considered to be quite large.

Figure 1(b) shows the one- and two-day yield responses to the announcement of the resumption of debt issuance on August 26, 2015. We note a very modest, almost indifferent reaction to this announcement, even though a two-day event window still registers the anticipated *positive* uptick in the bond yields.

For perspective and to put the market reaction above into context, we contrast the Danish bond market reaction to three key events in January 2015: the SNB announcement on January 15, 2015, when it discontinued its minimum exchange rate to the euro; the ECB's announcement of the PSPP on January 22, 2015; and the DNB's announcement to halt debt issuance on January 30, 2015. For consistency across events, we use the fitted zero-coupon yields from an arbitrage-free Nelson-Siegel (AFNS) model estimated on the full sample of daily Danish government bond prices covering the period from January 4, 1999, to December 31, 2021, as recommended by Andreasen et al. (2019). Table 2 reports the two-day yield response around each of these three announcements. First, we note a modest uniform reaction to the SNB announcement with a decline of about 3.5 basis points in the entire yield curve. We add that this would be our best estimate of the bond yield impact from an onset

SNB announcement on January 15, 2015						
Maturity	1-year	2-year	3-year	5-year	7-year	10-year
1/14-2015	0.86	-11.89	-11.66	6.68	31.62	64.90
1/16-2015	-2.38	-15.27	-15.14	3.10	27.99	61.25
Change	-3.24	-3.38	-3.47	-3.58	-3.63	-3.66

ECB announcement on January 22, 2015						
Maturity	1-year	2-year	3-year	5-year	7-year	10-year
1/21-2015	-16.71	-27.59	-25.97	-5.78	20.27	54.49
1/23-2015	-27.04	-38.08	-36.48	-16.13	10.15	44.72
Change	-10.33	-10.49	-10.51	-10.35	-10.11	-9.77

DNB announcement on January 30, 2015						
Maturity	1-year	2-year	3-year	5-year	7-year	10-year
1/29-2015	-32.93	-40.29	-36.69	-15.08	10.86	44.16
2/2-2015	-62.11	-68.61	-64.21	-41.21	-14.20	20.24
Change	-29.18	-28.32	-27.52	-26.14	-25.06	-23.92

Table 2: **Response of Danish Government Bond Yields to Key Announcements**
The table reports the two-day response of Danish government zero-coupon bond yields to the announcement by the SNB to discontinue its minimum exchange rate to the euro on January 15, 2015, the ECB's announcement of the PSPP on January 22, 2015, and the DNB's announcement to halt debt issuance on January 30, 2015. All numbers are measured in basis points.

of expectations about a potential appreciation of the Danish krone against the euro triggered by the SNB discontinuing its minimum exchange rate to the euro. With a positive probability of an appreciation of the Danish krone to the euro, foreign investors should be willing to hold Danish bonds at lower interest rates than otherwise in light of the potential to earn an extra return through the exchange rate appreciation in case the peg were to be abandoned. The market reaction offers suggestive evidence that the SNB announcement indeed gave rise to the formation of such expectations.

Second, we find a stronger uniform reaction to the ECB's announcement of the PSPP with a decline of about 10 basis points in the entire yield curve. This matches similar declines in euro area long-term interest rates and likely reflects a mix of both signaling and portfolio balance effects.

Against this background, the market reaction to the DNB's debt halt announcement is even more impressive, both in terms of its magnitude and given the fact that it took place from an overall lower yield level than the two previous announcements. Thus, the Danish debt halt announcement stands out in terms of its impact on Danish government bond yields. Moreover, provided the announcement was interpreted by investors to imply an elimination of any meaningful appreciation opportunities, Danish yields should have *increased* to maintain

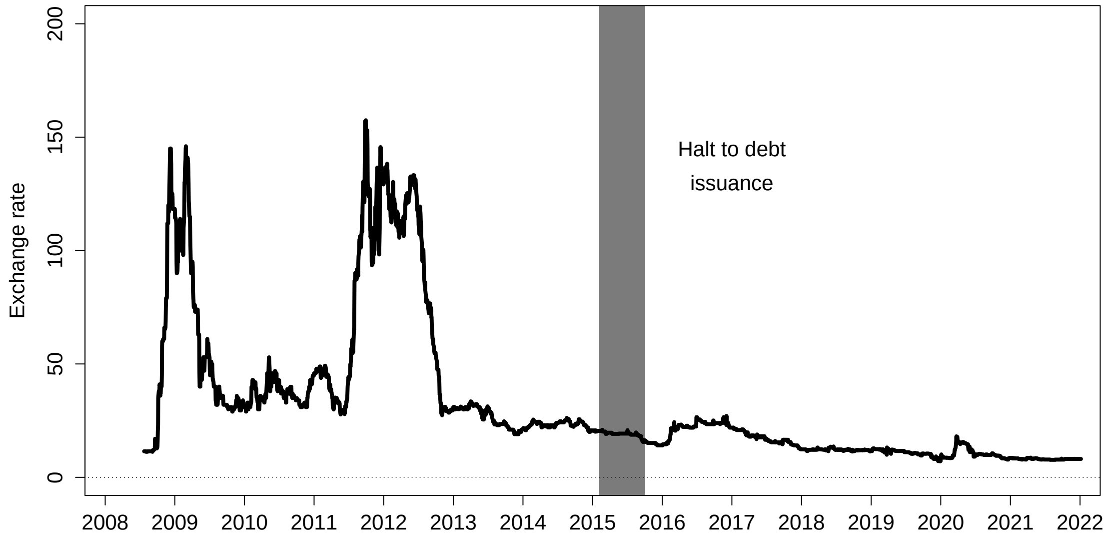


Figure 2: **Danish 5-Year CDS Rate**

an unchanged expected return measured in euros. Instead, they *declined*. As a consequence, our reported results are likely best interpreted as lower bound estimates of the true market impact of the reduced bond supply following the Danish debt halt.

As for the credit risk of Danish government bonds, we note that the Danish government has held a AAA credit rating with Moody's since August 23, 1999, and with Standard & Poor's since February 27, 2001.[14] Overall, this points to a very low level of credit risk in general for the bonds issued by the Danish government.

To provide further support in favor of this view, Figure 2 shows the Danish 5-year CDS rate from mid-2008 until December 2021. For our key period under analysis from January 30, 2015, to August 26, 2015, the Danish 5-year CDS rate averaged 19.42 basis points with a standard deviation of 0.52 basis point. Hence, credit risk remained low during this period and did not change in any material way.

As a final point to underscore the low level of credit risk of Danish government bonds, we note that the Danish government debt-to-GDP ratio had been on a downward trend since 2012 when it reached 60.6 percent as shown in Figure 3. By 2022, it had dropped to 34.7 percent. In 2015, the Danish government debt-to-GDP ratio was 53.4 percent, down from 59.1 percent in 2014.[15] This comfortable position of Danish government finances at the time also explains why the Danish government and the DNB could decide to simply halt debt issuance for an extended period in January 2015.

[14]Source: http://www.worldgovernmentbonds.com/credit-rating/denmark/
[15]Source: https://data.oecd.org/gga/general-government-debt.htm

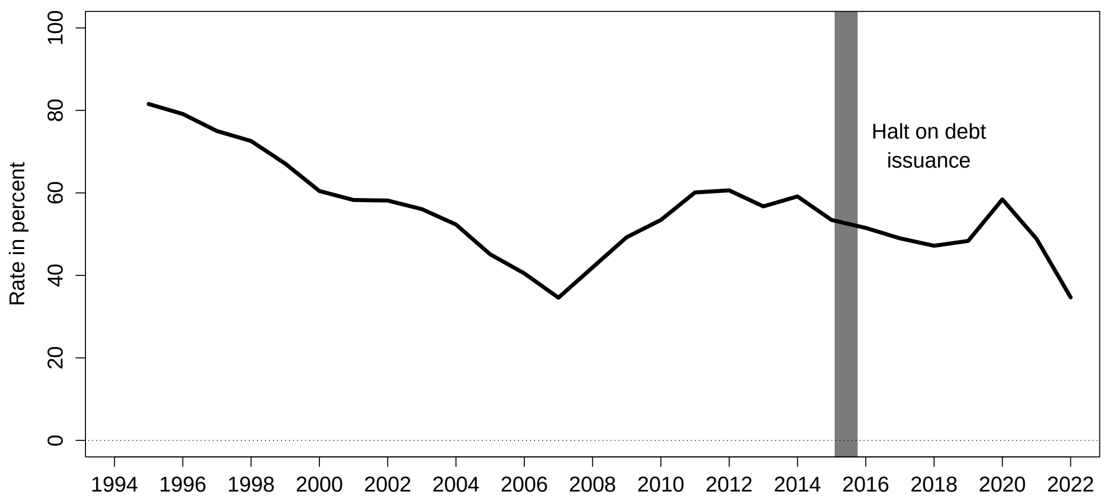


Figure 3: **Danish Government Debt-to-GDP Ratio**

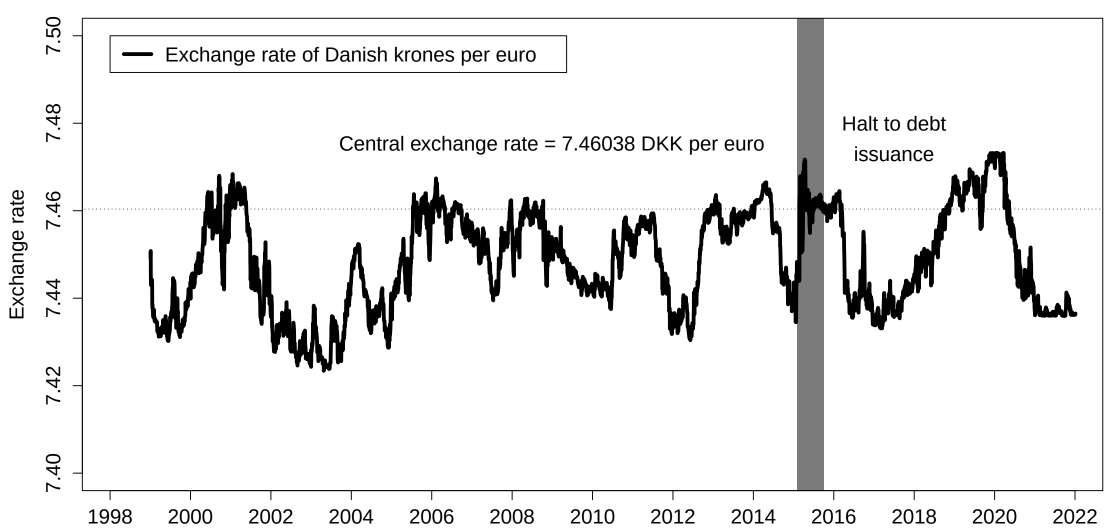


Figure 4: **Exchange Rate of the Danish Krone to the Euro**

Overall, we take this evidence to show that changes to the price of credit risk are not likely to have played any notable role during the period under analysis. Moreover, we stress that we include the debt-to-GDP ratio as a control variable in our regression analysis in an attempt to further minimize the role of credit risk for our results.

Finally, Figure 4 shows the exchange rate of the Danish krone to the euro since 1999. It

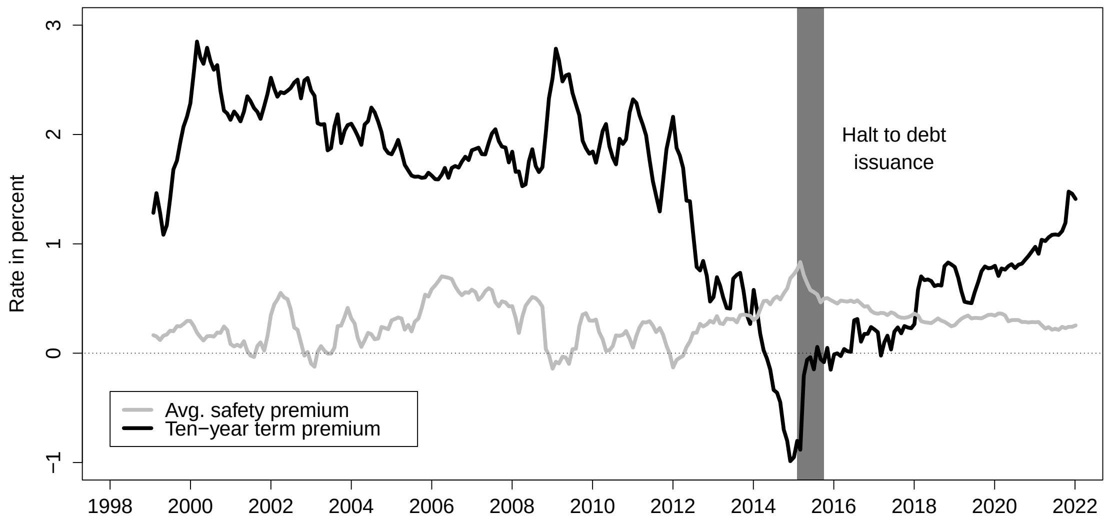


Figure 5: **Average Bond Safety Premium and Ten-Year Term Premium**
Illustration of the average estimated Danish government bond safety premium and the ten-year term premium of Danish government bonds. The data cover the period from January 31, 1999, to December 31, 2021.

reveals that the strong market dynamics in early 2015 in terms of volumes flowing into Danish money markets had little impact on the exchange rate. Thus, the price reaction to the debt halt announcement is entirely limited to interest rates and bond yields.

In our analysis, we are interested in going beyond the immediate market reactions documented above and examine the more persistent effects on Danish bond risk premia from this unique policy choice. The rest of the paper is devoted to this task.

3 The Estimated Danish Bond Risk Premia

For our analysis we consider the preferred dynamic term structure model of Danish government bond prices identified by CH. We use this model to extract the safety premium in Danish government bond prices and to calculate the ten-year Danish term premium.[16]

Figure 5 shows the average Danish government bond safety premium across the outstanding bonds at each point in time. The average estimated safety premium varies notably over time: it fell to a minimum of negative 12 basis points in late 2008; it later reached a maximum of 81 basis points in January 2015, shortly after the Swiss National Bank had abandoned its minimum exchange rate to the euro and the ECB had announced its first open-ended large-scale purchases of euro-area government bonds. For the entire period, the series has an average

[16]See online Appendix B for details of the model, its estimation, and the calculation of the bond risk premia.

of 29 basis points with a standard deviation of 19 basis points.

Figure 5 also shows the Danish ten-year term premium, which has changed little on net, but is characterized by fairly large persistent swings during our sample period. It averages 134 basis points with a standard deviation of 89 basis points. Thus, conventional term premia are an order of magnitude larger and more volatile than safety premia. Still, the two risk premium series have a negative correlation of -53 percent. Given that the safety premium represents the extra yield investors forgo by holding the very safe Danish government bonds, a higher safety premium is equivalent to a lower absolute yield. Hence, the negative correlation implies that changes in both premia tend to push the observed bond yields in the same direction, but the less-than-perfect correlation underscores that they represent distinct risk premia in the prices of Danish government bonds.

In terms of understanding the impact of the debt halt on Danish bond yields, we note up front that Denmark's exchange rate policy aimed at keeping the Danish krone stable against the euro is of particular importance. Accordingly, as shown in Figure 6, the DNB's key policy rate follows that of the ECB, with small deviations accounting for periods of extraordinary pressure on the krone in either direction. Consequently, the expectations component of longer-term Danish government bond yields tends to mirror those of core euro-area countries. That said, anticipated buying or selling pressures of the Danish krone vis-à-vis the euro may affect investors' near-term expectations about the spread between Danish and euro overnight rates. Overall, though, we are essentially assuming in our analysis that policy expectations in Danish and euro-area fixed-income markets are moving in tandem, and any unilateral actions by the DNB such as the halt to debt issuance analyzed here are assumed to *not* affect investors' policy expectations in any material way, in particular at medium- to long-term horizons. This effectively rules out any major yield effects materializing through the signaling channel.

In contrast, there are several tangible reasons why the risk premium components of Danish bond yields may not follow the same pattern as their euro-area counterparts, leading to interest rate spreads of considerable size at longer maturity horizons as described in Grønlund et al. (2022). First, because of the pegged exchange rate policy, unconventional monetary policy in the euro area is likely to have potential spillover effects on the risk premia of Danish government bonds. The ECB's government bond purchases reduce the free float of euro-area government bonds and lower their risk premia as documented by Eser et al. (2019). In a frictionless world, this should give investors an incentive to buy Danish government bonds as a close and safe substitute.[17] However, Danish government bonds cannot be used in euro-area general collateral repo agreements, which may make Danish government bonds comparatively less attractive to some investors, thereby dampening demand. Moreover, some

[17]Koijen et al. (2017) find that foreign investors exhibited the strongest reaction to the ECB's asset purchases under the PSPP in terms of rebalancing their portfolios toward more attractive investment opportunities elsewhere. That process could also have let them to reassess their perceptions about the relative safety of Danish safe assets.

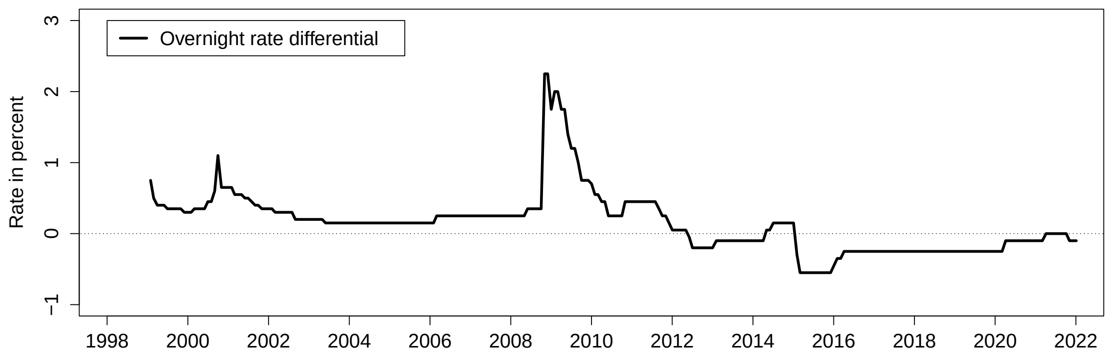


Figure 6: **Overnight Rate Differential**
Illustration of the difference between the Danish overnight interest rate of the certificates of deposits set by the Danish National Bank and the main overnight rate set by the European Central Bank. The data are monthly covering the period from January 31, 1999, to December 31, 2021.

investors may not be allowed to invest in Danish government bonds, say, due to restrictions on their investment mandates. Such financial frictions could adversely impact the substitution between euro-area government bonds and Danish bonds, thereby limiting the pass-through of unconventional monetary policy.

4 Regression Analysis

To examine the impact on Danish government bond risk premia from the announced halt to government debt issuance, we use the average Danish safety premium and the ten-year Danish term premium estimates at monthly frequency covering the period from January 1999 to December 2021. As stated earlier, we are interested in going beyond the immediate announcement effects on bond yields reported in Section 2 and measure the longer lasting impact on the Danish bond risk premia from this policy. We therefore regress these series on a dummy variable that is equal to one for the duration of the halt to debt issuance.

To control for the potential effects of the ECB's government bond purchases on the Danish bond risk premia, we consider two different measures of their size in our regression analysis. The first measure is the collateral scarcity premium of German government bonds, defined as the difference between the ECB deposit facility and general collateral repo rate for German government bonds and measured in percent; see Arrata et al. (2020). When the scarcity premium is positive, funds can be placed in the repo market below the ECB deposit facility rate, possibly reflecting that government bonds are scarce and in demand for repo transactions. The ECB's government bond purchases pushed the German scarcity premium into positive territory for all general collateral segments, as demonstrated by Schaffner et al. (2019). The second measure of the ECB's government bond purchases is the ECB's holdings of government-backed securities relative to annual nominal GDP in the euro area. This serves as a proxy for the amount of truly safe assets held by the ECB, as argued by Christensen and Mirkov (2022).

In addition to these main policy variables, we control for a variety of confounding factors. In a core set of control variables, we consider the CBOE's volatility index (VIX), the spread between Italian and German ten-year bond yields, the TED spread, and the ten-year on-the-run premium in U.S. Treasuries to proxy for investors' risk aversion, financial market uncertainty, and demand for safe-haven assets.[18] This set also contains the debt-to-GDP ratio—interpolated linearly from quarterly to monthly frequency—to control for effects tied to the supply of Danish government bonds.[19] In addition, it includes the Danish overnight deposit rate as a proxy for the opportunity cost of holding money and the associated liquidity premia of Danish government bonds, as explained in Nagel (2016). Furthermore, we include the average Danish government bond age and the one-month realized volatility of the ten-year Danish government bond yield as additional proxies for bond liquidity following the work of Houwling et al. (2005).[20] Inspired by the analysis of Hu et al. (2013), we also include a noise measure of Danish government bond prices to control for the variation in the amount of arbitrage capital available in this market. Finally, as a control for credit risk, we use both the yield spread between Danish and German ten-year government bonds and the difference in the debt-to-GDP ratio between Denmark and Germany,[21] and we include the EUR-DKK cross-currency basis to control for differences in funding costs. To go beyond this set of core control variables, we include a few additional potentially confounding factors in our regressions. We add the overnight federal funds rate to proxy for the U.S. safe-asset liquidity premium as in Nagel (2016), and reported earnings per share of companies in the S&P 500 stock price index to account for opportunity costs in the equity market. Finally, we also consider the MOVE volatility index to proxy for risk aversion in global bond markets.

To test for the potential effects of the halt to debt issuance, we run linear regressions that take the form:

$$Y_t = \alpha + \beta \cdot D_t^{halt} + \gamma \cdot QE_t + \delta \cdot X_t + \varepsilon_t, \tag{1}$$

where the dependent variable Y_t is the relevant outcome variable (the average safety premium or the ten-year term premium). In terms of the explanatory variables, D_t^{halt} is the key dummy variable for the government debt issuance stop in 2015, QE_t contains either the scarcity premium or the ECB's holdings of government bonds divided by the nominal euro-area GDP, and X_t contains the controlling variables. Finally, ε_t is an error term.

[18]See Grisse and Nitschka (2015).

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

[20]The one-month realized volatility is estimated based on a standard sample estimator using daily yields.

[21]An alternative measure is the credit default swap rate for Danish government bonds, which unfortunately only is available from 2008 onwards.

Panel A: Average Safety Premium

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D_t^{halt}	33.79***	34.83***	21.04***	19.48***	34.27***	20.01***	15.75**
	(6.41)	(7.12)	(6.37)	(6.90)	(6.65)	(6.98)	(7.55)
Scarcity premium		23.81*	-31.00***	-39.11**			
		(16.65)	(15.92)	(17.12)			
(PSPP+PEPP)/GDP					0.13	-0.50**	-1.06***
					(0.17)	(0.23)	(0.34)
Controls	None	None	Core	All	None	Core	All
Adj R^2	0.10	0.11	0.56	0.60	0.10	0.56	0.62
DW	0.15	0.15	0.32	0.38	0.15	0.30	0.36

Panel B: Ten-Year Term Premium

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D_t^{halt}	-164.25***	-186.26***	-67.37***	-68.19***	-179.38***	-51.00**	-35.11*
	(17.84)	(27.86)	(26.14)	(26.03)	(19.09)	(26.45)	(24.83)
Scarcity premium		-503.06***	-19.34	15.84			
		(82.82)	(78.52)	(78.54)			
(PSPP+PEPP)/GDP					-4.14***	2.42***	5.74***
					(1.04)	(0.91)	(1.31)
Controls	None	None	Core	All	None	Core	All
Adj R^2	0.11	0.35	0.75	0.77	0.28	0.77	0.81
DW	0.05	0.10	0.35	0.39	0.07	0.36	0.40

Table 3: **Estimated Effects of the Halt to Debt Issuance on Danish Government Bond Risk Premia**
The top panel reports the estimated coefficients of the regression in equation (1) with the average Danish safety premium as the dependent variable, while the bottom panel reports the estimated coefficients of the same regression with the Danish ten-year term premium as the dependent variable. The numbers in parentheses contain the estimated standard deviations using Newey-West standard errors with three monthly lags. The sample starts in January 1999 and ends in December 2021. Stars *, **, and *** indicate significance at the 10, 5 and 1 percent level, respectively.

We run seven regressions for each bond risk premium measure. The first includes no controls to demonstrate that our results carry through even in this naive case. For each proxy for the ECB government bond purchases, we then run three separate regressions, one with no additional controls, another with the core set of controls, and a final one with all controls.

The results of the regressions are reported in Table 3. The empirically relevant results with controls (regressions 3, 4, 6, and 7) show that the average Danish safety premium was 16-21 basis points higher than could otherwise have been anticipated for the duration of the halt to debt issuance. At the same time, the Danish ten-year term premium was reduced by 35-68 basis points. Given that the safety premium represents the extra yield investors forgo by holding the very safe Danish government bonds, a higher safety premium is equivalent to a lower absolute yield. Moreover, given that the two bond risk premia represent separate components in the government bond prices, the estimated effects can be added together. Hence, the combined results suggest that Danish government bond yields were significantly lower than they would otherwise have been by between 51 basis points and as much as 89 basis points for the duration of the halt to debt issuance. Based on these findings we conclude that passive QE works by lowering long-term bond yields through both reduced term premia, which would be consistent with supply-induced portfolio balance effects, and increased safety premia, which would be consistent with scarcity effects of safe assets. Furthermore, given that the size of the estimated effects is quantitatively similar to those reported in studies of QE programs in the United States and the United Kingdom, the results suggest that passive QE may be about as effective at lowering interest rate levels and easing financial market conditions as traditional active QE programs.

Finally, the regression results show that the ECB's bond purchases tend to lower Danish safety premia and lift Danish term premia. These observations are consistent with the findings of both CH for Danish bond risk premia specifically and Christensen et al. (2023) based on an international panel of safety premia. The negative impact on the Danish safety premia underscores that safe asset purchases by major central banks have the ability to produce international spillover effects by altering investors' perceptions about the scarcity of safe assets in nearby foreign bond markets and hence depress the premium that safe foreign bonds can command. The positive effect on Danish term premia points to an international substitution channel whereby investors rotate out of non-targeted foreign safe assets and use the revenue to increase their exposures to the euro-area government bonds targeted by the ECB's bond purchases.

5 Conclusion

In this paper, we argue that a temporary halt to debt issuance by the government is theoretically equivalent to the central bank launching a QE program of similar size in that they both reduce the anticipated future bond supply available to private investors. Operationally, however, this policy is unlikely to affect bond market liquidity conditions as it involves no active bond purchases by the central bank. Moreover, without the creation of any central bank reserves, it cannot produce any reserve-induced portfolio balance effects arising from banks' reaction to the dilution in the average interest rate risk of their asset portfolios. For these reasons it offers a unique opportunity to directly observe supply-induced portfolio balance effects.

For evidence on the effects of such a passive QE policy, we focus on Denmark, where the government unexpectedly announced a halt to debt issuance in January 2015 that ended up lasting until October 2015. An added advantage of focusing on Denmark is that its tight exchange rate peg of the Danish krone to the euro allows us to rule out any signaling effects about future monetary policy from the debt halt announcement. As a consequence, we can limit our analysis to changes in Danish bond-specific safety and general term premia, where our results suggest that the halt raised bond safety premia and lowered term premia for the duration of its enforcement. This points to two main transmission mechanisms of passive QE to financial markets. One operates by raising bond safety premia through a scarcity channel, while the other works by lowering long-term bond yields through standard supply-induced portfolio balance effects on term premia. Based on the latter finding, we claim to be the first to provide *direct* evidence of the supply-induced portfolio balance channel that is the main transmission channel emphasized in the empirical literature on financial market effects of QE.

In terms of the practical relevance of passive QE, it is important to stress that a halt to government debt issuance only represents a viable alternative to launching a regular QE program in order to ease financial conditions provided the government can credibly claim to have sufficient funds to sustain its operations for the committed period. This necessary precondition should be kept in mind when it comes to pursuing this policy. However, as for the identified transmission channels, we think they would apply equally well to other safe government bond markets.

Finally, given that QT in many ways can be viewed as a passive reversal of previous QE programs as explained in the introduction, our findings suggest that this policy may be quite contractionary on financial conditions. However, we leave it for future research to examine that conjecture.

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Online Appendix

Passive Quantitative Easing: Bond Supply Effects through a Halt to Debt Issuance

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&

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The views in this paper are solely the responsibility of the authors and should not be interpreted as reflecting either the views of the Federal Reserve Bank of San Francisco or the Federal Reserve System or those of the Danish National Bank.

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Contents

A Danish Government Bond Data

In this appendix, we briefly describe our sample of Danish government bond prices downloaded from Bloomberg. We use the same 40 bond prices as in Christensen and Hetland (2023) observed monthly from January 1999 to December 2021.

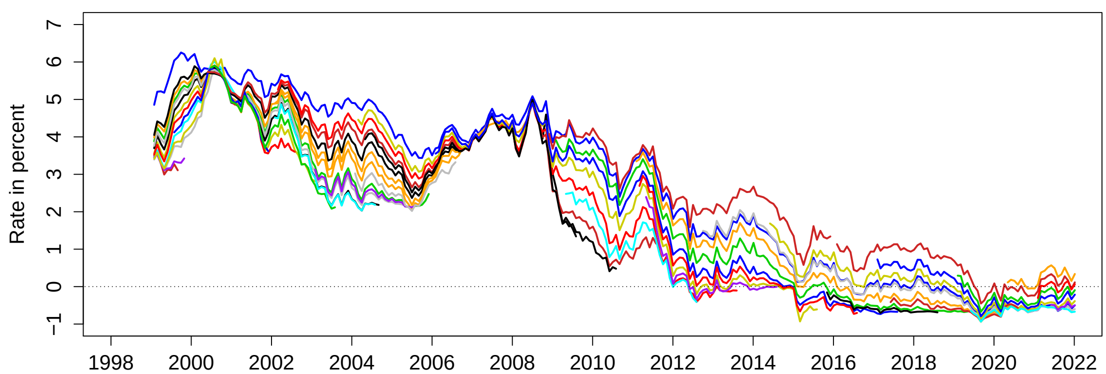

Figure 1: **Yield to Maturity of Danish Government Bonds**
Illustration of the yield to maturity of the Danish government bonds considered in the paper, which are subject to two sample choices: (1) sample limited to the period from January 31, 1999, to December 31, 2021; (2) censoring of a bond's price when it has less than three months to maturity.

Figure 1 shows the Danish government bond prices converted into yield to maturity. Several things are worth noting regarding these yield series. First, there is a trend lower in the general yield level during this period from roughly 6 percent in the early 2000s to around zero by the end of our sample. Second, there is pronounced business cycle variation in the shape of the yield curve around the lower trend. The yield curve tends to flatten ahead of recessions and steepen during the initial phase of economic recoveries. These characteristics are the practical motivation behind our choice of using a three-factor model for the frictionless part of the Danish yield curve, adopting an approach similar to what is standard for U.S. and U.K. data; see Christensen and Rudebusch (2012).

Finally, we note that shorter-term Danish yields turned negative for the first time in 2012 and were firmly in negative territory from summer 2014 when the ECB introduced negative policy rates through the end of our sample. As a consequence, we choose to focus on a model with Gaussian dynamics, which can easily handle negative interest rates.

B Model Estimation and Results

In this appendix, we first detail the model that serves as the benchmark in our analysis before we describe the restrictions imposed to achieve econometric identification of the model.

B.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 model we use. Here, L_t denotes a level factor, while S_t and C_t represent slope and curvature factors. Finally, X_t^R is the marketwide bond-specific risk factor structured as in Andreasen et al. (2021). Given that it is an augmented version of the arbitrage-free Nelson-Siegel (AFNS) models described in Christensen et al. (2011), we refer to it as the AFNS-R model.

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 the Danish government bond market, 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 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 Danish krone paid by bond i at time $t + \tau$ has the following exponential-affine form

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

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[1]

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

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,

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

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

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

$$dX_t = K^{\mathbb{P}}(\theta^{\mathbb{P}} - X_t) + \Sigma dW_t^{\mathbb{P}},$$

where $K^{\mathbb{P}}$ is an unrestricted 4×4 mean-reversion matrix, $\theta^{\mathbb{P}}$ is a 4×1 vector of mean levels, and Σ is a 4×4 lower triangular volatility matrix. This is the transition equation in the extended Kalman filter estimation of the AFNS-R model.

B.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

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

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 marketwide bond-specific risk factor is a latent factor that we do not observe, its level is not identified without additional restrictions. As a consequence, 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 security. This choice implies that the β^i sensitivity parameters measure sensitivity to this factor relative to that of the 30-year 2024 bond. Moreover, we note that the $\lambda^{R,i}$-parameters can be hard to identify if their values are too large or too small. As a result, 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.

Finally, we follow the finance literature and assume stationarity of the state variables,

$K^{\mathbb{P}}$	$K^{\mathbb{P}}_{\cdot,1}$	$K^{\mathbb{P}}_{\cdot,2}$	$K^{\mathbb{P}}_{\cdot,3}$	$K^{\mathbb{P}}_{\cdot,4}$	$\theta^{\mathbb{P}}$		Σ
$K^{\mathbb{P}}_{1,\cdot}$	0.0138	0	0	0	0.0632	σ_{11}	0.0062
	(0.0508)				(0.0462)		(0.0002)
$K^{\mathbb{P}}_{2,\cdot}$	0	0.8410	0	1.8676	-0.0297	σ_{22}	0.0116
		(0.2428)		(0.5291)	(0.0100)		(0.0009)
$K^{\mathbb{P}}_{3,\cdot}$	0	0	0.2147	0	-0.0162	σ_{33}	0.0156
			(0.1909)		(0.0209)		(0.0011)
$K^{\mathbb{P}}_{4,\cdot}$	0	0	0	0.4665	0.0020	σ_{44}	0.0070
				(0.2996)	(0.0051)		(0.0008)

Table 1: **Estimated Dynamic Parameters of the Preferred AFNS-R Model**
The table shows the estimated parameters of the $K^{\mathbb{P}}$ matrix, $\theta^{\mathbb{P}}$ vector, and diagonal Σ matrix for the preferred AFNS-R model. The estimated value of λ is 0.2921 (0.0058), while $\kappa_R^{\mathbb{Q}} = 1.9506$ (0.1103) and $\theta_R^{\mathbb{Q}} =$ -0.0030 (0.0003). The maximum log likelihood value is 16,179.75. The numbers in parentheses are the estimated parameter standard deviations.

which allows us to start the Kalman filter at their unconditional mean.

B.3 Estimation Results

For our analysis we consider the preferred specification of the AFNS-R model identified by Christensen and Hetland (2023, henceforth CH). They use a general-to-specific strategy starting from an unrestricted $K^{\mathbb{P}}$. In each step, the parameter in $K^{\mathbb{P}}$ with the lowest t-statistic is eliminated. They then rely on the Bayesian information criterion (BIC) and marginal likelihood ratio tests to find the optimal stopping point, as in Christensen et al. (2014b). Their preferred specification has $\mathbb{P}$-dynamics given by

$$\begin{pmatrix} dL_t \\ dS_t \\ dC_t \\ dX_t^R \end{pmatrix} = \begin{pmatrix} \kappa_{11}^{\mathbb{P}} & 0 & 0 & 0 \\ 0 & \kappa_{22}^{\mathbb{P}} & 0 & \kappa_{24}^{\mathbb{P}} \\ 0 & 0 & \kappa_{33}^{\mathbb{P}} & 0 \\ 0 & 0 & 0 & \kappa_{44}^{\mathbb{P}} \end{pmatrix} \left(\begin{pmatrix} \theta_1^{\mathbb{P}} \\ \theta_2^{\mathbb{P}} \\ \theta_3^{\mathbb{P}} \\ \theta_4^{\mathbb{P}} \end{pmatrix} - \begin{pmatrix} L_t \\ S_t \\ C_t \\ X_t^R \end{pmatrix} \right) dt + \Sigma \begin{pmatrix} dW_t^{L,\mathbb{P}} \\ dW_t^{S,\mathbb{P}} \\ dW_t^{C,\mathbb{P}} \\ dW_t^{R,\mathbb{P}} \end{pmatrix},$$

where Σ is a diagonal matrix as recommended by Christensen et al. (2011).

We note that the 11 parameters eliminated in the $K^{\mathbb{P}}$ mean-reversion matrix are statistically insignificant both individually and collectively as demonstrated by CH. Hence, the data are singling out this favored specification in a very strong way. As a consequence, we feel comfortable relying on this preferred specification for our analysis of bond-specific safety and general term premia in the Danish government bond market.

The estimated parameters of the preferred specification are reported in Table 1, while results reported in CH show that the AFNS-R model provides a very tight fit to the Danish bond price data and hence not repeated here. Furthermore, the fact that $\kappa_{24}^{\mathbb{P}}$ is large and positive implies that there is a fairly strong negative correlation between the slope factor S_t and the bond-specific risk factor X_t^R, i.e., a high value of X_t^R will tend to drive S_t lower. Practically speaking, this means that when X_t^R is high and the Danish safety premia are under pressure, Danish short-term interest rates have a tendency to fall. Economically, a declining Danish safety premium means that Danish government bond yields are being pushed up. All else being equal, this should be associated with capital inflows from abroad attracted by the higher interest rates. This will put upward pressure on the value of the Danish krone against the euro. To offset that pressure and keep the tight peg of the exchange rate to the euro, the DNB can at first intervene in the exchange rate market, but if the pressure is sustained, the ultimate remedy is to lower the Danish overnight rate, which will show up in our analysis as a decline in S_t.

B.4 The Estimated Bond Risk Premia

We first use the estimated AFNS-R model to extract the safety premium in the Danish 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 our sample. 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

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

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

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

Second, we define the term premium in the standard way as

$$TP_t(\tau) = y_t(\tau) - \frac{1}{\tau}\int_t^{t+\tau} E_t^{\mathbb{P}}[r_s]ds. \tag{7}$$

That is, the term premium is the difference in expected return between a buy-and-hold strategy for a τ-year bond and an instantaneous rollover strategy at the risk-free rate r_t. Importantly, $y_t(\tau)$ is the frictionless yield left over after the bond-specific safety premia have been accounted for and calculated using equation (2). The model thus allows us to decompose bond yields into their respective term premia and short-rate expectations components in addition to the safety premia described above.

B.5 Robustness Analysis of the Estimated Danish Safety Premium

This section examines the robustness of the average safety premium of Danish government bonds to some of the main assumptions imposed. Throughout the AFNS-R model with diagonal $K^{\mathbb{P}}$ and Σ matrices serves as the benchmark.

First, we examine the sensitivity of the estimated safety premium series to the choice of sample start date by repeating the model estimation, but using a sample that starts in January 1995 as in Christensen and Mirkov (2022). Figure 2 shows the two estimated average safety premium series where we note the almost identical results for the overlapping period. Hence, the choice to start our sample in January 1999 after the launch of the euro does not materially affect our safety premium results.[2]

Second, we assess whether the specification of the dynamics within the AFNS-R model matters for the estimated Danish government bond safety premium. To do so, we estimate the AFNS-R model with unconstrained dynamics, that is, the AFNS-R model with unrestricted $K^{\mathbb{P}}$ and lower triangular Σ matrix. Figure 3 shows the estimated Danish safety premium series from this estimation and compares it to the series produced by our benchmark model. Note that they are barely distinguishable. Thus, we conclude that the specification of the dynamics within the AFNS-R model only plays a very modest role for the estimated bond-specific risk

[2] Andreasen et al. (2021) report similar results for U.S. Treasury Inflation-Protected Securities.

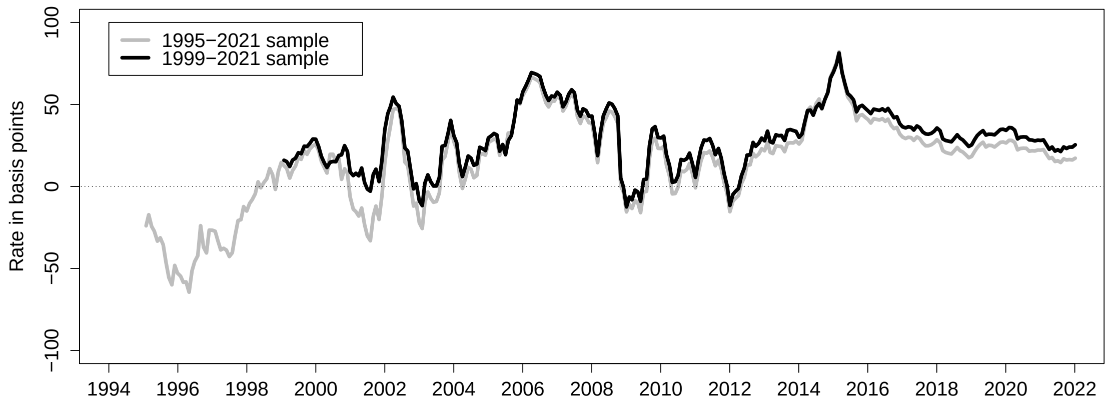

Figure 2: **Average Estimated Danish Government Bond Safety Premium: Sample Start Date**
Illustration of the average estimated safety premium of Danish government bonds for each observation date implied by the AFNS-R model estimated with monthly data from January 31, 1999, to December 31, 2021, as in the paper and compared with the corresponding premium from the same model estimated with monthly data from January 31, 1995, to December 31, 2021. In both cases, the AFNS-R model is estimated with a diagonal specification of $K^{\mathbb{P}}$ and Σ.

premia.[3]

Third, we assess whether the data frequency plays any role for our results. To do so, we estimate the AFNS-R model using weekly and monthly data, and based on the results above it suffices to focus on the most parsimonious AFNS-R model with diagonal $K^{\mathbb{P}}$ and Σ matrices. Figure 4 shows the estimated Danish safety premium series from the two estimations. Note that they are barely distinguishable. Thus, we conclude that data frequency matters little for our results. Clearly, at the higher weekly frequency, there are a few isolated spikes that are absent in the monthly series, but they are too few to have an impact on the estimation results.

Fourth, we explore whether allowing for stochastic volatility in one or more of the frictionless factors within the AFNS-R model affects the estimated Danish government bond safety premium. Specifically, we consider the four admissible combinations of allowing for spanned stochastic volatility generated by one or two factors in the model following the work of Christensen et al. (2014a). In light of the results above, it suffices to focus on the most

[3]This is consistent with similar findings by Andreasen et al. (2021) in the context of U.S. Treasury Inflation-Protected Securities.

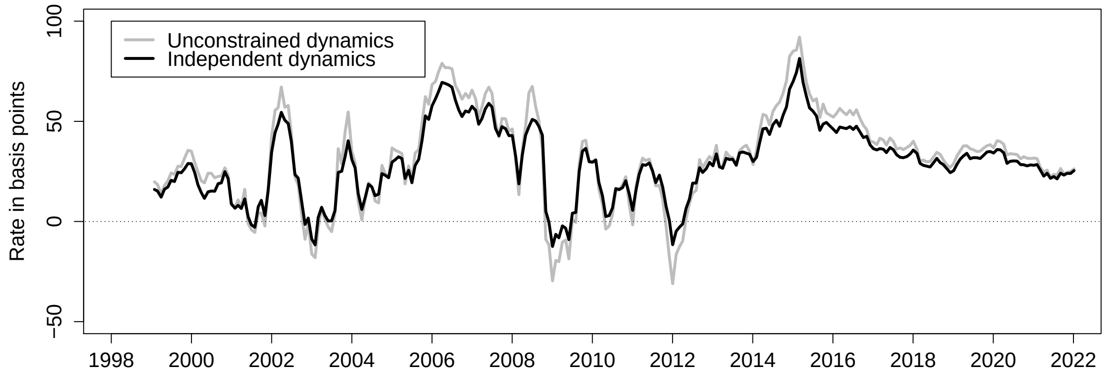

Figure 3: **Average Estimated Danish Government Bond Safety Premium: Alternative $\mathbb{P}$ Dynamics**
Illustration of the average estimated Danish government bond safety premium for each observation date implied by the AFNS-R model when estimated with unconstrained dynamics as detailed in the text instead of independent factor dynamics. In both cases, the 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. The data cover the period from January 31, 1999, to December 31, 2021.

parsimonious specification of each model with diagonal $K^{\mathbb{P}}$ and Σ matrices. We refer to these models as AFNS models because they share the key properties of the AFNS model. First, the three frictionless state variables have joint dynamics under the risk-neutral probability measure used for pricing closely matching the arbitrage-free Nelson-Siegel models described in Christensen et al. (2011). Furthermore, the frictionless short rate remains defined as $r_t = L_t + S_t$. Therefore, to keep the notation simple, we use AFNS(i) to denote a model as defined above with i referring to the factors generating stochastic volatility with letters—L, S, and C—used to indicate the source(s) of stochastic volatility in the model. Figure 5 shows the estimated safety premium series from these estimations. Note that they are very similar and highly positively correlated. Thus, we conclude that allowing for stochastic volatility within the AFNS-R model only plays a very modest role for our results. Hence, this provides support for our choice to only focus on the Gaussian AFNS-R model with constant volatility.

To summarize, we find the estimated safety premium series to be robust to both different sample start dates and alternative model dynamics. As a consequence, we are comfortable using the AFNS-R model preferred by CH in the empirical analysis in the paper. Furthermore,

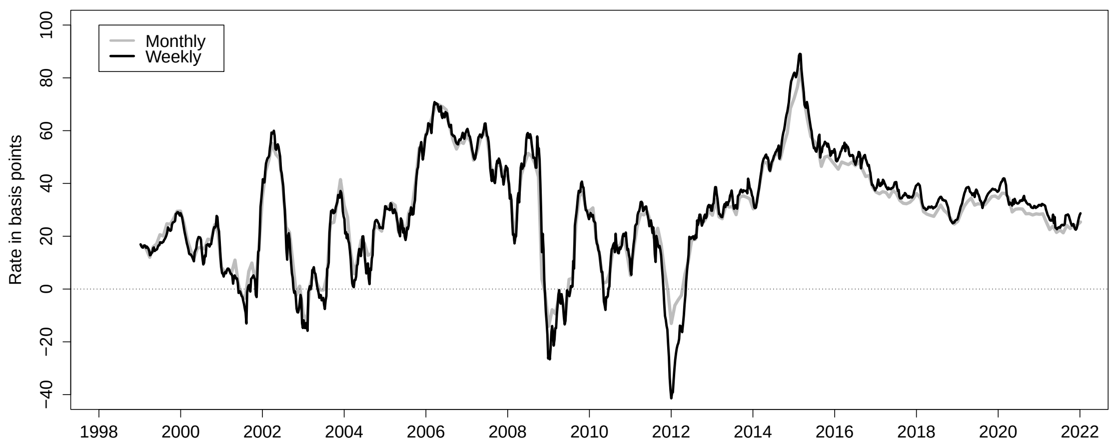

Figure 4: **Average Estimated Danish Government Bond Safety Premium: Data Frequency**
Illustration of the average estimated Danish government bond safety premium for each observation date implied by the AFNS-R model when estimated using weekly and monthly data. In all cases, the safety premia are measured 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. The data cover the period from January 4, 1999, to December 31, 2021.

given the persistence of the risk premium changes we are interested in, we are also comfortable focusing on the results from monthly data, which greatly reduces the computational time and simplifies the regression analysis in the paper.

B.6 Robustness Analysis of the Estimated Danish Ten-Year Term Premium

In this section, we examine the robustness of the estimated Danish ten-year term premium to some of the main model assumptions.

To assess the sensitivity of our ten-year term premium to the specification of the mean-reversion matrix $K^{\mathbb{P}}$, we compare it in Figure 6 to the corresponding estimates from the AFNS-R models with unrestricted and diagonal $K^{\mathbb{P}}$ matrix. We note some sensitivity of the ten-year term premium to the choice of $K^{\mathbb{P}}$ specification. Importantly, both of the alternative estimates suggest that the ten-year term premium has broadly followed a path similar to the one estimated by the preferred AFNS-R model.

Next, we explore the sensitivity of our yield decompositions to the data frequency by

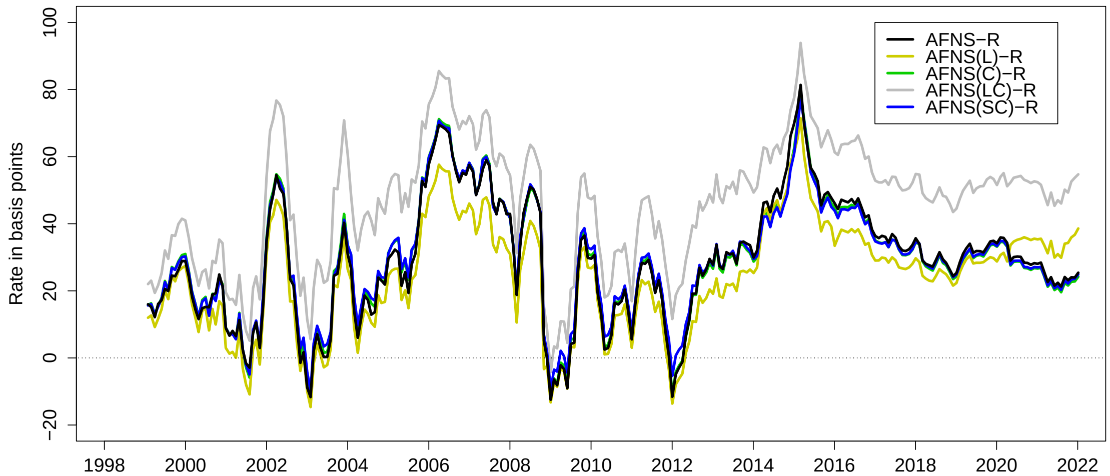

Figure 5: **Average Estimated Danish Government Bond Safety Premium: Allowing for Stochastic Volatility**
Illustration of the average estimated Danish government bond safety premium for each observation date implied by the AFNS-R model when estimated with and without allowing for stochastic volatility as detailed in the text. 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. The data cover the period from January 31, 1999, to December 31, 2021.

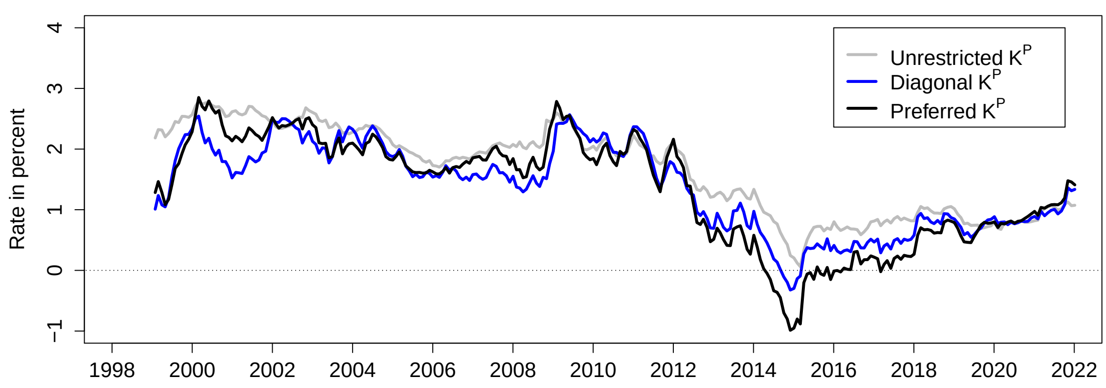

Figure 6: **Sensitivity of Ten-Year Term Premium to $K^{\mathbb{P}}$ Specification**

estimating our preferred AFNS-R model using weekly data instead of the monthly frequency considered throughout the paper. Figure 7 compares the ten-year term premium from the

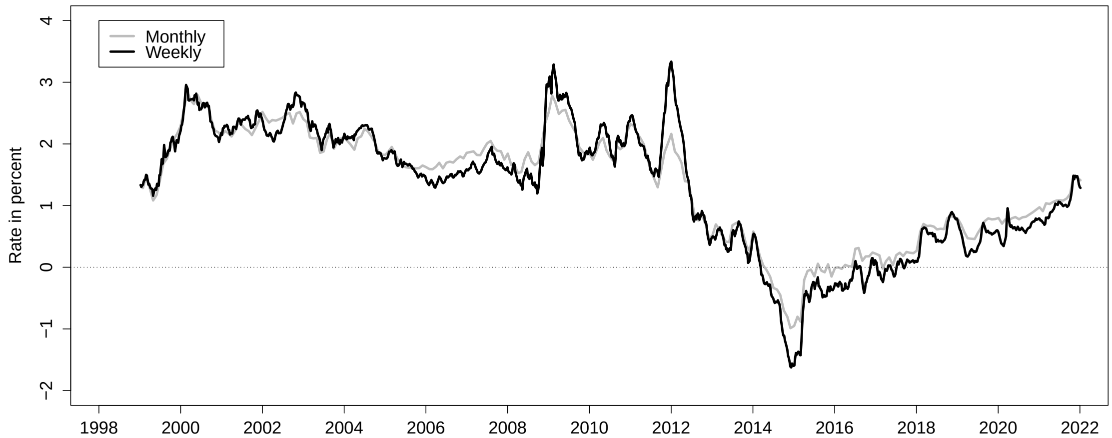

Figure 7: **Sensitivity of Ten-Year Term Premium to Data Frequency**

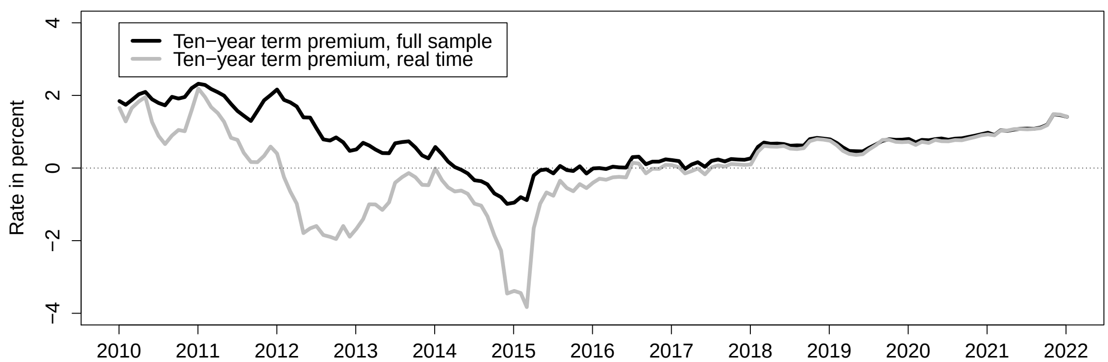

Figure 8: **Accuracy of Real-Time Estimates of the Ten-Year Term Premium**

two estimations. The results show that, with the exception of a few episodes with some high-frequency sharp short-lived deviations, the estimated ten-year term premium is robust to varying the data frequency.

A well-known criticism of macro-based estimates of term premia is that they can exhibit significant variation as additional and revised data become available. All else equal, finance-based estimates should be less subject to this line of criticism as the key model input, namely the observed bond prices, are available in real time and not subject to any revisions. However, finance-based estimates could still vary as the sample length increases, for example the estimated persistence of the state variables may change, and this could be particularly relevant in the current environment where the general level of interest rates declined for two decades before reversing some of the decline recently. To dispel such concerns, we estimate the preferred AFNS-R model in real time starting in 2010 through December 2021. This allows us to generate real-time estimates of the ten-year term premium and compare them to the corresponding full sample "look back" estimates, which is done in Figure 8. Although we do see some discrepancies between the estimates as we go back through time, these results show that the ten-year term premium estimates from our preferred AFNS-R model are reliable in real time.

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