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The Relation between Municipal and Government Bond Yields in an Era of Unconventional Monetary Policy*

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Abstract

In this paper we investigate how the five-year Swedish municipal bond yield has been related to the corresponding yield on government bonds during the period that the Riksbank has conducted unconventional monetary policy in terms of bond purchases. Using daily Swedish data on bond yields from February 2015 to January 2018, we first conduct an event study to assess the short-run effects of the Riksbank's bond-purchase announcements. We then estimate bivariate vector autoregressive models in order to study the dynamic relationship between the yields. Results from the event study suggest that the accumulated short-run effect of the Riksbank's announcements was to lower the government bond yield by approximately 40 to 50 basis points and municipal bond yields by 30 to 35 basis points. Our vector autoregressive analysis indicates – in line with the event study – that an unexpected decrease in the government bond yield initially increases the municipal bond-yield spread. However, after approximately four weeks, the effect has been reversed and the municipal bond-yield spread is lower than it was initially. By conducting this analysis, we contribute to the understanding of the transmission of unconventional monetary policy.

JEL Classification: C32, E44, G10

Keywords: Spread, Event study, Vector autoregression, Cointegration

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1. Introduction

The international recession that followed the global financial crisis was unusually deep. This meant that despite historically low policy interest rates in many countries, a number of central banks – including the Federal Reserve, the Bank of England, the ECB, the Swiss National Bank and Sveriges Riksbank – judged that additional measures were needed in order to make monetary policy more expansive. So-called unconventional monetary policy measures were accordingly introduced; see, for example, International Monetary Fund (2013) for an overview. One important such measure was asset purchases which, to a large extent, were directed towards government bonds.[1] One idea behind these purchases is that reduced yields on government bonds will induce investors to rebalance their portfolios, causing for example yields on other longer-term bonds to fall as well. As lower yields spread across various types of bonds, investment and consumption are stimulated and the recovery of the real economy is thereby supported. Empirical evidence supporting effects in assets where purchases have not been made – such as corporate bonds – has been established by, for example, Gagnon *et al.* (2011), Joyce *et al.* (2011), Krishnamurthy and Vissing-Jorgensen (2011) and Szczerbowicz (2015). The quantitative effects established do, not surprisingly, vary though depending on asset type. For example, Joyce *et al.* (2011) report that in light of a 75 basis point gilt yield reduction during the Bank of England's asset purchases in 2009 and 2010, investment-grade corporate bond yields fell by 70 basis points whereas non-investment corporate bond yields fell by 150 basis points. In order to find out how different interest rates have moved in relation to each other in the era of central bank asset purchases, the specific interest rates in question accordingly need to be studied.

The purpose of this paper is to investigate how yields on Swedish municipal bonds issued by Kommuninvest of Sweden – a credit institution owned collectively by Swedish municipalities – have been related to yields on government bonds during the period that the Riksbank has purchased Swedish government bonds. This is done by conducting two types of empirical analysis: *i)* We perform a traditional event study where we analyse the short-run impact – measured as the daily change – that the Riksbank's announcements of bond purchases have had on the five-year yield on government bonds and municipal bonds. In doing this, we largely follow a line of research which has assessed the effect of unconventional monetary policy by studying changes in prices or yields of various assets over a short period of time – the so-called "event window"; see, for example, Meaning and Zhu (2011), D'Amico and King (2013) and De Rezende *et al.* (2015). *ii)* Bivariate vector autoregressive (VAR) models employing five-year yields based on the two bond types are estimated. This is done in order to see how the two yields relate to each other from a more dynamic perspective. As has been pointed out by, for example, Joyce *et al.* (2011), it is likely to take some time for interest rate markets to adjust to the central bank's announcements of purchases; the quantitative easing experience provides a new challenge to investors and asset managers and they are therefore unlikely to rebalance their portfolios

[1] Other asset types have also been purchased though. The Federal Reserve, for example, bought mortgage backed securities in its QE1 programme; see, for example, Krishnamurthy and Vissing-Jorgensen (2011).

immediately upon the arrival of new information. We argue that the full effect on municipal bond yields seems particularly likely to come with a bit of a delay (relative to the full effect on government bond yields) since it is reasonable to assume that different government bonds are closer substitutes to each other than what a municipal bond and a government bond are.[2] Hence, using VAR models – which, unlike the event study, means taking a dynamic approach when studying the relationship between the yields – seems beneficial.

By conducting this analysis, we contribute to the literature in three ways. First, we provide further empirical evidence on the relationship between yields on bonds which have not been subject to purchases by the central bank and yields on government bonds. It hence complements international studies such as those mentioned above, as well as Swedish studies focusing on different types of assets – see, for example, De Rezende *et al.* (2015) and Sveriges Riksbank (2017a) – and adds to our understanding of how unconventional monetary policy works. Second, results for an important asset class in Sweden – that is, Kommuninvest of Sweden's municipal bonds – are presented. But this is not only of interest to investors. Debt issued by Kommuninvest of Sweden constitutes approximately 50 percent of the stock of debt of Swedish municipalities. Since the majority of the Swedish welfare system is financed through the municipalities, it is accordingly highly relevant to the municipal sector what happens to these rates. Third, the VAR analysis allows us to assess how the interest rates have been related to each other also outside the event window. Seeing that it is a stylised fact that interest rates are highly persistent – see, for example, Wu and Chen (2001) – we estimate the models both under the assumption that interest rates have a unit root and that they are mean reverting, where we in the former case rely on a cointegrated VAR. While cointegration analysis of interest rates obviously is not new in the academic literature, it has not been a frequently employed framework in analysis related to unconventional monetary policy. In closely related research though, Karagiannis *et al.* (2010) and Gambacorta *et al.* (2015) investigated the pass through of policy rates onto other interest rates using cointegration techniques.

The remainder of this paper is organised as follows: In Section 2, we present the data. We conduct an event study and discuss its results in Section 3. In Section 4 we present the VAR models and the results from the estimation of them. In Section 5 we conduct some sensitivity analysis and, finally, Section 6 concludes.

2. Data

We use daily data on five-year bond yields for municipal bonds issued by Kommuninvest of Sweden and government bonds. The focus on five-year yields is partly motivated by the fact that long-term interest rates typically are considered most important for monetary policy as they are the rates that have the largest effect

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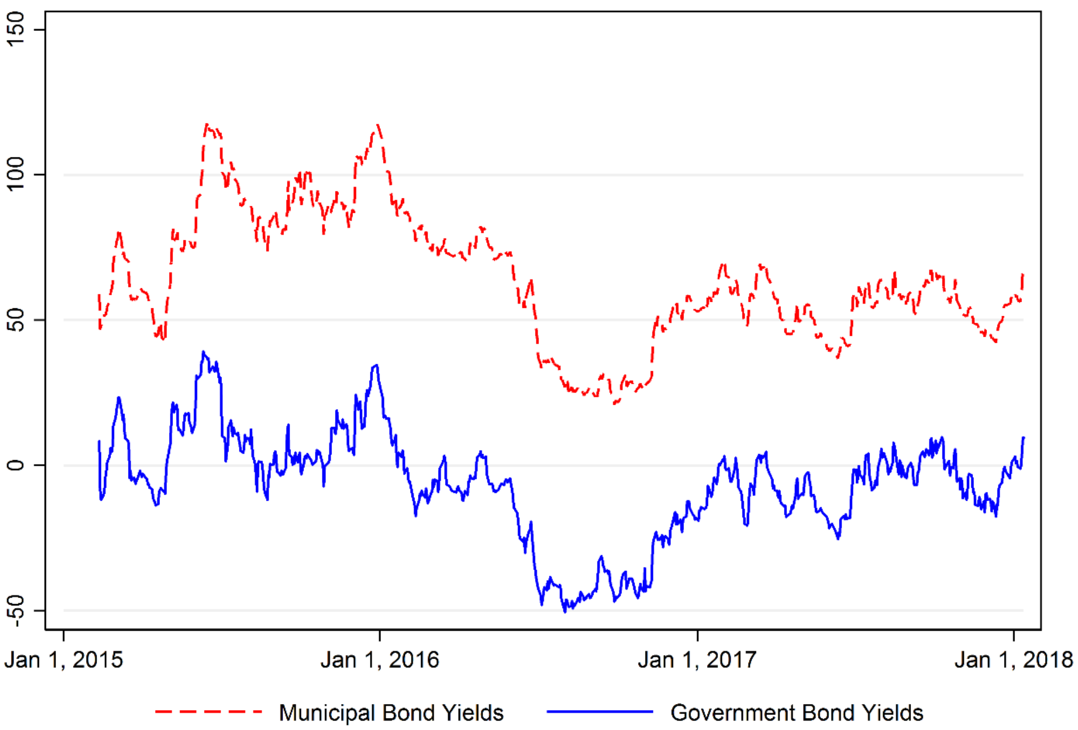
[2] Krishnamurthy and Vissing-Jorgensen (2011) also point out that assets that are less liquid than treasury bonds may react more slowly to the central bank's announcements.

on spending decisions; see, for example, Mishkin (1996). In addition, five years is reasonably close to the average duration of the bonds that the Riksbank has purchased. Furthermore, the five-year yield is close to the mean time to maturity of Kommuninvest of Sweden's funding portfolio which allows us to circumvent yield anomalies at the extremes of the term structure which are due to, for instance, bond repurchases by the issuer. The data range from the 11th of February 2015 to the 12th of January 2018, where the starting point is given by the day before Sveriges Riksbank acknowledged the start of its asset purchase programme. The data on Kommuninvest of Sweden's bonds consist of daily closing prices on all SEK denominated, fixed-coupon bonds available at Bloomberg. These are bonds issued in the Swedish and Luxembourg markets. Similarly, government bond-price data are based on all available fixed-coupon, non-index-adjusted Swedish SEK denominated government bonds available at Bloomberg. We primarily use bond prices for Kommuninvest of Sweden listed by the four major Swedish domestic banks and Danske Bank since these have market maker agreements with the issuer. If more than one bank has reported a price we use the mean. If no bank has reported a price we use Bloomberg's generic prices (BGN) or Bloomberg's evaluated pricing service (BVAL). To these data, we estimate yield curves for both Kommuninvest of Sweden and the Swedish government based on the model of Nelson and Siegel (1987) and evaluate the respective five-year yields.[3] As a robustness check, we also do all estimations using yields calculated by applying a smoothing spline approach in Section 5. Data on five-year bond yields from the Nelson-Siegel model are shown in Figure 1.

Figure 1. Five-year bond yields.



Note: Yields are given in basis points.

[3] Estimation is based on the standard model of Nelson and Siegel (1987), not related extensions such as, for example, those of Svensson (1995) or Diebold *et al*. (2006).

3. Event Study

As the first part of our empirical analysis, we aim to assess the short-run effects of the Riksbank's announcements of bond purchases on the two five-year yields. This is done by conducting an event study related to the eleven announcements that took place between the 12th of February 2015 and the 20th of December 2017; see Table A1 in Appendix A for a detailed list. It should be noted though that the last three announcements – that is, those made on the 4th of July 2017, the 7th of September 2017 and the 20th of December 2017 – were different from the others. The announcements in July and September simply stated that bond purchases were going to continue according to the previously stated plan, and the announcement in December declared that coupons and nominal amounts were to be reinvested until further notice; this can be contrasted with the first eight announcements which carried new information regarding volume and/or asset type and/or timing.[4] Seeing that the last three announcements had a different type of informational content that the rest, we will also conduct analysis based on only the first eight announcements.

We initially look at how interest rates moved around the Riksbank's announcements. An event window of one day is used, in line with, for example, Gagnon *et al.* (2011), Christensen and Rudebusch (2012), De Rezende (2017) and Sveriges Riksbank (2017a). We accordingly measure how much the five-year yields changed during the day of the announcement.[5] While these movements provide a measure of the effect of the announcement, they are unlikely to fully and purely reflect the effect. As was pointed out above, it might take time for investors and asset managers to rebalance their portfolios. In addition, to the extent that the market was expecting purchases to be announced, this should already have been priced in before the announcement. Finally, unexpected movements in the repo rate – as well as other relevant macroeconomic news – on the day of the announcement will also affect our measure. With these caveats in mind, it is nevertheless of interest to study the observed change in yields on the days of the announcements; it also means that our results can be immediately compared to results for other Swedish variables reported by, for example, Sveriges Riksbank (2017a).[6]

The changes in yields are shown in Figure 2. As can be seen, seven of the eleven announcements are associated with a falling government bond yield; for the municipal bond yield, the corresponding number is

[4] See Sveriges Riksbank (2015) and Sveriges Riksbank (2017b) for examples of announcements which carried new information.

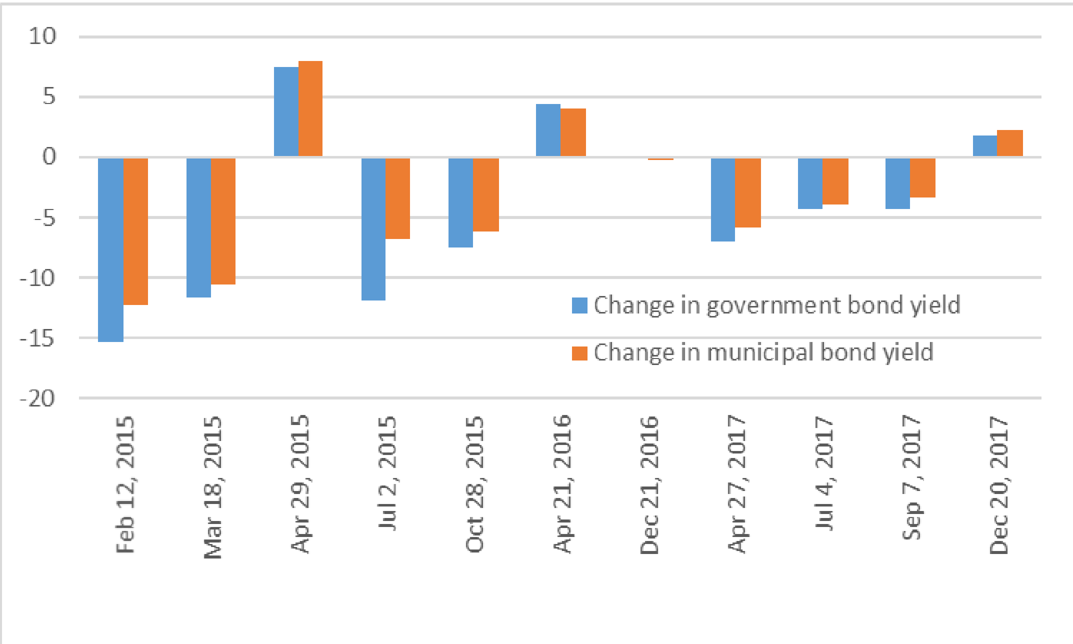
[5] That is, we observe the change in yield from (close of business) the day before the announcement to (close of business) the day of the announcement.

[6] In Appendix B we present alternative series of the effects of the bond-purchase announcements. These have been generated by taking the repo-rate surprise on each announcement day into account. More specifically, this has been done by subtracting the repo-rate surprise of Iversen and Tysklind (2017) corresponding to the day in question (see Figure A1) from each of the two observed daily changes – an approach which can be considered reasonable if interest rates have a unit root, that is, they are integrated of order one. Figure A2 shows these alternative series. As can be seen, this affects the estimated effect of the bond-purchase announcements for the individual days to some extent. However, the accumulated effect is essentially unchanged relative to our benchmark case shown in Figure 2 as positive and negative surprises largely cancel out. One might also want to control for other information in order to get a cleaner measure of the effect of the bond-purchase announcements, see, for example, De Rezende *et al*. (2015). We do not go down that path in this paper. While such a strategy might improve the estimate of the effect of the bond-purchase announcement, it is unlikely to affect our estimates of how the municipal and government bond yields co-move which is the primary concern of this paper.

eight out of eleven.[7] That bond yields do not fall on all announcement days is not completely surprising though. For example, on the 29th of April 2015 the market was expecting the repo rate to be cut. However, such a cut did not materialise. At the same time, the announced bond purchases were largely in line with expectations. Taken together, this made interest rates increase during the day. On the other hand, the effect on some days are probably larger than what was motivated by the bond-purchase announcement. On the 12th of February 2015, the repo rate was cut by 10 basis points – an action which to a large extent (but not completely) was expected by the market. The rather large effect on bond yields that day – despite the fairly low amount announced, 10 billion SEK – can likely be explained by the Riksbank's communication suggesting further measures in the future.

The accumulated effect over all eleven announcements is -48 basis points for the government bond yield and -35 basis points in the municipal bond yield. If we only look at the first eight announcements instead, the accumulated effects are instead -41 and -30 basis points respectively. These numbers provide an estimate of the overall short-run effect on yields of the Riksbank's bond-purchase announcements.[8]

Figure 2. Change in five-year bond yields at announcement dates.



Note: Change in yields are given in basis points.

[7] Results for the five-year government bond yield for the first four announcements can be compared to some of the results of De Rezende *et al*. (2015) and they turn out to be very similar. Since De Rezende *et al*. (2015) relied on yield curves based on Svensson's (1995) extension of the Nelson-Siegel approach, this indicates that differences in yield curve estimation methodology do not seem that important; we investigate this issue further though in Section 5.

[8] Interpreting the cumulative changes as a measure of the overall effect was also done by, for example, Gagnon *et al*. (2011).

Figure 2 indicates that the municipal bond yield tends to move less than the government bond yield. To more closely describe the short-run relationship on the days of the announcements, we run the regression

$$\Delta i_t^m = \delta + \theta \Delta i_t^g + v_t \qquad (1)$$

where i_t^m is the five-year municipal bond yield, i_t^g is the five-year government bond yield and v_t is an error term, $v_t \sim N(0, \sigma^2)$ – using data only from the announcement days. Equation (1) is estimated using OLS and results are shown in Table 1. In the first column containing results, we present the results when the regression has been based on all eleven announcements. The second column instead gives the results using only the first eight observations. As can be seen, the differences between the two samples are minor. The slope coefficient is 0.84 in both models and in neither case can we reject the null hypothesis that the intercept is zero. We would accordingly expect a ten basis point reduction in the government bond yield to be associated with a reduction in the municipal bond yield of approximately 8.4 basis points. This indicates that in the short run, the municipal bond-yield spread, $s_t^m = i_t^m - i_t^g$, increases in light of bond-purchase announcements.

Table 1. Estimated key parameters from equations (1) and (2).

	Equation (1)		**Equation (2)**	
	11 announcements	8 announcements	11 announcements	8 announcements
δ	0.50 (0.34)	0.59 (0.47)	0.01 (0.06)	0.01 (0.06)
θ	0.84[a] (0.04)	0.84[a] (0.04)	0.67[a] (0.03)	0.67[a] (0.03)
π	-	-	0.49 (0.28)	0.58 (0.38)
ϕ	-	-	0.17[a] (0.05)	0.16[a] (0.05)
R^2	0.97	0.97	0.66	0.66
# obs	11	8	736	736

Note: Newey-West standard errors in parentheses (). "a" indicates significance at the one percent level; "b" indicates significance at the five percent level. Equation (1) is $\Delta i_t^m = \delta + \theta \Delta i_t^g + v_t$. Equation 2 is $\Delta i_t^m = \delta + \theta \Delta i_t^g + \pi D_t + \phi \Delta i_t^g D_t + v_t$. i_t^m is the five-year municipal bond yield, i_t^g is the five-year government bond yield and D_t is a dummy variable which takes on the value one on announcement days and zero otherwise.

A natural question that arises is whether the co-movements found on the days of the Riksbank's announcements are different to those on other days. This can be assessed by estimating

$$\Delta i_t^m = \delta + \theta \Delta i_t^g + \pi D_t + \phi \Delta i_t^g D_t + v_t \qquad (2)$$

where i_t^m and i_t^g are defined as above, D_t is a dummy variable which takes on the value one on announcement days and zero otherwise, and v_t again is an error term, $v_t \sim N(0, \sigma^2)$. Results from OLS estimation are shown in Table 1 and show that estimate of π is not significantly different from zero, whereas the estimate of ϕ is; since the estimate of ϕ is larger than zero, the movement on announcement days is larger than otherwise. Accordingly, the two rates do co-move differently on days when announcements were made than they do otherwise.

Summing up our findings of this section, we note that in the short run the effect of the Riksbank's announcements has been larger on government bond yields than on municipal bond yields. A ten basis point reduction in the government bond yield due to announcements appears to be associated with a reduction in the municipal bond yield of approximately 8.4 basis points. Whether this is more or less than expected is difficult to say; there is limited comparable international evidence seeing that municipal bonds is a less common asset type.[9]

The accumulated effect on the government bond yield on the announcement days is a reduction of 41 to 48 basis points (depending on whether eight or eleven announcement days are considered). Keeping in mind that this constituted purchases of approximately 7 percent of Swedish GDP, we can compare this to some international numbers. Estimates of the effect of the Bank of England's asset purchases in 2009 and 2010 – which corresponded to approximately 14 percent of UK GDP – have been provided by Joyce *et al.* (2011) who suggested that the yield on long-run gilts fell by approximately 100 basis points. An effect around 100 basis points was also found for ten-year US Treasury bond yields by Gagnon *et al.* (2011) when studying the Federal Reserve's LSAP programs which – when measured as a share of US GDP – were of a similar size (12 percent) to the purchases of the Bank of England.[10] Compared to the effects on government bonds in the United Kingdom and the United States, the effect in Sweden hence appears to be of a similar magnitude or somewhat smaller (though one obviously should not overinterpret differences in point estimates). Finally, we note that the accumulated effect on the municipal bond yield on the announcement days was a reduction of 30 to 35 basis points.

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[9] As was pointed out in the introduction, we expect different types of assets to move with a different magnitude than the asset class being purchased. The results in Joyce *et al*. (2011) suggest that UK investment grade corporate bond yields fell approximately one-for-one with the yield on gilts with a similar maturity in response to the Bank of England's asset purchases. Non-investment grade corporate bond yields, on the other hand, fell by more than the yield on gilts, leading to a substantial reduction in the yield spread.

[10] It can be noted that Gagnon *et al*. (2011) provide several estimates based on different methods. This number refers to the results in Table 7 in their article.

4. VAR Analysis

Since we have reason to believe that the short-run changes in the municipal bond yield do not fully reflect the long-run effects, we now turn to VAR analysis in order to see how the yields have been related when we also look outside the event window. This analysis will be conducted both under the assumption that the yields are integrated or order one and that they are mean reverting. The reason for this choice is the stylised fact that nominal interest rates are highly persistent. In fact, they are so persistent that they often have been modelled as unit-root processes and have had cointegration techniques applied to them; see, for example, King *et al.* (1991), Bremnes *et al.* (2001), Liu *et al.* (2008) and Tsong and Lee (2013). However, there are good theoretical reasons why an assumption of a unit root in nominal interest rates can be questioned. For instance, many economic models predict that real interest rates have a long-run equilibrium value – a fact which, if combined with a stationary inflation target, means that nominal interest rates should be mean reverting. There is accordingly also a literature questioning the unit root in interest rates; see, for example, Wu and Zhang (1996) and Wu and Chen (2001). A highly reasonable alternative is that the yields are mean reverting processes but have very high persistence, that is, they are *near-integrated* processes.[11] It is well known that it is difficult to empirically distinguish near-integrated time series from those with a unit root. We therefore believe that it is reasonable to proceed with the analysis under both assumptions to see how this affects the results.

But we first want to confirm that the stylised fact of highly persistent interest rates is a feature of the data employed here. This is done by applying two standard unit-root tests to the yields using the full samples, namely the Augmented Dickey-Fuller test, (Said and Dickey, 1984) and the KPSS test (Kwiatkowski *et al.*, 1992). The Augmented Dickey-Fuller test has a unit root under the null hypothesis, whereas the KPSS test has stationarity under the null. Employing these two tests, mean reversion to a constant level is tested for. Lag length in the test equations for the Augmented Dickey-Fuller test was established using the Schwarz (1978) information criterion. As can be seen from Table 2, both tests conclude that both series are unit-root processes. This clearly indicates that our yield data are highly persistent.

Table 2. Results from unit-root tests.

	i_t^m	i_t^g
ADF	-2.04	-2.44
KPSS	1.32[a]	0.80[a]

Note: The table gives the test statistics from the Augmented Dickey-Fuller and KPSS tests. "a" indicates significance at the one percent level; "b" indicates significance at the five percent level.

[11] For a further discussion regarding near-integrated time series and examples of analysis, see, for example, Phillips (1988), Stock (1991), Lanne (2000) and Beechey *et al*. (2009.

4.1 VAR Analysis Assuming Yields that are Integrated of Order One

Seeing that the unit-root tests suggested that both yields are unit-root processes, we first study the dynamic relation between the yields under the assumption. Our methodological framework in this setting will be a cointegrated VAR model. While cointegration techniques have not been frequently used in the literature studying how various interest rates have been affected by central bank asset purchases, they have not been an uncommon choice when it comes to the fairly closely related issue of evaluating the pass-through of the central bank's policy rate onto other interest rates in the economy; studies conducted by, for example, de Bondt (2005), Karagiannis *et al.* (2010), Belke *et al.* (2013) and Gambacorta *et al.* (2015) all relied on cointegration techniques to investigate this matter empirically.

The model is given as

$$\Delta \boldsymbol{y}_t = \boldsymbol{\kappa} + \boldsymbol{\Pi} \boldsymbol{y}_{t-1} + \boldsymbol{B}_1 \boldsymbol{\Delta} \boldsymbol{y}_{t-1} \ldots + \boldsymbol{B}_p \boldsymbol{\Delta} \boldsymbol{y}_{t-(p-1)} + \boldsymbol{u}_t \qquad (3)$$

where $\boldsymbol{y}_t = \begin{pmatrix} i_t^g & i_t^m \end{pmatrix}'$ is the 2x1 vector of endogenous variables that we are modelling; as above i_t^g is the five-year government bond yield and i_t^m is the five-year municipal bond yield. $\boldsymbol{\kappa}$ is a 2x1 vector of intercepts, $\boldsymbol{B_1}, \ldots, \boldsymbol{B}_{p-1}$ are 2x2 matrices whose parameters describe the short-run dynamics of the model and $\boldsymbol{u_t}$ is a 2x1 vector of disturbances, $\boldsymbol{u}_t \sim N(\boldsymbol{0}, \boldsymbol{\Omega})$. If the coefficient matrix $\boldsymbol{\Pi}$ has a rank of unity, we have cointegration and there exist two 2x1-vectors, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$, such that $\boldsymbol{\Pi} = \boldsymbol{\alpha\beta}'$ and $\boldsymbol{\beta}' \boldsymbol{y}_t$ is stationary.[12] $\boldsymbol{\beta}$ is the cointegrating vector; $\boldsymbol{\alpha}$ contains the adjustment parameters. When estimating the model, $\boldsymbol{\kappa}$ is restricted such that we allow for a constant in the cointegrating relationship but no drift in the data. The lag length in the model was established using the Schwarz (1978) information criterion and set to $p - 1 = 1$.[13]

We test for cointegration using Johansen's (1988, 1991) framework, presenting results for both the trace test and the maximum eigenvalue test. As can be seen in Table 3, both tests suggest that there is one cointegrating vector in the system. This is very much in line with what we would expect *ex ante*; it is reasonable to assume that the same stochastic trend – reflecting wider macroeconomic developments – drives the two

[12] If the matrix $\boldsymbol{\Pi}$ has a rank of zero, there is no cointegration. If $\boldsymbol{\Pi}$ has full rank (that is, two), both variables in the model are stationary.

[13] Relying on this lag length, the residuals from the model are not white noise according to the Portmaneau test. If, for example, the null hypothesis that there is no residual autocorrelation up to lag four is tested, the null hypothesis is rejected at the five percent level. While this finding should not be ignored, we do not find it highly problematic. It is common to find some autocorrelation in the residuals when using VARs and it should also be noted that what the Schwarz information criterion says is that this remaining autocorrelation is not worth modelling.

yields.[14] We accordingly move on to estimate the VAR under this restriction using maximum likelihood. Key estimation results are shown in Table 4.

Table 3. Results from cointegration tests.

	Trace	Maximum eigenvalue
r=0	26.19[a]	19.54[b]
r=1	6.65	6.65

Note: The table gives the test statistics from the Johansen trace and maximum eigenvalue tests for cointegration. For "r=0", the null hypothesis of a cointegrating rank of zero is tested; for "r=1", the null hypothesis of a cointegrating rank of unity is tested. "a" indicates significance at the one percent level; "b" indicates significance at the five percent level.

Table 4. Estimated key parameters in cointegrated VAR.

κ	-77.650[a] (4.402)
β_1	-1.839[a] (0.226)
β_2	1.000 (-)
α_1	0.008 (0.006)
α_2	-0.007 (0.005)

Note: The table gives estimated key parameters from the cointegrated VAR model in equation (3). Standard errors in parentheses (). "a" indicates significance at the one percent level; "b" indicates significance at the five percent level.

Turning first to the estimated cointegrating vector, this is $\widehat{\boldsymbol{\beta}} = (-1.839, 1)'$ which implies that a reduction of the government bond yield by 10 basis points would be associated with a reduction in the municipal bond yield of almost twice as much in the long run.[15] The precision in this estimate is also reasonably high. It should be noted though that the properties of the model reflect all shocks that have hit the system during the sample. This means that shocks which are caused by government bond purchases are treated no differently from other shocks to the equation for the government bond yield. One accordingly might want to take

[14] As has been pointed out by, for example, Hjalmarsson and Österholm (2010), Johansen's cointegration tests can be subject to size distortions when the variables in the system are not unit-root processes but near-integrated processes. In this particular application, we believe that the risk of spurious relationships being confirmed is limited though as we have good reason to believe that the variables in question should be intimately related; it is certainly not unreasonable to assume that they are driven by a common trend. In order to reduce the risk of drawing erroneous conclusions, we nevertheless follow the recommendation of Hjalmarsson and Österholm (2010) and conduct tests of the hypotheses $\boldsymbol{\beta} = (1,0)'$ and $\boldsymbol{\beta} = (0,1)'$; both of these hypotheses imply that if a single cointegrating vector is found in the system, this is due to a stationary variables in the system, not cointegration between the two variables. As can be seen from Table 5 though, both of these hypotheses are rejected.

[15] The constant of the cointegrating relationship has been omitted for notational convenience.

some caution when interpreting the cointegrating vector. Nevertheless, if shocks originating in unconventional monetary policy are similar in kind to the other shocks to the government bond-yield equation, the reasonable conclusion to draw is that the long-run effect on the municipal bond yield is likely to be larger than the short-run effect which was reported in Section 3.[16]

The more detailed dynamics of the model are illustrated through the impulse-response functions in Figure 3 which shows the effect that a shock to the government bond yield has on the two yields.[17] As can be seen, the profiles of the two impulse-response functions in Figure 3 are quite different from each other. The effect on the government bond yield starts wearing off after two periods whereas the effect on the municipal bond yield keeps increasing with time. The implications of the impulse-response functions for the municipal bond-yield spread are shown in Figure A3 in Appendix C. It can be noted that in light of a *negative* shock to the government bond yield – which is what an unexpected bond-purchase announcement by the Riksbank should be thought of – the estimated model implies that initially, the municipal bond-yield spread would increase. (Recall that the impulse-response functions are plotted for a positive shock.) This finding is consistent with what we found in the event study in Section 3. After this initial increase, the municipal bond-yield spread would turn negative after 18 business days and then stay negative. The fact that the effects of the shock are permanent is of course due to the assumption of yields being unit-root processes.

Returning to the estimated cointegrating vector, we note that this is unlikely to be valid globally since it implies an implausibly high level of the municipal bond yield for a level of the government bond yield considered more normal historically. For example, a government bond yield of 4.5 percent would be associated with a municipal bond yield of approximately 9 percent. So while we believe that the cointegrating vector might be valid locally – that is, in the present regime with extremely low interest rates – the relation between the two yields is likely to look differently in "normal" times. While it does not appear unreasonable to model the cointegrating relation with constant parameters using the present sample, we argue that there is some kind of time variation in the relation when looking at longer periods.[18] The estimated cointegrating vector could therefore perhaps be used as evidence against the modelling of interest rates as unit-root processes.

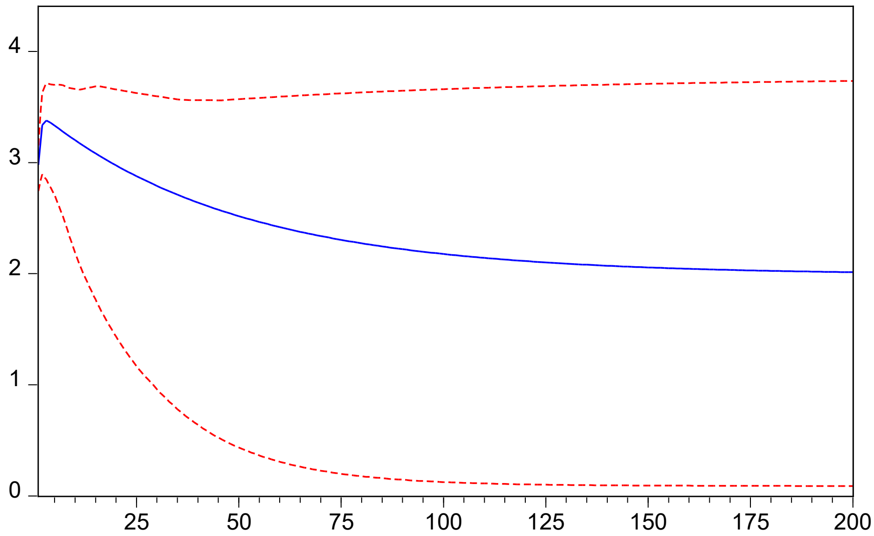
[16] It can be noted that while the results in Section 3 indicate that the effect on announcement days is different from that of other days, the results from our sensitivity analysis in Section 5 suggest that this is not the case.

[17] We use a Cholesky decomposition for the impulse-response functions.

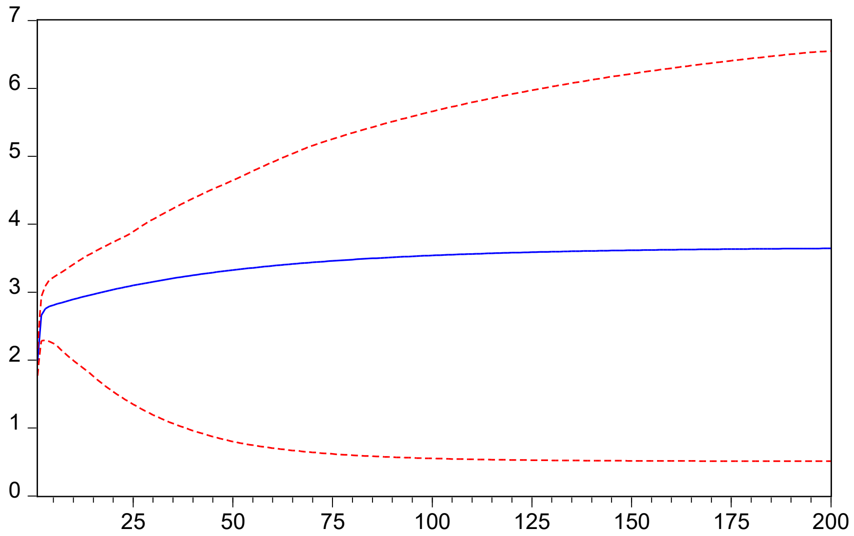
[18] Discussions of time-varying cointegrating relations and examples thereof can be found in, for instance, Bierens and Martins (2010) and Jochmann and Koop (2013).

Figure 3. Impulse-response functions from the cointegrated VAR in equation (3).

Response of government bond yield to shock in government bond yield



Response of municipal bond yield to shock in government bond yield



Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Dashed bands are ±2 standard errors.

While it is natural to see the central bank's policy rate as driving other interest rates in the economy, there is a less clear-cut causality regarding the yields being studied in this paper. Even if it from a monetary policy perspective is more intuitive to think of government bond yields as driving municipal bond yields – the central bank has after all purchased government bonds with a purpose to affect the price and yield on other assets – it seems reasonable to assume that both yields could not only affect each other but also both adjust in order to remove disequilibria. As can be seen from Table 4, the two error-correction terms were estimated with fairly low precision. Testing that they are zero (one at a time), we find that the null hypothesis is not rejected in either of the two cases; see the results in Table 5.[19] Based on the results in Table 5 though, it is not obvious which, if any, of these restrictions that should be placed on $\boldsymbol{\alpha}$. We accordingly leave $\boldsymbol{\alpha}$ unrestricted in our estimations.

Table 5. Test results from imposed restrictions on cointegrated VAR in equation (3).

Restriction	Test statistic
$\beta_1 = -1, \beta_2 = 1$	9.00[a]
$\beta_1 = 1, \beta_2 = 0$	4.90[b]
$\beta_1 = 0, \beta_2 = 1$	11.16[a]
$\alpha_1 = 0$	1.09
$\alpha_2 = 0$	1.35

Note: The table gives test statistics from likelihood ratio tests of the restriction in question.

With this in mind, we again return to the cointegrating vector. Table 5 shows that the hypothesis that the municipal bond-yield spread has been stationary during the sample – that is, that the cointegrating vector is $\boldsymbol{\beta} = (-1, 1)'$ – is forcefully rejected by the data. This is of course not surprising given the point estimate reported in Table 4 and the fairly high precision with which it was estimated. The spread is illustrated in Figure 4 and as can be seen, it did not move much during the first part of sample; between February and May 2015, it hovered around 60 basis points. It then rose to more than 90 basis points in July 2015 and stayed reasonably large until October the same year when it started falling. It has been on a downward trajectory since then and is approximately 55 to 60 basis points at the end of the sample.

Are there economic reasons which can explain the evolution of the municipal bond yield spread and thereby help us understand our estimated cointegrating vector? Given our methodological framework, we have look beyond the model in order to answer this question; while our chosen framework has several benefits, its highly reduced form means that it is not well suited to give detailed economic explanations. Before discussing explanations, it can also be noted that while we focus on Sweden, the evolution is unlikely to have been driven solely by developments in Sweden seeing that international corporate bond yield spreads have evolved in a somewhat similar manner during the time period in question.

[19] Restricting one of the error-correction terms in the model to be zero affects the estimate of the other error-correction term: When imposing the restriction $\alpha_1 = 0$, we get an estimate of α_2 which is -0.015 with a standard error of 0.003. Similarly, when the restriction $\alpha_2 = 0$ is imposed, we get an estimate of α_1 which is 0.011 with a standard error of 0.003.

Figure 4. Municipal bond-yield spread.

Note: Spread is given in basis points.

One extra-model explanation that is highly likely to have contributed to the decrease in the spread which has taken place since the autumn of 2015 is search for yield by investors. As the yield on government bonds has become extremely low – where the five-year yield at times has even been in negative territory – some investors have likely turned to municipal bonds instead of government bonds, thereby pushing down the yields on the former (and the spread between them);[20] the bonds should be reasonable substitutes for many investors as Kommuninvest is rated Aaa by Moody's and AAA by Standard and Poor's. Furthermore, both government and Kommuninvest issued bonds are categorized as being "Level 1" assets in the Basel III liquidity coverage ratio regulation, implying that both asset are viewed as being highly liquid. This fact further strengthens the argument that investors would view these bonds as being reasonable substitutes. A second explanation for why the spread has decreased it that the liquidity premium likely has increased over time on government bonds as liquidity on government bonds has deteriorated. The deteriorated liquidity is partly explained by the Riksbank's purchases of government bonds; the Riksbank presently owns a substantial share of the stock of government bonds with a maturity of ten years or shorter.[21] In terms of interpreting our results, we note that the share of the reduced spread which originates in decreased liquidity due to the Riksbank's bond purchases should be seen as an effect of the unconventional monetary policy.

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[20] That investors search for yield has been established by, for example, Ammer *et al*. (2018) and Lian *et al*. (2018). It is of course also a reasonable assumption to make given that many investors and fund managers may have a nominal return requirement that they are to meet.

[21] Other factors also contribute to the deterioration in liquidity, such as financial market regulations and a lower volume of government debt being issued (due to stronger government finances); see, for example, Swedish National Debt Office (2018) for a discussion.

In a similar manner, the liquidity premium on municipal bonds may have decreased during this period as demand for them has increased. The liquidity premium on municipal bonds could, however, change for other reasons too. For example, six new members joined Kommuninvest during 2016 and two more during 2017. (During 2015, the number of members was unchanged.) One effect of new members is that Kommuninvest lending and issuing volumes are likely to increase. Since liquidity is usually positively correlated with issuing volume this would likely reduce the liquidity premium. During 2016 and 2017, the Kommuninvest issuing volume in the Swedish market increased by 22.8 billion SEK and 12.2 billion SEK respectively. It is not impossible that this decreased the liquidity premium on municipal bonds but it can also be noted that these numbers are smaller than the increase in issuing which took place during 2015 – namely 38.2 billion SEK – which coincided with an increasing municipal bond spread on average. Finally, we also note that the inclusion of new Kommuninvest members may have a positive or negative effect on the credit risk premium depending on the creditworthiness of the new members. The new members who joined in 2016 and 2017 were relatively small though and few in comparison to the total number of Swedish sub-sovereigns. Their membership is accordingly unlikely to have had any substantial effect on the Kommuninvest credit risk premium.[22]

Summing up, we conclude that our cointegration analysis suggests that the long-run effect on the municipal bond yield is larger than what the analysis in the event study suggested. It does not seem unlikely that government bond purchases in Sweden from a monetary policy perspective would be associated with a more than proportional reduction in the yield of municipal bonds at longer horizons and, accordingly, a reduction in the municipal bond-yield spread.

4.2 VAR Analysis Assuming Stationary Yields

Having conducted analysis under the assumption of a unit root in yields, we next follow the more theoretical line of reasoning from above and assume that interest rates are mean reverting. The natural tool for our analysis then becomes a VAR model in levels. We accordingly specify the bivariate model

$$\boldsymbol{y}_t = \boldsymbol{\mu} + \boldsymbol{A}_1 \boldsymbol{y}_{t-1} \dots + \boldsymbol{A}_p \boldsymbol{y}_{t-p} + \boldsymbol{e}_t \quad (4)$$

where $\boldsymbol{y}_t = \begin{pmatrix} i_t^g & i_t^m \end{pmatrix}'$ is the 2x1 vector of endogenous variables. i_t^g and i_t^m are defined as before. $\boldsymbol{\mu}$ is a 2x1 vector of intercepts, $\boldsymbol{A}_1, \dots, \boldsymbol{A}_p$ are 2x2 matrices whose parameters describe the dynamics of the model and $\boldsymbol{e}_t$ is a 2x1 vector of disturbances, $\boldsymbol{e}_t \sim N(\boldsymbol{0}, \boldsymbol{\Sigma})$. Based on the Schwarz (1978) information criterion, we employ a lag length of $p = 2$.[23]

[22] In total there are 290 Swedish municipalities and 21 counties.

[23] Also for this model can it be noted that the residuals are not white noise according to the Portmaneau test.

We turn straight to the information that we are primarily interested in – namely the impulse-response functions – and focus on the effect of a shock to the government bond yield (since, as was pointed out above, the government bond purchases should manifest as such shocks). Just like in Section 4.1, the shocks which are caused by government bond purchases are treated no differently from other shocks to the equation for the government bond yield and we accordingly assume that the shocks affect the system in the same way. Figure 5 shows the impulse response functions.[24] As can be seen, a one-standard deviation shock to the government bond yield initially moves the government bond yield more than the municipal bond yield; the initial reaction is 2.98 and 1.99 basis points respectively. The effect on the two yields increases somewhat for the following two periods but then decreases with time. The decrease is, however, more rapid in the government bond yield.[25]

The implications of the impulse-response functions for the municipal bond-yield spread, are shown in Figures A4 and A% in Appendix C.[26] These indicate that a *negative* shock to the government bond yield initially would increase the municipal bond-yield spread. (Again recall that the impulse-response functions are plotted for a positive shock.) After 18 business days though, the effect on the spread would become negative (still judging by the point estimates). The maximum effect in terms of compressing the municipal bond-yield spread comes after 75 business days when the spread is 0.77 basis points lower. A significant decrease in the municipal bond-yield spread is established up until 123 days after the shock; see Figure A3.

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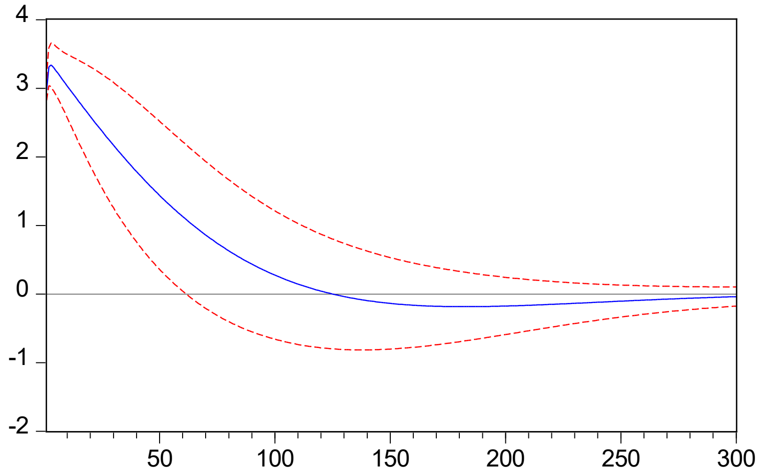
[24] Also here we use a Cholesky decomposition for the impulse-response functions.

[25] The effect of the shock appears to have a half life of 48 business days for the government bond yield and 99 business days for the municipal bond yield. This can be compared to the effect that Wright (2012) estimated that unconventional monetary policy shocks had on the ten-year government bond yield in the United States. He suggests that the half-life of shocks was approximatly two months. This conclusion has been questioned by Neely (2016) though who argues that the half life is higher.

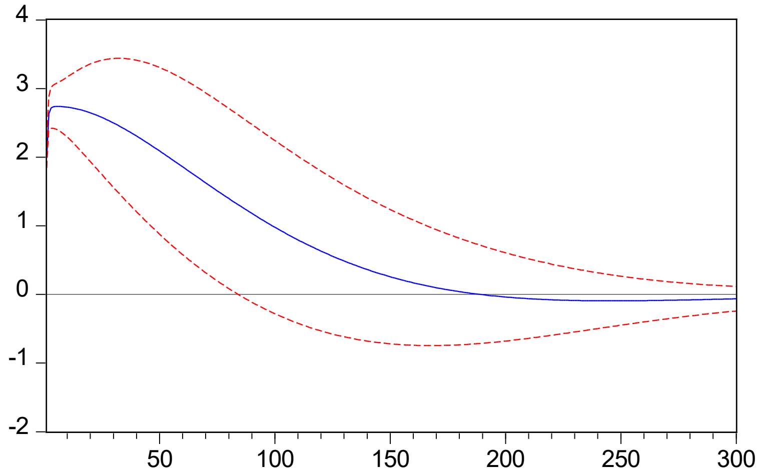
[26] In Figure A2, we simply present point estimates based on the difference between the point estimates in the bottom and top panels of Figure 5. Figure A3 instead presents the impulse-reponse function of the municipal bond-yield spread with respect to a shock to the government bond yield calculated based on a bivariate VAR model according to equation (4) but where the vector of dependent variables is given by $\boldsymbol{y}_t = (i_t^g \quad s_t^m)'$. Such a specification allows us to calculate standard errors for the impulse-response function in question.

Figure 5. Impulse-response functions from the VAR in equation (4).

Response of government bond yield to shock in government bond yield



Response of municipal bond yield to shock in government bond yield



Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Dashed bands are ±2 standard errors.

In line with what we saw in Section 4.1, the model hence suggests that a negative shock to the government bond yield generates a compression of the municipal bond-yield spread with a bit of a delay. We conclude this analysis by noting that this finding is consistent with investors taking their time to reallocate portfolios in light of shocks.

5. Sensitivity Analysis Using Data Based on Smoothing Spline

As pointed out in Section 2, we rely on the Nelson and Siegel (1987) model in our main analysis in Sections 3 and 4. In order to see how sensitive our findings are to the choice of yield-curve estimation method, we also conducted the same analysis using data based on a smoothing spline. Using spline-based techniques for estimating term structures has a long history and has been investigated by numerous researchers; see, for example, McCulloch (1971, 1975), Fong and Vasicek (1982), Shea (1984) and Fisher *et al.* (1995).[27] The methodology is briefly described in Knezevic *et al.* (2019). The results from this analysis are given in Figures A6 to A12 and Tables A2 to A6 in Appendix D and show that our findings appear robust with respect to the choice of method for yield curve estimation.

For the event study, we find that accumulated effect based on all events is -49 basis points for the government bond yield and -37 basis points for the municipal bond yield. Excluding the last three announcements, we instead get -43 and -30 basis points respectively. That is, we get a very similar picture to that painted with the Nelson-Siegel data. One minor difference can be noted though: We cannot reject the null hypothesis that ϕ is zero – that is, the relation is the same on days of announcements as on other days.

Turning to the VAR analysis, we note that the results support the same conclusions that were drawn in Section 4. Minor quantitative differences exist of course. For example, the estimated cointegrating vector, $\hat{\boldsymbol{\beta}} = (-2.243, 1)'$, implies a larger long-run effect than what we found when using the Nelson-Siegel data but given the uncertainty of the two estimates this difference should not be exaggerated. In addition, the null hypothesis that the cointegrating vector is $\boldsymbol{\beta} = (1, 0)'$ cannot be rejected at the five percent level; that is, there is some evidence that the government bond yield might be stationary.

6. Conclusions

In the aftermath of the financial crisis, the Riksbank has – like several other central banks – made substantial purchases of government bonds. As these purchases push down yields on government bonds, investors are expected to rebalance their portfolios and turn to other types of assets, thereby causing yields on other bonds to fall as well. In this paper, we have investigated how the yield on an important Swedish asset class – Kommuninvest of Sweden's municipal bonds – has been related to the government bond yield during the period of the Riksbank's asset purchases.

The results from our event study indicate that the municipal bond yield moves less than the government bond yield on announcement days; a ten basis point reduction in the government bond yield seems to be associated with a reduction in the municipal bond yield of approximately 8.4 basis points. This analysis also suggests that the cumulative short-run effect of the Riksbank's bond purchase announcements has been to lower government bond yields with 40 to 50 basis points and municipal bond yields with 30 to 35 basis points. Scaling the purchases by GDP, the effect on the government bond yield is quantitatively similar to what was achieved by the Federal Reserve and the Bank of England in their programmes.

[27] For a discussion of benefits and shortcomings of this method, see Waggoner (1997).

Portfolio reallocation in light of unconventional monetary policy is, however, unlikely to be completed within the event window. We therefore also conducted bivariate VAR analysis of the municipal and government bond yields in order to assess their dynamic relationship. Regardless of whether yields were assumed to be generated by a unit-root process or mean reverting, our results suggest that with some delay the municipal bond-yield spread would decrease in light of an unexpected decrease in the government bond yield. The findings in this paper are consistent with the process of rebalancing portfolios not being an excessively swift process.

To conclude, it seems that the Riksbank's purchases of government bonds have had the desired effect. The transmission of lower interest rates, from government bonds to other types of bonds, works even if our analysis indicates that it is a process which may take some time before the full effect is reached. That said, it is not the case that this type of unconventional monetary policy is unproblematic. Search for yield is likely to increase the risks in the financial system; see, for example, Rajan (2005), Borio and Zhu (2012) and Bernanke (2013). This might be somewhat less problematic in this specific case seeing that Kommuninvest of Sweden has a top rating and that its creditworthiness is backed by the right of its members to levy taxes. Another negative aspect worth considering – which appears to be empirically relevant in Sweden – is that the purchases have contributed to lower liquidity of government bonds. As pointed out by the Swedish National Debt Office (2018), a further deterioration in the liquidity of Swedish government bonds might cause investors to leave the market which could result in higher borrowing costs increased risks due to poorer borrowing preparedness. This is relevant to keep in mind since unconventional monetary policy measures are likely to have a role also in the future. It does not seem unlikely that a recession will hit the Swedish economy while the repo rate (the Riksbank's policy rate) is still at a low level, thereby leaving limited scope for conventional monetary policy. It is accordingly worth to keep in mind the trade-offs that different types of unconventional monetary policy are associated with.

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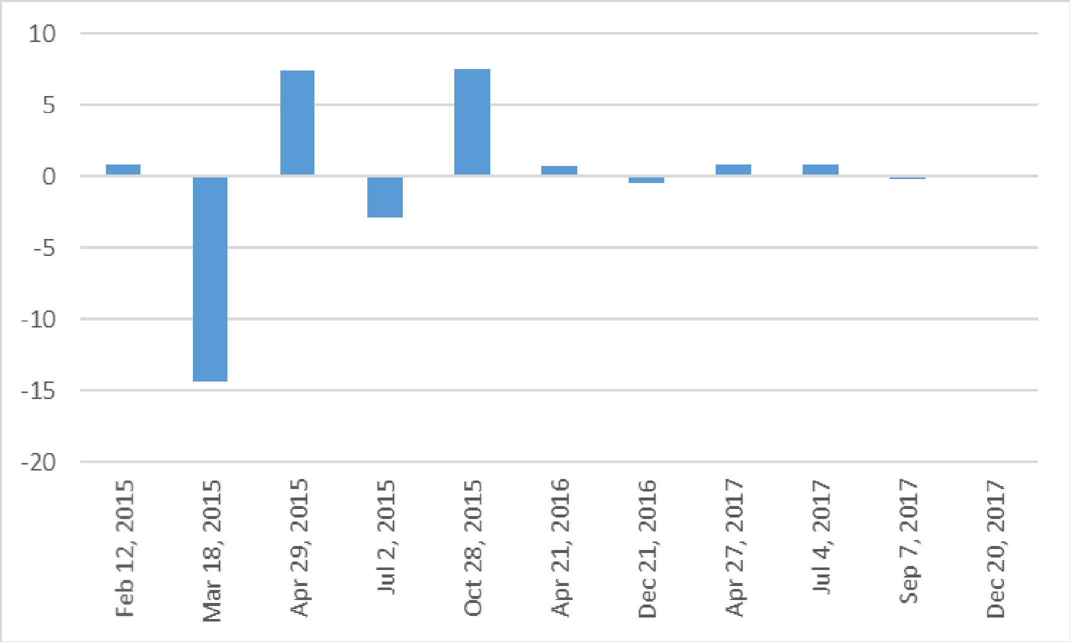
Appendix A – Monetary Policy Announcements

Table A1. Monetary policy announcements by the Riksbank.

Date	Repo rate	Repo rate change	Announcement (billion SEK)	Comments
Feb 12, 2015	-0.10%	-0.10	10	The Riksbank stated preparedness to further purchases at short notice.
Mar 18, 2015	-0.25%	-0.15	30	Unexpected meeting in-between two regularly scheduled meetings.
Apr 29, 2015	-0.25%	0	40-50	The Riksbank lowered the repo rate path markedly.
Jul 2, 2015	-0.35%	-0.10	45	Unexpected QE announcement. Market participants expected no further purchases.
Oct 28, 2015	-0.35%	0	65	
Apr 21, 2016	-0.50%	0	45	
Dec 21, 2016	-0.50%	0	30	
Apr 27, 2017	-0.50%	0		Announcement of bond purchases amounting to SEK 15 billion for the second half of 2017.
Jul 4, 2017	-0.50%	0		Announcement that purchases were to continue in accordance with the Apr 27, 2017 decision.
Sep 7, 2017	-0.50%	0		Announcement that purchases were to continue in accordance with the Apr 27, 2017 decision.
Dec 20, 2017	-0.50%	0		Announcement that coupons and nominal amounts are reinvested until further notice.

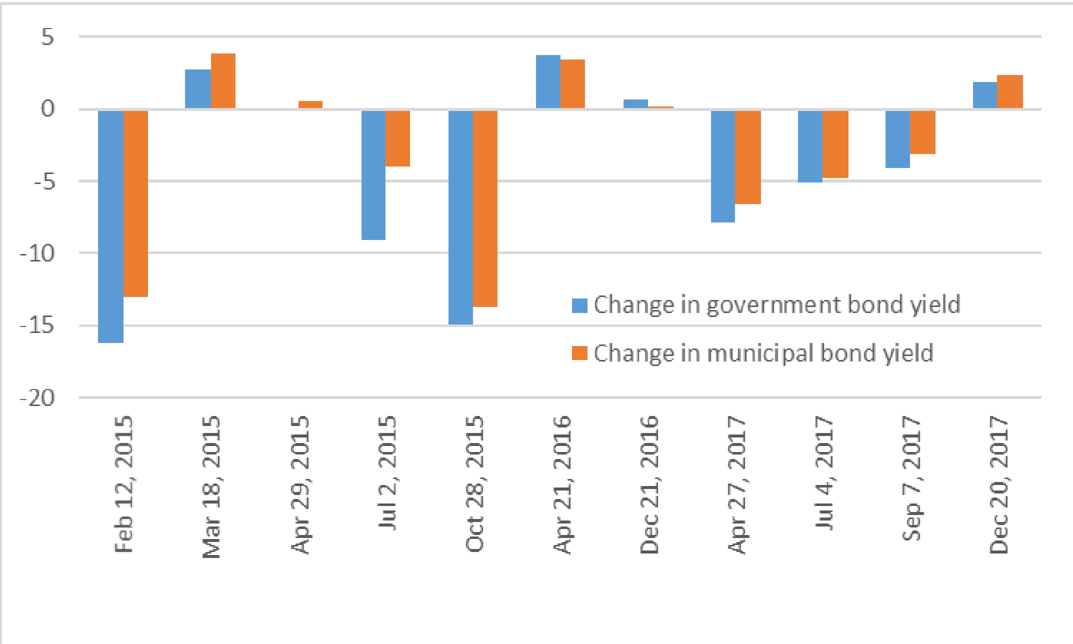
Appendix B – Repo-Rate Surprises and Adjusted Change in Five-Year Bond Yields

Figure A1. Repo-rate surprises.



Source: Sveriges Riksbank

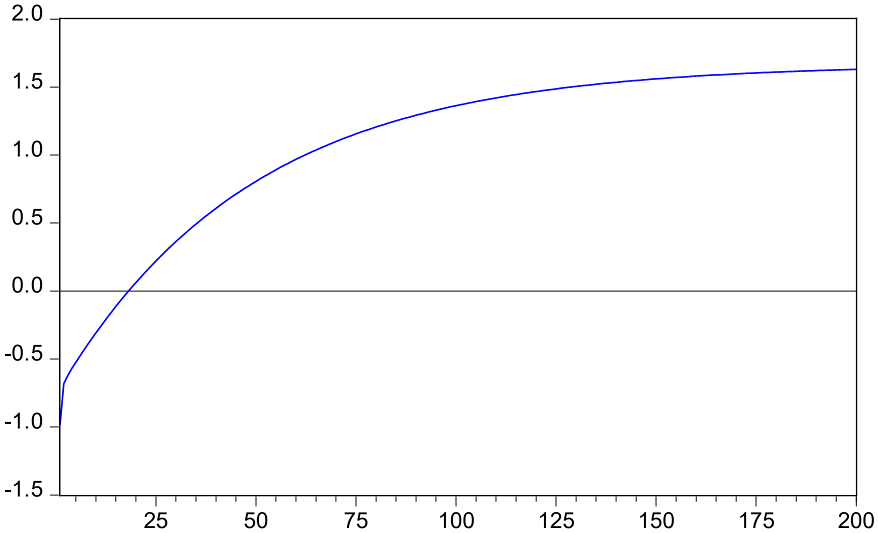
Figure A2. Change in five-year bond yields at announcement dates adjusted for repo-rate surprises.



Note: Change in yields is given in basis points.

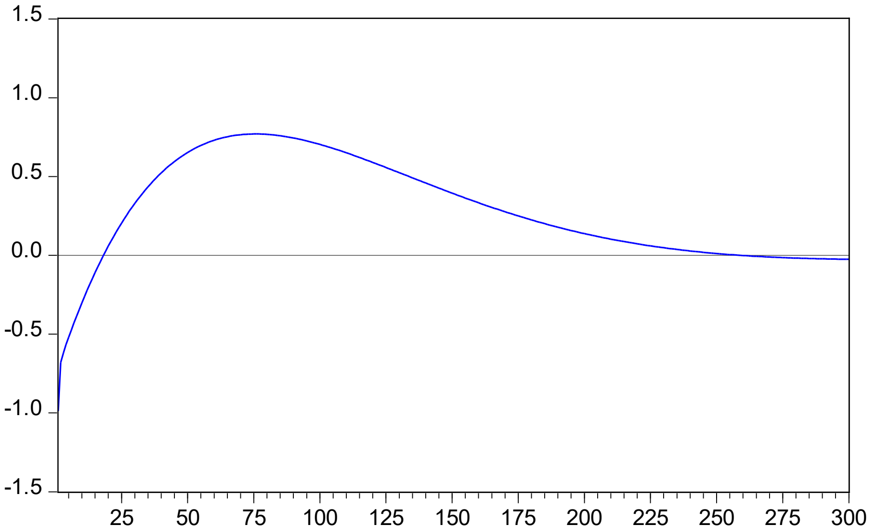
Appendix C – Effects on Municipal Bond-Yield Spreads from Government Bond-Yield Shock from Estimated VAR Models

Figure A3. Effect on municipal bond-yield spread based on the cointegrated VAR in equation (3).



Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Effect calculated by taking the difference between the point estimate in the bottom panel of Figure 3 and the top panel of Figure 3.

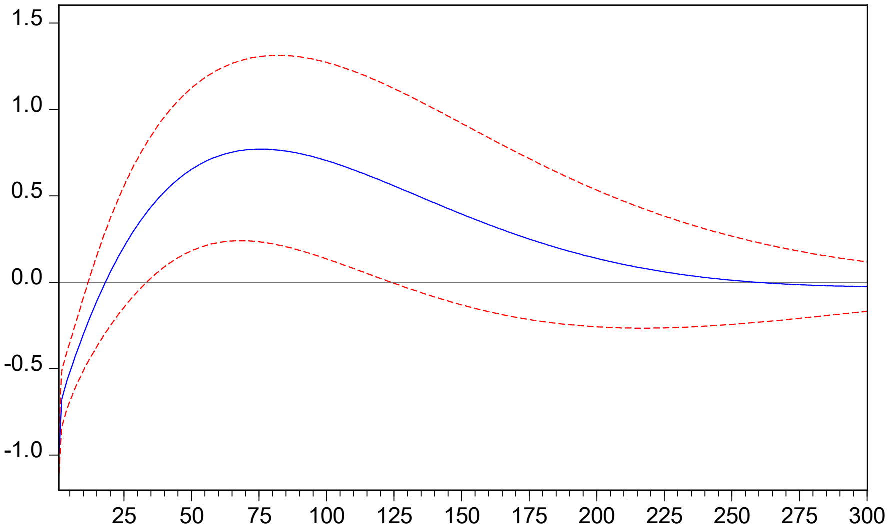
Figure A4. Effect on municipal bond-yield spread based on the VAR in equation (4).



Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Effect calculated by taking the difference between the point estimate in the bottom panel of Figure 5 and the top panel of Figure 5.

The effect in Figure A4 has been calculated by taking the difference between the point estimates in the bottom and top panels of Figure 5. However, rather than doing this, one can specify a bivariate model according to equation (4) but where the vector of dependent variables is given by $\boldsymbol{y}_t = \left(i_t^g \quad s_t^m\right)'$, where s_t^m is the municipal bond-yield spread, $s_t^m = i_t^m - i_t^g$. With this specification, we can calculate standard errors for the above impulse-response function; these are shown in Figure A5.

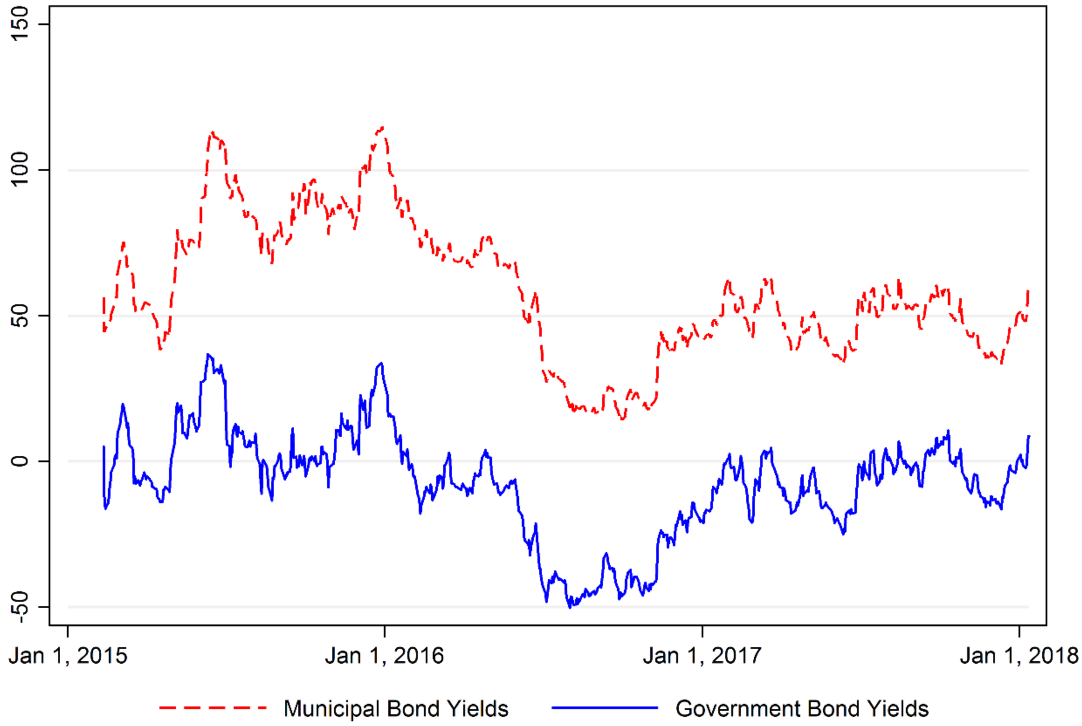
Figure A5. Effect on municipal bond-yield spread based on the VAR in equation (4) with $y_t = \left(i_t^g \quad s_t^m\right)'$.



Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Dashed bands are ±2 standard errors.

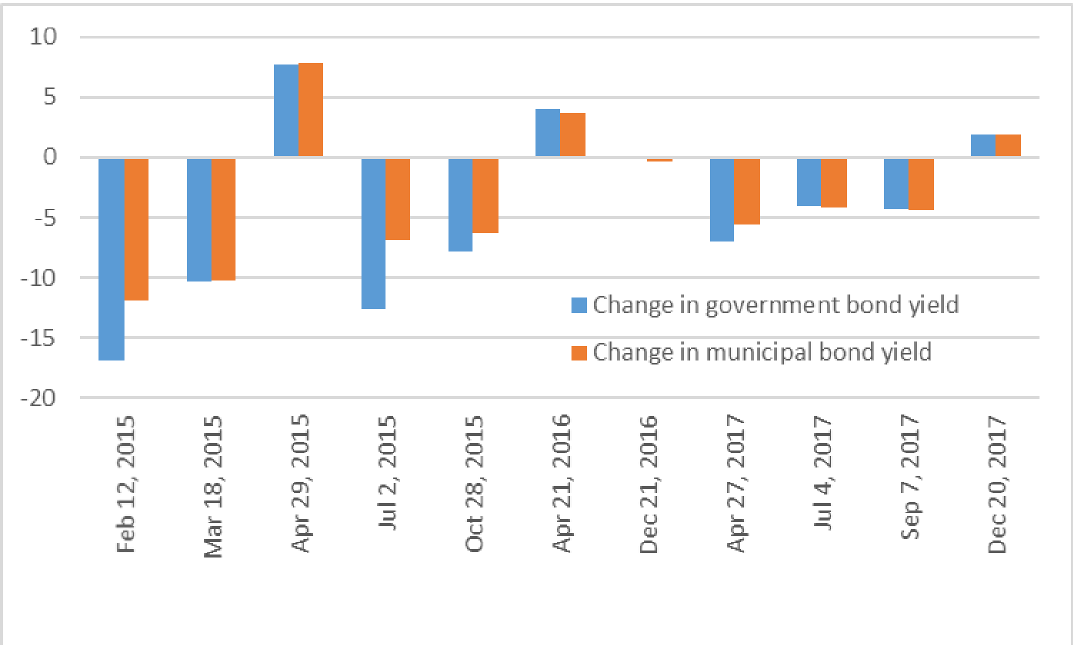
Appendix D – Results Using Smoothing Spline Data

Figure A6. Bond yields, smoothing spline data.



Note: Yields are given in basis points.

Figure A7. Change in five-year bond yields at announcement dates, smoothing spline data.



Note: Change in yields is given in basis points.

Table A2. Estimated key parameters from equations (1) and (2), smoothing spline data.

	Equation (1)		Equation (2)	
	11 announce-ments	8 announce-ments	11 announce-ments	8 announce-ments
δ	0.17 (0.41)	0.47 (0.44)	0.00 (0.06)	-0.00 (0.06)
θ	0.78[a] (0.04)	0.79[a] (0.04)	0.76[a] (0.02)	0.76[a] (0.02)
π	-	-	0.17 (0.38)	0.47 (0.44)
ϕ	-	-	0.02 (0.06)	0.02 (0.06)
# obs	11	8	736	736
R^2	0.94	0.95	0.73	0.73

Note: Note: Newey-West standard errors in parentheses (). "a" indicates significance at the one percent level; "b" indicates significance at the five percent level. Equation (1) is $\Delta i_t^m = \delta + \theta \Delta i_t^g + v_t$. Equation 2 is $\Delta i_t^m = \delta + \theta \Delta i_t^g + \pi D_t + \phi \Delta i_t^g D_t + v_t$. i_t^m is the five-year municipal bond yield, i_t^g is the five-year government bond yield and D_t is a dummy variable which takes on the value one on announcement days and zero otherwise.

Table A3. Results from unit-root tests, smoothing spline data.

	i_t^m	i_t^g
ADF	-1.90	-2.49
KPSS	1.39[a]	0.74[a]

Note: The table gives the test statistics from the Augmented Dickey-Fuller and KPSS tests. "a" indicates significance at the one percent level; "b" indicates significance at the five percent level.

Table A4. Results from cointegration tests, smoothing spline data.

	Trace	Maximum eigenvalue
r=0	22.32[b]	17.46b
r=1	4.86	4.86

Note: The table gives the test statistics from the Johansen trace and maximum eigenvalue tests for cointegration. For "r=0", the null hypothesis of a cointegrating rank of zero is tested; for "r=1", the null hypothesis of a cointegrating rank of unity is tested. "a" indicates significance at the one percent level; "b" indicates significance at the five percent level.

Table A5. Estimated key parameters in cointegrated VAR in equation (3), smoothing spline data.

μ	-76.000[a] (6.060)
β_1	-2.243[a] (0.311)
β_2	1.000 (-)
α_1	0.007 (0.005)
α_2	-0.001 (0.004)

Note: The table gives estimated key parameters from the cointegrated VAR model in equation (3). Standard errors in parentheses (). "a" indicates significance at the one percent level; "b" indicates significance at the five percent level.

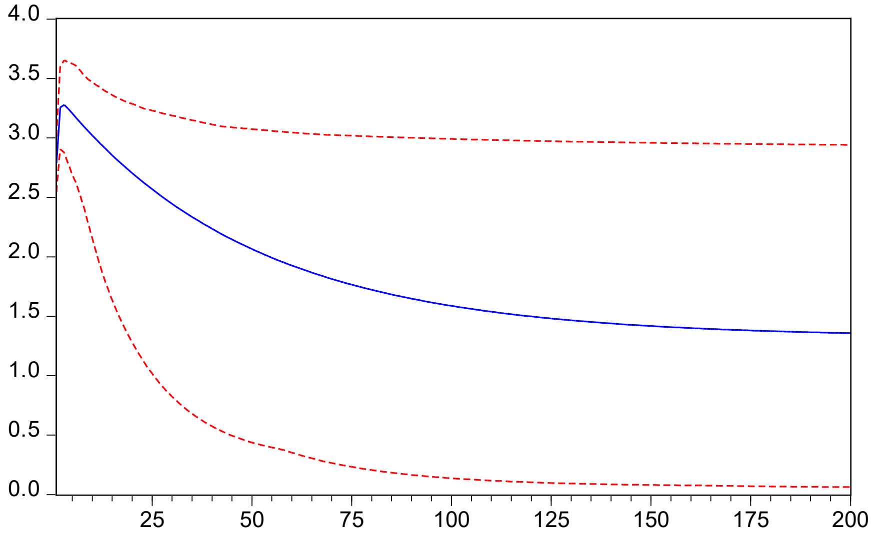
Table A6. Test results from imposed restrictions on cointegrated VAR in equation (3), smoothing spline data.

Restriction	
$\beta_1 = -1, \beta_2 = 1$	11.08[a]
$\beta_1 = 1, \beta_2 = 0$	3.41
$\beta_1 = 0, \beta_2 = 1$	9.87[a]
$\alpha_1 = 0$	1.59
$\alpha_2 = 0$	0.47

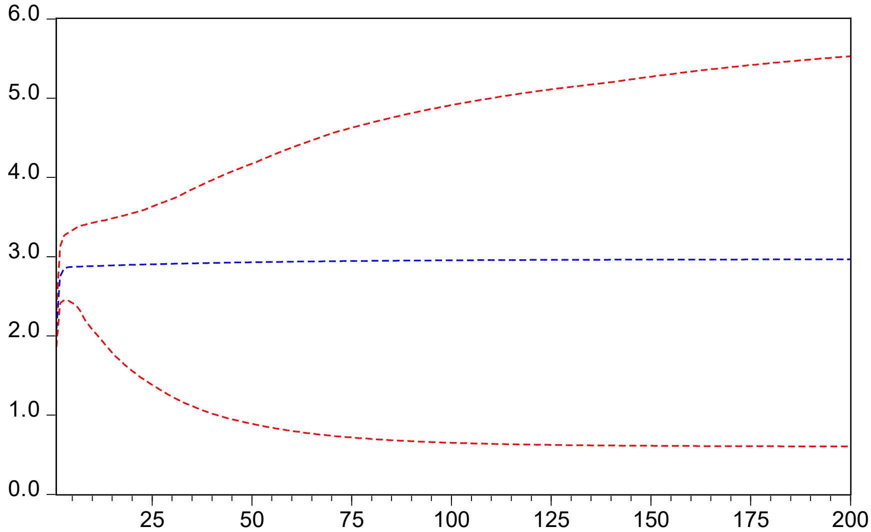
Note: The table gives test statistics from likelihood ratio tests of the restriction in question.

Figure A8. Impulse-response functions from the cointegrated VAR in equation (3), smoothing spline data.

Response of government bond yield to shock in government bond yield

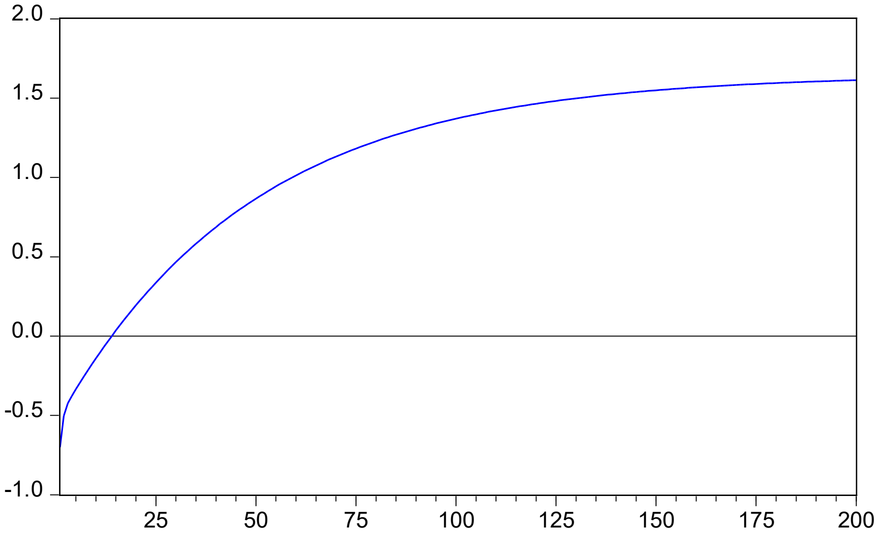


Response of municipal bond yield to shock in government bond yield



Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Dashed bands are ±2 standard errors.

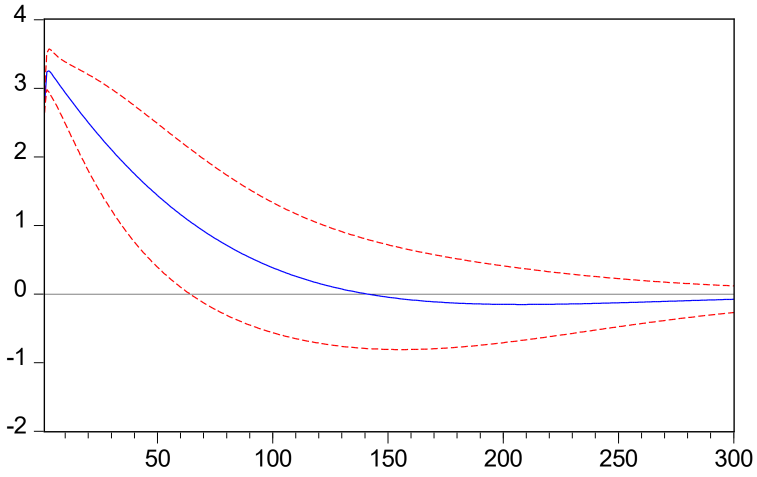
Figure A9. Effect on municipal bond-yield spread from government bond-yield shock based on the cointegrated VAR in equation (3), smoothing spline data.



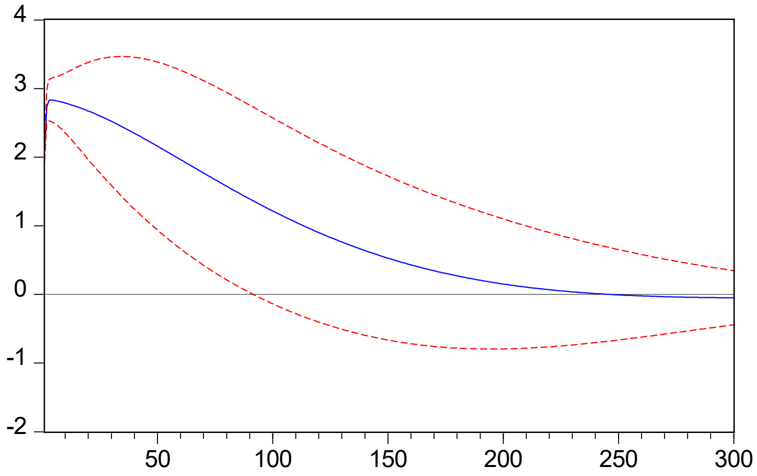
Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Effect calculated by taking the difference between the point estimate in the bottom panel of Figure A8 and the top panel of Figure A8.

Figure A10. Impulse-response functions from the VAR in equation (4), smoothing spline data.

Response of government bond yield to shock in government bond yield

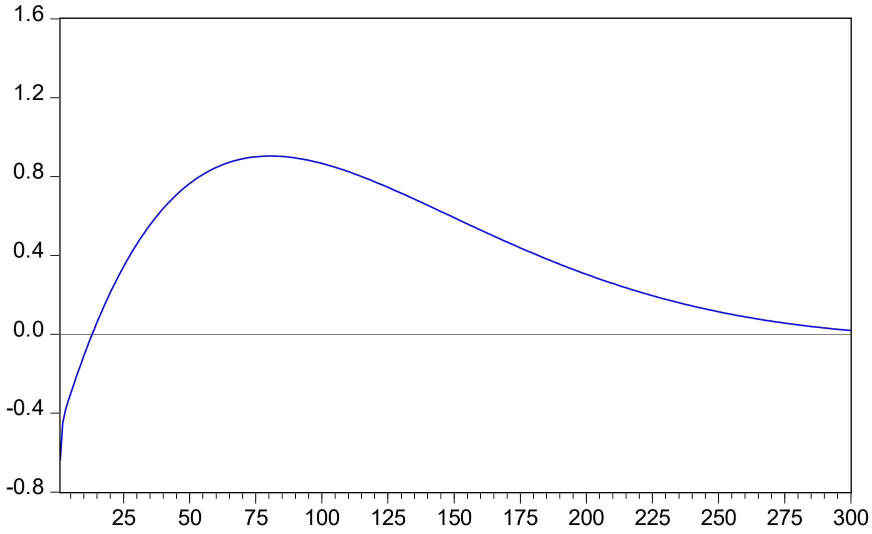


Response of municipal bond yield to shock in government bond yield



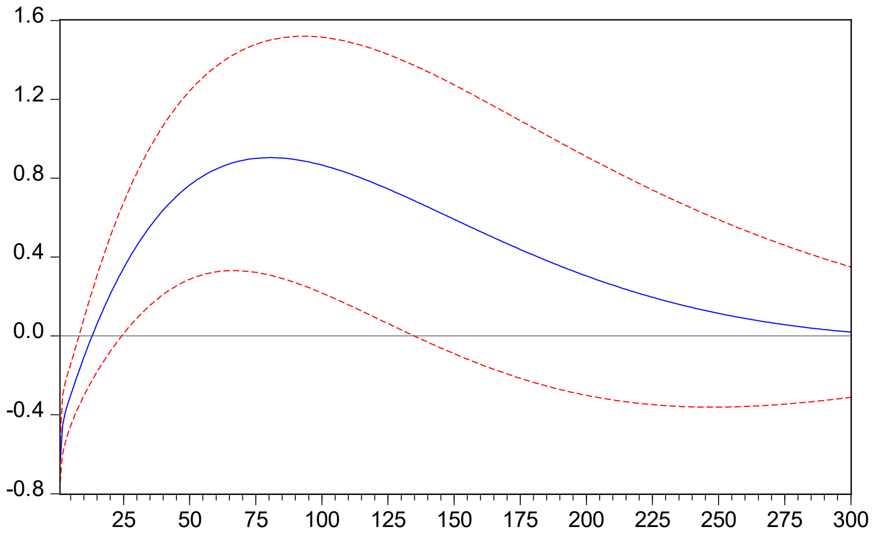
Note: Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Dashed bands are ±2 standard errors.

Figure A11. Effect on municipal bond-yield spread from government bond-yield shock based on the VAR in equation (4), smoothing spline data.



Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Effect calculated by taking the difference between the point estimate in the bottom panel of Figure A10 and the top panel of Figure A10.

Figure A12. Effect on municipal bond-yield spread from government bond-yield shock based on the VAR in equation (4) with $y_t = \left(i_t^g \quad s_t^m\right)'$, smoothing spline data.



Note: Basis points on vertical axis. Time in days on horizontal axis. Size of impulse is one standard deviation. Dashed bands are ±2 standard errors.