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When domestic and foreign QE overlap: evidence from Sweden*

Paola Di Casola† Pär Stockhammar‡

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Abstract

We estimate the effects of domestic and foreign quantitative easing (QE) programmes on a small open economy, Sweden, using a structural BVAR model. Domestic QE raised GDP, lowered unemployment and depreciated the currency, while effects on inflation are less clear. The ECB QE had large positive effects on both GDP and inflation in Sweden, also due to the endogenous response of domestic QE to the foreign one. In terms of transmission channels, domestic QE improved lending conditions for households and lowered expected future rates, while foreign QE improved financing conditions for firms.

Keywords: Quantitative Easing, international spillovers, transmission channels, small open economy, Bayesian VAR models.

JEL classification: E44, E52, F41, G15.

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1 Introduction

The Covid-19 pandemic has forced many central banks around the world to intervene to help the functioning of the financial markets and cut their interest rates close to the effective lower bound to stimulate the economy. The pandemic marked the return of unconventional monetary policy tools that were used during and after the Great Financial Crisis, such as large-scale asset purchases.[1] Sveriges Riksbank (the Swedish central bank) also restarted its asset purchase programme. While it is fairly straightforward to assess the effects of asset purchase programmes on the financial markets around the time of announcements, it has proven more difficult to evaluate their effects on the macroeconomy (Borio and Zabai, 2016). In a meta-analysis of the macroeconomic effects of asset purchases in the US, UK and the euro area provided by Fabo et al. (2020), effects are overall positive on output and inflation, but large variations exist across countries and across different methodologies (Di Casola, 2021).

Evaluating the effects of asset purchase programmes is particularly challenging in small open economies, which may be also subject to spillovers from asset purchase programmes conducted in large economies. This makes the estimation of the effects of domestic unconventional monetary policy more complex, since it gives room to an endogenous response to the foreign unconventional monetary policy in expectation of its domestic repercussions. Indeed, the literature on the effects of domestic and foreign asset purchases in small open economies is scarce.[2] Our paper fills this important gap in the literature, by estimating the effects on the Swedish economy of the Quantitative Easing (QE) programme conducted by Sveriges Riksbank and the ECB during the period 2015-2018. Sweden is a particularly interesting case to study,

[1] See Bernanke (2020) for a review of unconventional monetary policy tools used by the Fed and other central banks since the Great Financial Crisis. Bernanke (2009) distinguishes the asset purchases conducted for expansionary purposes, labelled as Quantitative Easing policy, from those conducted with the purpose of improving the functioning of those financial markets that are experiencing problems, known as Credit Easing.

[2] See Johnson et al. (2020) for an overview, where examples of small open economies are UK and Sweden.

because it is a small open economy strongly affected by shocks originating from its main trading partners, such as the euro area (Corbo and Strid, 2020).[3] Both asset purchases programmes were aimed at making monetary policy more expansionary and were not primarily aimed at improving the functioning of impaired financial markets (hence we label them QE). Moreover, interest rates in Sweden were cut into negative territory during the period the Riksbank purchased government bonds. Hence, QE was conducted at the same time as conventional monetary policy.

In order to address the specific features of the Swedish QE programme, we use a structural BVAR model with two identification schemes with impact restrictions, inspired by Weale and Wieladek (2016). One identification strategy relies on zero restrictions, while the other relies on zero and sign restrictions. The main benefit of this approach is the use of the cumulative announcement of purchases by *both* the ECB *and* the Riksbank, scaled by GDP, as proxy for QE, thereby accounting for the effects of foreign and domestic QE announcements in a BVAR model. The distinction of the two types of QE shocks relies on the assumption that only the Swedish QE programme was determined by Swedish economic conditions and the ECB QE programme — in line with the idea of a small open economy.

We find that the Riksbank QE programme had expansionary effects on the real economy, both in terms of output and unemployment, while the effects on prices are less clear, even though the Swedish krona weakened in real terms in response to QE. Using the scaling of purchases over GDP, the effects on output are comparable to the effects found in the empirical literature for the US, the euro area and UK. At the same time, the ECB QE programme had expansionary effects both on output and inflation in Sweden, despite the Swedish krona strengthening on impact. Following the ECB QE shock, inflation expectations and households' confidence increased in Sweden. The effects on output and inflation are comparable to the effects found in

[3]The share of Swedish imports and exports over GDP equalled 82 percent over the period 1995-2019. The euro area represents more than 40 percent of Sweden's trade.

the literature for the ECB QE on the euro area. The positive spillover effects are partly due to the response of the Swedish asset purchase programme to the ECB's programme, that limited the appreciation of the real exchange rate. To the best of our knowledge, our paper is the first one to assess the spillovers of the ECB QE programme on a small open economy and the induced response from its domestic QE.

As explained in Haldane et al. (2016) and Borio and Zabai (2016), there are various channels through which large-scale asset purchases can affect the economy and make monetary policy more expansionary: monetary policy signalling, portfolio balance and the exchange rate channel. We find evidence of the exchange rate channel of QE and low exchange rate pass-through. Regarding the signalling channel, the Riksbank QE lowered the interest rate expectations six months, two and five years ahead, unlike the ECB QE. There is also evidence of the portfolio balance channel for both the domestic and foreign QE, but in different ways. The domestic QE shock improved the domestic financing conditions more than the ECB QE shock. The ECB QE transmitted through a drop in risk premia, for both corporate and mortgage bonds in Sweden. These results are consistent with the large role of funding in global financial markets of Swedish banks and firms. The Riksbank QE shock raised stock prices and housing prices, lowered the term spread and households' lending rates.

Our work is related to the literature studying the effects of QE on the macroeconomy. Overviews of the literature on the effects of large-scale asset purchases across various countries and methodologies are provided in Borio and Zabai (2016), Bhattarai and Neely (Forthcoming), Dell'Ariccia et al. (2018), Kuttner (2018) and BIS (2019).

One approach to study effects of QE on the macroeconomy is based on structural (DSGE) models with financial frictions or with a shadow rate as measure of the monetary policy stance.[4] One such example is De Rezende and Ristiniemi (2020),

[4]For the portfolio balance channel of QE see, among others, Chen et al. (2012), Gertler and Karadi (2013), Carlstrom et al. (2017) and Sims and Wu (2020). Mouabbi and Sahuc (2019) relies

the only other paper studying the effects of the Riksbank's 2015-2017 QE programme on the macroeconomy.[5] The authors first derive a shadow rate for Sweden without a lower bound to track the stance of monetary policy when unconventional tools are used, in addition to conventional ones. Then, they introduce it into the Riksbank's DSGE model at the time (Ramses II) and find positive effects of QE on the real economy (proxied by unemployment) and inflation.

Another approach is based on VAR models, where asset purchases are proxied with their effects on mortgage spreads (Walentin, 2014), term spreads (Baumeister and Benati, 2013), government bond yields (Gilchrist et al., 2015) or the shadow rate (Wu and Xia, 2016).[6] Examples of papers that directly use the amounts of central bank's purchases in VAR models to identify asset purchase shocks are Gambacorta et al. (2014) Gambetti and Musso (2017), Boeckx et al. (2017) and Weale and Wieladek (2016). While the first three papers use effective purchases, Weale and Wieladek (2016) use announced purchases. Their methodology has been extended to other countries and other sample periods in Haldane et al. (2016), Garcia Pascual and Wieladek (2016) and Panizza and Wyplosz (2018), but none of these studies analyse the recent Swedish QE experience and the spillovers of the ECB QE to small open economies.

Few papers in the empirical literature on QE discuss the spillovers of foreign QE for a small open economy. Covering the period before 2015, Bluwstein and Canova (2016) find positive effects for the real economy in advanced economies (including Sweden) from the ECB's unconventional monetary policy. However, effects on inflation are slightly negative. Chen et al. (2017) find positive spillovers from the Fed's

on a shadow rate to account for the effects of QE. Alpanda and Kabaca (2020) and Kolasa and Wesolowski (2020) focus on spillovers of foreign QE.

[5]The announcement effects of the Riksbank QE on the financial market have been studied extensively in De Rezende (2017), de los Rios and Shamloo (2017), De Rezende and Ristiniemi (2020), Knezevic et al. (forthcoming) and Melander (2021). Blix Grimaldi et al. (2020) focus on the effects on the liquidity of the Swedish government bonds.

[6]See Rossi (2020) for a review of the time series approaches to identify the effects of unconventional monetary policy.

and the ECB's asset purchases in terms of GDP and inflation for advanced economies, including Sweden, for the period before 2015. Our paper shows that these conclusions hold also for the QE programme started in 2015 by the ECB. Our results on positive spillovers are also in line with studies of the effects of the Fed's QE programme on GDP and inflation of Canada, such as MacDonald and Popiel (2017) and Dahlhaus et al. (2018).

The paper proceeds in the following way. Section 2 provides some historical background on the Riksbank QE programme. Section 3 describes the theoretical transmission channels of QE. Section 4 and 5 describe the data and the methodology used, respectively. In section 6 we present the main results, study the response of domestic QE to foreign QE, and dig deeper into the transmission channels of the Riksbank and the ECB QE in the Swedish economy. Section 7 contains robustness exercises and Section 8 concludes.

2 Some history and institutional details

The Riksbank has been an inflation-targeting central bank since 1993, in operational terms since 1995. At the beginning of 2015, inflation in Sweden had been below the 2 percent target for long, inflation expectations were low and trending downwards. Since Sweden is a small open economy with a large share of trade with the euro area, the economic developments and the monetary policy decisions concerning the euro area are closely followed in Sweden. In January 2015 the ECB announced to extend its private bond purchase programme to buy also government bonds, with purchases divided between countries on the basis of its capital key. The programme is known as APP (Asset Purchase Programme).[7] At the monetary policy meeting of February 2015, the Riksbank decided to cut interest rates into negative territory

[7]The ECB announced the total amount it intended to purchase on a monthly base, both for private and public bonds. In the end, though, the share of public bonds for those purchases was around 90 percent, hence we can consider it mostly a programme of public debt purchases.

for the first time in history. Thereby, it signalled that zero was not the lower bound for the policy rate. At the same time, the Riksbank started its QE programme, by announcing purchases of SEK 10 billion of government bonds. The discussions about the decision involved, beyond domestic factors, also the extension of the asset purchases programme announced by the ECB and its potential consequences for the Swedish krona.[8]

The Riksbank's asset purchases were funded by increasing reserves from the monetary policy counterparties. The Riksbank purchased bonds with the help of reverse auctions in which the Riksbank's monetary policy counterparties and the National Debt Office's dealers could participate. The National Debt Office is responsible for managing the Swedish government debt. It is important to note a specific feature of the Swedish government debt market, that forces a lower bound on the level of interest rates on long-term government bonds. The National Debt Office provides a repo facility such that, at any point in time, without any volume restrictions, it endogenously supplies all government bonds at a one-day holding period interest rate amounting to the Riksbank policy rate minus 0.40 percentage points. Therefore, there is a limit to how much asset purchases can lower the term premium on government bonds. This limit could of course affect the effectiveness of QE on the macroeconomic variables.

The Riksbank concluded its active QE programme at the end of 2017, and carried out only reinvestments from 2018 onwards. The ECB concluded its QE programme in 2018. Overall, the Riksbank' holdings at the end of the program amounted to SEK 290 billions, corresponding to around 44 percent of the outstanding stock of nominal government bonds and roughly 7 percent of GDP. As regards the ECB, according to data reported in BIS (2019), the share of purchases over the total outstanding stock corresponded to slightly less than 30 percent in 2019, while the share over GDP

[8]See the minutes from the Executive Board's monetary policy meeting of February 11, 2015.

was roughly 25 percent.[9] Therefore, the Riksbank QE programme was smaller than the ECB QE programme in terms of the country's GDP but larger in terms of the outstanding stock.

3 How QE can affect the economy

There is a large literature discussing how the effects of asset purchases transmit to the economy to make monetary policy expansionary (Borio and Zabai (2016), Haldane et al. (2016)). The main channels discussed are the following:

- monetary policy signalling channel - QE can convey extra information about the future path of short-term interest rates.;
- portfolio balance channel - QE can induce a switch into longer duration or higher risk assets;
- exchange rate channel - QE lowers the price of domestic asset relative to overseas assets.

Without frictions, general equilibrium effects make asset purchases irrelevant for the economy, as first argued by Wallace (1981). For the channels of QE to be working, there should be frictions or imperfections in the functioning of financial markets. In the literature, different models have been suggested to rationalize these channels and study the effects of asset purchases on macroeconomic variables. Vayanos and Vila (2021) develop a model to understand how large-scale asset purchases affect long-term rates, based on the assumption of imperfect substitutability between short-term and long-term bonds and market segmentation. Building on the same type of frictions, Chen et al. (2012) study the macroeconomic effect of asset purchases in a New Keynesian DSGE model, through their effect on long-term rates and the term

[9]The outstanding value is proxied with the iBoxx market value for each asset class.

premium. On the other hand, Gertler and Karadi (2013), Carlstrom et al. (2017) and Sims and Wu (2020) build models with a banking sector that faces a leverage constraint. The effects on the economy of central bank's purchases of public and private assets take place through their impact on risk premia, by easing financing conditions.

The models mentioned above focus on closed economies, hence they lack the exchange rate channel of asset purchases. Greenwood et al. (2020) provide a generalized version of Vayanos and Vila (2021)'s model to explain how the US QE programme affect the US dollar exchange rate. Kolasa and Wesolowski (2020) and Alpanda and Kabaca (2020) introduce the imperfect asset substitutability and segmented markets in a two-country DSGE model. Cross-border holdings of government bonds imply that the exchange rate is affected by the change in term premia across two economies.

According to the event-study analyses in De Rezende (2017) and Melander (2021), the announcement effects of the Riksbank's government bond purchases during 2015-2017 suggest that the above mentioned channels were at work. QE announcements contributed to lower long-term government bond yields, together with corporate and mortgage bond yields, suggesting a drop in both term premia and risk premia according to the portfolio balance channel. The weaker exchange rate can be seen as evidence of the exchange rate channel. Lower interest rate expectations at various horizons suggest also a signalling channel at work. Our analysis can provide evidence on whether these effects were short-lived or not and how they transmitted to output and prices.

4 Data

We use data at monthly frequency, covering the period of active Swedish and ECB QE, from 2015 to 2018. More details on the data sources and graphs of the vari-

ables are reported in Appendix A. As measure of real economic activity, we use the monthly GDP indicator (activity indicator) published by Statistics Sweden. Prices are measured with the Swedish CPIF price level.[10] The stock market is measured with the OMX stock market index, transformed into real terms by dividing it by the price level. In terms of interest rate variables, we include the difference between the ten-year and the three-month government bond yields (the term spread). We also use the five-year corporate spread and mortgage spread, the households' lending rate and the Financial Conditions Index (FCI). The Financial Conditions Index, provided by Alsterlind et al. (2020), reflects financial conditions in Sweden, by summarising the status of five important submarkets in the Swedish financial system: the housing market, the bond market, the money market, the stock market and the foreign exchange market. Inflation expectations are measured through the five-year break even inflation and the real effective krona exchange rate is measured relative to Sweden's main trading partners, the US and the euro area, with weights equal to 15 and 85 percent, respectively. Interest rate expectations six months, two years and five years ahead are measured through the forward rates implied by the RIBA contracts.[11]

Finally, the most important variable is the measure of asset purchases. Following Weale and Wieladek (2016), we construct the cumulative announced purchases by the Riksbank (Table A.2 in Appendix A) and divide it by the annualized nominal GDP of quarter 4 of 2014. By considering the purchases as ratio of 2014 GDP, i.e. before the start of QE, we can eliminate endogeneity effects coming from effects of QE on contemporaneous GDP levels. We construct a similar measure of announced purchases for the ECB, as done in the analysis for the ECB QE in Garcia Pascual and Wieladek (2016). Since the ECB announced its monthly pace of purchases, we

[10]CPIF is the consumer price index inflation with fixed interest rate. The CPIF has been the Riksbank's operational target variable for several years and the formal inflation target variable for monetary policy as of September 2017.

[11]RIBA contracts are three month swap contracts with the repo rate as the underlying asset. The derivates curves are estimated using the extended Nelson Siegel method.

have aggregated these to obtain the total amount announced (Table A.3 in Appendix A). Figure 1 shows the announced purchases by the ECB and the Riksbank.

All the variables, except for the interest rates and the asset purchase series, are expressed in natural logarithms.

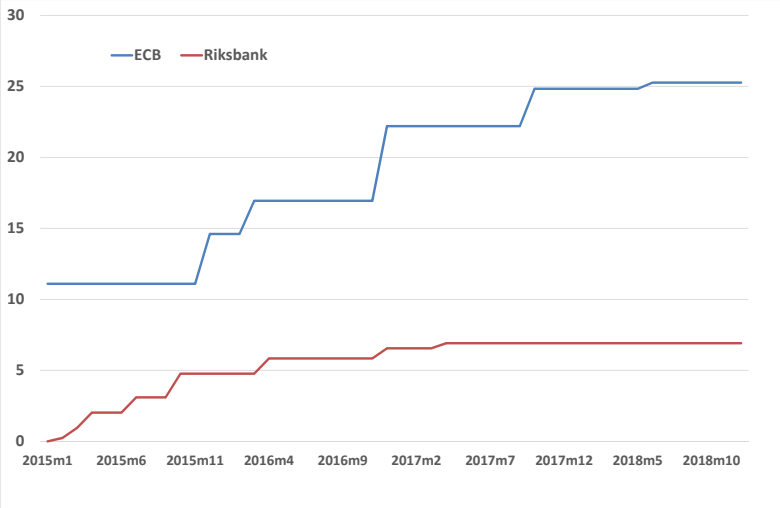

Figure 1: Asset purchases announced by the ECB (blue lines) and the Riksbank (red line). Shares over 2014:Q4 annualized GDP of each region.

5 Methodology

We use a BVAR model with 2 lags and Minnesota prior (see Appendix B for more details).[12] We use 2000 draws for the simulation and additional 500 initial draws of burn-in.[13] The baseline model contains 6 variables: ECB asset purchases, Swedish price level, Swedish GDP indicator, Riksbank asset purchases, Swedish term spread (differences between the 10-year and the 3-month government bond yields) and the Krona real exchange rate. We modify the model in Weale and Wieladek (2016) to

[12]Results are robust to replacing the Minnesota prior with the independent Wishart prior.
[13]We also carried out a sensitivity analysis with 10000 draws and results still hold.

fit the case of a small open economy. We introduce the ECB asset purchase variable as part of the exogenous block, meaning that it is assumed not to be affected by Swedish variables, since Sweden is a small open economy. With respect to Weale and Wieladek (2016), our baseline system contains the Swedish real exchange rate, in order to account for the exchange rate channel of QE. Our short sample period can rule out concerns of structural breaks in the series of interest, due to the exceptional times and tools used by central banks. However, it also restricts the degrees of freedom of the model. For this reason, we do not include one more variable to account for the conventional monetary policy carried out by the Riksbank, when it cut rates below zero. Instead, we replace the long-term rate, as used in Weale and Wieladek (2016), with the term spread, i.e. the difference between long and short-term rates.

The main benefit of the identification proposed by Weale and Wieladek (2016) is the use of the cumulative announcement of purchases as a proxy to identify the effects of QE, therefore allowing for the effects of QE announcements in a BVAR model. Note that some of these variables may contain unit roots, but we include them in levels, as done in Weale and Wieladek (2016).[14] Given the large uncertainty on the nature of a QE shock, we provide results with two identification strategies relying on zero and sign restrictions, inspired by Weale and Wieladek (2016)(Table 1).[15] The contemporaneous imposition of zero and sign restrictions is carried out through the algorithm developed in Arias et al. (2014). Compared to Weale and Wieladek (2016), we identify also an exchange rate shock, that is usually found to be an important driver of the Swedish krona (see Corbo and Di Casola (2020)).

The first identification strategy relies on recursive ordering of the variables, where the Riksbank QE shock is assumed to affect the term spread and the exchange rate

[14] If one suspects that there are common trends among the variables (cointegration) but the nature of those trends is uncertain, Hamilton (1994) suggests to run the VAR in levels because the trends would still be preserved, while running it in first difference would take away the trends.

[15] Weale and Wieladek (2016) impose their restrictions for 5 months after the shock hits. Our restrictions are, therefore, less stringent.

	ECB purchases	Prices	GDP	Riksbank purchases	Term spread	RER
	Identification I					
ECB purchases	1	0	0	0	0	0
Prices		1	0	0	0	0
GDP			1	0	0	0
Riksbank purchases				1	0	0
Term spread					1	0
Stock prices						1
	Identification II					
ECB QE shock	+					
Supply shock		-	+	0		
Demand shock		+	+	0		
Riksbank QE shock				+	-	+
Exchange rate shock		+				+

Table 1: Identifying restrictions for the baseline model. The sign restrictions are imposed for five periods.

on impact, while it affects prices and GDP with a delay. Unlike Weale and Wieladek (2016), we assume that the Riksbank's asset purchases do not only respond on impact to GDP and prices, but also to the ECB's purchases.

The second identification strategy introduces sign restrictions.[16] The effect of the Riksbank QE shock on GDP and prices is always left unrestricted. The Swedish QE shock is assumed to decrease the term spread and depreciate the real exchange rate. The assumed effect on the term spread and exchange rate is in line with the mechanism of the QE channels discussed before and also the results from studies of effects of QE in the Swedish financial market (De Rezende, 2017). On the other hand, the effects of the ECB shock are left unrestricted. Thanks to the exogeneity assumption, the ECB QE shock is the only shock that can affect all the Swedish variables on impact and is a novelty with respect to Weale and Wieladek (2016).

[16]This identification scheme is similar to identification scheme III in Weale and Wieladek (2016). We do not apply their second identification scheme because it relies on the presence of stock prices in the system instead of the exchange rate. A version of identification scheme IV is provided in Section 7.4.

With this identification scheme, we can identify also domestic demand and supply shocks, since the former generates positive comovement between prices and GDP and the latter generates negative comovement. Both shocks are assumed to have no effect on the Riksbank's asset purchases on impact. This restriction is justified by the fact that it is usually difficult for monetary policy to respond to supply or demand shocks within a month. Finally, the exchange rate shock is assumed to increase prices when the currency depreciates in real terms.

One key difference between the two identification schemes is that in Identification I only the ECB shock is allowed to affect prices and output on impact. In Identification II also the Riksbank QE shock can affect them on impact. A comparison of the results can inform us about whether this assumption affects the results and the relative importance of domestic versus foreign QE.

6 Results

In this section, we discuss the results from our baseline model, study the role of the response of domestic QE to foreign QE and focus on the transmission channels at work. Due to the limited degrees of freedom, we replace the measure of the term spread with, alternatively, measures of the corporate spread, mortgage spread, lending rates, inflation expectations, the financial conditions index, forward rates. In addition, we replace the GDP indicator with unemployment or households' consumer confidence to understand how the QE shock transmits to the real economy.

6.1 Baseline model

Figure 2 reports the impulse response functions to the ECB and the Riksbank QE shock, using the two identification schemes presented above. Both the ECB and the Riksbank QE shocks are highly correlated across the two identification schemes (0.98

and 0.82, respectively). The signs and size of the median responses are very similar across the identification schemes. However, the credible intervals are larger using sign restrictions, possibly due to the small data sample. Hence, the credible intervals for the impulse responses of GDP and prices contain zero (Figure C.1 in Appendix C).

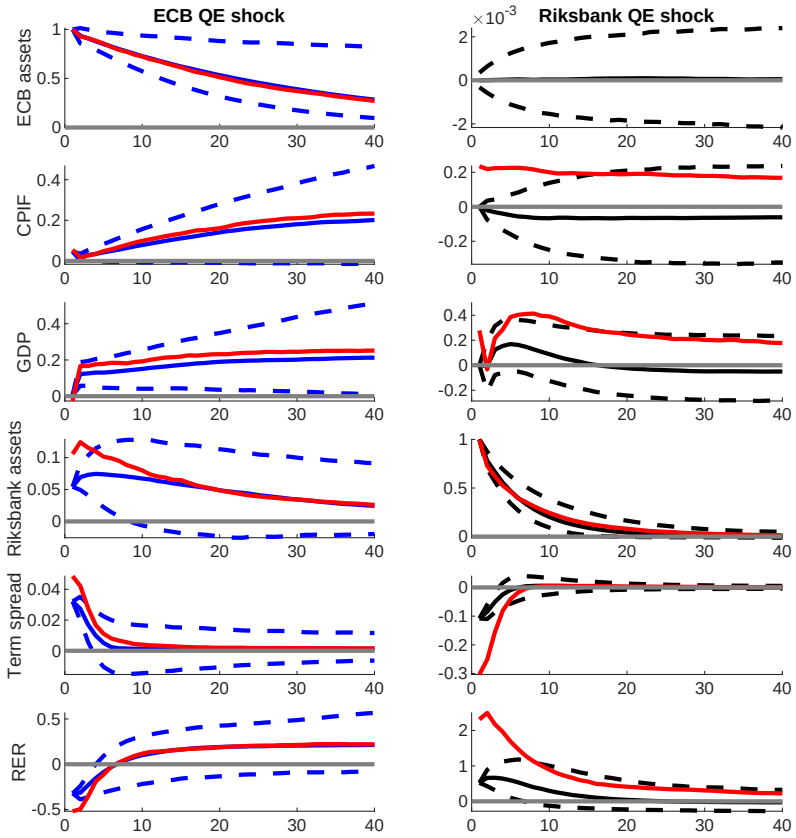

Figure 2: Impulse response functions to the ECB QE shock and the Riksbank QE shock. We use the baseline Bayesian VAR model, Minnesota prior, 2 lags. Results refer to Identification I (blue and black lines) and Identification II (red lines). Sample period is 2015:01-2018:12. We use 2000 simulations and 500 more for burn-in. Responses are in percentage terms. The blue and black solid lines represent the median responses of the ECB QE shock and the Riksbank QE shock, respectively. The dashed lines denotes a 68 per cent credible interval around the median responses of Identification I.

The ECB shock has an expansionary effect on the Swedish economy, raising the GDP level and the price level. These results are in line with other studies on QE

spillovers, such as Chen et al. (2017). This happens despite the fact that the term spread rises and the krona appreciates on impact.[17] From studies on the euro area we know that the ECB QE programme contributed to boost economic activity by, among other channels, lowering the long-term rate in the euro area (Garcia Pascual and Wieladek, 2016), hence through the portfolio balance channel. Here we find that at the same time as lowering long-term rates in the euro area, the ECB QE increased the term spread in Sweden. The resulting appreciation of the Swedish krona, implying a depreciation of the Euro, is in line with the exchange rate channel of the ECB QE.

The additional value of our analysis is that we study the case of a small open economy running its QE programme at the same time as the ECB. In fact, the Riksbank responded to the ECB QE shock with its own QE programme, due to the potential implications on the Swedish economy, as explained in Section 2. It is possible that the positive contribution of the ECB QE to GDP and prices in Sweden, come also from the induced response of the small open economy's central bank. In fact, in the forecast error variance decomposition the ECB shock grows in importance for GDP and the price level, while growing also in importance for the Riksbank QE programme. We will propose a way to disentangle the direct from the indirect effect of the ECB QE in the next section.

As regards the domestic QE shock, it increases the GDP level, and the size of the effect is larger with sign restrictions. The effect on the price level is very imprecisely estimated, since the credible intervals contain zero with both identification schemes and the median value changes sign across identification schemes (the only case). As expected, the QE shock decreases the term spread and depreciates the Swedish krona.[18] These responses are in line with the portfolio balance and the ex-

[17] In particular, in an extension of the model where we include both the long-term and the short-term rate, we observe that the effect on the spread comes mostly from an increase in the long-term rate.

[18] From the extended model with both long-term and short-term rate, we know that the drop in the term spread comes mostly from the drop in the long-term rate.

change rate channel of QE. One can also compare the spillovers of conventional and unconventional monetary policy. Corsetti et al. (2021) show that the ECB conventional monetary policy shocks generate a similar response of output and inflation in the euro area as in its neighbouring countries. Therefore, our results for the ECB QE shocks are in line with evidence on spillovers of conventional monetary policy.

One should note also that the Riksbank QE shock is less persistent than the ECB QE shock, hence part of the difference in effects may come from the expected duration of the shock. Moreover, the responses of the price level and the exchange rate suggest a low exchange rate pass-through to consumer prices after the Riksbank and the ECB QE shocks. The fact that the pass-through may be low after a specific shock is not unusual for Swedish data. For example, Corbo and Di Casola (2020) find evidence of reverse-sign (negative) pass-through to consumers prices in Sweden after domestic and global demand shocks. This result implies that after specific shocks the pressure on prices stemming from demand may dominate the effect of exchange rate movements on producers' costs.

Looking at the meta-analysis provided in Fabo et al. (2020), we can draw a comparison of the effects of QE on GDP and prices across countries. The authors provide standardized effects, based on purchases equal to one percent of GDP, from 48 studies published up to 2019 on US, UK and euro area data. Given the variability of the effects depending on the method used, we focus on the effects reported in VAR models. In Table 2 we report this comparison for the standardized peak effect on GDP and total effect on inflation in VAR studies, along with the results from our two identification schemes. The results show that the effect of the ECB QE on Swedish GDP is comparable to the effect on the euro area GDP and larger for prices. This is not surprising. Bluwstein and Canova (2016) and Chen et al. (2017) also find large spillovers of the ECB and Fed's QE conducted before 2015 on Swedish GDP, where effects are even larger than on the domestic economies. Our result may of course be

partly due to the endogenous response of the Riksbank to the ECB QE programme.

As for the domestic QE, the effects vary by identification scheme, being larger for the one with sign restrictions. This is in line with results in Weale and Wieladek (2016), who attribute the larger effects to the stronger theoretical assumptions behind the sign restrictions. The effect on GDP is on average equal to 0.29, hence between the effects found in the US and the euro area. The effect on prices is never different from zero in a probabilistic sense, and the average median effect (0.06) is comparable to the small effects found in UK and the euro area.

Another way to compare effects across countries would be to standardize them over the outstanding amount of assets. As mentioned before, in those terms the purchases by the ECB were tree fourth of the ones by the Riksbank. If one uses this form of normalization, the effects of the Riksbank QE on Sweden look smaller than the effects of the ECB QE in the euro area even in terms of GDP (roughly one fifth of those in the euro area).

Table 2: Standardized effects

Country	**Peak effect on GDP**	**Total effect on inflation**
	Baseline model Identification I / II	
ECB → Sweden	0.21*/0.25	0.22*/0.23
Riksbank → Sweden	0.16*/0.41	-0.06/0.17
	VAR models in the literature (Fabo et al., 2020)	
USA	0.32	0.24
UK	0.14	0.05
Euro area	0.26	0.08

Results for Sweden come from baseline model with Identification I and II, standardized to one percent of GDP of the correspective economy. * refers only to results for Sweden and indicates that at the time of the effect the 68 per cent credible intervals are excluding zero. Data for UK, USA and euro area from Fabo et al. (2020), average values from 48 studies. Effects in percentage terms.

Given the large uncertainty surrounding the responses with sign restrictions, we proceed our analysis relying on Identification scheme I, that is also more conservative in terms of size of effects.

6.2 Digging deeper into the effects of domestic and foreign QE

In order to understand the transmission of the shock to domestic demand and households, we consider a variation of the baseline model with additional variables. Figure 3 shows the response of market-based inflation expectations, households' confidence and unemployment to QE shocks, normalized to one percent purchases over GDP. We can notice that only the ECB QE shock increases inflation expectations and households' confidence in Sweden and this may explain the large positive effect on prices. In terms of labor market, unemployment drops after the Riksbank QE shock, while it increases temporarily after the ECB QE shock.

6.3 Direct and indirect effects of foreign QE

In order to disentangle the direct from the indirect effect of the ECB QE on Sweden we need to evaluate the role of the Riksbank's response to the ECB QE programme. For this purpose, we conduct a conditional forecast exercise. This type of exercise is also used in other studies of QE, such as Lenza et al. (2010) for the euro area, to evaluate the effects of QE. We follow these steps, each with specific assumptions about domestic and foreign QE:

1. We assume that neither the ECB, nor the Riksbank conducted their QE programme.

2. We assume that only the ECB conducted its QE programme.

3. We first assume that the ECB did not conduct its QE programme and filter out the exogenous component of the Riksbank QE. In a second step, we assume that the ECB conducted its QE programme and the Riksbank did not respond to it, but only executed the exogenous component of its QE.

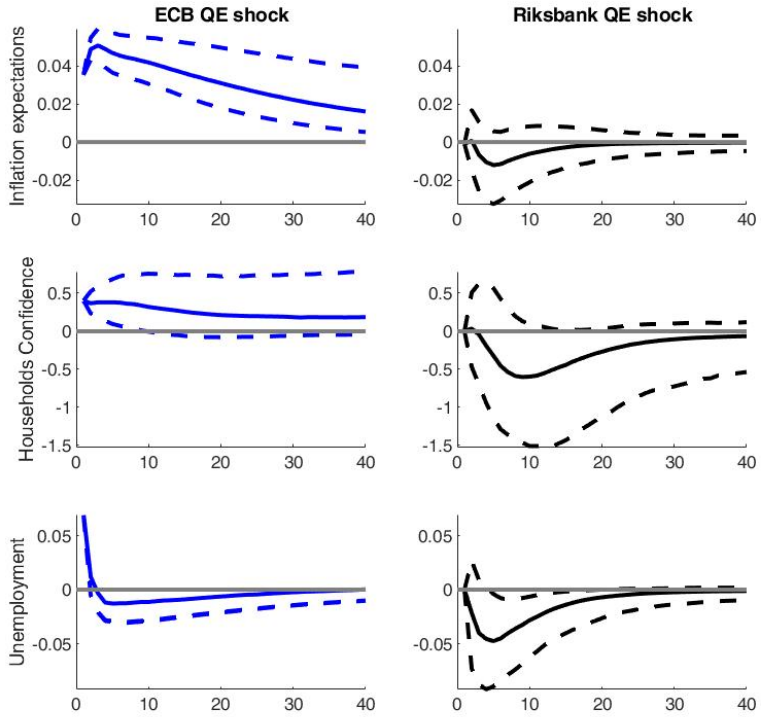

Figure 3: Impulse response functions to the ECB QE shock and the Riksbank QE shock, normalized to one percent of purchases over GDP. We use the baseline Bayesian VAR model, Minnesota prior, 2 lags, where households' confidence or inflation expectations replace the term spread or unemployment replaces GDP. Results refer to Identification I. Sample period is 2015:01-2018:12. We use 2000 simulations and 500 more for burn-in. Responses are in percentage terms. The blue and black solid lines represent the median responses of the ECB QE shock and the Riksbank QE shock, respectively. The dashed lines denotes a 68 per cent credible interval.

Results are reported in Figure 4. Comparing the outcome to the case of ECB QE and only exogenous QE from the Riksbank (case 3), we can identify the indirect effects of the ECB QE on Sweden. The endogenous QE response from the Riksbank affected positively the GDP level and weakened the currency in real terms, while results for the term spread are mixed. The impact on prices is positive but small. The direct impact of the ECB QE can be gauged by comparing the case without QE (case 1) to the case with only ECB QE (case 2). The effect is very large for prices and GDP, while the real exchange rate is first appreciated and then depreciated.

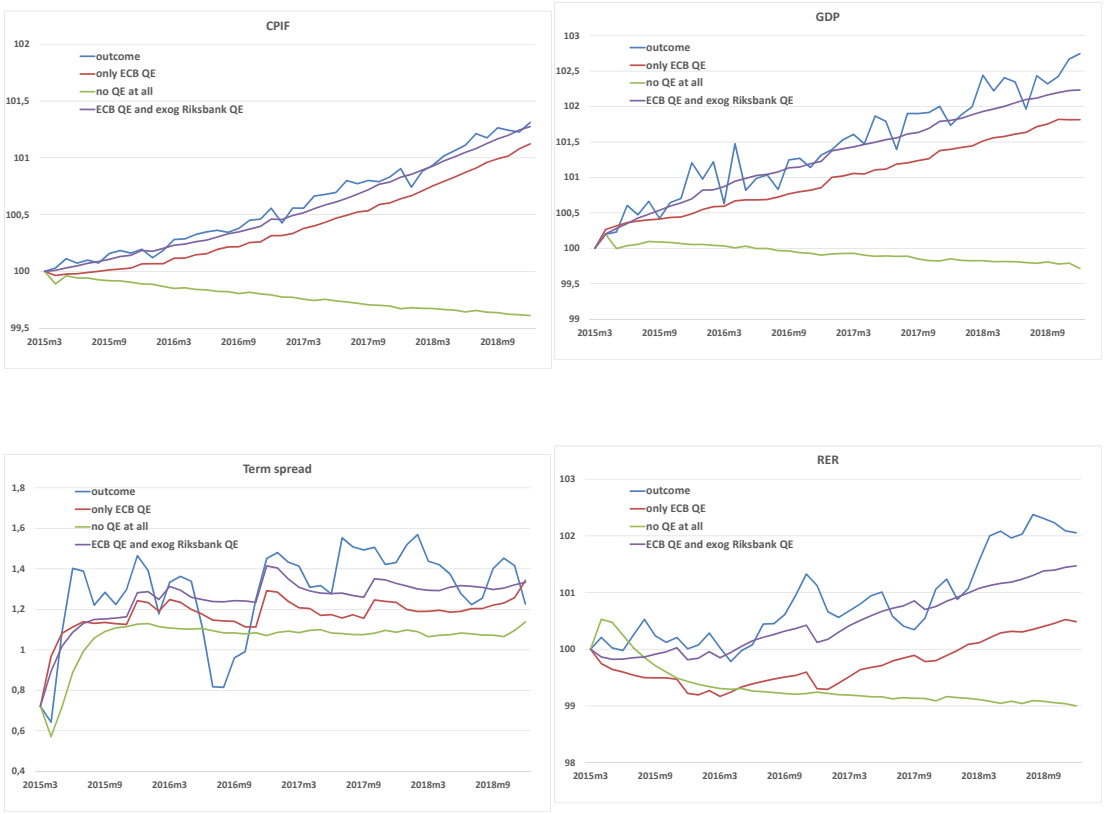

Figure 4: Conditional forecasts of CPIF, GDP, term spread and real exchange rate for outcomes (blue), the case of no QE (green), only ECB QE (red), ECB QE and exogenous Riksbank QE (violet). The level of CPIF, GDP and real exchange rate is normalized to 100 in 2015:03.

Overall, taking together the conditional forecast exercise with the impulse responses analysis we conclude that the endogenous response of the Riksbank did strengthen the effect of the ECB QE on GDP and reduced the appreciation of the Swedish currency.

6.3.1 Role of the open economy

In the previous sections we have discussed the important role of foreign QE and the exchange rate for the Swedish economy. As an additional confirmation of their importance, we now estimate the model omitting the ECB or omitting both the ECB and the exchange rate (replaced with stock prices). In this way, our model

specification is the same as in Weale and Wieladek (2016) and it is likely that the effects of foreign QE will be mixed with the effects of domestic QE. Indeed, we find a larger effect, even double in some specifications, of Swedish QE on GDP. The effect on prices is also larger and always positive, although the credible intervals still contain zero. We conclude that we need to account for the ECB QE in order not to overestimate the effect of the Riksbank QE on the Swedish economy. On the other hand, our experiment highlights that the exchange rate channel of QE does not seem crucial for the effects on output and inflation.

Table 3: Role of the open economy

Model	**Peak effect on GDP**	**Total effect on inflation**
	Identification I / II	
model without RER& ECB	0.37*/0.57*	0.10/0.34
model without ECB	0.36*/0.62*	0.10/0.40
Baseline	0.16*/0.41*	-0.06/0.17

Values come from baseline model with Identification I and II, standardized to one percent of GDP. * indicates that at the time of the effect the 68 per cent credible intervals are excluding zero.

6.4 Exploring the channels of QE

The baseline model with and without exchange rate has provided evidence on the exchange rate channel of QE and its role for the macroeconomic effects. More analysis is required to delve deeper into the functioning of the portfolio balance and the signalling channels. The next two subsections serve this purpose.

6.4.1 Signalling channel

In order to analyse the signalling channel of QE we need to analyse its effects on the RIBA interest rate expectations. Therefore, we replace the term spread in the baseline model with a measure of interest rate expectations six months, 2 years or 5 years ahead. Results are reported in Figure 5. Interest rate expectations in the short

and the medium term drop after the Riksbank QE shock, while they slightly increase or do not move in connection with the ECB shock. Combining these results with the baseline model's results, we conclude that the signalling channel was at work after the Riksbank QE shock, but had stronger effects on the real economy than on prices.

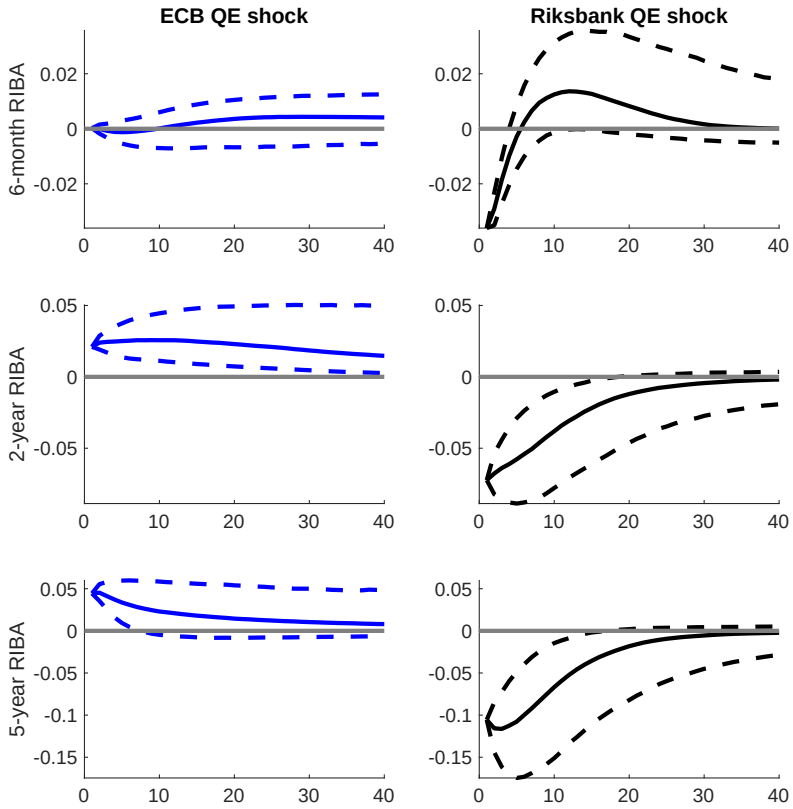

Figure 5: Impulse response functions to the ECB QE shock and the Riksbank QE shock, normalized to one percent of purchases over GDP. We use the baseline Bayesian VAR model, Minnesota prior, 2 lags, where the the 6-month, 2-year and 5-year ahead interest rate expectations from RIBA contracts replace the term spread. Results refer to Identification I. Sample period is 2015:01-2018:12. We use 2000 simulations and 500 more for burn-in. Responses are in percentage terms. The blue and black solid lines represent the median responses of the ECB QE shock and the Riksbank QE shock, respectively. The dashed lines denotes a 68 per cent credible interval.

6.4.2 Portfolio balance channel

We study more in details the transmission of QE through the financial sector. From the baseline model we know that the Riksbank QE has a negative impact on the term spread, through a negative impact on the long-term rate. Instead, the ECB QE has a positive impact on the term spread and the long-term rate. This is evidence of the portfolio balance channel, to analyse its effects on risk premia and financing conditions overall. We replace the term spread with various measures: corporate spread, mortgage spread, equity prices, housing prices, Financial Conditions Index (FCI), the component of the FCI related to housing prices and households' lending rates.

Before discussing the results it is useful to note some distinctive features of the Swedish financial market, discussed in Gustafsson and von Brömsen (2021). Swedish banks are funded using deposits but also largely through financial markets. In particular, their short-term funding largely consists of borrowing in US dollars and euros. Moreover, mortgages represent a large share of the major Swedish banks' assets and about 70 percent of them are funded through covered bonds. As for firms' financing, most Swedish companies rely on bank loans, but many companies, especially the larger ones, issue corporate bonds in foreign currency. For these reasons, corporate and mortgage spreads are important indicators of financing conditions for firms, but also foreign market conditions are extremely important for Swedish banks and firms.

In Figure 6 we can see that both the ECB and the Riksbank QE shocks improve financing conditions in Sweden (i.e. the FCI index increases), but the size and the reason for the improvements differ. The effect of the ECB QE shock on the FCI is smaller and transmitted through an improvement of financing conditions for financial and non-financial firms, that fund themselves in the market through corporate bonds and covered bonds backed by mortgages. The ECB QE effect on equity prices is small, while it is slightly negative for housing prices. On the other hand, the effect of the

Riksbank QE shock on the FCI is large and transmits mostly through equity prices, housing prices and households' lending rates. The Riksbank QE slightly increases corporate and mortgage spreads.

Overall, we can conclude that the positive effect of the ECB QE on output and prices in Sweden was transmitted primarily through firms' financing conditions and domestic demand. This points towards a portfolio balance channel at work after the ECB QE, through the effect on risk premia. The effects of the Riksbank QE were transmitted primarily through the term premium and households' financing conditions. On a similar note, Kaat et al. (2021) propose a housing portfolio channel of QE, where intermediaries rebalance their portfolios from bonds to housing. By using German regional-level data, they find evidence of such channel for the ECB QE.

7 Robustness

In this section we discuss various robustness analyses we have carried out for our baseline model with Identification I.

7.1 Alternative measure of purchases

One of the advantages of Weale and Wieladek (2016) is to use announced asset purchases as proxy for QE, in order to account also for announcement effects. It is worth verifying whether our results change substantially if we instead use the effective purchases by the ECB and the Riksbank. The best proxy available for the effective purchases is the measure of asset holdings in the balance sheets of the ECB and the Riksbank, that we divide, as before, by the annualized nominal GDP of quarter 4 of 2014 (Figure C.3 in Appendix C).

The direction of the effects and the size of the credible intervals are similar (see

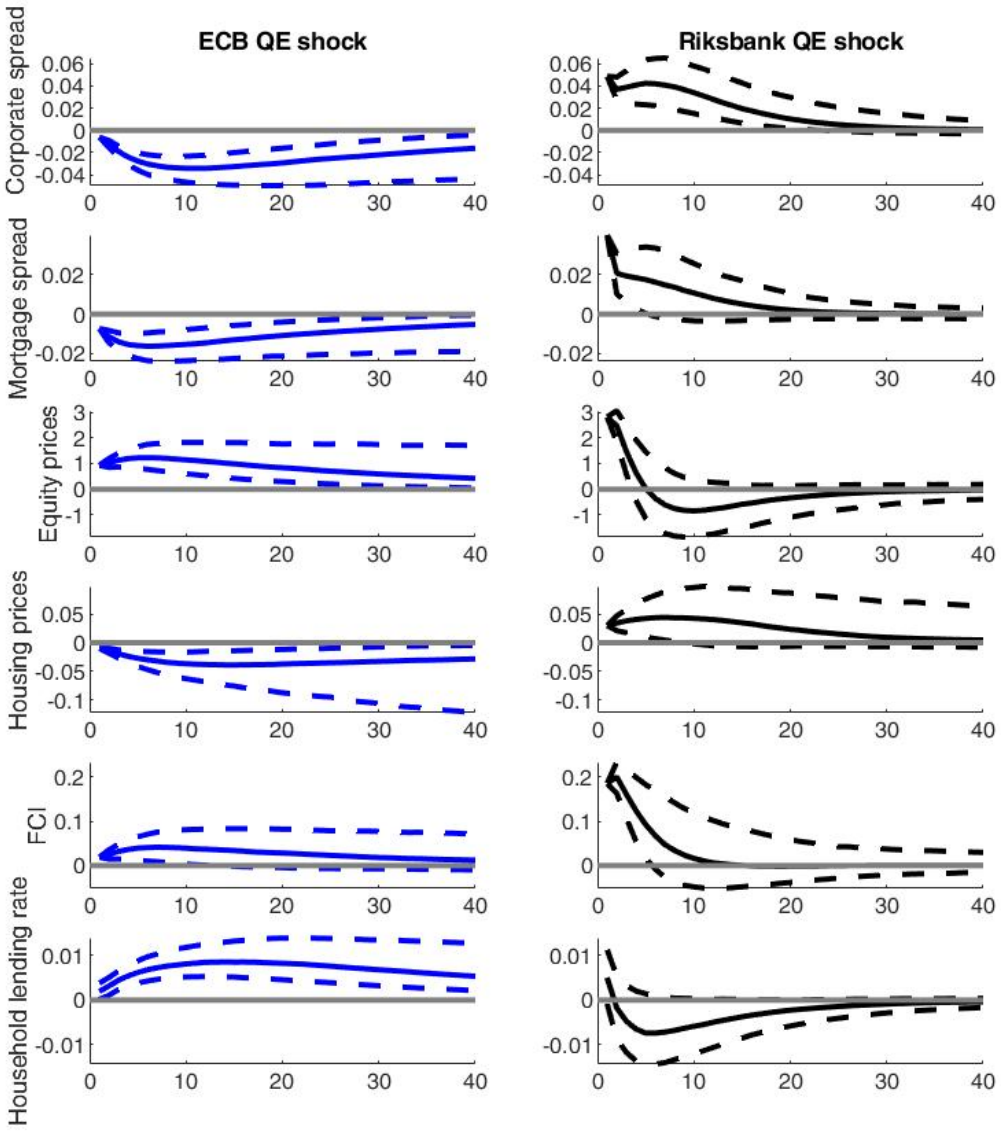

Figure 6: Impulse response functions to the ECB QE shock and the Riksbank QE shock, normalized to one percent of purchases over GDP. We use the baseline Bayesian VAR model, Minnesota prior, 2 lags, where the financial variable replaces the term spread. Results refer to Identification I. Sample period is 2015:01-2018:12. We use 2000 simulations and 500 more for burn-in. Responses are in percentage terms. The blue and black solid lines represent the median responses of the ECB QE shock and the Riksbank QE shock, respectively. The dashed lines denotes a 68 per cent credible interval.

Table D.1 in Appendix D). The effects are slightly larger, possibly because balance sheet holdings have a different timing than the announcements and may account

differently for their expectations.

7.2 Other proxies for QE

As discussed before, the portfolio channel of the Riksbank QE seems to have worked through a drop in the long-term rate, while the ECB QE reduced risk premia. Here we carry out a robustness exercise to verify this finding. By replacing the measures of announced amounts for both the ECB and the Riksbank with the long-term rate, we can understand the importance of the term premium channel of QE, along the lines of the exercise carried out in Weale and Wieladek (2016).[19] The long-term rate in Sweden follows a similar pattern as the euro area long-term rate after the ECB shock. However, after a one percent drop in the euro area long-term rate, we observe an initial drop and then an increase in GDP, while the effect on prices is very imprecisely estimated and the Swedish krona depreciates (Figure C.4 in Appendix C). These results are different from those found in the baseline model in Figure 2, suggesting that the ECB QE did not transmit mostly through the effect on the long-term rate.

Regarding the domestic QE, we observe a depreciation of the Swedish krona and an increase in GDP after few months, as in the baseline model. The effects on inflation are still imprecisely estimated, but the median response is positive. These results confirm that the Riksbank QE did transmit through the effect on the long-term rate. that the evidence suggests that the risk premium channel was more important then the portfolio balance channel for the spillover effects of the ECB QE in Sweden.

[19]In order to avoid collinearity, we also replace the term spread with the short-term rate, that controls for the conventional monetary policy conducted by the Riksbank.

7.3 Omitted variables and extended sample

The size of our model is limited by the short sample period available. However, we have run some robustness exercises including a seventh variable. For instance, the Fed funds rate has been added to make sure we are not confounding our shocks with the US monetary policy shock. We have also included the euro area price level in order to account for the possible comovement with the Swedish price level. Finally, real oil prices have been added to account for international energy price developments. In all cases, the variables have been added first in the VAR systems and are subject to the block-exogeneity assumption. We have also extended the sample period to include all of 2019, a period without new purchases but only reinvestments, or to include all of 2014, before the measure were announced. The main results are confirmed in terms of direction of effects and size of credible intervals and the shocks are highly correlated (above 0.9) across the specifications (Table D.1 in Appendix D). The extension of the sample makes the effects of ECB QE on Swedish inflation look negligible, due to the inclusion of periods without asset purchases, as explained in Weale and Wieladek (2016).

7.4 Alternative identification

Weale and Wieladek (2016) provide an identification scheme for the QE shock based on the assumption that it is the shock explaining the largest fraction of the forecast error variance of asset purchases from impact until a long-enough horizon. The methodology, known as "max-FEV" approach, is based on Uhlig (2003) and Francis et al. (2014). This identification strategy is not suitable in our case, because we study a small open economy. The asset purchases decided by the Riksbank were partly also a response to the contemporaneous QE carried out by the ECB and its potential repercussion in Sweden, as discussed in section 2 and confirmed by our analysis. Hence, there are at least two QE shocks, not just one, that can explain the forecast

error variance of the Riksbank asset purchases. What we can do, however, is to apply a "max-FEV" strategy to identify the ECB QE shock. We run a BVAR model as in baseline case, but do not assume that the ECB variable is exogenous to Sweden. We then identify the ECB QE shock as the shock that maximizes the forecast error variance of the ECB announced purchases at horizon 40 (the results hold if we slightly vary the number of the horizon).

The ECB QE shock we obtain has a correlation equal to 0.88 with the shock from the baseline model, using either of the identification schemes. Impulse responses, shown in Figure C.2 in Appendix C, are comparable with Figure 2. The shock has positive effects on GDP and prices and induces the Riksbank to announce purchases. In terms of standardized effects, the peak effect on the Swedish GDP is 0.28, compared to 0.21 (0.25) with Identification I (II). The total effect on inflation in standardized terms is 0.16, compared to 0.22 (0.23) with Identification I (II). The only difference is that the response of the Swedish krona is roughly null in the first months, while it is strengthening in the baseline model with Identification I. Overall, we conclude that the identification of the ECB QE shock is robust to different identification strategies.

8 Conclusion

Unconventional monetary policy has come back to the forefront of the international policy agenda due to the Covid-19 pandemic. This has forced many central banks around the world to intervene to help the functioning of the financial markets with large-scale asset purchases. It is difficult to evaluate the effects of large-scale asset purchases on the macroeconomy, possibly due to the short sample availability. There is even larger uncertainty on the effects of asset purchases in small open economies, such as Sweden, which may be subject to spillovers from contemporaneous QE conducted abroad.

Our contribution to the literature is to study the effects of domestic and foreign QE in a small open economy, namely Sweden, taking into account the endogenous response to foreign QE. The period of the analysis is 2015-2018, when both the Riksbank and the ECB conducted QE programmes to make monetary policy more expansionary. We have used a structural Bayesian VAR at monthly frequency, with identification strategies inspired by Weale and Wieladek (2016) and we have identified both domestic and foreign QE shocks.

We have found positive effects of the Swedish QE on Swedish GDP, with a decrease in unemployment, and a weakening currency in real terms. The effects come through the improved lending conditions for households and lowered expected future rates. The effects on Swedish inflation are less clear. The ECB QE programme had large positive spillover effects on both GDP and inflation in Sweden and generated an initial appreciation of the krona real exchange rate. These spillovers are partly explained by the response of domestic QE to foreign QE, in expectation of its repercussions on the Swedish economy. The ECB QE transmitted to the economy through improved financing conditions for firms.

The main contribution of our paper to the current policy debate is the importance of evaluating the role of spillovers of foreign unconventional monetary policy for small open economies and the response of the central banks of those economies with their domestic unconventional monetary policy. This is particularly relevant in the current situation, when the Covid-19 pandemic has hit all over the world and central banks have reacted with more expansionary monetary policy.

However, some caveats apply when comparing our estimates to the current situation. Our analysis refers to asset purchases conducted with the aim of making monetary policy more expansionary (QE according to Bernanke (2009)), but not to improve the functioning of financial markets during a period of financial distress (credit easing, according to Bernanke (2009)). The current wave of unconventional

monetary policy has been initially aimed at alleviating financial market distress. As argued by Bailey et al. (2020), in periods of financial market distress, large asset purchases programmes implemented quickly may be even more effective than in normal times.

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A Data

Table A.1: Data description

Series	**Transformation**	**Source**
Activity monthly indicator	log	Statistics Sweden
Unemployment		Statistics Sweden
CPIF price level	log	Statistics Sweden
Household's confidence		Statistics Sweden
10y yield on Swedish government debt		Macrobond
OMX all share index	log	Macrobond
Break-even 5y ahead inflation		Macrobond
5y corporate bond spread		Sveriges Riksbank
5y mortgage bond spread		Sveriges Riksbank
Households' lending rate		Sveriges Riksbank
Financial Conditions Index,		Sveriges Riksbank
6m, 2y, 5y RIBA forward rates,		Sveriges Riksbank
Nominal effective krona exchange rate	log	Sveriges Riksbank
10y yield on German government debt		Macrobond
Euro area price level	log	Fred database
Fed funds rate		Fred database
ECB balance sheet, assets		Macrobond
Riksbank balance sheet, assets		Sveriges Riksbank

Table A.2: Riksbank's announcements

Date	**Purchase announcements**
February 2015	10 billions Sek
March 2015	30 billions Sek
April 2015	40-50 billions Sek
July 2015	45 billions Sek
October 2015	65 billions Sek
April 2016	45 billions Sek
December 2016	30 billions Sek
April 2017	15 billions Sek

Table A.3: ECB's announcements

Date	**Purchase announcements**
January 2015	60 billions Eur per month from March 2015 until end of September 2016, tot. new=1140 (60*19m)
December 2015	extension to end of March 2017, tot. new=360 (60*6m)
March 2016	80 billions Eur from April 2016 until end of March 2017, tot. new=240 (20*12)
December 2016	60 billions Eur per month from April 2017 to end of December 2017, tot. new=540 (60*9m)
October 2017	30 billions Eur from January to September 2018, tot. new=270 (30*9m)
June 2018	15 billions Eur from October to end of December 2018, tot. new=45 (15*3m)

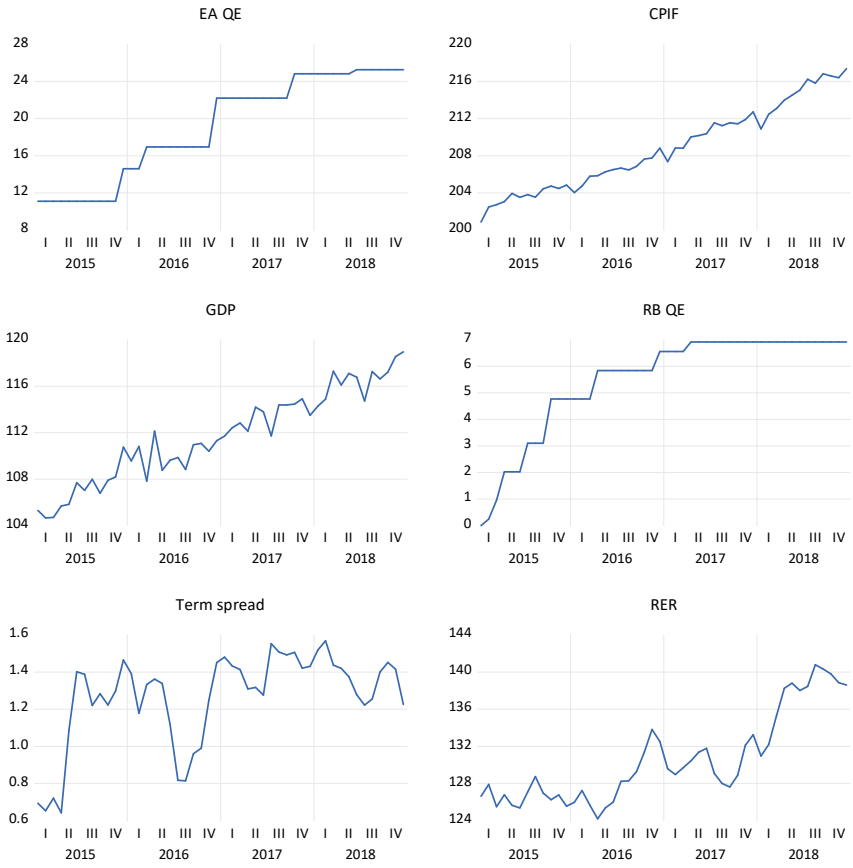

Figure A.1: Data used in the baseline model.

B BVAR model

In this memo we use the Bayesian VAR model written in the following way:

$$\mathbf{G}(L)\mathbf{x}_t = \eta_t \tag{B.1}$$

where $\mathbf{G}(L) = \mathbf{G}_1 L + \mathbf{G}_2 L^2 + ... + \mathbf{G}_m L^m$, is a lag polynomial of order m. The lag length of the model is in all cases set to 2. $\mathbf{x}_t$ is an nx1 vector of variables and η_t is an nx1 vector of iid error terms fulfilling $E(\eta_t) = 0$ and $E(\eta_t \eta_t') = \mathbf{\Sigma}$. The priors of the model largely follow convention in the literature. For $\mathbf{\Sigma}$ the prior is given by $p(\mathbf{\Sigma}) \propto |\mathbf{\Sigma}^{-(n+1)/2}|$ and the prior on $vec(\mathbf{G})$ is given by $vec(\mathbf{G}) \backsim N_{mn}(\mathbf{\Theta_G}, \mathbf{\Omega_G})$. The priors on the dynamics have been modified, relative to the traditional Minnesota prior. The prior mean on the first own lag for each variable is here set equal to 0.9 and all other coefficients in $\mathbf{G}$ have a prior mean of zero. The hyperparameters of the model are also in line with mainstream choices in the literature. We set the overall tightness to 0.2, the cross-variable tightness to 0.5 and the lag decay parameter to 1. Since Sweden is a small open economy, we need to assume that Swedish shocks do not affect the foreign economy. The block exogeneity parameter is set equal to 0.001 so that the ECB variable is not affected by Swedish variables.

C Additional figures

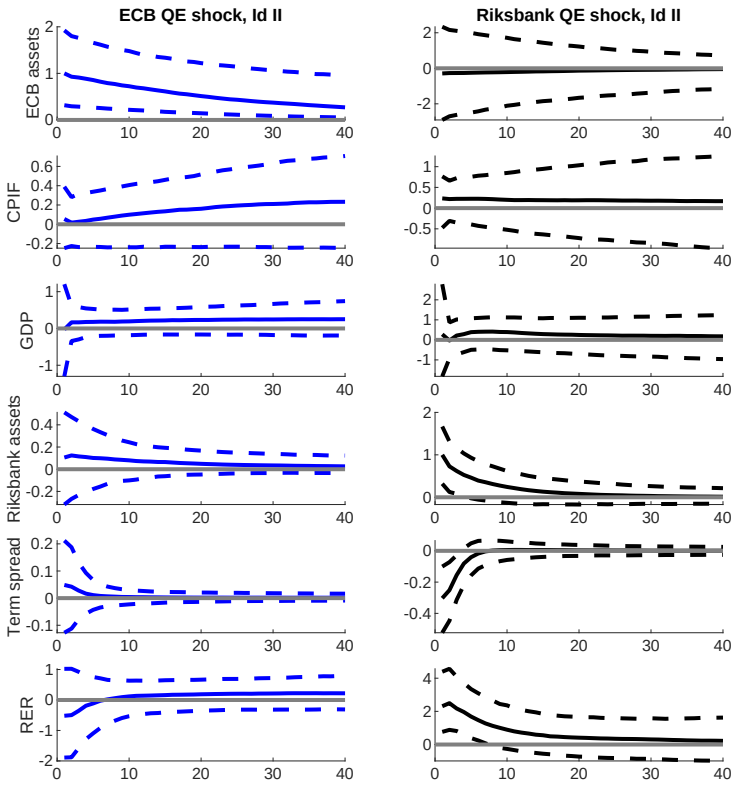

Figure C.1: Impulse response functions to the ECB QE shock and the Riksbank QE shock. We use the baseline Bayesian VAR model, Minnesota prior, 2 lags. Results refer to Identification II. Sample period is 2015:01-2018:12. We use 2000 simulations and 500 more for burn-in. Responses are in percentage terms. The blue and black solid lines represent the median responses of the ECB QE shock and the Riksbank QE shock, respectively. The dashed lines denotes a 68 per cent credible interval.

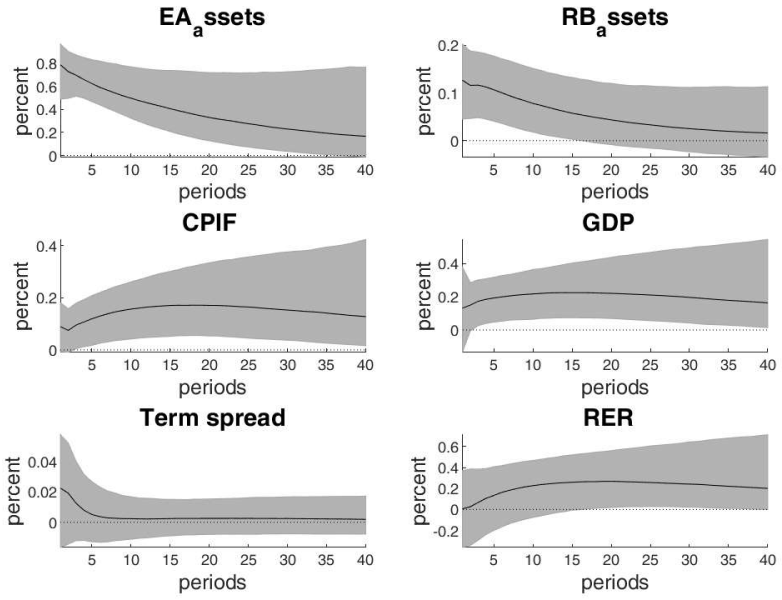

Figure C.2: Impulse response to ECB QE shock. We use the Bayesian VAR model, Minnesota prior, 2 lags. Results refer to max FEV identification at 40 months. Sample period is 2015:01-2018:12. Responses are in percentage terms. The black solid lines represent the median response. The shaded area denotes a 68 per cent credible interval.

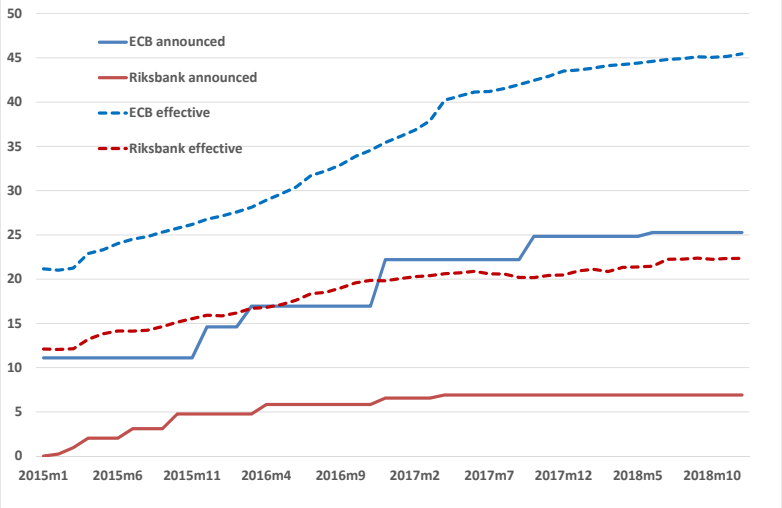

Figure C.3: Announced asset purchases (continuous lines) and asset holdings in the balance sheet (dashed lines) of the ECB (blue lines) and the Riksbank (red lines). Shares over 2014:Q4 annualized GDP of each region.

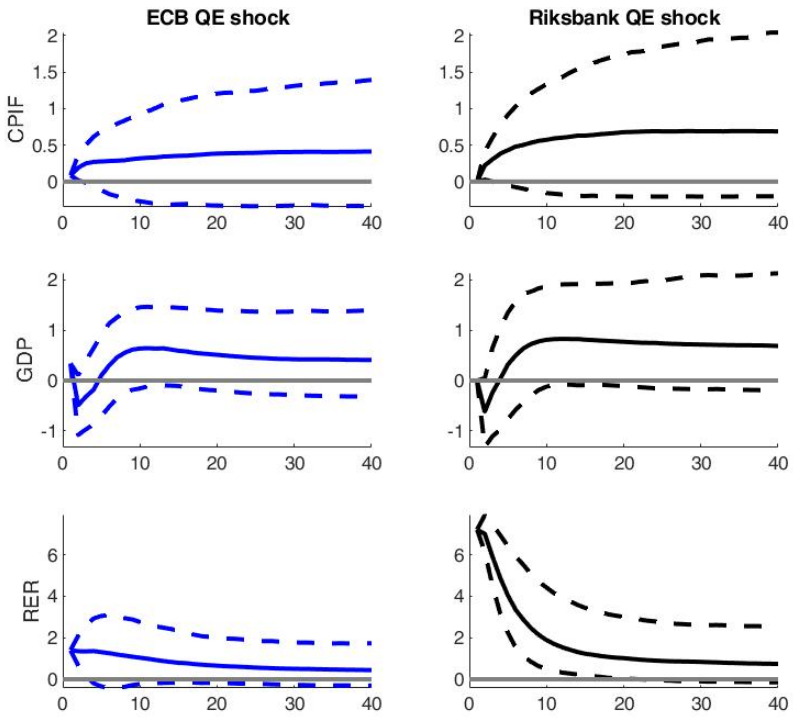

Figure C.4: Impulse response functions to the ECB QE shock and the Riksbank QE shock, normalized to one percent decrease in the long-term rate. We use the baseline Bayesian VAR model, Minnesota prior, 2 lags, where the long-term rates replace the announced asset purchases and the short-term rate replaces the term spread. Results refer to Identification I. Sample period is 2015:01-2018:12. We use 2000 simulations and 500 more for burn-in. Responses are in percentage terms. The blue and black solid lines represent the median responses of the ECB QE shock and the Riksbank QE shock, respectively. The dashed lines denotes a 68 per cent credible interval.

D Additional tables

Table D.1: Alternative model specifications

Model	**ECB QE shock**		**Riksbank QE shock**	
	Peak effect GDP	**Total effect inflation**	**Peak effect GDP**	**Total effect inflation**
Baseline	0.21*	0.22*	0.16*	-0.06
w Effective purchases	0.33*	0.29*	0.29*	0.13
w Fed funds	0.12*	0.13*	0.16*	-0.07
w Euro area prices	0.26*	0.25*	0.36*	0.002*
w oil prices	0.21*	0.20*	0.15*	-0.06
up to 2019	0.13*	0.09	0.17*	-0.05
from 2014	0.12*	0.05	0.33*	-0.06

Values come from baseline model, model with effective purchases replacing announced purchases, baseline model with the addition of Fed funds rate, oil prices or euro area inflation and baseline model extended to 2019. All models use Identification I, effects are standardized to one percent of GDP. * indicates that at the time of the effect the 68 per cent credible intervals are mostly excluding zero.

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