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Medium term treatment and side effects of quantitative easing: international evidence

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Abstract

We use a cross-country sample of monthly observations for quantitative easing (QE) treatments in order to study the causal effect of such policies on a large set of economic and financial outcome variables. We address potential endogeneity by re-randomising the sample and applying the augmented inverse probability weighting (AIPW) estimator. Our results show that QE policies do affect the central bank balance sheet and asset prices, in particular long term yields, equity prices and exchange rates in the expected direction. Most importantly, we find that QE policies lead to a sustained rise in the CPI and in inflation expectations. However, our findings suggest that the main transmission channel does not appear to be stronger aggregate demand impacting inflation through the Phillips curve, but rather exchange rate depreciation. Finally, we do not find any evidence for side effects and increases in risk taking following QE, with real house prices and real credit not increasing or falling, and no downward effect on stock market volatility.

Keywords: Unconvential monetary policy, Quantitative Easing, augmented inverse probability weighting estimation, AIPW.

JEL: E5, F3.

Non-technical summary

In response to the global financial crisis, central banks took unprecedented measures to counter risks to price stability. With policy rates approaching the zero lower bound, large scale asset purchases often referred to as 'quantitative easing' (QE) replaced interest rates as the main policy instrument.

As a result, the balance sheets of central banks increased considerably. An intense and partly controversial policy debate with regard to the effectiveness of unconventional monetary policy has emerged. While the central banks which have embarked on QE point to the fact that the immediate financial market effects of these measures have been positive, it is less clear what their longer-term impact on macroeconomic conditions is. In addition, several observers have raised concerns with regard to the build-up of new financial stability risks stemming from such polices.

Against this backdrop, we use a cross-country sample of monthly observations for quantitative easing (QE) treatments in order to study the causal effect of such policies on a large set of economic and financial outcome variables. Our contribution to the empirical literature on the effect of QE policies is twofold:

(i) Compared with most of the empirical literature on QE policies, based on event studies, we look at the effects at lower frequency and from a longer term perspective;

(ii) we address the problem of the endogeneity of QE using an approach that is novel, at least in this literature, by using the augmented inverse probability weighting (AIPW) estimator proposed by Jordà and Taylor (2016) to account for the endogeneity of QE policies across countries and over time.

The AIPW approach allows us to rebalance our sample to reproduce a situation where the decision to embark on QE had been taken at random. We apply this approach to a panel of 41 countries, using monthly data between 1999 and 2016.

Our main results are three:

(i) we find that QE policies lead to a sustained rise in the CPI and in inflation expectations;

(ii) the main transmission channel does not appear to be stronger aggregate demand impacting inflation through the Phillips curve, but rather the exchange rate depreciation;

(iii) we do not find any evidence for side effects and increases in risk, with real house prices and real credit not increasing or falling, and no downward effect on stock market volatility.

It should be emphasised, however, that our results refer only to the marginal impact of Quantitative Easing on these variables and not to the "low for long" level of interest rates, which we largely control for in our methodology by restricting ourselves to ZLB observations.

The fact that most of the effect seems to go through the exchange rate deserves further analysis. At the same time, the lack of a visible effect on credit and real house prices may suggest that some of the financial stability risks of QE policies may have been overstated. This finding should, however, be treated with caution as the house price and credit data available to us tend to be less harmonised compared to the macroeconomic data in our analysis.

Our results are surrounded by further caveats and qualifications. First, we consider proxies for QE policies as, in the end, they are not perfectly observable. Second, each QE policy has some unique features that we cannot take into account. For example, QE policies have been carried out under very different circumstances in terms of fiscal stance and state of the financial sector. In addition, in our approach we do not distinguish between QE and forward guidance, and our estimated effects should be seen as the combination of the two policies since they have often been taken simultaneously. Finally, it would be good to investigate the potential international spill-over of QE policies using our empirical approach. Overall, many interesting research questions remain to be addressed.

1 Introduction

In response to the global financial crisis, central banks took unprecedented measures to counter risks to price stability. With policy rates approaching the zero lower bound, large scale asset purchases often referred to as 'quantitative easing' (QE) replaced interest rates as the main policy instrument. As a result, the balance sheets of central banks increased considerably. An intense and partly controversial policy debate with regard to the effectiveness of unconventional monetary policy has emerged. While the central banks which have embarked on QE point to the fact that the immediate financial market effects of these measures have been positive, it is less clear what their longer-term impact on macroeconomic conditions is. In addition, several observers have raised concerns with regard to the build-up of new financial stability risks stemming from such polices.

For a long time, empirical studies on the effects of QE exploited mainly the time dimension of the limited number of cases where central banks, in particular the Bank of Japan and the Federal Reserve, have used an increase in their balance sheet via asset purchases to influence macroeconomic outcomes. With time, the ECB and several other European central banks have also embarked on large scale asset purchase programs in order to prevent - in the aftermath of the European sovereign debt crisis - a very low inflation scenario from materializing. This increase in data availability allows exploiting the cross-country dimension using panel estimation techniques. Yet, countries which make use of QE typically share common characteristics and use such measures because they respond to changes in key variables which they are supposed to influence. For the econometric estimation of the effect of QE on certain outcome variables, these patterns lead to selection bias and endogeneity.

The contribution of this paper is fourfold. First, compared with most of the empirical literature on QE policies, based on event studies, we look at the effects at lower frequency and from a *medium term perspective*. Financial markets can over- or under-shoot, and the effects may be transitory; what counts in the end are the effects seen over quarters or years. Second, we address the problem of the endogeneity of QE using an approach that is novel, at least in this literature. In particular, we address this challenge and use the *augmented inverse propensity score weighted (AIPW)* estimator proposed by Jordà and Taylor (2016) to account for the endogeneity of QE policies across countries and over time. This method

can be combined with local projections and thus also account for possible non-linear effects of QE.[1] Intuitively, this approach allows us to rebalance our sample to mimic a situation where the decision to embark on QE had been taken at random. We apply this approach to a panel of countries, using monthly data between 1999 and 2016. Third, our approach allows us to look at the effects of QE policies on a wide range of outcome variables, more than is typically possible in event and VAR studies. In turn, this gives us a broader overview of the effects of these policies than has been done thus far. Fourth and importantly, our approach is essentially a difference-in-difference framework and we are therefore comparing countries both to their past as well as to their non-QE peers. This may allow us to better control for common trends and sharpen the inference on the specific domestic effects of QE.

The key questions that we want to address with this methodology are three:

(i) Do QE policies lead to a sustained increase in inflation?

(ii) If they do, what is the main transmission channel?

(iii) Do QE policies lead to an unsustainable expansion of credit and lower volatility (or higher risk taking), therefore stoking financial stability risks?

Overall, our results show that QE policies do affect the central bank balance sheet and asset prices, in particular long term yields, equity prices and exchange rates, in the direction that is plausible to expect and qualitatively in line with the results of event studies. In terms of the medium term macroeconomic effects, we find that QE policies do lead to a sustained rise in the CPI and in inflation expectations. Quite surprisingly, the main transmission channel does not appear to be stronger aggregate demand impacting inflation through the Phillips curve, but rather exchange rate depreciation. In addition and importantly, we do not find any evidence for side effects and increases in risk, with real house prices and real credit not increasing or even falling, and no downward effect on stock market volatility. This finding should, however, be treated with caution as the house price and credit data available to us tend to be less harmonised compared to the macroeconomic data in our analysis. Note, in addition, that our results refer only to the marginal impact of Quantitative Easing on these variables and not to the "low for long" level of interest rates, which we largely control for in our methodology.

As every empirical analysis, also our work is subject to caveats and qualifications. There

[1] In macroeconomics, this methodology has been used in the context of fiscal policy by Jordà and Taylor (2016) and sovereign defaults by Kuvshinov and Zimmermann (2016).

are at least three of them to keep in mind here. First, QE policies are not perfectly observable. We consider what in our view are reasonable proxies in our analysis, but alternative definitions are possible. Second, and most important, each QE policy has some unique features that we unavoidably need to keep out in our panel analysis. Our results, therefore, cannot be directly applied to each specific QE policy. Third, we are not controlling for forward guidance in measuring our QE policy indicator, essentially because forward guidance and QE are often implemented jointly. The effects that we measure, therefore, should be seen as a combination of QE and forward guidance as mutually reinforcing policies.

The paper is organised as follows. Section 2 contains a literature review, which also puts our contribution into context. Section 3 elaborates on the empirical strategy. Section 4 presents the results, and Section 5 concludes.

2 Relation to previous literature

There are already useful literature surveys on the effects of unconventional monetary policies and QE in particular, for example Kuttner (2018), Dell'Ariccia et al. (2018) and Gagnon (2016). Dell'Ariccia et al. (2018), in particular, focus on unconventional policies in countries other than the US, notably the euro area, Japan and the United Kingdom, finding that (i) these policies are more effective during financial distress, (ii) there is convincing evidence of a significant impact on financial conditions, (iii) the impact on macro variables is harder to measure but is likewise likely significant, and finally (iv) no major side effects have materialized thus far.

At the same time, especially given that the evidence on the economic effects of QE was so far mainly provided by central bank researchers, many observers have remained sceptical about the effectiveness of asset purchase programs (Gros et al. (2015); Martin and Milas (2012)).[2] In particular, it is often noted that most of the evidence on the effects of QE comes from event studies. Some recent contributions, such as Thornton (2017), shed some doubt on the validity of this evidence. Notably, some papers point to the possibility of overreaction, in particular Swanson (2017) and Greenlaw et al. (2018). The latter paper, in particular, argues that there is the possibility of confusing QE events with other policies, notably forward guidance. Based on an alternative way to define news based on Reuters

[2]See also John Cochrane at https://voxeu.org/article/sense-and-nonsense-quantitative-easing-debate.

reports, they find that QE looks less powerful and predictable than stated in the event study literature.[3] At the opposite end, other papers have already suggested to mainstream QE and incorporate it systematically in the central bank policy framework. Gagnon and Sack (2018), for example, suggest to devise a policy rule defined in terms of QE, including considerations related to the level versus the change of central bank bond holdings and inertia, similar to the discussion on optimal interest rate rules.

To some extent, lack of consensus derives from the fact that the causal impact of QE on the economy is still less understood than that of conventional monetary policy (i.e. changes in the short term rate). In fact, former Fed Chairman Ben Bernanke quipped in 2012, *"Well, the problem with QE is it works in practice, but it doesn't work in theory."*And indeed, a prominent view in monetary economics is that asset purchases should by themselves produce no effects.[4] The reason is that the stance of monetary policy can in principle be fully described by the current and expected future level of the short-term policy interest rate. In a recent survey of the theoretical literature, Andrade et al. (2016, pp.9) therefore point to three possible transmission channels of QE, namely the signalling channel, the asset valuation (or portfolio rebalancing) channel, and the reanchoring channel.[5]

Under the *signalling channel*, QE is interpreted as a signal that the future path of interest rates will be lower than previously expected. In this respect, QE is very similar to forward guidance. The marginal benefit over forward guidance would be to make the announcement more credible.[6]

For a given expected path of future interest rates, QE could produce additional effects via changes in investor's valuation of future returns. Andrade et al. (2016) subsume under this *asset valuation channel*, several mechanisms, namely the "duration risk channel" under which it is important for central banks to purchase long-maturity bonds; the "capital relief channel" under which the increase in asset prices acts like a capital injection for leverage-

[3]Our paper is perhaps close in spirit to Belke et al. (2017), who study the effects of US unconventional policy by looking at interest rate differentials between the US and the euro area, finding that bond-buying in the US appears to have had little impact on US interest rates.

[4]See Andrade et al. (2016) and the literature quoted there, in particular Curdia and Woodford (2011).

[5]Harrison (2017) studies optimal monetary policy in a simple New Keynesian model with portfolio adjustment costs. In this model the adoption of QE is welfare-enhancing and rapid, with large-scale asset purchases triggered when the policy rate hits the zero bound.

[6]One explicit argument developed in the literature is that credibility is higher because large-scale purchases of long-term assets expose the central bank to the risk of losses on its balance sheet, in case short-term rates are abruptly increased. This provides an incentive for keeping policy rates low and to increase them only gradually on the exit from the crisis. See Andrade (2016, p. 9) and the literature quoted there.

constrained institutions; and the "portfolio rebalancing channel" stressing that changing asset prices will increase the weights of risky assets in investors' portfolios.

Finally, QE working through the *reanchoring channel*, is stabilizing inflation expectations at the zero lower bound. In fact, in a regime where only conventional monetary policy tools are available, economic agents might question the ability of the central bank to ensure price stability and avoid a liquidity trap scenario which would be characterized by persistent deflation and deflation expectations. Under this reasoning, QE policies reassure private agents of the central bank's ability to reanchor inflation expectations.

So far, the empirical literature on QE has mainly focused on the financial market impact of unconventional monetary policy measures around announcements or actual asset purchases using high-frequency financial data. Overall, these studies find that such policies were effective in reducing financial market risk spreads or yields.[7] In terms of identification strategies in this literature, most studies are event studies which focus on the short-term impact of QE on financial markets. Most advanced and comprehensive in this regard is a paper by Rogers, Scotti and Wright (2014) who use intraday data to identify the causal effect of monetary policy surprises.

In addition, a few papers have looked at the effects of unconventional monetary policy by using VAR models with traditional identification strategies. Behrendt (2013) uses a standard VAR with Cholesky decomposition to analyse the effects of unconventional monetary policy on consumer as well as asset price inflation, economic activity and bank lending. Gambacorta et al. (2014) use a mixture of zero and sign restrictions in a panel VAR setting to isolate unconventional monetary policy shocks identified as an exogenous innovation to the central bank balance sheet. Baumeister and Benati (2013) use a time-varying VAR on US data in which a term spread shock is identified that leaves the (short term) policy rate unchanged; with this method, they found that QE had expansionary effects in the US. Meinusch and Tillmann (2016) use a Qual VAR method to estimate the "Fed propensity to QE" and incorporate this propensity into VAR-based estimates of the effects of QE based on US monthly data between 2007 and 2013. They find that the response to "QE shocks" as identified in their framework include a positive reaction of US GDP (not statistically

[7] For early evidence of the Fed's QE1 programme, see D'Amico and King (2010), Gagnon et al. (2010), Hamilton and Wu (2010), Neely (2010), Joyce et al. (2011). More recently, taking also into account the effects of the Fed's QE2 programme, Fratzscher, Lo Duca and Straub (2012) also look at international spill-overs.

significant) and inflation, a fall in the US long term yield, and a rise in US equity prices. Finally, Weale and Wieladek (2015) identify an asset purchase announcement shock with four different identification schemes, always leaving the reactions of real GDP and CPI unrestricted, to test whether these variables react to asset purchases.

The upshot of this literature is that QE generates, in addition to positive effects on financial markets, real effects on output which are qualitatively similar to the ones typically found in the literature on the effects of conventional monetary policy.[8] But given that it is not clear whether the financial market effects found in event studies are lasting, and that the identification strategies used to assess medium-term effects of QE were so far not fully convincing, there is a need for estimating the causal effects of QE over longer horizons. Similarly to studying the effects of a medical treatment, such an analysis should control for the endogeneity of the treatment. Within our analogy with the medical treatment, sick people are more likely to take the medicine, therefore simply comparing the health of treated and non-treated individuals after the treatment would be misleading. In addition, a comprehensive analysis of a treatment should also try to look at the side effects of the medicine, especially at longer horizons.

3 Empirical strategy

We proceed in three steps. We first identify QE episodes using a narrative approach. We then compute via a logit model propensity scores that are subsequently used for re-randomising the sample. Finally, we apply the augmented inverse propensity score estimator (AIPW) explained in Jorda and Taylor (2016). The logic behind this estimator is to apply local projections to a sample that has been re-randomised using the propensity scores. In this way, we can evaluate treatment and side effects of the non-standard monetary policy measures.

Observe that in the main analysis we restrict the estimation to countries that are at, or close to, the zero lower bound (ZLB). We implement this by ruling out all observations where the short term interest rate is above 0.5%. This has three important advantages and

[8] Using a Bayesian VAR, Hesse et al. (2017) find that the early asset purchase programmes of the Federal Reserve and the Bank of England had significant positive macroeconomic effects, while those of the subsequent ones were weaker and in part not significantly different from zero. The authors attribute the reduced effectiveness of QE to a stronger anticipation of asset purchase programmes over time. In our framework, we work with narrative QE events which are unlikely to have been fully anticipated. In addition, we control for anticipation effects in one of our robustness checks.

one cost. The advantages are that (i) by restricting to the ZLB observations, much of the endogeneity of undertaking QE is already controlled for, hence increasing the probability that the treatment is random; (ii) we compare countries in similar situations; and (iii) we avoid the risk of over-determining the treatment, in particular the no treatment observations (since no country has undertaken QE, at least in our definition, outside of the ZLB), which would be a significant problem for the AIPW approach. The cost of this choice is the fall in the number of observations.

3.1 Data

We use a sample composed of theoretically 41 advanced and emerging countries (the complete list can be found in the Appendix, *see Table A.1*), with the euro area included as individual member states to exploit the fact that the ECB's monetary policy is to some extent exogenous for them.[9] The data are used at monthly frequency and start in January 1999, i.e. our sample starts with the modern history of QE, around the time when the Bank of Japan first considered to "implement a quantitative easing by targeting the monetary base", according to Haldane et al (2016). The sample ends in December 2016, where data availability allows. This amounts to a maximum of 10108 country-month observations. Note, however, that we consider the full sample only for a robustness check, as in fact we only include countries at the ZLB (more on this later). For each observation we have country – month specific information on central bank total assets, broad money, consumer price indices (CPI), nominal effective exchange rates (NEER), real effective exchange rates (REER), 3-month interest rates, 1-year interest rates, long term interest rates, stock market indices, bank stock market indices (as a ratio of the overall index), credit to the private sector, industrial production, unemployment, consumer confidence index, net exports, inflation expectations, portfolio assets and liabilities, net portfolio inflows, stock market volatility and house prices. A list with sources for each of these variables can be found in the Appendix (*Table A.2*). This large amount of information is needed first for looking at a broad set of outcome variables which include a variety of transmission channels of QE and, second, for the computation of propensity scores.

[9] We also include a robustness analysis considering the euro area as a single country, because the inclusion of euro area countries implies that a majority of treated observations are in euro area countries.

3.2 Identification of QE episodes

In order to identify QE episodes, we use a narrative approach based on an updated and expanded version of the data set by Rogers, Scotti and Wright (2014, RSW).[10] The authors consider announcements of unconventional monetary policy initiatives of the Federal Reserve, the Bank of Japan (BoJ), the ECB and the Bank of England (BoE). Most of these announcements consist of statements after policy meetings, but some important speeches and other events are included as well. According to RSW, many of these announcements were either not very consequential, or largely anticipated. Nevertheless, their data set includes several policy announcements that came as big surprises to market participants. Examples mentioned by the authors are the BoE and FOMC announcements of Treasury purchase programmes in March 2009 and the announcement of open-ended asset purchases by the BoJ on 4 April 2013.

For our identification of QE episodes, we also limit ourselves to such major, largely unanticipated, events and update the RSW data set until end-2016. In addition, we perform a couple of changes to the data set. First, we expand the narrative approach to all countries in our sample and cross-check the RSW data set against other sources (e.g. Fawley and Neely (2013) in the case of the Federal Reserve). Second, we also purge the RSW data set of events related to the exit from unconventional monetary policy such as the speech of Chairman Bernanke which triggered the "taper tantrum" episode in May 2013.[11] Finally, we remove from the RSW dataset episodes which are related to central bank balance sheet increases, but are unrelated to monetary policy, such as those put in place for liquidity provision (e.g. in the euro area before the APP was launched).[12] Such episodes relate, for example to the ECB's full alotment policy since October 2008 and the use of long-term refinancing operations as well as very small, largely sterilised, asset purchase programs during the first phase of the sovereign debt crisis as well as the ECB's announcement of its

[10] In a previous version of this paper, we also used a quantitative measure based on large changes in central bank balance sheets at the zero lower bound. While such a measure has the advantage of being less based on judgement compared to a narrative identification, it does not pick up well-known QE episodes when changes in balance sheets occur more gradually.

[11] In this paper, we don't look at the effects of exit-related QE episodes since we are interested in the effects of asset purchase programs once implemented. RSW consider such events because they weight them by their market reaction which was, in the case of the taper tantrum, negative.

[12] Haldane et al. (2016) find that balance sheet expansions boost economic activity and prices only when interventions are badged as monetary policy. This suggests, according to the authors, that the signalling and confidence channel of QE may be particularly potent.

so-called OMT programme at the peak of sovereign debt crisis.[13]

Compared to the RSW dataset, our data set includes a couple of interesting very recent QE episodes (see Table A.3, A.5, A.7, A.9, A.11 and A.13 in the Appendix). For the euro area, we study the effect of the ECB's asset purchase programme which was officially launched in January 2015, with preparatory work commencing in June 2014[14]; in the case of Sweden, we look at the government bond purchase programme of the Riksbank, launched in February 2015; with regard to Switzerland we consider the SNB's relatively small bond purchase programmes of 2009 and the expansion of central bank reserves in 2011 which can be seen as quantitative easing even without the purchase of long-term securities, as explained in Christensen and Krogstrup (2015); for the UK our QE treatments include the re-activation of the Bank of England's Asset Purchase Facility after the Brexit vote in August 2016; for Japan we include the BoJ's launch of "Quantitative and Qualitative Monetary Easing with Yield Curve Control".

Based on these QE episodes, we define a dummy variable $QEnarr1_{it}$ which assumes the value of one if country i embarked on a major QE at time t, and which is set to zero otherwise. We also employ an alternative measure $QEnarr2_{it}$ which includes in addition to our major QE episodes more minor events (see Table 1). For example, in the case of Federal Reserve, we consider the announcement of "Operation Twist" in September 2011, the decision to not no longer sterilize purchases under the Fed's "QE3 programme" through the sale of short-term Treasuries of December 2012, as well as the clarification that a tapering of asset purchases will remain data-dependent in September 2013 (see Table A.3 in the Appendix). In the case of the euro area, we consider for example a speech of President Draghi delivered in May 2014 as minor QE treatment because some market participants may have interpreted it as a signal to possibly launch a large-scale asset purchase programme for the euro area (see Table A.7 in the Appendix).

[13] More specifically, we exclude the ECB's "Securities Markets Programme" under which the Eurosystem started in May 2010 to purchase public and private debt securities to ensure depth and liquidity in market segments that were deemed dysfunctional, i.e. the bond markets of Ireland, Greece, Spain, Italy and Portugal. The impact of these interventions was sterilised to ensure that the monetary policy stance was not affected, i.e. they did not constitute monetary policy and were too small to generate macroeconomic effects (218 billion euro in total). In addition, we exclude the announcement of Outright Monetary Transactions (OMT) since this programme was aimed at "safeguarding an appropriate monetary policy transmission and the singleness of the monetary policy", i.e. preserving the euro area rather than standard monetary policy.

[14] Our classification of QE episodes in the case of the ECB is consistent with other recent studies on the short-term announcement effects of uncoventional monetary policy in the euro area, see Altavilla, Carboni and Motto (2015). Using daily frequencies, the authors consider a few additional speeches of the ECB's President held in particular during the last quarter of 2014. At the level of monthly data, their QE episodes are the same as ours, with the only exception that their sample starts only in September 2014.

In another robustness check we also consider a third dummy variable, $QEnarr3_{it}$ in which

Table 1: Description of QE episodes

Measure	*Description*
QEnarr1	Narrative measure based on an updated and expanded version of the data set by Rogers, Scotti and Wright (2014) as described in the text. The monthly dummy variable *QEnarr1* assumes the value of "1" during QE treatments and is otherwise set to zero.
QEnarr2	Narrative measure based on an updated and expanded version of the data set by Rogers, Scotti and Wright (2014) including, in addition to all treatments of *QEnarr1*, minor QE treatments as described in the text. The monthly dummy variable *QEnarr2* assumes the value of "1" during QE treatments and is otherwise set to zero.
QEnarr3	Narrative measure based on public information about the duration of QE programs. The dummy variable QEnarr3 assumes the value "1" throughout the duration of the respective programs

we consider QE to be a permanent "treatment" throughout the duration of officially announced asset purchase programs (e.g. QE1, QE2 and QE3 in the case of the Federal Reserve, see Tables A.4 A.6, A.8, A.10, A.12, A.14 in the Appendix).
In order to account for the fact that the announcements collected by RSW or our updated QE episodes might still be anticipated by financial markets at an earlier point in time, we also lag our QE variable by one month in a robustness check.

In our sample of ZLB observations, the frequency of the treatment is as shown in Table 2 for the case when euro area countries are included separately and when the euro area is taken as a single unit. More observations are not treated than treated, but for $QEnarr3$ almost half of the observations are treated.

Table 2: Summary statistics for the QE treatment variables

	All ZLB observations		Euro area as a single unit	
	0	1	0	1
$QEnarr1$	1345	165	593	46
$QEnarr2$	1215	295	582	57
$QEnarr3$	740	770	396	243

3.3 Computing the propensity scores

Re-randomising using the propensity scores. Countries that choose to apply QE measures may be different from countries that do not apply QE measures, i.e. the QE measures may be endogenous, making it difficult to compute the effect of QE by simply comparing economic outcomes between the two types of countries.

To deal with endogeneity, we make use of the selection-on-observables assumption (or conditional ignorability or conditional independence) of Rosenbaum and Rubin (1983):

$$[y_{i,t+h}(qe) - y_{i,t}] \perp QE_{i,t} \mid X_{i,t} \tag{1}$$

where $QE_{i,t}$ is our QE dummy variable for both definitions, qe takes values 0 or 1 and $X_{i,t}$ are controls. Essentially, this assumption says that the treatment allocation is independent of potential outcomes, given the controls. Therefore, within this methodology there is a need to control for all possible covariates that might be correlated to the outcome and treatment variables. In addition, Rosenbaum and Rubin (1983) show that for the selection-on-observables assumption to hold, it is enough to condition on a propensity score, which is actually the probability of receiving a treatment $\pi(X) = Pr(QE = 1 \mid X)$. This propensity score summarizes the information embedded in controls X and it is usually modeled through a logit or a probit model. In this paper, we use a logit model[15] to compute the propensity scores:

$$\pi(X) = \frac{e^X}{1 + e^X} \tag{2}$$

Possible covariates of QE policies. In computing the propensity scores, we control for several country-specific and global factors which are likely to affect the probability of a country to undertake QE policies. Note that all these variables, with the exception of the VIX, are lagged one month, to mitigate the risk of reverse causality and to allow for reasonable information lags in monetary policy decisions. With respect to country-specific factors, we control for (i) inflation as measured by the annual change in the consumer price index (CPI); (ii) private sector credit growth; (iii) the output gap (proxied by the annual growth in industrial production); (iv) the unemployment rate, (v) the real equity price,

[15] The propensity scores produced with the logit or probit model should be the same (see Davidson and MacKinnon, 2004).

which should also reflect market expectations about future developments and (vi) the bank stock market index relative to the overall index. As regards global covariates we control for the the Brent oil price in USD and the VIX index, to proxy for global risk aversion and volatility.

Ideally, we would like to include additional, and in particular forward looking, variables to the list of covariates. Unfortunately, other potentially interesting variables such as inflation expectations or growth forecasts were either not available at monthly frequency or presenting a large number of missing data, which would in turn reduce the sample for the estimates of the effects of QE. However, we check at least if, for the available data, inflation expectations from Consensus forecasts and additional lags of the covariates enter in a statistically significant way, and we find that they do not. Therefore, we are rather confident that our list of covariates does a good job at removing the endogeneity of QE decisions.

Table 3 shows the fitted parameters of the logit model for our narrative QE treatment variables. Although the coefficients cannot be interpreted as marginal effects (as it would be the case for a linear regression), their sign indicates in what direction the probability of embarking on QE policies would change, given a change in the control variables. Lower inflation and credit growth are independently associated with a higher probability to do QE given that a country is at the ZLB, whereas a higher VIX and (more surprisingly) oil price contribute positively. Finally, the real equity price is insignificant and the unemployment rate is statistically significant but wrongly signed (higher unemployment associated with a lower probability to do QE). Likewise, industrial production growth is wrongly signed for $QEnarr2$ and $QEnarr3$. Fundamentally, however, these results suggest that for countries at the ZLB implementing QE policies is almost random, as confirmed by the low R^2. This is exactly what one would expect since being at the ZLB already soaks up a lot of the influence of the macroeconomic environment on the monetary policy stance.

Most coefficients are similar for the two other treatment definitions, showing that independent of the source of information that we choose in defining the treatment, results are generally the same. One exception is the relative equity price of banks, which is significant for $QEnarr3$, and industrial production growth as already mentioned.

ROC curve. Figure 1 reports the area under the curve for $QEnarr1$ (ROC curves for

Table 3: Logit regressions for estimating the propensity to QE

	(1) QEnarr1	(2) QEnarr2	(3) QEnarr3
Annual CPI inflation, t-1	-20.629**	-18.653**	14.415**
	(9.985)	(8.220)	(6.431)
Unemployment rate, t-1	-0.082**	-0.092***	-0.091***
	(0.033)	(0.027)	(0.021)
Annual industrial production growth, t-1	0.625	2.222*	3.758***
	(1.373)	(1.180)	(1.218)
Annual credit growth, t-1	-4.908**	-4.497**	-5.457***
	(2.391)	(1.976)	(1.789)
Real equity price, t-1	-0.125	-0.130	-0.216
	(0.348)	(0.285)	(0.317)
Relative stock price of banks, t-1	-0.067	-0.074	-0.459***
	(0.074)	(0.060)	(0.060)
VIX	0.045**	0.044***	-0.011
	(0.018)	(0.015)	(0.014)
Log Brent oil price, t-1	0.608*	0.187	-1.541***
	(0.344)	(0.270)	(0.242)
Observations	1,018	1,018	1,018
Pseudo R2	0.0398	0.0502	0.154

Logit regressions. Sample period 1999:1 to 2016:12.

the other two dummies are reported in the online Appendix). In general, the model does better than a purely random guess as measured by the area under the curve at 0.66, hence well above the uninformed level of 0.5. At the same time, the value is also very far from 1, suggesting that a substantial part of the treatment is indeed random, which can be expected in our sample of countries at the ZLB.

Un-predictability of the re-randomised QE treatment. In order to illustrate that after correcting with the propensity scores our treatments can be considered as good as random, we regress the treatment variable corrected with the propensity score on up to 12 lags of all variables included in the logit equation. The R^2s for all these equations are very low, confirming that we are left with near-exogenous treatments for which we can legitimately study their causal effects on economic outcomes.[16]

[16] A reader could observe at this point that a (lagged) covariate that could explain the re-randomised QE dummy belongs to the first stage regression. However, including all possible variables at all possible lags is beyond the possibility in terms of degrees of freedom, and for this reason we do this separate check. This also relates to the observation we made before about including additional covariates in the first stage regression.

Figure 1: ROC curve for QEnarr1.

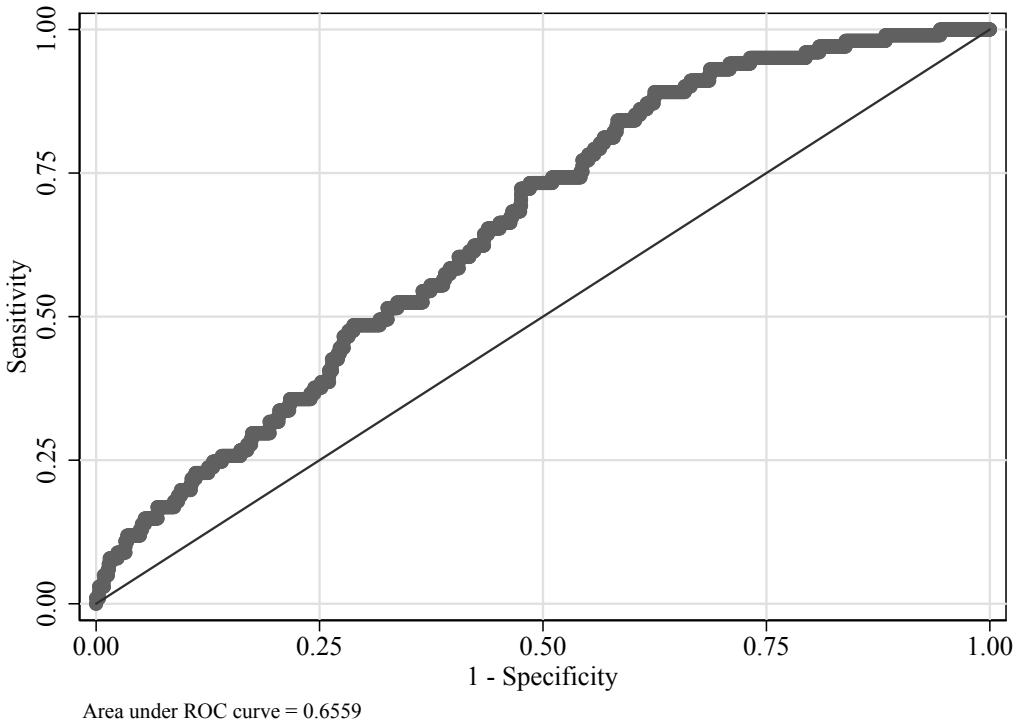

Figure 2: The figure reports the ROC (receiver operating characteristic curve), illustrating the diagnostic ability of the logit model by computing the true positive rate against the false positive rate at various threshold settings.

3.4 Applying the AIPW estimator

According to our first-stage regression, the decision to embark on QE policies is highly endogenous. Thus, if we were to simply compare economic outcomes during QE and non-QE episodes our sample would be biased towards countries at the ZLB with a high level of financial development and periods during which the VIX was high. Therefore, differences in economic outcomes would not necessarily reflect the causal impact of QE policies.

A first way to take endogeneity into account is to include potential covariates of QE episodes in OLS regressions estimated as local projections as follows:

$$y_{i,t+h} = \alpha_i + \lambda_t + \rho_h y_{i,t-1} + \eta_h (y_{i,t-1} - y_{i,t-12}) + \beta_h QE_{it} + \gamma_h X_{i,t-1} + \epsilon_{i,t+h} \qquad (3)$$

where y is a variable of interest (say, central bank assets), QE are the dummy variables for QE episodes, and X is a vector of variables entering the first stage regression for QE. To the extent that the controls X soak up all the endogeneity of QE, the coefficients β_h help us identifying an impulse response function to its implementation and hence the (dynamic) Average Treatment Effect (ATE). In the regressions we consider local projections up to 36 months. i.e. 3 years.

Note that we include country and time dummies in the estimates, so that this is essentially a *difference-in-difference* estimate. It should be emphasised that this is an important innovation of this study compared with the existing literature on QE, which has tended to look at QE "shocks" on the countries involved without, at least explicitly, comparing them with non-QE countries and hence controlling for common trends. It is particularly important to include country dummies, in particular, due to the heteroegeneity in the country sample that we use.

In order to control for "pre-trends", we also include as a control variable the difference between the dependent variable at $t-1$ and $t-12$. For example, countries may have a faster or slower rate of economic growth on a lasting basis which, if not properly controlled for, may be reflected in the estimates of the effects of QE policies on, say, economic activity.

In addition to OLS, an alternative way to measure the ATE is the Augmented Inverse Propensity Weighted Estimator (AIPW) where we first estimate the propensity score, $\widehat{\pi}_{it}^{QE}$ and then run the same regression as above, but weighting the observations according to the *inverse* of $\widehat{\pi}_{it}^{QE}$. In this way, we re-randomise the sample whereby countries and episodes

with a high propensity score are under-weighted for the treated observations and countries and episodes with a low propensity score are over-weighted among non-treated observations. Moreover, as the treatment is a dummy variable, the average treatment effect shown in equation (3) is equivalent to the coefficient in a local projection regression estimated on the rebalanced sample at horizon h. (Kuvshinov and Zimmermann, 2016, p. 8).[17]

As a caveat, it should be noted that the AIPW estimator is valid only if the treatment affects the treated unit, and not the other units. This may not necessarily be the case for QE policies, in particular for the US. While this is a caveat to be kept in mind, two considerations suggest that this is not a major problem. First, most event studies suggest that the domestic effects are larger than the international spill-overs. Second, we report results excluding the US QE policies, for which a substantial international spill-overs are far more likely, and these are not very different from the baseline ones.

4 Results

Before describing the results in detail, it is useful to give an overview of the main findings. Regarding the questions we pose in the Introduction, we find that (i) QE policies lead to a sustained rise in the CPI and in inflation expectations; (ii) the main transmission channel does not appear to be stronger aggregate demand impacting inflation through the Phillips curve, but rather the exchange rate depreciation; and (iii) we do not find any evidence for side effects and increases in risk, with real house prices and real credit not increasing or falling, and no downward effect on stock market volatility.[18]

Baseline results. The baseline results for all countries at the ZLB for $QEnarr1$ are shown in Figure 3 and for $QEnarr2$ in Figure 4 (results for $QEnarr3$ are in the online Appendix). Note that in all these figures the blue lines refer to the AIPW estimates, and the green lines to the OLS with controls. For our estimates to be credible we should at least find that QE episodes lead to an expansion in the central bank balance sheet, and

[17] One key advantage of this approach compared with OLS is that this estimator is "doubly-robust" to regression misspecification. This implies that it is unbiased as long as at least one of the regression stages (estimating the propensity scores and the local projections regression) is specified correctly. Note that if the adjustment for the propensity of being treated is done fully and correctly with the AIPW estimator, there is no difference between measuring the Average Treatment Effect (ATE) and Average Treatment Effect of the Treated (ATT).

[18] Note that we are only looking at the purely QE side of this question in this paper. Because all countries in our ZLB sample have very low interest rates, we cannot judge whether those very low rates lead to financial stability risks down the road, since these would be captured by the common time fixed effects.

this is indeed what we find (the rise in real central bank assets is between 10% and 20% in the medium term). Short term and long term interest rates also fall over time, although the effects are not very large, broadly in line with previous literature (respectively 20 to 50 basis points at the peak). Equity prices tend to rise, but not particularly so in the banking sector, as could have been expected. Among asset prices, the most notable reaction is the sharp depreciation in the nominal effective exchange rate, by about 5% at its peak, which is quite persistent and also mirrored by real depreciation. However, we find little evidence that this is accompanied by gross or net portfolio outflows or by a rise in net exports.

In terms of the medium term macroeconomic effects, three results stand out. First, the effects on economic activity are mixed. While we find a positive effect of the treatment on industrial production (more with OLS than AIPW estimates), the effects on consumer confidence are insignificant and unemployment is found to even increase in the medium term. Second, and most important, we find that the treatment appears to achieve its main objective, which is to raise the CPI over the medium term, where the effect over 3 years is found to be about 1% (somewhat higher with the OLS estimates). This is accompanied and confirmed by a gradual rise over time in long term inflation expectations, by about 0.2%. Third, we find little evidence on the side effects of QE that are often surmised by researchers and observers. Notably, we find no increase (and actually a decrease) in real credit to the private sector and the real house price, no decline in stock market volatility (against the common idea that QE policies breed low volatility and complacency) and no particularly large shift in capital flows.

Variants and robustness. After having illustrated the main results, we now turn to discuss several variants and robustness checks. First, results for $QEnarr2$ are similar to those of $QEnarr1$, which is not surprising since the two dummies are very similar. When treating the euro area as a single unit for $QEnarr1$ (Figure 5; baseline results are in black lines, euro area as a single unit in purple lines), results are generally less clear for interest rates, in particular showing no durable downward impact of the QE treatment on the long term rate, and also less positive impact on equity prices; the other results are otherwise largely unchanged. In the online Appendix we also report results for $QEnarr1$ excluding the US or Japan. As noted, the exclusion of the US is motivated by the fact that US QE is the most likely to have important international spill-overs, which in our approach may lead to an under-estimation of the effects (since we control for all time fixed effects). In

the case of Japan, the large number of QE episodes stands out for an individual country. Despite the potential for leading to different results, however, we find little difference from the baseline.

5 Conclusions

In this paper we have aimed at contributing to the empirical literature on the effects of QE policies in two ways. First, we focused on the medium term effects of QE policies, which are those that eventually matter, while most of the literature looks at the short term effects of QE announcements in event studies. Second, we apply a rather novel methodology to account for the fact that QE policies are endogenous, i.e. they are not carried out independent of the economic conditions. By applying the Augmented Inverse Propensity Weighted estimator (AIPW), we re-randomise the sample and can therefore directly compare outcomes in QE and non-QE countries and times.

We identify four main findings. First, in our estimates QE policies do affect the central bank balance sheet and asset prices, in particular long term yields, equity prices and exchange rates, in the direction that is plausible to expect and qualitatively in line with the results of event studies. Second, QE policies do lead to a sustained rise in the CPI and in inflation expectations. Third, and somewhat more surprisingly, the main transmission channel does not appear to be stronger aggregate demand impacting inflation through the Phillips curve, but rather exchange rate depreciation. Fourth, we do not find any evidence for side effects and increases in risk, with real house prices and real credit not increasing or falling, and no downward effect on stock market volatility. It should be emphasised, however, that our results refer only to the marginal impact of Quantitative Easing on these variables and not to the "low for long" level of interest rates, which we largely control for in our methodology by restricting ourselves to ZLB observations.

The fact that most of the effect seems to go through the exchange rate deserves further analysis. At the same time, the lack of a visible effect on credit and risk taking in particular may suggest that some of the financial stability risks of QE policies may have been overstated. This finding should, however, be treated with caution as the house price and credit data available to us tend to be less harmonised compared to the macroeconomic data in our analysis.

Effect of Quantitative easing, $QEnarr1$, all countries under ZLB: AIPW (blue lines) and OLS (green lines).

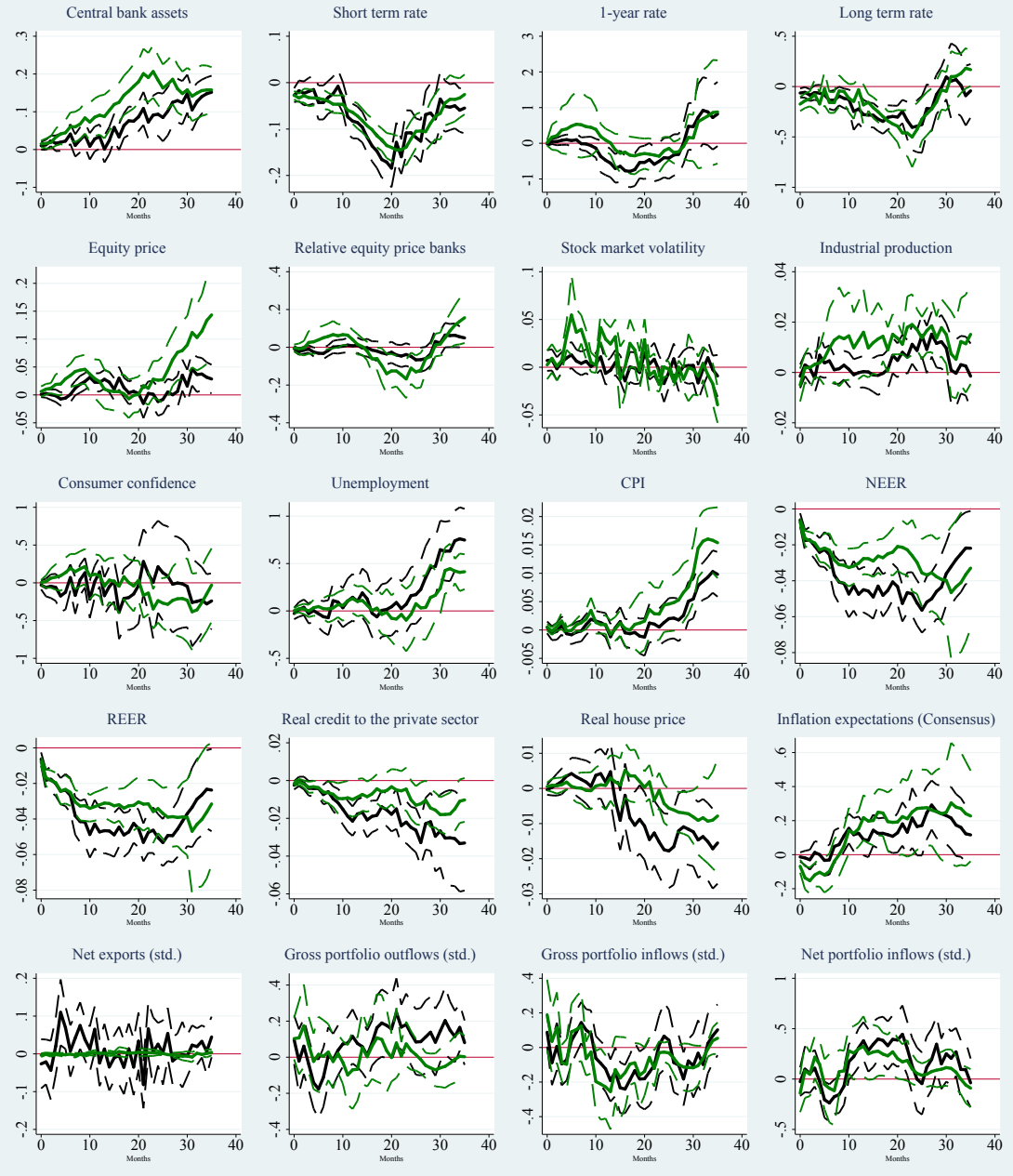

Figure 3: The figures report impulse responses derived from the estimated β_h coefficients in equation (3). The confidence bands are based on a 90% confidence interval and are based on standard errors that are robust to serial correlation and heteroscedasticity.

Effect of Quantitative easing, $QEnarr2$, all countries under ZLB: AIPW (blue lines) and OLS (green lines).

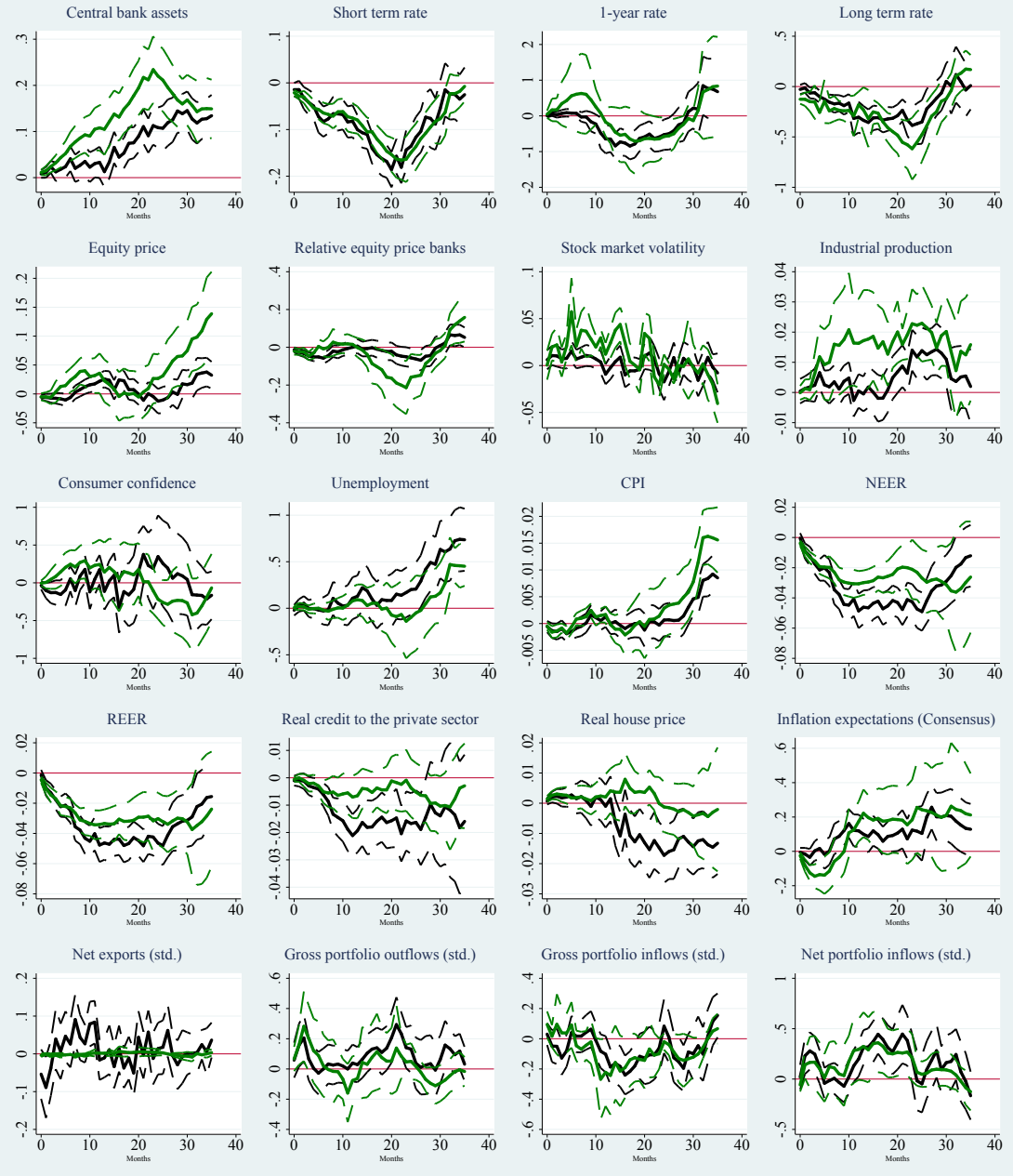

Figure 4: The figures report impulse responses derived from the estimated β_h coefficients in equation (3). The confidence bands are based on a 90% confidence interval and are based on standard errors that are robust to serial correlation and heteroscedasticity.

Effect of Quantitative easing, $QEnarr1$, all countries under ZLB (blue lines) vs. euro area treated as a single unit (purple lines).

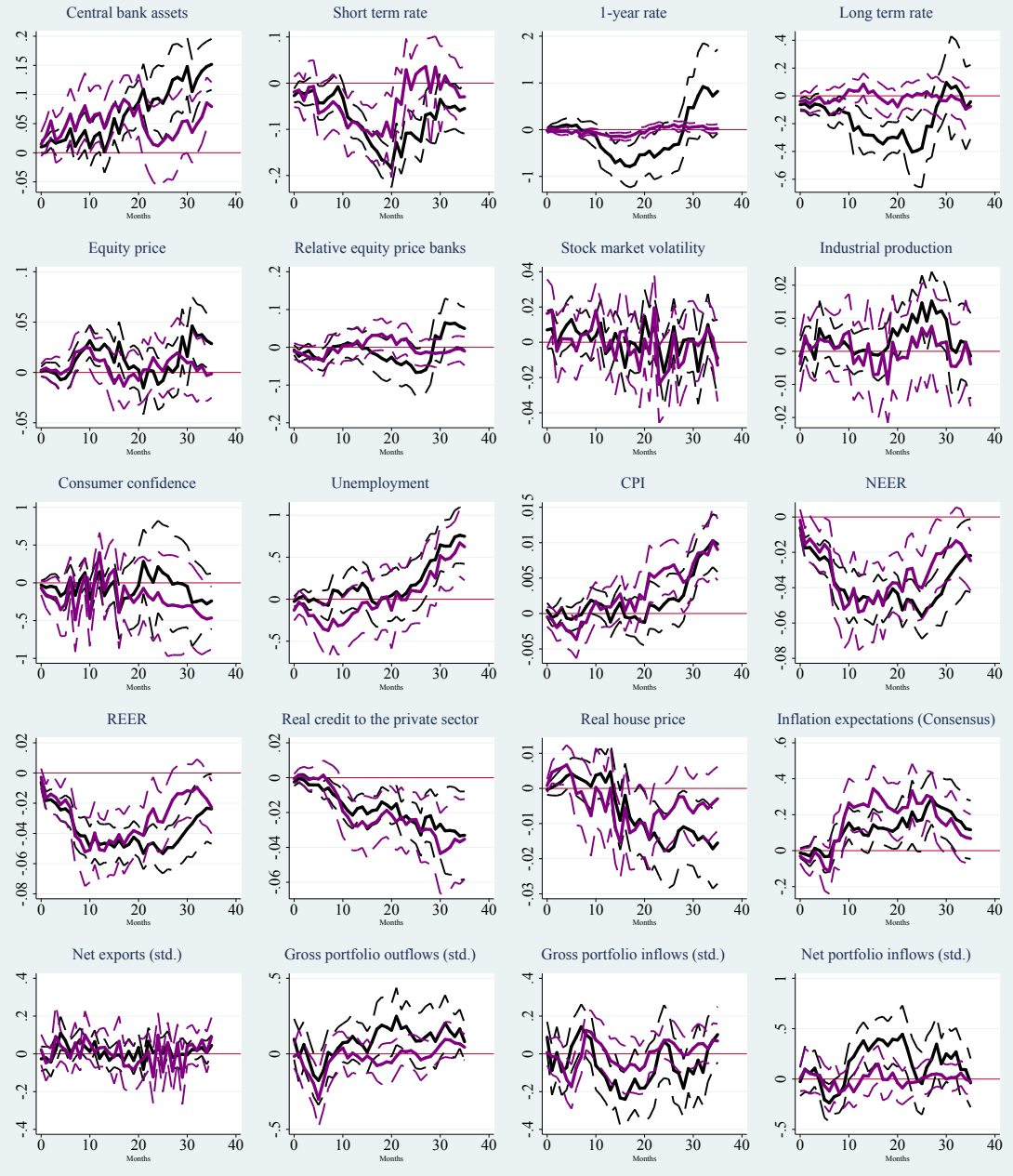

Figure 5: The figures report impulse responses derived from the estimated β_h coefficients in equation (3). The confidence bands are based on a 90% confidence interval and are based on standard errors that are robust to serial correlation and heteroscedasticity.

As we have already emphasised, our results are surrounded by important caveats and qualifications. First, we consider proxies for QE policies because, in the end, they are not perfectly observable. Second, each QE policy has some unique features that we cannot take into account. For example, QE policies have been carried out under very different circumstances in terms of fiscal stance and state of the financial sector. In addition, in our approach we do not distinguish between QE and forward guidance, and our estimated effects should be seen as the combination of the two policies since they have often been taken simultaneously. Finally, it would be good to investigate the potential international spill-over of QE policies using our empirical approach. Overall, many interesting research questions remain to be addressed.

To conclude, if we want to go back to our medical analogy, a QE treatment does cure the main disease, but not all of the patient's ailments. In addition, the medicine appears to operate through a different channel compared to what is often assumed. Finally, we find among the outcome variables considered little evidence for negative side effects of QE treatments.

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Appendix

Table A.1: Country list

Australia	Austria	Belgium	Brazil	Canada	Chile
Colombia	Czech Republic	Estonia	Finland	France	Germany
Greece	Hungary	Iceland	Indonesia	Ireland	Israel
Italy	Latvia	Lithuania	Luxembourg	Mexico	Netherlands
New Zealand	Norway	Philippines	Poland	Portugal	Romania
Slovakia	Slovenia	Spain	South Africa	South Korea	Sweden
Switzerland	Thailand	Turkey	United Kingdom	United States	

Table A.2: Data sources

Data	*Source*	*Observations*
Central bank total assets	IMF, national central banks, HaVEr	National sources for New Zealand, Norway, Sweden, Switzerland, Czech Republic, Hungary, Poland, Israel, United States; Haver for all Euro Area (EA) countries
Broad money	IMF and national central banks	National Sources for Israel, Norway
Consumer Price Index (CPI)	IMF and Haver (International Financial Statistics)	Haver for all EA countries
Nominal Effective Exchange Rate (NEER)	IMF and JP Morgan, Haver (International Financial Statistics)	JP Morgan for Turkey, Indonesia, South Korea, Thailand; Haver for EA countries
Real Effective Exchange Rate (REER)	IMF, Haver (International Financial Statistics)	Haver for EA countries
3 months interest rates	3 months treasury bills and 3 months interbank rates - Haver (OECD) and Datastream	
1 year interest rates	12 months treasury bills and 12 months interbank rates - Haver and Datastream	
Long term interest rates	10 years government bonds interest rates - OECD	
Stock market index	OECD	
Bank market index	Data Stream and Haver	

Continued on next page

Table A.2 continued

Data	*Source*	*Observations*
Credit to private sector	IMF and national Sources, Haver (International Financial Statistics)	National sources for New Zealand, Norway, Switzerland, UK; Haver for EA countries
Industrial production index	OECD	
Market volatility index VIX	Haver	
Unemployment	OECD	
Consumer Confidence Index	OECD	
Net exports	Haver (OECD)	
Inflation expectations	Consensus	
Portfolio assets	Haver (International Financial Statistics)	
Portfolio liabilities	Haver (International Financial Statistics)	
Net portfolio inflows	Haver	
Stock market volatility		
House prices	Haver (OECD)	

Table A.3: Dates of QE treatments in the US

Day of QE treatment	*Description*
25/11/08	Fed announced purchases of MBS and Agency Bonds.
01/12/08	Bernanke states that Treasuries may be purchased.
16/12/08	FOMC meeting: FFTR decreased to 0-0.25%, first suggestion of extending QE to Treasuries by FOMC.
28/01/09	FOMC meeting: "The Committee also is prepared to purchase longer-term Treasury securities."
18/03/09	FOMC meeting: "The Committee decided today to increase the size of the Federal Reserve's balance sheet further."
10/08/10	FOMC meeting: "The Fed will reinvest principal payments from LSAP's in Treasuries."
27/08/10	Bernanke speech at Jackson Hole: "I believe that additional purchases of longer-term securities, should the FOMC choose to undertake them, would be effective in further easing financial conditions."

Continued on next page

Table A.3 continued

Day of QE treatment	*Description*
21/09/10	FOMC meeting: "[...]are likely to warrant exceptionally low levels for the federal funds rate for an extended period. The FOMC is prepared to provide additional accommodation if needed."
12/10/10	FOMC minutes released. FOMC members "sense" is that additional accommodation may be appropriate before long.
15/10/10	Bernanke speech at Boston Fed "the FOMC is prepared to provide additional accommodation if needed"
03/11/10	QE2 announced. Fed will purchase US dollar 600 billion in Treasuries.
26/08/11	Bernanke speech in Jackson Hole: "In addition to refining our forward guidance, the Federal Reserve has a range of tools that could be used to provide additional monetary stimulus."
21/09/11 (minor event)	FOMC statement: Maturity extension program ("Operation Twist") announced.
20/06/12	FOMC meeting: "The Committee also decided to continue through the end of the year its program to extend the average maturity of its holdings of securities. [...]The Committee is maintaining its existing policy of reinvesting principal payments from its holdings of agency debt and agency mortgage-backed securities."
22/08/12	FOMC minutes released. FOMC members "judged that additional monetary accommodation would likely be warranted fairly soon."
13/09/12	FOMC meeting: QE3 announced. "The Committee agreed today to increase policy accommodation by purchasing additional agency mortgage-backed securities at a pace of US dollar 40 billion per month. [...]"
12/12/12 (minor event)	FOMC statement: QE3 expanded. "The Fed will continue to purchase US dollar 45 billion of long-term Treasuries per month but will no longer sterilize purchases through the sale of short-term Treasuries."
18/09/13 (minor event)	FOMC meeting: "In judging when to moderate the pace of asset purchases, the Committee will [...] assess whether incoming information continues to support the Committee's expectation of ongoing improvement in labour market conditions and inflation moving back toward its longer-run objective."

Sources: Rogers, Scotti and Wright (2014), Fawley and Neely (2013) and authors' compilation.
Notes: The table shows all treatment events included in QE_narr1 and QE_narr2 as indicated with the label "minor event".

Table A.4: Dates of QE programs in the US

Duration of QE programme	*Description*
November 2008 to April 2009	"QE1"
August 2010 to June 2011	"QE2"
September 2011 to August 2012	"Operation Twist" (Maturity Extension Programme)
September 2012 to October 2014	"QE3"

Sources:Fawley and Neely (2013) and authors' compilation.

Notes: Throughout the duration of the shown programmes, the dummy variables QE_narr3 assumes a value of "1".

Table A.5: Dates of QE treatments in the UK

Day of QE treatment	*Description*
19/01/09	The chancellor of the Exchequer announces the BOE will set up an APF; 29 Jan. APF announcement
11/02/09	Inflation report and press conference give strong indication that QE is likely.
05/03/09	APF announcement: GBP 75 billion of Gilts, 5 to 25 years; bank rate decreased to 0.5%
07/05/09	APF extended to 125 billion.
06/08/09	APF extended to GBP 175 billion, with maturity greater than three years.
05/11/09	APF extended to 200 billion.
04/02/10	APF will be maintained at 200 billion.
06/10/11	APF extended to 275 billion.
09/02/12	APF extended to 325 billion
05/07/12	APF extended to 375 billion
04/08/16	APF extended to 435 billion after Brexit vote.

Sources: Rogers, Scotti and Wright (2014), Bank of England and authors' compilation.

Notes: The table shows all treatment events included in QE_narr1 and QE_narr2 as indicated with the label "minor event".

Table A.6: Dates of QE programs in the UK

Duration of QE programme	*Description*
January 2009 to October 2012	Asset Purchase Facility (APF)
Since August 2016	Renewal of APF due to Brexit

Sources: Bank of England and authors' compilation.

Notes: Throughout the duration of the shown programmes, the dummy variables QE_narr3 assumes a value of "1".

Table A.7: Dates of QE treatments in the euro area

Day of QE treatment	*Description*
26/05/14 (minor event)	Speech of the ECB's President in Sintra: "[...] This would call for a more expansionary stance, which would be the context for a broad-based asset purchase programme. [...]"
04/06/14	GovC meeting, further reductions in the key ECB interest rates, TLTROs, preparatory work related to outright purchases of asset-backed securities and a prolongation of fixed rate, full allotment tender procedures, suspension of the weekly fine-tuning operation sterilising the liquidity injected under the Securities Markets Programme.
24/08/14	Speech by the President of the ECB, in Jackson Hole, "We stand ready to adjust our policy stance further."
04/09/14	GovC meeting, interest rates lowered by 10 basis points, decision to start purchasing non-financial private sector assets including ABSs and covered bonds under a new covered bond purchase programme (CBPP3).
02/10/14 (minor event)	Release of operational details of both the asset-backed securities purchase programme and the new covered bond purchase programme.
06/11/14 (minor event)	GovC meeting, "Together with the series of targeted longer-term refinancing operations to be conducted until June 2016, these asset purchases will have a sizeable impact on our balance sheet, which is *expected* to move towards the dimensions it had at the beginning of 2012."
04/12/14	GovC meeting, "Taken together, our measures will have a sizeable impact on our balance sheet, which is *intended* to move towards the dimensions it had at the beginning of 2012."
22/01/15	GovC meeting, expanded asset purchase programme, combined monthly purchases of public and private sector securities amounting to 60 billion euro until end-September 2016 and will in any case be conducted until we see a sustained adjustment in the path of inflation.

Continued on next page

Table A.7 continued

Day of QE treatment	*Description*
05/03/15	GovC meeting, "Following up on our decisions of 22 January 2015, we will, on 9 March 2015, start purchasing euro-denominated public sector securities in the secondary market."
03/09/15 (minor event)	GovC meeting, increase the issue share limit from the initial limit of 25% to 33%, subject to a case-by-case verification that this would not create a situation whereby the Eurosystem would have blocking minority power, in which case the issue share limit would remain at 25%.
03/12/15 (minor event)	GovC meeting, lower the interest rate on the deposit facility by 10 basis points to -0.30%. As regards non-standard monetary policy measures, extend the APP. The monthly purchases of âĆň60 billion under the APP are now intended to run until the end of March 2017, or beyond, if necessary.
21/01/2016 (minor event)	GovC meeting, "It will therefore be necessary to review and possibly reconsider our monetary policy stance at our next meeting in early March, when the new staff macroeconomic projections become available which will also cover the year 2018."
10/03/2016	GovC meeting, "The rate on the deposit facility was lowered by 10 basis points to -0.40%. Second, we decided to expand the monthly purchases under our asset purchase programme from 60 billion euro at present to 80 billion euro."
21/04/2016 (minor event)	GovC meeting, "in June, we will conduct the first operation of our new series of targeted longer-term refinancing operations (TLTRO II) and we will commence purchases under our corporate sector purchase programme (CSPP)."
02/06/2016	GovC meeting, "As a next step, on 8 June we will start making purchases under our corporate sector purchase programme (CSPP). Moreover, starting on 22 June, we will conduct the first operation in our new series of targeted longer-term refinancing operations."
20/10/2016 (minor event)	GovC meeting, "To that end, we will continue to act, if warranted, by using all the instruments available within our mandate. In December the Governing Council's assessment will benefit [...] from the work of the Eurosystem committees on the options to ensure the smooth implementation of our purchase programme until March 2017, or beyond, if necessary."

Continued on next page

Table A.7 continued

Day of QE treatment	*Description*
08/12/2016	GovC meeting, "From April 2017, our net asset purchases are intended to continue at a monthly pace of 60 billion euro until the end of December 2017, or beyond, if necessary, and in any case until the Governing Council sees a sustained adjustment in the path of inflation consistent with its inflation aim."

Sources: ECB and authors' compilation.

Notes: The table shows all treatment events included in QE_narr1 and QE_narr2 as indicated with the label "minor event".

Table A.8: Dates of QE programs in the euro area

Duration of QE programme	*Description*
June 2014 to December 2016	Asset purchase programme (APP) including the CBPP3 (Sept. 2016) PSPP (Jan. 2015) CSPP (June 2016) and its anticipation since June 2016

Sources: ECB and authors' compilation.

Notes: Throughout the duration of the shown programmes, the dummy variables QE_narr3 assumes a value of "1".

Table A.9: Dates of QE treatments in Japan

Day of QE treatment	*Description*
19/03/01	BoJ adopts quantitative easing policy (QEP). The new framework allows the BoJ to also increase the amount of outright purchases of long-term Japanese government bonds (JGBs) should the BOJ consider such an increase to be necessary for providing liquidity smoothly. Current account balances (CAB) increased to 5 trillion yen
14/08/01	CAB increased to 6 trillion yen
19/12/01	CAB increased to 10-15 trillion yen
28/02/02	Increase of long-term bond purchases
30/10/02	CAB increased to 15âĂŞ20 trillion yen
25/03/03	CAB increased to 17âĂŞ22 trillion yen
30/04/03	CAB increased to 22âĂŞ27 and 27âĂŞ30 trillion yen
25/06/03	BoJ starts buying ABS
20/01/04	CAB increased to 30âĂŞ35 trillion yen

Continued on next page

Table A.9 continued

Day of QE treatment	*Description*
05/10/10	The BOJ responds to persistently low inflation by setting a target for a CPI increase of 1 percent and embarks on an Asset purchase programme (APP) of 35 trillion yen.
14/3/11	APP extended to 40 trillion yen
04/08/11	APP extended to 50 trillion yen
27/10/11	APP extended to 55 trillion yen
14/02/12	APP extended to 65 trillion yen
27/04/12	APP extended to 70 trillion yen
19/09/12	APP extended to 80 trillion yen
30/10/12	APP extended to 91 trillion yen
20/12/12	APP extended to 101 trillion yen
22/01/13	APP extended to 13 trillion yen monthly, 2% inflation target, open-ended QE
04/04/13	The BoJ launches "Quantitative and Qualitative Monetary Easing" (QQE) under which it commits that, within two years, the monetary base would be doubled and a new inflation target of 2 percent would be reached.
31/10/14	BoJ announced to accelerate the pace of increase in the monetary base, increasing asset purchases and extending the average remaining maturity of JGB purchases.
01/12/15 (minor event)	BoJ decided to introduce supplementary measures for QQE, including extending the average remaining maturity of JGB purchases; and establishing a new program for purchases of exchange-traded funds (ETFs).
29/01/16 (minor event)	At the Monetary Policy Meeting held today, the Policy Board of the Bank of Japan decided to introduce "Quantitative and Qualitative Monetary Easing (QQE) with a Negative Interest Rate".
29/07/2016 (minor event)	An increase in purchases of exchange-traded funds (ETFs) . Measures to ensure smooth funding in foreign currencies by Japanese firms and financial institutions.
21/09/2016	The BoJ commits to a new framework for strengthening Monetary Easing: "Quantitative and Qualitative Monetary Easing with Yield Curve Control."

Sources: Rogers, Scotti and Wright (2014), Greenwood (2017), Bank of Japan and authors' compilation.
Notes: The table shows all treatment events included in QE_narr1 and QE_narr2 as indicated with the label "minor event".

Table A.10: Dates of QE programs in Japan

Duration of QE programme	*Description*
March 2001 to March 2006	Quantitative easing policy (QEP)
October 2010 to March 2013	Asset Purchase Programme (APP)
April 2013 to December 2016	Quantitative and Qualitative Monetary Easing (QQE)

Sources: Greenwood (2017), Bank of Japan and authors' compilation.

Notes: Throughout the duration of the shown programmes, the dummy variables QE_narr3 assumes a value of "1".

Table A.11: Dates of QE treatments in Sweden

Day of QE treatment	*Description*
11/02/15	The Riksbank will also buy government bonds for SEK 10 billion.
28/04/15	At its monetary policy on 28 April, the Executive Board of the Riksbank decided to purchase government bonds for a further SEK 40-50 billion.
01/07/15	At the monetary policy meeting on 1 July, the Executive Board of the Riksbank decided to cut the repo rate by 0.10 percentage points to -0.35 per cent and to extend the purchases of government bonds by a further SEK 45 billion from September and until the end of the year.
02/09/15 (minor event)	The Riksbank remains highly prepared to make monetary policy even more expansionary in the event of the inflation outlook deteriorating.
27/10/15	At the Monetary Policy Meeting on 27 October, the Executive Board of the Riksbank decided to purchase more government bonds during the first half of 2016 to a value of SEK 65 billion.
14/12/15 (minor event)	Purchases of government bonds will continue for the first six months of 2016, as was decided in October. The Board is also highly prepared to make monetary policy even more expansionary, even between the ordinary monetary policy meetings.
11/02/16 (minor event)	The Executive Board of the Riksbank has therefore decided to cut the repo rate by 0.15 percentage points to âĹŠ0.50 per cent. Purchases of government bonds will continue for the first six months of this year, in accordance with the plan adopted in October. The Executive Board has also decided to reinvest maturities and coupons from the government bond portfolio until further notice.

Continued on next page

Table A.11 continued

Day of QE treatment	*Description*
21/04/16	The Executive Board has decided to continue purchasing securities for a further SEK 45 billion during the second half of 2016, so that the purchases will total SEK 245 billion at the end of 2016.
06/07/16	The Executive Board of the Riksbank has therefore decided to hold the repo rate unchanged at -0.5 per cent and now assesses that there will be a longer delay until the repo rate begins to be raised. The purchases of government bonds will continue during the second half of 2016, as decided in April.
27/10/16 (minor event)	The Executive Board assesses that the repo rate needs to be held at minus 0.50 per cent for six months longer than was forecast in September. The probability that the rate will be cut further has increased. The purchases of government bonds will continue during the second half of 2016, as decided in April. Prior to the monetary policy meeting in December, the Executive Board is prepared to extend the purchases of government bonds.
21/12/16	The Executive Board of the Riksbank has decided to continue purchasing government bonds during the first six months of 2017, both nominal and real bonds, each corresponding to SEK 15 billion. The repo rate is retained at minus per cent and there is still a greater probability that the rate will be cut than that it will be raised in the near term. Increases in the repo rate are not expected to begin until the beginning of 2018.

Sources: Riksbank and authors' compilation.

Notes: The table shows all treatment events included in QE_narr1 and QE_narr2 as indicated with the label "minor event".

Table A.12: Dates of QE programs in Sweden

Duration of QE programme	*Description*
February 2015 to December 2016	Purchase of Government Bonds

Sources: Riksbank and authors' compilation.

Notes: Throughout the duration of the shown programmes, the dummy variables QE_narr3 assumes a value of "1".

Table A.13: Dates of QE treatments in Switzerland

Day of QE treatment	*Description*
12/03/09 (minor event)	The SNB will increase liquidity substantially by engaging in additional repo operations, buying Swiss franc bonds issued by private sector borrowers and purchasing foreign currency on the foreign exchange markets.
06/04/09 (minor event)	The SNB commenced purchases of non-bank corporate bonds in addition to continuing the purchases of covered bonds.
03/08/11	Target range for three-month CHF LIBOR lowered to 0 to 25 basis points. In addition, banks' sight deposits at the SNB will be expanded from CHF 30 billion to CHF 80 billion.
10/08/11	Banks' sight deposits at the SNB will rapidly be expanded from CHF 80 billion to CHF 120 billion.
17/08/11	Banks' sight deposits at the SNB will immediately be expanded from CHF 120 billion to CHF 200 billion.

Sources: Christensen and Krogstrup (2015), SNB and authors' compilation.
Notes: The table shows all treatment events included in QE_narr1 and QE_narr2 as indicated with the label "minor event".

Table A.14: Dates of QE programs in Switzerland

Duration of QE programme	*Description*
March 2009 to September 2009	Credit Easing
August 2011 to September 2011	Expansion of sight deposits

Sources: Christensen and Krogstrup (2015), SNB and authors' compilation.
Notes: Throughout the duration of the shown programmes, the dummy variables QE_narr3 assumes a value of "1".

Online Appendix

In this Online Appendix we report the summary statistics for the variables we use as well as the ROC curves for $QEnarr2$ and $QEnarr3$ and some additional robustness checks for the main results using AIPW.

Table 1: Summary statistics

	count	mean	sd	min	max
lassetsr	1508	7.31	3.66	-0.52	10.50
3 Months Interest Rate	1507	0.11	0.67	-0.85	17.93
interest rate 1 year	1083	1.16	5.45	-1.05	59.41
long term interest rate 10Y	1456	2.13	2.15	-0.54	29.51
lstockr	1510	0.04	0.30	-1.23	0.79
lstockr_bank	1175	-0.00	1.62	-4.63	10.82
Ann. Historical Stock Market Volatility	1101	0.19	0.10	0.04	1.11
lipi	1491	4.64	0.12	3.92	5.20
Consumer Confidence Index	1145	99.91	1.71	93.97	105.06
u_season	1187	7.70	3.51	0.43	20.12
lcpi	1510	4.66	0.05	3.98	4.74
lneer	1364	4.59	0.09	4.19	4.86
lreer	1364	4.59	0.09	3.88	4.85
lcreditr	1507	6.30	2.49	1.71	10.02
lhpr	1201	-0.04	0.18	-0.47	0.40
Inflation expectations	1290	1.11	1.01	-1.16	8.25
Standardized values of (netexp)	1447	0.20	1.02	-3.49	7.12
Standardized values of (Port_Ass)	1374	0.17	1.36	-2.04	9.76
Standardized values of (Port_Liab)	1344	0.16	1.62	-2.37	14.67
Standardized values of (Port_Net)	1344	-0.04	1.49	-14.33	4.77
QE_narr1	1510	0.11	0.31	0.00	1.00
QE_narr2	1510	0.20	0.40	0.00	1.00
QE_narr3	1510	0.51	0.50	0.00	1.00
VIX	1510	17.08	5.28	10.82	52.41
loilp	1497	4.02	0.38	2.21	4.55
Observations	1510				

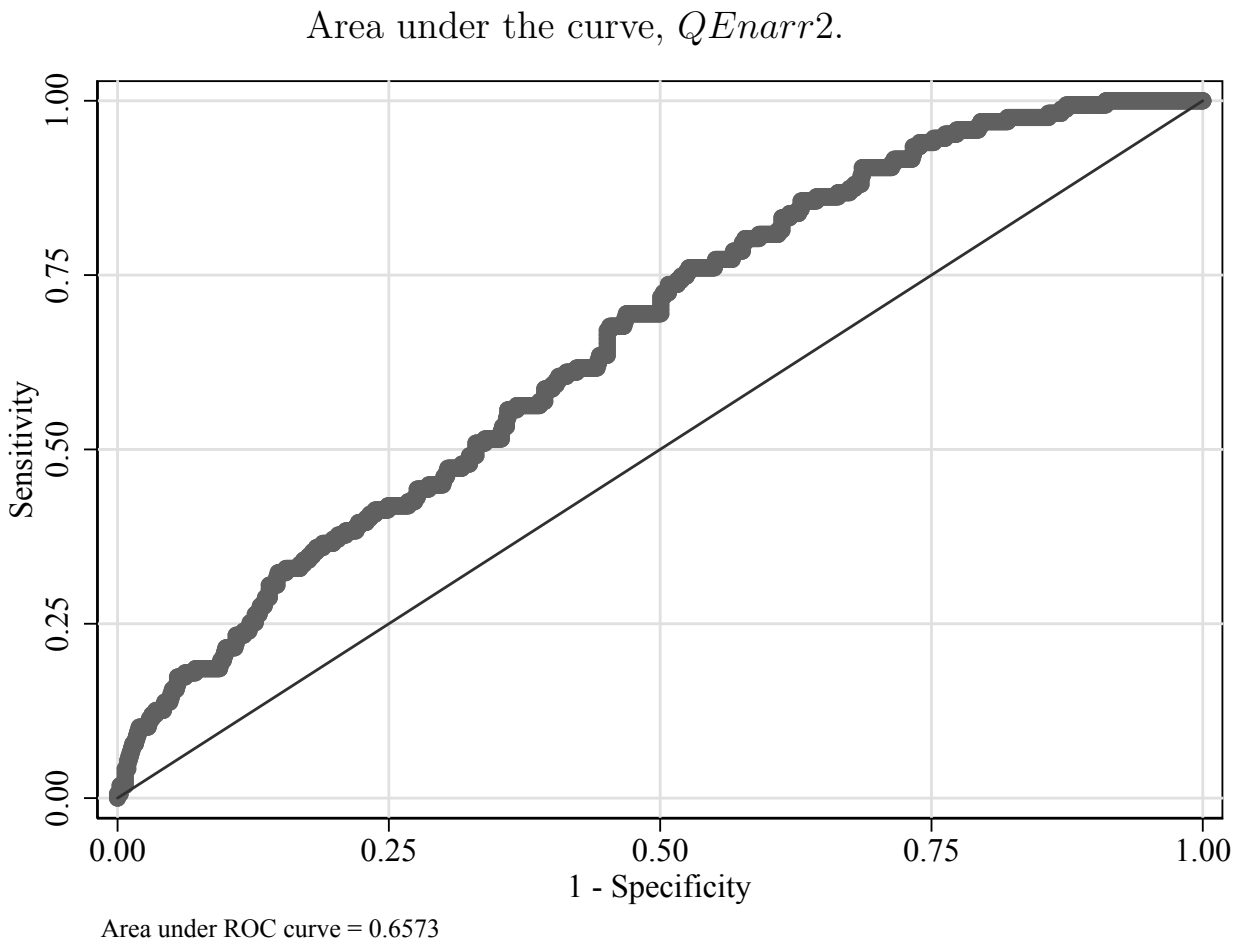

Figure 1: The figure reports the ROC (receiver operating characteristic curve), illustrating the diagnostic ability of the logit model by computing the true positive rate against the false positive rate at various threshold settings.

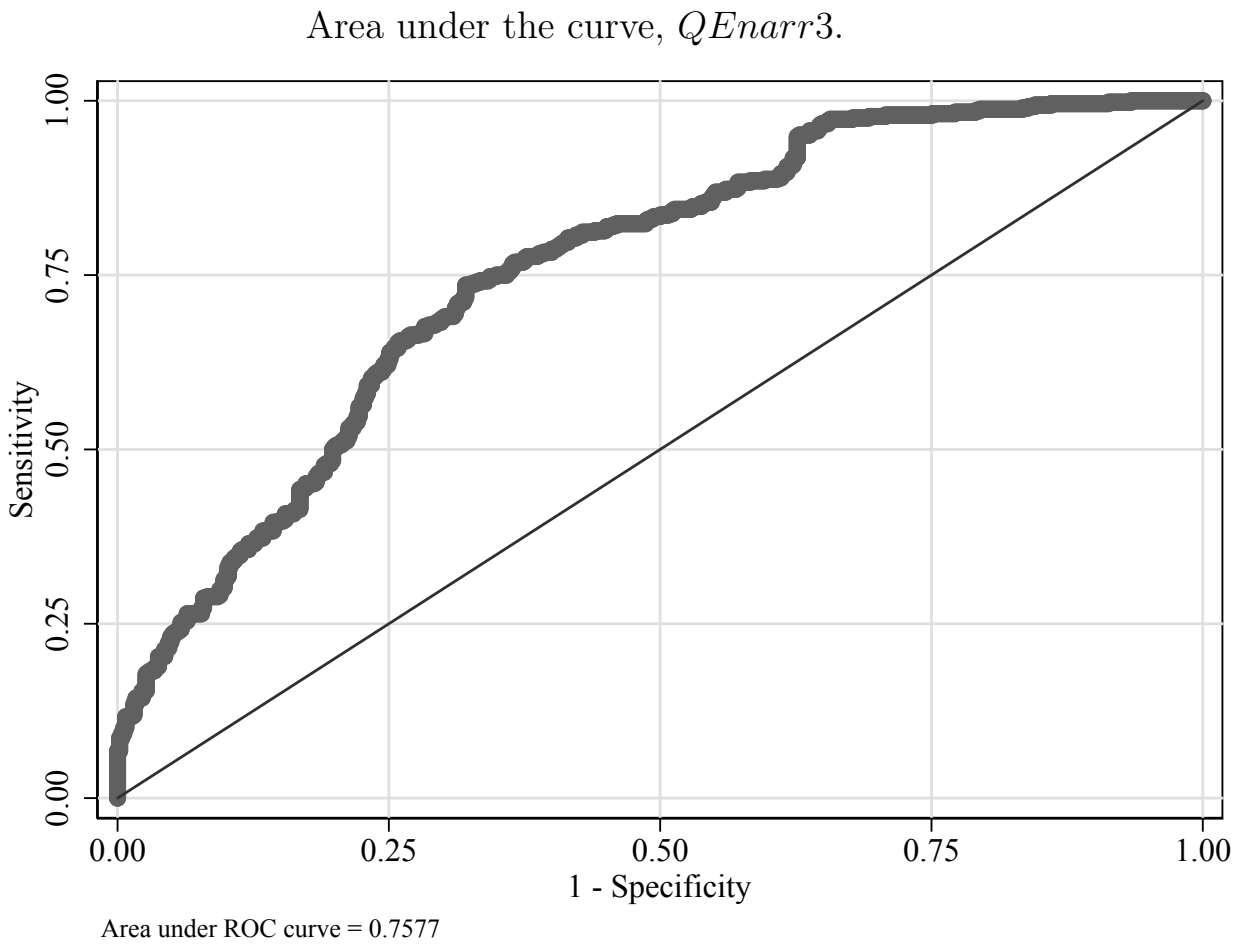

Figure 2: The figure reports the ROC (receiver operating characteristic curve), illustrating the diagnostic ability of the logit model by computing the true positive rate against the false positive rate at various threshold settings.

Effect of Quantitative easing, $QEnarr3$, AIPW (black lines) vs. OLS (green lines).

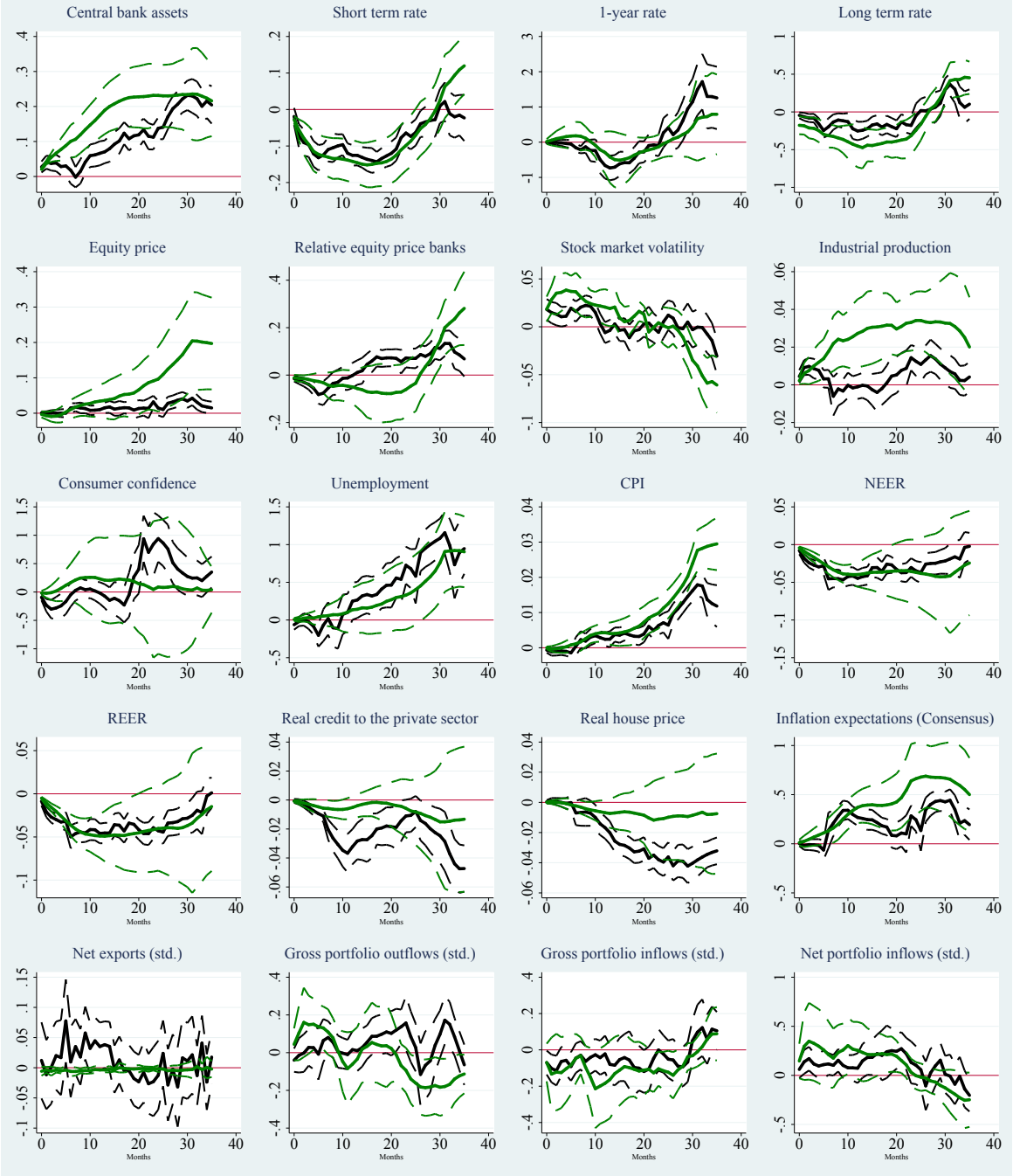

Figure 3: The figures report impulse responses derived from the estimated β_h coefficients in equation (3). The confidence bands are based on a 90% confidence interval and are based on standard errors that are robust to serial correlation and heteroscedasticity.

Effect of Quantitative easing, $QEnarr1$, all countries under ZLB (black lines) vs. excluding the US (purple lines).

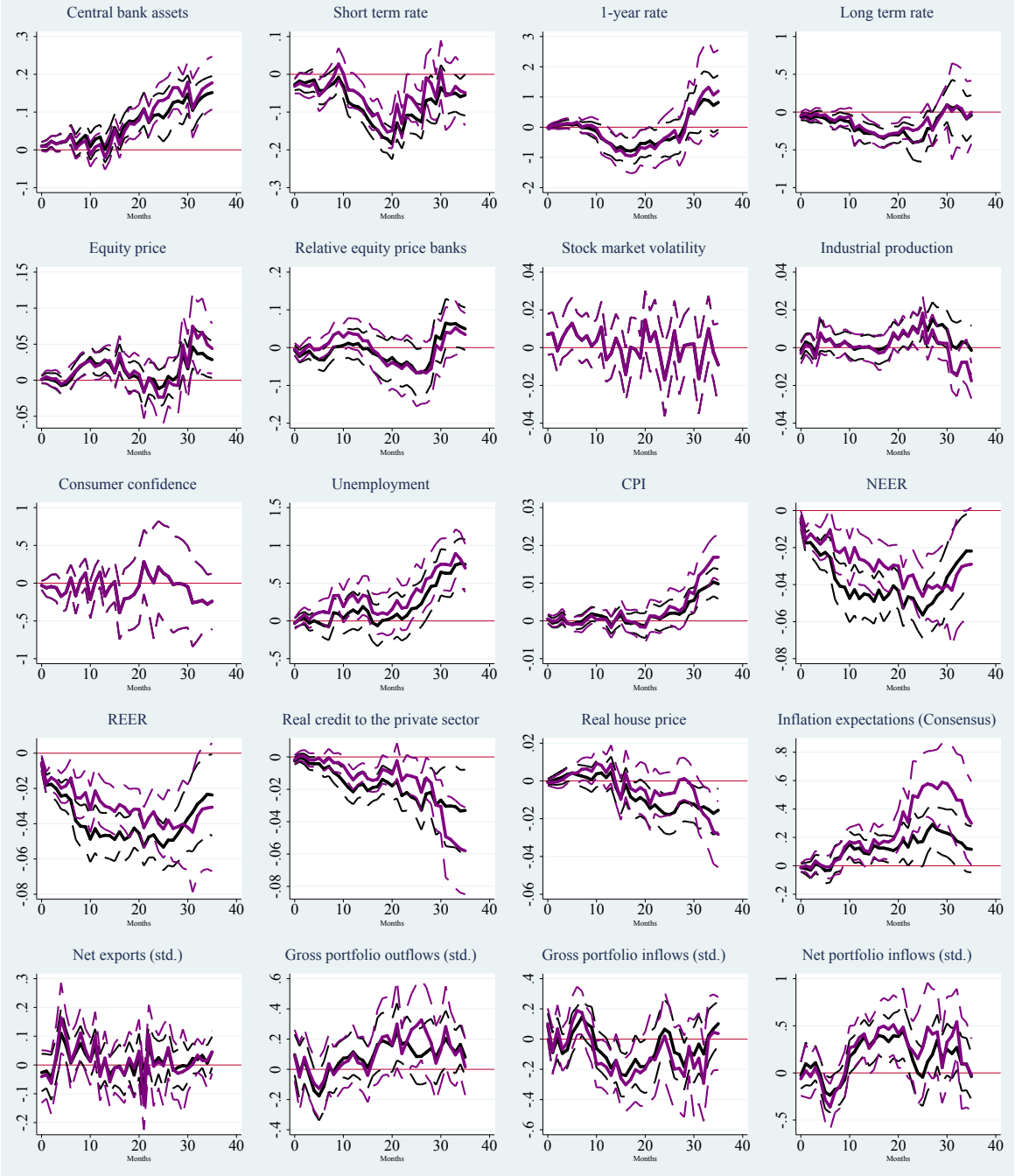

Figure 4: The figures report impulse responses derived from the estimated β_h coefficients in equation (3). The confidence bands are based on a 90% confidence interval and are based on standard errors that are robust to serial correlation and heteroscedasticity.

Effect of Quantitative easing, $QEnarr1$, all countries under ZLB (black lines) vs. excluding Japan (purple lines).

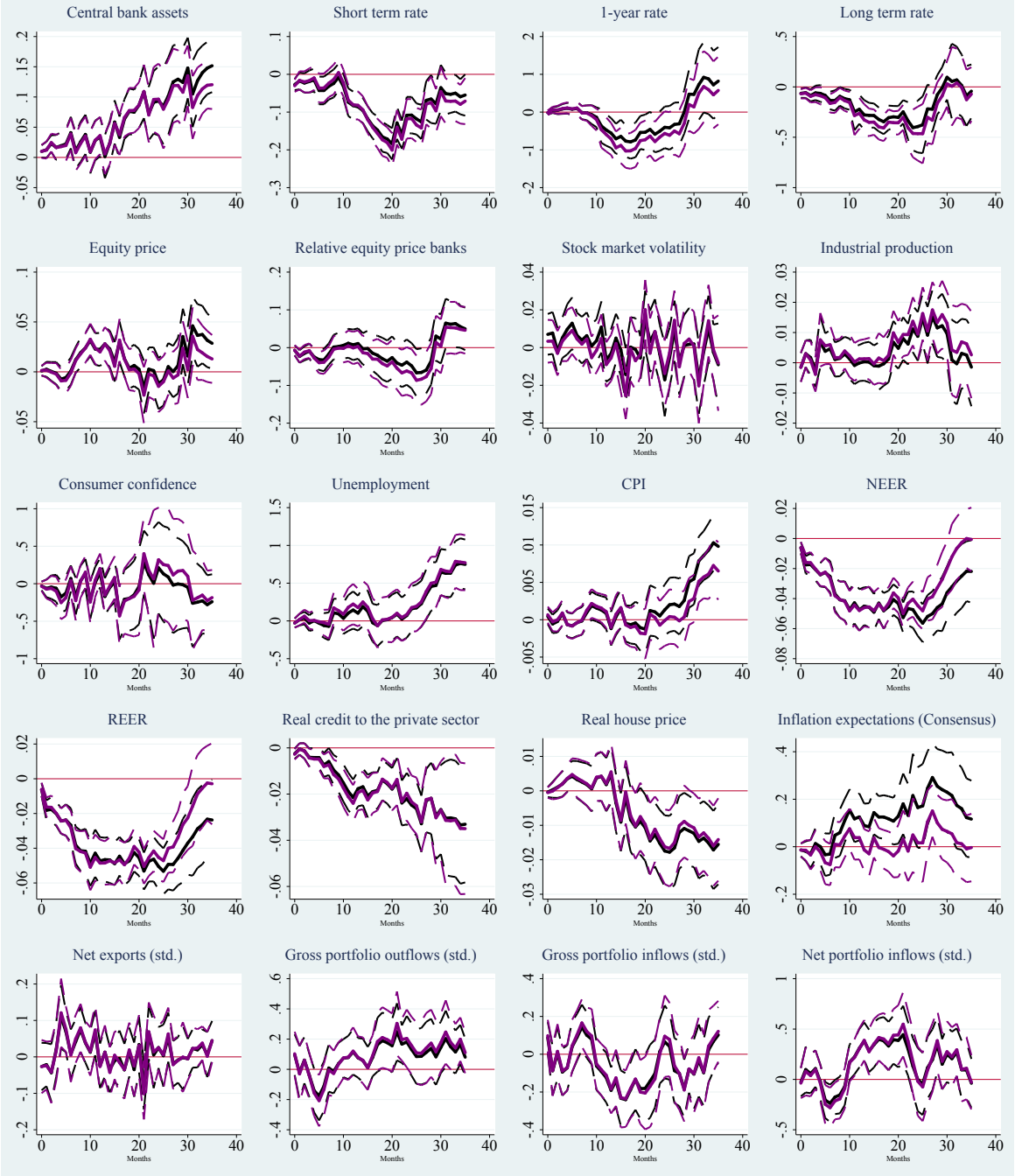

Figure 5: The figures report impulse responses derived from the estimated β_h coefficients in equation (3). The confidence bands are based on a 90% confidence interval and are based on standard errors that are robust to serial correlation and heteroscedasticity.

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