Real Effects of Quantitative Easing at the Zero Lower Bound: Structural VAR-Based Evidence from Japan∗

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Abstract

Using post-1995 Japanese data we propose a novel sign restriction SVAR approach to identify monetary policy shocks when the economy is at the zero lower bound. The identifying restrictions are based on predictions of corresponding DSGE models. A quantitative easing shock leads to a significant decrease in long-term interest rates and significantly increases output and prices. However, the effects are transient. This suggests that while the Japanese Quantitative Easing experiment was successful in temporarily stimulating real activity, it did not lead to a persistent increase in inflation. These results are interesting not only for Japan, but also for other advanced economies that recently adopted very low interest rates.

JEL Classification: E43, E51, E52, E58

Keywords: monetary policy, zero lower bound, structural vector autoregression, sign restrictions

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1 Introduction

We study the real effects of Quantitative Easing (QE) in a structural VAR (SVAR) when the short-term interest rate is constrained by the zero lower bound (ZLB). Using monthly Japanese data since 1995 - a period during which the Bank of Japan’s target rate, the overnight call rate, has been very close to zero - and sign restrictions based on corresponding DSGE models, we find that a QE-shock which raises reserves by about 8% leads to a significant drop in long-term interest rates and significantly raises industrial production by 0.5% after about two years. The same shock, however, only has a transient effect on prices. Our results thus provide mixed evidence on the successfulness of QE in Japan. Whilst real economic activity does seem to pick up after a QE-shock, it does not seem to affect inflation in such a way that Japan could exit its deflationary period. However, this conclusion strictly holds only under the usual caveat in SVAR-analysis that the monetary policy shock we consider must be a small one - one that is not allowed to change the policy regime or any other of the structural relations we estimate.1

Our study adds to the existing literature in various important ways. First, focusing specifically on post-1995 Japanese data where the policy rate of the Bank of Japan was very close to zero allows us to identify a monetary policy shock at the ZLB. In particular, we identify a shock that raises reserves held at the Bank of Japan, which was the main monetary instrument during the ZLB period we consider. We call such a shock unconventional monetary policy shock or QE-shock for short. Thus, we mainly focus on the effects of quantitative easing as opposed to other non-standard measures.2 Second, including standard macro variables in our VAR allows us to analyze the effects of such a QE-shock on a broader set of variables

1We implicitly argue that this is precisely the kind of monetary shock one would currently expect. However, we should be careful not to conclude that more aggressive policy changes by central banks to escape the deflationary period of the liquidity trap - for instance along the lines of Krugman (1998) or Svensson (2003) - are doomed to fail.

2The literature generally defines as unconventional such monetary measures adopted by central banks that differ from traditional interest rate setting decision. For more details on the different dimensions along which unconventional policy measures can be classified see Bernanke and Reinhart (2004) or Meier (2009).
than usually studied in the literature on unconventional monetary policy effects. In particular, we assess the effects of a QE-shock on real economic activity and on prices. Third, using a sign restriction approach to identify the QE-shock allows us to remain agnostic about whether, how, and when real activity and the long-term rate respond to the shock. In particular, in contrast to most of the existing literature, we do not have to restrict long-term rates nor the exchange rate in order to credibly identify an unconventional monetary shock, which allows us to let the data speak concerning the effects on these variables. Because short-term policy rates in the US, the Euro Area, the UK and other economies around the world are currently very close to zero and therefore possibly also constrained by the ZLB, our results shed light on the effects of the currently implemented non-standard policy measures adopted by the leading central banks in the world. The effects of monetary policy shocks when monetary policy is not constrained by the ZLB has been well documented in the literature. There is a broad consensus that expansionary monetary policy, by lowering the policy interest rate, affects inflation and output positively, but only sluggishly and temporarily.\(^3\) There is much less empirical evidence on the real effects of monetary policy shocks at the ZLB. One obvious reason might be that most economies until very recently have not been in such a situation and that sample periods to use in estimation would thus be notoriously short. However, at least since 2000, when the Fed was fast to lower the Federal Funds rate to very low levels in response to the bursting of the IT-bubble, there has been an important theoretical discussion on how to avoid liquidity traps and how to escape them once an economy found itself in the trap.\(^4\) The recent financial crisis has led to renewed interest in the empirical effects of the non-standard monetary policies implemented by the leading central banks. However, most of these studies focus on the effect unconventional policies have on various long-term interest rates or interest rate spreads. Examples include Gagnon et al. (2010), Hamilton and Wu (2011) and Stroebel and Taylor (2009) for the US,

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\(^3\)Compare Christiano et al. (1998). But note that different identifying restrictions can in fact lead to different results; compare Uhlig (2005) and Lanne and Lütkepohl (2008).

Meier (2009) for the UK, ECB (2010) for the Euro Area, and Oda and Ueda (2007) and Ueda (2010) for Japan. Analysing the effects of monetary expansions, most notably in the form of large-scale central bank purchases of government bonds, these studies generally find negative effects on yield spreads of such non-standard policies, or more precisely of announcements of such measures. In particular, the yields of various assets do tend to decline thereby narrowing the spread to the corresponding riskless rate. However, these effects are generally found to be rather small.

It is important to note that the theoretical impact of such a policy announcement on long-term yields is not clear. Theoretical studies such as, for instance, Doh (2010), refer to imperfect substitutability between assets and explain the expansionary effect of such a policy decision by arguing that the purchase of long-term bonds by the central bank will naturally lower long-term bond yields. This lower yield on government bonds then feeds through - via portfolio shifts (Meltzer, 1995) - to other asset markets, like the corporate bond market and the stock market making long-term financing for investment and durable goods cheaper thereby stimulating aggregate demand. This argument is partly supported by the empirical evidence of the above mentioned studies. However, theoretically it is not clear that long-term yields are indeed supposed to fall after such a policy announcement. Indeed, if market participants believe the central bank intervention is successful in stimulating the economy by increasing aggregate demand, inflation and real rates are likely to rise in the future. Inflationary expectations as of today should thus rise and long-term nominal yields should in fact rise as well. Moreover, even if long-term yields were negatively affected by such a policy, there is no broad consensus on whether the portfolio rebalancing channel described above would actually function successfully.\footnote{On the theoretical side, for instance Eggertsson and Woodford (2003) argue that unconventional policy can only work through changing expectations concerning the future policy outlook and thus inflation rates. Empirically, doubts concerning the role of the portfolio rebalancing channel are raised by, for instance, Oda and Ueda (2007).}

We therefore argue that it is important to remain agnostic about the behaviour of long-term yields following expansionary QE-policy shocks. In addition, and impor-
tantly, we supplement previous studies by focusing on the effects unconventional policies have on the real economy and on prices. These variables are of ultimate interest to the central bank and general public and of course important for welfare considerations. So far, the corresponding empirical evidence of unconventional policies on these variables is rather scarce and a consensus on the effectiveness of these measures has not yet been reached. Studies using sign restrictions to identify unconventional monetary shocks include Baumeister and Benati (2010), Peersman (2010) and Kamada and Sugo (2006). While Baumeister and Benati (2010) find some significant real effects of quantitative easing in different countries including Japan, results reported by Kamada and Sugo (2006) are less optimistic. Both studies rely, however, on relatively restrictive identification schemes restricting financial variables such as interest rate spreads or the exchange rate. Peersman (2010) finds that unconventional shocks can in principle affect macroeconomic variables in the Euro Area; the responses of output and prices are, however, much more delayed compared to standard policy measures during normal times. However, only those non-standard shocks are identified that actually have an effect on the supply of credit. Using a Bayesian shrinkage VAR model, Lenza et al. (2010) report some significant effects of unconventional monetary shocks on macroeconomic variables in the Euro Area by means of a counterfactual analysis. However, their exercise implies that only those policy measures are analyzed that actually had an effect on the interest rate spread. Finally, Chung et al. (2011), using a set of structural and time series statistical models, find that asset purchases by the Fed have been successful at mitigating the macroeconomic costs of the ZLB in the US.

The remainder of the paper is organized as follows: Section 2 gives a brief overview of key features of the monetary policy decisions implemented by the Bank of Japan since the stock market crash in the early 90s. Section 3 describes the setup of our SVAR model as well as the identification strategy for the unconventional monetary shock. Results are then presented in Section 4. Finally, Section 5 concludes.

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6 More traditional VAR studies on the monetary transmission in Japan include Miyao (2000, 2002), Fujiwara (2006) and Inoue and Okimoto (2008). However, analyzing sample periods at most up to 2003, these studies are not particularly informative concerning the effects of QEP.
2 Monetary Policy in Japan Since the Early 1990s

This section briefly sketches key monetary policy developments in Japan since the early 1990s. For a thorough discussion please refer to Mikitani and Posen (2000), Ugai (2007) and Ueda (2010).

The bursting of the Japanese stock market bubble and the accompanying period of economic distress can be seen in Figure 1. The stock market was rising dramatically until around 1990. This went together with a rapid increase in industrial production under fairly low and constant rates of inflation. Realizing that the elevated stock and land prices seemed out of touch with fundamentals the Bank of Japan did in fact continuously increase the call rate. Optimism turned into pessimism around 1990/91 and both stock and land prices started falling rapidly. Some have argued that the initial response of the Bank of Japan to the bursting of the asset price bubbles was too slow and not aggressive enough (Jinushi et al., 2000).

Figure 1: Industrial Production, Consumer Price Index and NIKKEI Stock Index
In fact, Figure 2 shows that the call rate was high until 1992/3 and decreased gradually until it reached 0.5 percent in the course of 1995. At the same time, GDP growth decreased; whilst GDP grew in the pre-1991 period by an average rate of 3.9 percent per year, it slowed down to only 0.8 percent post-1991. This of course is the numerical basis for the well-known label ”Japan’s lost decade.” Meanwhile the usually low Japanese unemployment rate has more than doubled while the core inflation rate has steadily trended below zero since 2000. In 1999 the Bank of Japan officially introduced its so-called Zero Interest Rate policy (ZIRP) when it lowered the call rate to 0.03 percent (see Figure 2). It also tried to steer market expectations by adding commitments to its policy statements indicating that it would keep the call rate low for a longer time.

Following the bursting of the IT-stock market bubbles the Bank of Japan introduced a more aggressive policy programme. From March 2001 until March 2006 it implemented the so-called ”Quantitative Easing Policy” (QEP) which consisted of three main elements: (i) the operating target was changed from the call rate to the outstanding current account balances held by banks at the Bank of Japan, (ii) to commit itself to continue providing ample liquidity to banks until inflation stabilized at zero percent or a slight increase, and (iii) to increase the amount
of outright purchases of long-term Japanese government bonds. The monetary development and the effect of the Bank of Japan’s QEP measures can be seen in Figure 3. We plot that part of the monetary base that is the current account holdings of banks at the Bank of Japan. The figure shows the enormous increase in reserves during the QEP period and later again when the recent financial crisis hit. At the same time we see a short-lived decline in the broader monetary aggregate M2 plus Certificates of Deposits (CDs) with a subsequent stagnation. Having these macroeconomic and monetary developments in mind we next want to present our identification strategy based on the reasonable assumption that the Bank of Japan since 1995 did not conduct its monetary policy through the call rate anymore - which was constrained by the ZLB - but by changing the reserve holdings of banks at the Bank of Japan.

Figure 3: Monetary Aggregates in Japan

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7 See the authoritative survey by Ugai (2007) for more details.
3 Identification of Structural Shocks in a Sign Restriction VAR

3.1 Specification of the VAR Model

To analyze the effects of monetary policy on economic activity and the price level at the ZLB, the following reduced-form VAR model is estimated:

\[ Y_t = c + A(L)Y_{t-1} + u_t, \]  

(1)

where \( c \) is a vector of intercepts. \( Y_t \) is a vector of endogenous variables, \( A(L) \) is a matrix of autoregressive coefficients of the lagged values of \( Y_t \) and \( u_t \) is a vector of residuals. In this model, the reduced-form error terms are related to the uncorrelated structural errors \( \epsilon_t \) according to:

\[ u_t = B^{-1}(L)\epsilon_t. \]  

(2)

In our benchmark regression we include the following four macroeconomic variables in the VAR-system:

\[ Y_t = [CPI_t, IP_t, RES_t, LTY_t], \]  

(3)

where \( CPI_t \) denotes the core consumer price index and \( IP_t \) indicates the Japanese industrial production index. Moreover, we include reserves \( (RES_t) \) and the 10-year yield of Japanese government bonds \( (LTY_t) \) in the set of regressors. The VAR model is estimated by means of Bayesian methods using monthly data over the period January 1995 to September 2010. In the benchmark case, six lags of the endogenous variables are included in the estimation, which seems to be sufficient to capture the dynamics of the model.\(^8\) Except for the long-term yield, all variables are seasonally adjusted and included as log-levels.\(^9\) We linearly detrend

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\(^8\)While different lag length criteria lead to different suggestions concerning the number of lags to include, all of them tend to propose an even shorter lag length. Our main results are, however, robust to varying the lag length.

\(^9\)According to Sims et al. (1990) this leads to consistent parameter estimates even in the presence of unit roots.
all variables prior to estimation. With respect to the Bank of Japan’s monetary instrument we argue above that Japan has been at the ZLB during the whole sample period under consideration. In the course of 1995, the call rate has been reduced to 0.5% severely reducing its importance as a policy instrument. Because the call rate has at the same time been more or less constant over our sample period we do not include this variable in our VAR. Instead we treat as monetary policy instrument bank reserves held at the Bank of Japan. Specifically, we choose the outstanding current account balances of banks held at the Bank of Japan as our measure of reserves. A detailed description of the data is given in Appendix A.

Within the theoretical literature on monetary policy at the ZLB the role of the exchange rate in the transmission of unconventional policy has been stressed by a number of studies (Orphanides and Wieland, 2000; Coenen and Wieland, 2003; McCallum, 2000). These models usually imply a real depreciation of the domestic currency following a base money injection due to portfolio rebalancing effects. In order to shed more light on the role of the exchange rate at the ZLB we estimate an additional specification including the real effective exchange rate of the Yen against other currencies ($EX_t$):

\[ Y_t = [CPI_t, IP_t, RES_t, LTY_t, EX_t]. \]  

(4)

## 3.2 Identification of Structural Shocks

As in Uhlig (2005), Canova and Nicolo (2002) and Peersman (2005) identification of the structural shocks is achieved by imposing sign restrictions on the impulse response functions. Additionally, following Peersman (2010) we employ exact zero restrictions on the contemporaneous coefficient matrix. Using a mixture of sign restrictions and zero restrictions on selected impact responses allows us to improve identification of the structural shocks and thus to enhance the interpretation of the respective impulse response functions by exploiting additional economic information (Kilian, 2009). In order to prevent that other disturbances enter the identified unconventional monetary shock we additionally identify two traditional
shocks; a positive demand and a positive supply shock. To be able to distinguish between the responses to the respective shocks, we require these disturbances to be orthogonal to the monetary shock.\(^\text{10}\) Using this specification we make sure that the expansionary monetary shock is not confused with disturbances related to business cycle fluctuations. In contrast to identification strategies based on Cholesky or Blanchard-Quah decompositions, the sign restriction approach explicitly incorporates assumptions that are often used implicitly allowing a more transparent procedure. Moreover, we avoid to impose zero restrictions on long-run impulse responses, which may be problematic both regarding the economic interpretation (Faust, 1998) as well as from a statistical perspective (Faust and Leeper, 1997).

The sign restriction approach is implemented by taking draws for the VAR parameters from the Normal-Wishart posterior, constructing an impulse vector for each draw and calculating the corresponding impulse responses for all variables over the specified horizon.\(^\text{11}\) In particular, the reduced-form innovations \(u_t\) relate to the structural shocks according to equation (2) above with \(B = W\Sigma_\epsilon^{1/2}Q\), where \(W\Sigma_\epsilon^{1/2}\) is the Cholesky factor obtained from the Bayesian estimation of the VAR model for each of the 1000 draws, and \(Q\) is an orthogonal matrix with \(QQ' = I\). To generate \(Q\), we draw a random matrix \(U\) from an N(0,1) density and decompose this matrix using a QR decomposition. For each of the 1000 Cholesky factors we search over possible \(U\) matrices until we find a matrix generating responses to the respective shocks that are in line with the sign restrictions we impose. Additionally, as has been mentioned above, exact zero restrictions are imposed on selected elements of the coefficient matrix \(B\). The impulse response functions \(r_{ijkt}^k\) of variable \(j = 1, \ldots, 4\) to shock \(i = 1, 2, 3\) at horizon \(t = 1, \ldots, 60\) constructed using model \(k = 1, \ldots, 1000\) (where \(k\) indexes the different values of \(Q\)) are then summarized by computing the median over \(k\) of \(r_{ijt}^k\).

It is important to note, however, that solely reporting the median of all admissible impulse responses may be problematic, especially if several shocks are identified

\(^{10}\) Mountford and Uhlig (2009) show how the identification setup in Uhlig (2005) can be extended to control for additional shocks. Our estimation strategy closely follows their approach.

\(^{11}\) Estimation was performed on the basis of Fabio Canova’s SVAR Matlab codes, which can be downloaded from his website http://www.crei.cat/people/canova/.
at the same time (Fry and Pagan, 2007). First, since the median over \( k \) summarizes information obtained from different models, the reported structural impulse response functions may be hard to interpret. Second, and related, since two shocks may be generated from two different models, the structural disturbances are not necessarily orthogonal. We account for these issues by following Fry and Pagan (2007) and additionally reporting impulse responses generated by one model \( Q_k \) the model that leads to impulse responses that are as close to the median over \( k \) of \( r_{ijt}^k \) as possible. This model is found by first standardizing the impulse responses \( r_{ijt}^k \) by subtracting off their median and divide by their standard deviation over the 1000 models satisfying the sign restrictions. The standardized impulse responses are then grouped into a vector \( \phi^k \) for each value \( Q^k \). We subsequently choose the model that minimizes \( \phi^k \phi^k \) and report the corresponding impulse responses in our section on robustness (Section 4.5).

### 3.3 Demand, Supply and Monetary Shocks at the ZLB in the Theoretical Literature

As has been stressed above, the existing empirical VAR literature on the transmission of unconventional monetary policy is rather scarce and thus a broad consensus about the identification of a QE-shock at the ZLB is yet to be reached. Moreover, it is not clear ex ante whether the usual identifying restrictions for aggregate demand and supply shocks are still valid if the interest rate is close to zero. In particular, the main impediment to disentangling the monetary shock from business cycle disturbances at the ZLB is the fact that the interest rate cannot move following either shock. Nevertheless, we show below that it is still possible to derive a clear identification setup using a mix of exact zero and sign restrictions that are implied by theoretical models. Thus, as a first step, we take a closer look at the theoretical DSGE literature concerned with the modelling of the ZLB before deriving our identifying restrictions.

One approach within the theoretical literature on monetary policy at the ZLB has been to calibrate (McCallum, 2000; Orphanides and Wieland, 2000) or estimate (Coenen and Wieland, 2003) open-economy macromodels allowing for zero inter-
est rates. Allowing the quantity of base money to affect output and inflation even if the interest rate is zero these models imply that liquidity injections lead to an increase in output and inflation, respectively, given that these policy measures are sufficiently aggressive. The particular channel that these models rely on is the portfolio rebalancing effect along the lines of Meltzer (1995, 2001) and Mishkin (2001) implying a rebalancing of investors’ portfolios following a base money injection. More specifically, these models put emphasis on the role of assets denominated in foreign currency; the real exchange rate depreciation resulting from such a surge in demand of these assets in turn helps to increase output and prices. Relative to this class of macromodels, more microfoundation is provided by a growing DSGE literature aiming at a characterization of optimal monetary policy in a situation of zero interest rates including Eggertsson and Woodford (2003), Jung et al. (2005), Eggertsson (2006) and Nakov (2008). This stream of literature stresses changing expectations of future monetary policy as the main channel of transmission of base money injections instead of a direct quantity effect. Thus, if a base money injection is successful in that it leads to lower expected interest rates in the future and increases inflationary expectations as of today, it may increase output and inflation. While these different approaches focus on diverging channels underlying the effect of quantitative easing, the outcome is similar: a rise in the reserve component of the monetary base in a situation of zero interest rates should lead to a non-negative effect of output and prices.

Yano (2009) presents a New Keynesian DSGE model under liquidity trap conditions that is estimated using Japanese data and thus offers more insights on the reaction of output, inflation and the interest rate following different business cycle shocks at the ZLB. In particular, the model implies that prices and output move in the same direction following a demand shock and in opposite directions after a supply shock. The interest rate stays fixed at zero after both shocks. Finally, Eggertsson (2010) provides a DSGE model in which the ZLB is the outcome of an exogenous negative shock moving the economy away from the zero-inflation natural rate steady state and into the ZLB. Again, in this model a positive aggregate demand shock increases output and inflation. However, in contrast to the
responses implied by the model of Yano (2009) an aggregate supply shock also leads output and inflation to move in the same direction. More specifically, a positive supply shock boosts deflationary expectations, which further raises the real rate of interest. Since at the ZLB this increase cannot be offset by a reduction in the nominal interest rate the result of such a shock is a decline in aggregate demand.\footnote{While in Eggertsson (2010) the focus is on fiscal shocks or, more specifically, on the adverse consequences of tax reductions at the ZLB, the results of the model similarly apply to other shocks that tend to enhance deflationary expectations such as a positive supply shock.}

### 3.4 Identifying Sign Restrictions

Using the implications of these theoretical models we now present our identifying set of sign restrictions. As far as the identification of the business cycle shocks are concerned we will take into account the diverging predictions of the DSGE models of Yano (2009) and Eggertsson (2010), respectively, by implementing restrictions implied by the former in our benchmark identification, while the restrictions in line with the latter model are used in an alternative identification scheme.

#### 3.4.1 Benchmark Identification

We first describe our benchmark identification scheme for the benchmark specification. Sign restrictions are binding for twelve months following the shock,\footnote{A similar restriction horizon is used by e.g. Scholl and Uhlig (2006).} while the zero restrictions are imposed on impact only. Table 1 summarizes the restrictions considered for the benchmark model. Restrictions on the sign of the impulse response functions are indicated in the columns “sign” in the table, while exact zero restrictions are given in the column “exact impact”. The latter restrictions are employed only for identification of the QE-shock. As Table 1 shows, to identify an aggregate demand shock we restrict output and prices to move in the same direction; both variables are assumed to increase following a positive demand shock. For an aggregate supply shock we impose that output and prices move in opposite directions. These assumptions allow us to disentangle these two shocks.

\begin{table}[ht]
\end{table}
As has been explained above, our restrictions are in line with the predictions of DSGE models explicitly modeling the zero lower bound, such as Yano (2009). Moreover, similar restrictions are implied by standard DSGE models (Straub and Peersman, 2006; Canova and Paustian, 2010) and are also imposed in more traditional VAR studies (Peersman, 2005; Canova et al., 2007). The unconventional monetary shock is identified by restricting reserves to increase following the shock; this is our key assumption for the identification of a reserves shock. Furthermore, we follow the usual approach in the VAR literature assuming a lagged impact of a monetary shock on output and prices; the contemporaneous coefficient of these variables is restrained to zero. Similar zero restrictions have also been used by Peersman (2010). Additionally, we assume a non-negative response of the price level to the QE-shock. As outlined above, this is in line with a wide range of theoretical models incorporating the ZLB (Coenen and Wieland, 2003; Eggertsson and Woodford, 2003; Eggertsson, 2006). Because the central question assessed in this paper is concerned with the effectiveness of unconventional monetary policy measures on the real economy at the zero lower bound, which is the ultimate concern of central banks facing a liquidity trap situation, we leave the response of industrial production to a QE-shock unrestricted. Moreover, we abstain from restricting the 10-year government bond yield. As discussed in the Introduction, the effects of quantitative easing on long-term yields are theoretically not clear; observing rising yields following a base money expansion may be possible as a consequence of increasing inflation expectations or increasing risk premia. In this

\[ \text{Table 1: Identifying Sign Restrictions - Benchmark Identification} \]

<table>
<thead>
<tr>
<th>variable</th>
<th>Demand shock</th>
<th>Supply shock</th>
<th>QE-shock</th>
<th>horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPI</td>
<td>&gt; 0</td>
<td>&lt; 0</td>
<td>0</td>
<td>≥ 0</td>
</tr>
<tr>
<td>Ind. production</td>
<td>&gt; 0</td>
<td>&gt; 0</td>
<td>0</td>
<td>&gt; 0</td>
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<tr>
<td>Reserves</td>
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<td>Long-term yield</td>
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sense our identification scheme can be considered agnostic in that we let the data speak concerning the effects of an unconventional monetary shock on the real economy and long-term interest rates. Crucially, the contemporaneous zero restrictions following a QE-shock imposed on CPI and industrial production are sufficient to disentangle the unconventional monetary shock from the business cycle disturbances (Peersman, 2010). The set of identifying restrictions for our alternative specification given in equation (4) are very similar; the restrictions imposed on the CPI, industrial production and reserves are the same as those used for the benchmark specification above. We abstain from restricting the exchange rate; leaving the response of the exchange rate unrestricted allows us to let the data speak concerning the effect of the QE-shock on this variable and thus its role in the transmission of unconventional policy.

3.4.2 Alternative Identification Scheme

In order to check whether our results concerning the QE-shock are still valid when we account for the somewhat diverging effects of a positive supply shock at the ZLB predicted by Eggertsson (2010) we try to implement these restrictions in an alternative setup, summarized in Table 2. Since both the demand and supply shocks should now induce output and prices to move in the same direction, we cannot easily differentiate the two shocks. To deal with this problem we propose another way to disentangle shocks using the different slope properties of the aggregate supply and demand equations in the model. In particular, in the model of Eggertsson (2010) the AD-curve will always be steeper than the AS-curve and thus a positive demand shock leads to a proportionately larger impact on the value of output versus inflation than a positive supply shock. Thus, we restrict the response of this ratio to be larger than one in absolute value for the demand shock, and less than one for the supply shock. At the same time, a positive demand shock is assumed to lead to a positive reaction of both output and prices, while a positive supply shock is restricted to lower these variables. The QE-shock is identified as before and can again be disentangled from the other shocks by imposing the exact zero restrictions.
Table 2: Identifying Sign Restrictions - Alternative Identification

<table>
<thead>
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<tr>
<td>Long-term yield</td>
<td>&gt; 1</td>
<td>&lt; 1</td>
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4 Results

4.1 Impulse Response Analysis - Benchmark Regression

Figures 4, 5 and 6 show the impulse responses to the three shocks based on the benchmark specification and identification scheme explained above. Figure 4 shows the responses to our unconventional monetary policy shock. In the figure, the inner lines denote the median impulse responses from a Bayesian vector autoregression with 1000 draws, while the outer lines indicate one-standard error confidence bands. The response of reserves has been restricted not to decrease following the shock, so the immediate positive response is not surprising by construction. In particular, reserves rise by up to 8% and stay significantly above the zero line for much longer than preset; about three years. As restricted, CPI does not react on impact and responds positively thereafter. It can be seen that the response of the price level is rather weak staying around 0.05%. The mild and transient response of the price level to the QE-shock implies that the rate of inflation also reacts only temporarily and weakly. Nevertheless, the effect lasts for somewhat longer than restricted; about 18 months. Crucially, the main variable of interest, industrial production, has been left unrestricted except for the contemporaneous zero restriction. It can be seen in the figure that an expansionary QE-shock leads to a significant increase of industrial production by about 0.5% after 20 months.
This response is temporary and fades after about one and a half years. Thus, our VAR-based results suggest that an unconventional monetary policy shock can in fact increase economic activity for some time. Finally, in contrast to some previous studies we did not restrict the response of the long-term government bond yield since its reaction following a QE-shock is theoretically unclear. In fact, Figure 4 shows an initial significantly negative reaction of this variable; the 10-year government bond yield falls by about 0.1 percentage points on impact. Hence, our result can in fact be interpreted as evidence for the view that QE works by lowering long-term rates. Importantly, this result has been obtained by using an agnostic approach with respect to the long-term yield. The transient nature of the responses of industrial production and prices suggests that it is important to explicitly analyze these variables; a fall in long-term yields alone cannot guarantee a persistent increase in economic activity nor a strong raise in the price level.

Figure 4: Impulse Responses to a QE-Shock - Benchmark Identification and Model

The figure displays responses over a 60-month horizon to a QE-shock as identified in Table 1. The inner lines denote the median impulse responses from a BVAR (1000 draws), the outer lines indicate one std. error confidence bands. Vertical lines indicate the restriction horizon.
All in all, the results presented in Figure 4 suggest that a quantitative easing strategy in a situation of near-zero interest rates has the potential to successfully stimulate real economic activity, at least in the short run. However, our results also show that the Bank of Japan’s second main goal motivating such a policy, namely to permanently raise inflation and to eventually bring an end to Japan’s deflationary episode, is difficult to achieve by such measures. Hence, our benchmark results provide mixed evidence for the overall effects of unconventional monetary shocks on the economy.

The impulse response functions for the demand and supply shocks are shown in Figures 5 and 6, respectively. These two shocks are mainly identified for the purpose of controlling for other business cycle disturbances the QE-shock might be confused with. Because most variables have been restricted we only briefly discuss the results here. Following a demand shock, industrial production and the CPI are restricted to rise. Hence the initial increase in these variables is not surprising. However, note that CPI rises significantly over a much longer period than restricted. Industrial production does also stay significantly positive for somewhat longer than the restriction horizon. Turning to the responses of reserves and long-term yields to the demand shock, we find reserves falling significantly and in a hump-shaped pattern by around 4%, possibly due to reserves being run down by banks needing to increase lending in response to the positive demand shock. Figure 6 finally shows the impulse response functions following a supply shock. Again, the initial increase in industrial production and decrease in CPI are by construction. Again, the responses last somewhat longer than preset.
The figures display responses over a 60-month horizon to a demand and supply shock as identified in Table 1. The inner lines denote the median impulse responses from a BVAR (1000 draws), the outer lines indicate one std. error confidence bands. Vertical lines indicate the restriction horizon.
4.2 Alternative Specification

We now focus on the responses to the QE-shock only and discuss the results of the second specification. Figure 7 shows the impulse responses to the QE-shock resulting from the specification including the exchange rate. This serves both as a robustness test and may shed some light on whether the exchange rate follows an interesting pattern that might help explaining the transmission mechanism of the QE-shock.

Figure 7: Impulse Responses to a QE-Shock - Including the Exchange Rate

![Graph showing impulse responses over a 60-month horizon to a QE-shock as identified in Table 1. The inner lines denote the median impulse responses from a BVAR (1000 draws), the outer lines indicate one std. error confidence bands. Vertical lines indicate the restriction horizon.](image)
As can be seen in the figure, the qualitative results do not change after including the exchange rate as an additional variable. Industrial production still rises by up to 0.3-0.4%; however, error bands are somewhat wider. As in the benchmark case, the response of the consumer price index becomes insignificant after a while, however, the delay is somewhat longer. The responses of the other variables are very similar to those in the benchmark case. Thus, our extended identification scheme does not change our main conclusion that while it may be possible to temporarily increase production and prices by quantitative easing measures, it seems to be much harder to affect the long-term inflation environment by this policy. Moreover, the response of the long-term yield is robust to this extended specification confirming that long-term rates do in fact fall after such an unconventional shock. However, adding the exchange rate does not help us in shedding more light on the specifics of the transmission mechanism. In fact, the real effective exchange rate is insignificant over the entire horizon.

4.3 Alternative Identification Scheme

We next turn to our benchmark specification results when we identify our three shocks according to the alternative sign restrictions given in Table 2. These restrictions differ from the benchmark restrictions only in the identification of the demand and supply shocks. Because the theoretical predictions from the DSGE-model are the same for a positive demand and a negative supply shock, we need to impose the additional restriction on the relative magnitudes of the output and price responses. Results for the three shocks are given in Figures 8, 9 and 10.
The figure displays responses over a 60-month horizon to a QE-shock as identified in Table 2. The inner lines denote the median impulse responses from a BVAR (1000 draws), the outer lines indicate one std. error confidence bands. Vertical lines indicate the restriction horizon.

Figure 8 shows the impulse responses to the QE-shock using our alternative identification scheme. As expected, the results are very similar to those from our benchmark identification. Moreover, interestingly, results for the demand shock are very similar to those for the benchmark identification, as can be seen in Figure 9. Again, the initial increase in industrial production and CPI is by construction. Again, the price level remains significantly positive for longer than the restricted horizon. Overall, the response is somewhat reduced compared to our benchmark identification scheme. Similarly, reserves do not react significantly in this case.
More interestingly, turning to the impulse responses to the supply shock under the alternative identification scheme, we naturally find some differences. Figure 10 shows the effects of the supply shock under this identification: industrial production and CPI are restricted to fall following a positive supply shock. The crucial identification restriction regarding the relative magnitudes of the responses of production and prices can be seen by comparing the absolute size of the response of production to the demand and supply shocks. Industrial production is restricted to respond stronger than CPI following the demand shock, but less strong than CPI following the supply shock. This is confirmed by Figures 9 and 10. But note now the difference in the responses to the supply shock as shown in Figure 10 from the benchmark model shown in Figure 6. The initial fall of industrial production, which was specified within the restriction setup, is partly offset by an increase in activity after about two years. CPI remains significantly negative for almost three years, while reserves significantly rise after around 1-2 years, and the long-term
yield shows a similar reaction as in the benchmark case.

Figure 10: Impulse Responses to a Supply Shock - Alternative Identification Scheme

The figure displays responses over a 60-month horizon to a supply shock as identified in Table 2. The inner lines denote the median impulse responses from a BVAR (1000 draws), the outer lines indicate one std. error confidence bands. Vertical lines indicate the restriction horizon.

4.4 Forecast Error Variance Decomposition

In order to get a better understanding of the relative importance of our identified shocks for the variables of interest we calculate the forecast error variance decomposition which gives the estimated shares of the variability of each variable due to the respective shocks. Our main interest is of course focused on the variance shares of the QE-shock because they can be interpreted as measures of the quantitative effect of unconventional policy shocks on the real economy. Table 3 displays the median of the forecast error variance shares of the endogenous variables for each of the three identified shocks at the one to five-year forecast horizon. The last column of the left panel shows the sum of the variance shares of the respective variables due to all identified shocks.
Table 3: Forecast Error Variance Decomposition

<table>
<thead>
<tr>
<th>Variable</th>
<th>horizon</th>
<th>Benchmark specification</th>
<th>Including exchange rate</th>
</tr>
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<tr>
<td></td>
<td></td>
<td>QE</td>
<td>SU</td>
</tr>
<tr>
<td>Ind. prod.</td>
<td>1 year</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>2 years</td>
<td>4</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>3 years</td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>4 years</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>CPI</td>
<td>1 year</td>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>2 years</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>3 years</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>4 years</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Reserves</td>
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<td>5</td>
</tr>
<tr>
<td></td>
<td>2 years</td>
<td>48</td>
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<td></td>
<td>3 years</td>
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<tr>
<td></td>
<td>4 years</td>
<td>40</td>
<td>7</td>
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<td></td>
<td>5 years</td>
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<td>8</td>
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<td>LT yield</td>
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<td></td>
<td>2 years</td>
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<td></td>
<td>4 years</td>
<td>34</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
<td>33</td>
<td>12</td>
</tr>
<tr>
<td>Exch. rate</td>
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<td>8</td>
</tr>
<tr>
<td></td>
<td>2 years</td>
<td>21</td>
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</tr>
<tr>
<td></td>
<td>3 years</td>
<td>18</td>
<td>14</td>
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</table>

It can be seen that together the structural shocks explain between 58% and 68% of the variations in the endogenous variables for the benchmark specification, which is a relatively large share. Moreover, it can be seen that the QE-shock explains some of the variations in the CPI and industrial production, our main variables of interest; however, these shares are rather small. The unconventional shock explains fluctuations in output and the CPI by up to 9%, respectively. For both variables, the demand shock is the dominant source of variation with variance.
shares of around 35 - 40%. Interestingly, the long-term yield is heavily affected by the QE-shock, which accounts for about 35-55% of variations in this variable. Naturally, variations in reserves are largely explained by the unconventional shock as well. The right panel of Table 3 shows some interesting findings for the alternative specification including the exchange rate. While the QE-shock still has a relatively minor role in explaining variations in output and prices (around 5-15%), it seems to be relatively more important for fluctuations in the exchange rate explaining around 20% of exchange rate variability. At the same time, business cycle fluctuations seem to be relatively unimportant for movements in the exchange rate. This suggests that while the response of this variable to the unconventional shock is found to be insignificant, this shock still has some explanatory power with regard to exchange rate fluctuations pointing to a non-negligible role of the exchange rate in the transmission of such shocks at the ZLB.

4.5 Robustness

Close-to-Median Model
The first robustness check is concerned with the median as a way to summarize the information obtained from the Bayesian approach to calculating impulse responses. Figures 11 to 13 replicate the median impulse responses along with the 68% confidence intervals to the respective shocks. The red dashed lines additionally show the impulse responses generated by the one model that is closest to the median over all 1000 models. It can be seen that generally, the impulse responses generated by this “close-to-median model” are very similar to the median over all models.

Varying the Restriction Horizon
The second robustness check involves specifying the restriction horizon k. As noted by, for instance, Uhlig (2005), it is difficult to base the choice of the appropriate restriction horizon on economic theory resulting in some degree of arbitrariness in specifying this parameter. We therefore check sensitivity of our results to this choice by estimating the benchmark model for different restriction horizons. Fig-
Figure 14 shows the impulse response functions for our variables of interest, CPI and industrial production, for a lower restriction horizon compared to the benchmark model $k = 6$ and for a longer horizon $k = 18$ (displayed in the first and the third row, respectively). The benchmark case, $k = 12$ is given in the second row. The blue vertical lines indicate the respective restriction horizon. It can be seen in the figure that our main results are largely insensitive to variations in $k$; industrial production shows a significant and positive response at least over several months. However, the magnitude of this increase differs among the respective cases. While for $k = 6$ the positive impact on economic activity vanishes rather fast following the shock\textsuperscript{14}, the response is stronger and lasts somewhat longer for $k = 18$.\textsuperscript{15} A similar pattern can be observed for the effect on CPI.

Figure 11: Impulse Responses to a QE-Shock - Close-to-Median Model

Responses to a QE-shock. The inner lines denote the median impulse responses from a BVAR (1000 draws), the outer lines indicate one std. error confidence bands. The red dotted lines display the response generated by the close-to-median model.

\textsuperscript{14}Similar results are obtained for a restriction horizon of nine months or eight months.  
\textsuperscript{15}Again, results are very similar for even longer restriction horizons of, say, 24 months.
Responses to a demand and supply shock, respectively. The inner lines denote the median impulse responses from a BVAR (1000 draws), the outer lines indicate one std. error confidence bands. The red dotted lines display the response generated by the close-to-median model.
Further Robustness Checks

Furthermore, our main results are robust to changing the number of lags included in the VAR model to 4, 9 or 12. Similarly, extending the sample period to, for instance, 1990:01-2010:09 does not alter our main findings. Furthermore, starting the sample in 1996 or 1997 leads to robust results.\textsuperscript{16} As far as the variables in the model are concerned, we included headline CPI instead of core CPI that we include in the benchmark specification. Although the latter measure leads to an economically more plausible specification, our results concerning the effects on industrial production or the long-term yield are unchanged to this modification. Similarly, including the Dollar/Yen bilateral exchange rate instead of the real effective exchange rate does not change our results. All these results are available upon request.

\textsuperscript{16}Given that Inoue and Okimoto (2008) find evidence for a break in the Japanese economic system around 1996 this result is particularly reassuring.
The figure displays responses of industrial production and the CPI to a QE-shock for different restriction horizons. The inner lines denote the median impulse responses from a BVAR (1000 draws), the outer lines indicate one std. error confidence bands. The blue vertical lines indicate the respective restriction horizon.
5 Discussion and Conclusion

The primary objective of this paper has been to agnostically assess the real effects of QE measures adopted by the Bank of Japan for a liquidity trap episode. We suggest to use results from the theoretical literature to derive our identifying restrictions for our SVAR. In particular, we propose a set of sign restrictions based on predictions of DSGE models explicitly taking into account the ZLB, which clearly identify an unconventional shock without imposing restrictions on interest rates, yield spreads or the exchange rate. Given that a broad consensus is still missing as to how to identify monetary shocks at the ZLB, we used two different identification strategies. Our results show that a QE-shock does positively and significantly affect industrial production. After around two years industrial production has risen by about 0.5% following an unconventional shock; a shock that at the same time leads to an increase in reserves by about 8%. Moreover, the shock has a significant effect on core CPI, which is, however, not very strong and of transient nature. Overall, therefore, our empirical results tend to suggest that unconventional policy actions can positively affect real economic activity even when the economy is in the liquidity trap. However, the QE-shock we identify does not significantly affect prices over the longer term. We believe these results are interesting not only for the Japanese economy, but also for other advanced economies where monetary policy is constrained by the ZLB.

Concerning possible transmission channels of unconventional monetary policy our empirical results only allow limited conclusions. We report a clear and significant decrease in long-term yields which could potentially induce portfolio shifts in the spirit of Meltzer (1995). On the other hand, we do not find any significant effect on the exchange rate suggesting that potential portfolio rebalancing effects - at least in terms of shifts towards assets denominated in foreign currency - have not been effective in lowering the exchange rate. One possible interpretation - along the lines of Svensson (2003) could be that the Bank of Japan simply did not do enough to depreciate the exchange rate thereby fostering economic activity. A more detailed empirical analysis to clearly identify the particular transmission channels at work following unconventional policy shocks is left for future research.
A Data

In the benchmark case we include four variables reflecting the macroeconomic and monetary environment of the Japanese economy. We use monthly observations for the period 1995:01-2010:09. The start of the sample period is motivated by the fact that the Bank of Japan first decreased interest rates to around 0.5% during the course of 1995 and we are mainly interested in the effectiveness of monetary policy at near-zero interest rates.

Monetary variables
We include the long-term interest rate as well as a measure of reserves; both series have been obtained from the Bank of Japan’s statistics website. To be able to identify the QE-shock we include the average outstanding current account balances held by financial institutions at the Bank of Japan. This is the part of the monetary base that can be referred to as reserves held at the central bank. Under the QE policy this variable has gained importance as the main operating target for the Bank of Japan. As a measure of long-term rates we include the 10-year government bond yield.

Prices
We include the core consumer price index, which measures the development of consumer prices excluding energy and food. Base year is 2005. The core CPI has been obtained from Datastream. Moreover, we include a narrow index of the real effective exchange rate of the Yen against other currencies as published on the Bank for International Settlements’ (BIS) website. Both series are seasonally adjusted by X12-ARIMA.

Industrial Production
We include a measure of the Japanese industrial production as a generally used indicator of economic activity. Base year is 2005. The series has been obtained from Datastream and is seasonally adjusted by X12-ARIMA.
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