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Abstract

With the Federal Funds rate approaching the zero lower bound, the U.S. Federal Reserve adopted a range of unconventional monetary policy measures known as Quantitative Easing (QE). Quantifying the impact QE has on the real economy, however, is not straightforward as standard tools such as VAR models cannot easily be applied. In this paper we use the Qual VAR model (Dueker, 2005) to combine binary information about QE announcements with an otherwise standard monetary policy VAR. The model filters an unobservable propensity to QE out of the observable data and delivers impulse responses to a QE shocks. In contrast to other empirical approaches, QE is endogenously depending on the business cycle, can easily be studied in terms of unexpected policy shocks and its dynamic effects can be compared to a conventional monetary easing. We show that QE shocks have a large impact on real and nominal interest rates and financial conditions and a smaller impact on real activity.

Keywords: Qual VAR, unconventional monetary policy, LASP, zero lower bound, quantitative easing

JEL classification: E32, E44, E52

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1 Motivation

In the wake of the recent financial crisis, the policy rates of almost all central banks in industrialized countries reached the zero lower bound of nominal interest rates, and will remain at historically low levels for the time being. Nominal interest rates near their lowest possible level create a challenge for central banks leaving little room for further cuts to provide stimulus to the financial sector and the wider economy when necessary.

Facing this limitation central banks such as the U.S. Federal Reserve introduced Quantitative Easing (QE) measures to implement a further monetary stimulus. Quantitative Easing covers actions that expand the central bank's balance sheet such as large-scale asset purchases (LSAP) and those that change the maturity composition of the Fed's bond portfolio, i.e. the Maturity Extension program also known as "Operation Twist". Another powerful instrument of the central bank's unconventional toolkit is a measure known as Forward Guidance. While the Federal Reserve started to gradually reduce, i.e. 'taper', its program of monthly purchases of government and mortgage bonds in late 2013/early 2014, expectations are mounting that the European Central Bank may soon adopt a quantity-based program to stimulate the sluggish euro area economy.

Against this background, the central question from both a policy and a research perspective is how QE actions affect fundamentals. In this paper, we want to give a quantitative answer to this question. For macroeconomists intending to analyze monetary policy, vector autoregressive (VAR) models introduced by Sims (1980) are the tool of first choice. However, unconventional monetary policy measures such as QE actions pose a challenge to standard VAR analysis. Since there is no single policy instrument whose variation reflects unconventional policy steps, QE measures are often modeled as a binary indicator which could be used, for example, for event study regressions but which cannot easily be implemented in a conventional VAR model. Likewise, QE steps are likely to be endogenously depending on the state of the business cycle and cannot simply be modelled as dummy variables only.

We offer an alternative approach to estimate the impact of QE on the macroeconomy. The model integrates the information from the announcements of QE into an otherwise standard monetary policy VAR. One can think of the observable binary indicator of QE actions as a variable behind which lies a continuous latent, i.e unobservable variable, reflecting the propensity to unconventional monetary policy. The resulting model is a Qual VAR (Dueker, 2005). Based on the dynamic interaction within the VAR model, Markov Chain Monte Carlo techniques can filter this latent

variable out of the data which then provides us with a continuous series on monetary policy's propensity to QE. Next, this variable enters the VAR model as a regressor and enables the derivation of impulse response functions.

The advantages of the Qual VAR are fourfold: first, we take explicit account of the endogenous nature of Quantitative Easing. Rather than including QE announcements as an exogenous variable in an event study or a panel model, we model the interaction with business cycle variables - very much like in a standard monetary policy VAR. Second, since we eventually estimate a standard VAR, we can discuss the effects of policy in terms of shocks. That is, we focus on the unexpected part of QE only. Third, the model provides a way to link macroeconomic, i.e. low-frequency data to QE announcement days which are often modelled as a binary variable. Fourth, since we can use impulse response analysis, again very much like in the standard monetary policy VAR literature, we can directly compare the dynamic effect of a QE shock with that of a conventional monetary easing.

The model is estimated on U.S. data since the end of 2007. We extract a very plausible evolution of the Fed's latent propensity to enter QE. The resulting impulse response functions suggest that QE does indeed have a significant and sizable effect on both real economic activity and the financial sector. Shocks to QE raise industrial production and employment and lower nominal and real long-term interest rates, respectively. Furthermore, QE shocks push equity returns and reduce financial market uncertainty as reflected by the CBOE volatility index (VIX). We are also able to track the impact of QE over time. While QE1 had only a small effect on all variables mentioned before, the effects of QE2 and QE3 were substantially larger. For example, stock returns in 2011 were almost entirely explained due to the impact of QE.

The remainder of this article is organized as follows. Section 2 gives account of previous empirical work on the effects of QE and explains in what sense this paper improves upon previous research. Section 3 lays out the empirical methodology. The data set and the alternative model specifications are introduced in Section 4. Our results are discussed in Section 5. Section 6 compares the results to conventional monetary policy shocks. A set of robustness tests is presented in Section 7. Finally, Section 8 draws some conclusions.

2   The effects of QE: what do we know?

Over the recent years, the empirical literature on the effectiveness of unconventional monetary policy grew in tandem with the Fed's balance sheet. When it comes

to quantifying the effects of QE, however, the basic difficulty is that there is no well-defined policy instrument whose variation indicates the Fed's policy stance and which is easily observable. Over the past 30 years the monetary policy literature had agreed to interpret the Federal Funds rate as the Fed's main instrument for conventional monetary policy. With the Fed Funds rate at zero, however, it no longer serves this purpose.

One way to provide an overview over the relevant literature is to argue that the empirical literature differs in the choice of the policy instrument used to measure unconventional policies. The biggest strand of the literature focuses on the announcements of QE measures themselves.[1] Often, high frequency data is used to study the immediate response of financial variables to QE surprises. These surprises are extracted from futures markets. The most important contributions to the event-study literature are Gagnon et al. (2011), Krishnamurty and Vissing-Jorgensen (2011), D'Amico et al. (2012), Swanson (2011), Glick and Leduc (2013) and Neely (2013). It is typically found that domestic interest rates fall upon a QE announcement. In addition, the USD weakens against major currencies.[2] The problem with this line of research is that it is confined to financial data only. Linking macroeconomic variables to QE announcements while controlling for business cycle dynamics is difficult. The approach proposed in this paper, however, is able to proceed along these lines. Furthermore, the size and the timing of unconventional policy actions are endogenous and reflect the business cycle. Thus, the model should allow for a feedback from macroeconomic variables to policy actions.

Another strand uses the Fed's balance sheet directly. Gambacorta et al. (2013) estimate a panel VAR model consisting of countries that adopted QE such as the US, the euro area and Japan. QE shocks are identified using sign restrictions requiring, among other things, an immediate increase in the Fed's balance sheet following a QE shock.[3] The advantage is that this approach allows the inclusion of macroeconomic variables - very much as in our approach. The drawback, however, is that not all QE measures directly lead to an increase in the balance sheet of the central bank. "Operation Twist" or the announcement of an entire path of future asset purchases either leave the balance sheet unchanged or lead to a small increase only. The total impact of the entire future stream of asset purchases might not be fully reflected in

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[1]For a critical view on the event-study evidence on the effectiveness of QE see Thornton (2013).

[2]Wright (2012) offers an SVAR model in which QE shocks are identified using volatility clustering on announcement days. Neely (2014), however, questions the stability of this VAR model.

[3]Schenkelberg and Watzka (2013) also use sign restrictions to study the effects of unconventional monetary policy by the Bank of Japan since the mid-1990s. A quantitative easing shock leads to a significant decrease in long-term interest rates and significantly increases output and the price level.

today's balance sheet.

As QE most likely reduces long term interest rates, another strand of the literature uses either the long rate or the spread between long and short rates as a policy instrument. For example, Gilchrist et al. (2013) use the two year nominal treasury yield as an instrument. They find a significant reduction in real borrowing costs following a reduction of the policy instrument. Chen et al. (2012) use the term spread as the policy variable within a global vector error-correction model for a large set of countries. In a very interesting paper, Baumeister and Benati (2013) estimate a time-varying VAR model in which a spread shock is identified that leaves the policy rate unchanged. They show that the Fed's and the Bank of England's unconventional measures have avoided a large, Great Depression-like output collapse.

Our paper is also related to recent endeavors to uncover a latent policy stance from observables if the usual policy instrument is stuck at the zero lower bound. Examples include Lombardi and Zhu (2014), who derive a shadow policy rate from a dynamic factor model. Hamilton and Wu (2012), Christensen and Rudebusch (2013) and Wu and Xia (2014) extract the Fed's shadow policy rate from nonlinear term structure models.

In this paper, we propose to study the effects of unconventional monetary policies on the macroeconomy by employing Dueker's (2005) Qual VAR model that originally was used to forecast business cycle turning points. In doing so, we combine a binary choice model with the workhorse method to analyze monetary policy and its implications - the VAR model. This allows us to integrate QE announcements into an otherwise standard monetary policy VAR model and to uncover the Fed's latent propensity for Quantitative Easing.

3   The estimation of a Qual VAR

In this section we explain the econometric specifications of Dueker's (2005) multivariate dynamic probit model, also referred to as a Qual VAR. As a first component of the model, we consider a latent variable y_t^* as shown in equation (1) to determine unconventional monetary policy measures. It is defined as an autoregressive process of order ρ depending on a constant δ, its own lagged values and a set of lagged explanatory variables $X_{t-\rho}$; ϕ and β are vectors of the coefficients; ϵ_t is a random error term following standard normal distribution and $t = 1, ..., T$ is the time index

$$y_t^* = \delta + \sum_{l=1}^{\rho} \phi_l y_{t-l}^* + \sum_{l=1}^{\rho} \beta_l X_{t-l} + \epsilon_t, \quad \epsilon_t \sim \mathcal{N}(0, 1). \tag{1}$$

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We assign the value of one to a binary variable y_t if unconventional policy actions (QE) occur in period t and zero otherwise. Using equation (1), the value of the binary variable y_t takes the form

$$y_t = \begin{cases} 0 & \text{if } y_t^* \leq 0 \\ 1 & \text{if } y_t^* \geq 0. \end{cases} \tag{2}$$

The second component of the model is a VAR(ρ) process for the dynamics of k regressors

$$Y_t = \mu + \sum_{l=1}^{\rho} \Phi^{(l)} Y_{t-l} + \nu_t, \quad \nu_t \sim \mathcal{N}(0, \Sigma) \tag{3}$$

with a $k \times 1$ vector $Y_t = (X_t, y_t^*)'$ where X_t incorporates k-1 time series of observed macroeconomic data and y_t^* constitutes a vector of the latent variable. The set of VAR coefficients is described by

$$\Phi^{(l)} = \begin{bmatrix} \Phi_{XX}^{(l)} & \Phi_{Xy^*}^{(l)} \\ \Phi_{y^*X}^{(l)} & \Phi_{y^*y^*}^{(l)} \end{bmatrix},$$

μ is a $k \times 1$ vector of constants and ν_t constitutes the $k \times 1$ error vector. The covariance matrix of the errors is Σ.

Hence, the complete Qual VAR system comprises the linear relation between the latent variable, which below will be interpreted as the Fed's propensity for QE, and the regressors, see equation (1), the mapping with the binary observation, equation (2) and the VAR representation, equation (3).

Dueker (2005) and Assenmacher-Wesche and Dueker (2010) show that the model can be estimated by Markov Chain Monte Carlo (MCMC) techniques, in particular via Gibbs Sampling. Gibbs Sampling enables the joint estimation of the VAR coefficients Φ, the covariance matrix of the VAR residuals Σ and the latent variable y_t^*. For this purpose the iterative algorithm generates a sequence of draws from the following conditional distributions

$$\begin{aligned} \text{VAR coefficients} \quad &\sim \quad \text{Normal} \\ \pi(\Phi^{(i+1)} \quad &| \quad \{y_t^{*(i)}\}_{t=1,\dots,T}, \{X_t\}_{t=1,\dots,T}, \Sigma^{(i)}) \\ \text{Covariance matrix} \quad &\sim \quad \text{inverted Wishart} \\ \pi(\Sigma^{(i+1)}) \quad &| \quad \{y_t^{*(i)}\}_{t=1,\dots,T}, \{X_t\}_{t=1,\dots,T}, \Phi^{(i+1)}) \\ \text{Latent variable} \quad &\sim \quad \text{truncated Normal} \\ \pi(y_t^{*(i+1)} \quad &| \quad \{X_t\}_{t=1,\dots,T}, \{y_j^{*(i+1)}\}_{j<t}, \{y_k^{*(i)}\}_{k>t}, \Phi^{(i+1)}, \Sigma^{(i+1)}). \end{aligned}$$

Under the Jeffrey's prior the conditional posterior for the VAR coefficients will be multivariate Normal and the conditional posterior of the variance will be Wishart distributed. In each period a single observation of the latent variable is truncated Normal with truncation limits that are imposed by the observable binary variable y_t.

For a sufficiently large number of iterations i, the obtained draws constitute the true joint posterior distribution. Thus, Gibbs Sampling only requires knowledge of the full conditional posterior distribution of the VAR coefficients Φ, the covariance matrix Σ and the latent variable y_t^*.

Several remarks concerning our estimation are in order here. In each iteration cycle we generate a draw for the latent variable by first setting up a state space model. The state equation is expressed as

$$
\begin{bmatrix} y_t^* \\ y_{t-1}^* \\ y_{t-2}^* \\ \vdots \\ y_{t-\rho+1}^* \end{bmatrix} = \begin{bmatrix} c_{y^*} \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \begin{bmatrix} \Phi_{y^*y^*}^{(1)} & \Phi_{y^*y^*}^{(2)} & \Phi_{y^*y^*}^{(3)} & \ldots & \Phi_{y^*y^*}^{(\rho)} \\ 1 & 0 & 0 & \ldots & 0 \\ 0 & 1 & 0 & \ldots & 0 \\ \vdots & \vdots & \ddots & & 0 \\ 0 & 0 & \ldots & 1 & 0 \end{bmatrix} \begin{bmatrix} y_{t-1}^* \\ y_{t-2}^* \\ y_{t-3}^* \\ \vdots \\ y_{t-\rho}^* \end{bmatrix}
$$
$$
+ \begin{bmatrix} \Phi_{y^*X}^{(1)} & \ldots & \Phi_{y^*X}^{(\rho)} \\ 0 & \ldots & 0 \\ 0 & \ldots & 0 \\ \vdots & \vdots & \vdots \\ 0 & \ldots & 0 \end{bmatrix} \begin{bmatrix} X_{t-1} \\ X_{t-2} \\ X_{t-3} \\ \vdots \\ X_{t-\rho} \end{bmatrix} + \begin{bmatrix} \epsilon_{y^*,t} \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{4}
$$

with the following measurement equation

$$
y_t^* = \begin{bmatrix} 1 & 0 & 0 & \ldots & 0 \end{bmatrix} \begin{bmatrix} y_t^* \\ y_{t-1}^* \\ y_{t-2}^* \\ \vdots \\ y_{t-\rho}^* \end{bmatrix}. \tag{5}
$$

Secondly, we apply Kalman Smoothing in order to determine the mean and the variance of the states e.g. the latent variable, conditional on past and future values of it and also conditional on the macroeconomic data. The Smoother requires initial values that are obtained from the binary data for the latent variable and from OLS

estimates for the coefficients given the binary data. Based on the first two moments a latent variable for each period is drawn from the truncated Normal. For the pre-sample draws of the latent variable that constitutes the first ρ periods, Dueker (2005) proposes an Accept-Reject Metropolis-Hastings (AR-MH) algorithm. We, however, start the Kalman Smoother in period $\rho - 1$, e.g. one period before the working start of the data and generate conditional draws from a small multivariate Normal.

Thirdly, in each iteration we estimate the VAR in equation (3) given the sampled time series of the latent variable and obtain OLS estimates for Φ and Σ denoted by $\hat{\Phi}$ and $\hat{\Sigma}$. Based on this information and the assumed Jeffrey's prior a draw for Σ is made from the inverted Wishart distribution with $T - k$ degrees of freedom where T is the number of observations, k the number of explanatory variables and $(T\hat{\Sigma})^{-1}$ describes the covariance from OLS

$$\Sigma \sim \mathcal{IW}\left\{(T\hat{\Sigma})^{-1}, T - k\right\}. \tag{6}$$

Equation (1) shows that the variance of the latent variable is 1. We take this into account by equally adjusting the appropriate element in Σ and by normalizing the other elements in the corresponding column.

Given Σ we obtain a draw for Φ by adding the mean from the OLS estimates to a draw from a multivariate Normal distribution with a covariance matrix that is denoted by the Kronecker product of the draw for Σ and $(Y'Y)^{-1}$

$$\Phi \sim \mathcal{N}\left\{\hat{\Phi}, \Sigma \otimes (Y'Y)^{-1}\right\}. \tag{7}$$

In each estimation the Gibbs Sampler was run for a total of 2,000 iterations with 1,000 initial iterations that were discarded to not only allow the sampler to converge to the posterior distribution but also to be less dependent on the initial values. Our estimates did not differ significantly using a higher number of burn-in iterations. Draws of the VAR coefficients from the OLS distribution that were not stationary and thus implied a unit root were rejected and resampled. From the resulting sample of 1,000 iterations, we calculate the mean of the latent variable, the VAR coefficients and the variance.

The Qual VAR as a forecasting model has been applied by Bordo et al. (2007), Amstad et al. (2008) and Assenmacher-Wesche and Dueker (2010). Dueker (2005) discusses the response of the economy to Romer-dates, i.e. binary information on policy tightening derived from FOMC transcripts. We provide the first application to unconventional monetary policy.

4 Data

We estimate the Qual VAR on monthly U.S. data over a sample period from 2007:08 to 2013:03. Since the Fed announced the first round of QE in late 2008, the sample from the start of QE1 to the end of QE3 is inevitably fairly short. At the same time, however, estimating a VAR system requires sufficient degrees of freedom. We address this concern by starting the sample roughly a year before the Lehman collapse. Although at that time adjusting the Federal Funds rate as the Fed's main policy instrument was still feasible, we include this period to extent our sample. Since the rationale for the drastic interest rate cuts in 2007-2008 was maintaining financial stability, these interest steps in some sense already reflected a non-standard monetary policy easing. Therefore, we consider including these observations and thereby improving the efficiency of the estimation is justified. Gambacorta et al. (2013) also start their panel VAR in 2008:01, i.e. before the inception of unconventional policy measures.

We feed the Qual VAR with a set of four endogenous variables. We restrict ourselves to just four variables in light of the short sample period. That also forces us to use data which is available on a monthly frequency. As a robustness check, however, we will report the results from various alternative combinations of these variables below. Furthermore, we estimate the model in first differences instead of (frequently used) log levels for two reasons. First, the variables have to be stationary in order to be consistent with the assumptions in the MCMC estimations. Second, growth rates appear to be more consistent with the idea of the latent variable reflecting the propensity to easing - that is, with the accumulated latent series indicating the stance of unconventional monetary policy.

In a standard VAR, information criteria are used to determine the appropriate lag lengths. Since these criteria are defined for non-binary data only, they are not meaningful in our case. Therefore, we include three lags in our Qual VAR system. This number is chosen with an eye on the short sample that we have available. A multivariate Q test is unable to reject the absence of serial correlation in the residuals of each estimated model.

The first variable to include is a binary index of QE announcements. This index is equal to one in months with an important QE announcement and zero otherwise. To construct this index, we use the dates given in table (1). These include all important announcements of QE1, QE2, QE3 and the Maturity Extension Program, either being speeches of Chairman Bernanke, minutes released from FOMC meetings or FOMC announcements. This binary variable together with the remaining

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variables in the X_t vector are used to derive the latent propensity for Quantitative Easing, y_t^*. As can be seen from table (1), our list of policy actions included announcements of LSAP and the Maturity Extension Program. We do not include the Forward Guidance announcements, which often but not always coincide with LSAP announcements. The robustness section also presents results for a larger set of policy actions.

Besides the binary QE indicator we include three U.S. macro variables that are among the variables that are either closely watched by policymakers or explicitly targeted by unconventional measures. The first variable is a measure of real economic activity. We choose the year-on-year growth rate of the index of industrial production (ΔIP). In alternative specifications, we replace this variable with the growth rate of non-farm payroll employment (ΔEMPL) or real GDP (ΔGDP). The latter is derived from interpolating quarterly GDP growth rates to monthly frequency. Both variables are taken from FRED at the Federal Reserve Bank of St. Louis. The second variable is the nominal 10-year Treasury constant maturity rate (Yield). As an alternative, we will use the yield on Treasury Inflation Index Securities (TIPS) or the long-term real interest rate (RIR), which is measured as the 10-year Treasury constant maturity rate minus the median 10-year inflation expectations taken from the Survey of Professional Forecasters, accessed through the website of the Federal Reserve Bank of Philadelphia. All financial variables measure the last observation in a given month. We do not incorporate the inflation rate since the implementation of unconventional policies was not guided by concerns about inflation considerations. In the robustness section below, however, we also report results for a specification that includes inflation.

Finally, we include a variable reflecting the financial markets' impact of QE. We choose either the year-on-year growth rate of the CBOE Volatility Index of implied stock market volatility (ΔVIX) or the rate of change of the S&P 500 U.S. stock market index (ΔSTOCKP), again both taken from FRED. The former is often interpreted as a measure of financial market uncertainty. The latter captures the likely impact of QE on asset markets.

To summarize our different models, the vector of variables for our baseline Qual VAR is $Y_t = (X_t, y_t^*)'$ where the following variables are included:

model I:	$X_t' = (\Delta IP, Yield, \Delta STOCKP)$
model II:	$X_t' = (\Delta IP, TIPS, \Delta STOCKP)$
model III:	$X_t' = (\Delta IP, TIPS, \Delta VIX)$
model IV:	$X_t' = (\Delta IP, RIR, \Delta STOCKP)$
model V:	$X_t' = (\Delta GDP, Yield, \Delta STOCKP)$
model VI:	$X_t' = (\Delta EMPL, Yield, \Delta STOCKP)$

Since the adoption of QE was guided by the Federal Reserve's desire to improve firms' long-term refinancing costs and, as a result of that, foster the economic recovery, we expect our measure of real activity to increase after a QE shock. The long-term interest rate should fall after a shock while the VIX should also fall.

The Qual Var methodology shown in section 3 allows to apply standard VAR tools such as impulse response functions and historical decompositions. For this purpose the QE shock has to be identified. Over the past 30 years a huge literature discusses the appropriate scheme to identify monetary policy shocks. Here, we follow Christiano et al. (1999) and adopt the most standard approach. We use a Cholesky decomposition based on the following ordering of variables for model I: ΔIP, y_t^*, Yield, $\Delta STOCKP$. The other models are identified analogously. This implies that within a month unconventional monetary policy affects the real interest rate and the $\Delta STOCKP$ but not industrial production. Likewise, monetary policy is allowed to respond to industrial production within a given month.

5 Results

The results of the Qual VAR estimation are presented in three steps. We first discuss the estimated latent variable behind the observable QE announcements. This variable is interpreted as the Fed's propensity to QE. Then we present the estimated impulse response functions. Finally, a historical decomposition of the VAR model is used to illustrate the explanatory power of QE shocks over time.

5.1 The Fed's propensity to QE

Figures (1) to (6) show the estimated latent propensity to QE for each of the five models. As a matter of fact, this series is required to be positive at each of the announcement dates which in the graphs are depicted as shaded areas. The model clearly uncovers mounting pressure before each announcement date which is reflected in sharp increases in the latent QE propensity. Furthermore, the intensity of the

propensity for QE differs between announcement days. While the series reach their maximum level in late 2008 at the initialization of QE1, the subsequent QE episodes result from a somewhat weaker propensity. Finally, the series of QE propensities are very similar across estimated models, which also underlines the robustness of these findings.

The latent propensity to QE can also be interpreted as the change in the Fed's policy unobservable stance. Hence, the stance can be derived by cumulating the latent propensity over time. One way to assess the quality of the Qual VAR in describing the Fed's policy is to compare this indicator of the policy stance with the shadow Federal Funds rate estimated by Wu and Xia (2014). Figure (7) plots the policy stance derived from the Qual VAR against their estimate of the shadow rate since November 2008.[4] The shadow rate is of course persistently negative since mid 2009. It can be seen that the latent stance tracks the evolution of monetary conditions reflected in the shadow rate quite well. In particular, both lines are roughly parallel suggesting that the overall amount of monetary stimulus between 2008 and 2012 is very similar across these different estimation approaches. We interpret this as a further confirmation of our model's strength to replicate unconventional policies.

5.2   The response to QE shocks

Once the latent variable is uncovered through MCMC estimation, the VAR coefficients are available and standard impulse response functions can be derived based on the Cholesky identification discussed before. Figures (8) to (13) show the dynamic responses of all endogenous variables to a QE shock, that is, an unexpected increase in the propensity to QE by one standard deviation. It is important to note that this perspective is most likely underestimating the policy impact on the announcement days. The reason for this is that on a specific date with a QE announcement the standard deviation of the latent propensity is much larger than the full sample standard deviation. All impulse responses are shown together with 90% bootstrapped confidence bands reflecting the estimation uncertainty of the VAR coefficient matrix.

In all models, an unconventional easing of monetary conditions raises the growth rate of industrial production, GDP or private nonfarm payroll employment, respectively. A year after the policy impulse industrial production grows by 0.6 percentage points. The response of GDP growth, however, is smaller, about 0.15 percentage points, occurs a bit later and lacks statistical significance, see figure (12). The response of employment growth is of similar magnitude and highly significant(13). Within three

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[4]The shadow rate is downloadable at http://faculty.chicagobooth.edu/jing.wu/.

month after the QE shock, long-term interest rates, both nominal and real, have fallen by about 0.075 to 0.125 percentage points. This response is highly significant. The similarity in the response patterns of the nominal bond yield and the measure of the real interest rate in models I and V suggests that long-term inflation expectations as reflected in the SPF's mean 10-year inflation projection do not appear sensitive to QE. Taken together, QE shocks do indeed have the intended consequences of stimulating the real economy and reducing firms' long-term refinancing conditions.

As expected, the change in stock prices included in models I, II, IV and V responds positively to an unconventional easing of monetary conditions and peaks after five months. A shock to QE raises nominal stock returns by two to three percentage points. Bernanke and Kuttner (2005) find that a typical cut in the Federal Funds rate of 25 basis points leads to an increase of stock prices of 1%. In light of their findings, our results suggest that a QE shock is equivalent to 50 basis point cut in the Federal Funds rate.

Model III, see figure (10), also depicts the response of the change in the index of implied stock market volatility. This frequently used measure of financial instability falls by 10 percentage points within three months after the easing announcement. Thus, QE not only pushed the real economy but also calmed financial markets.

5.3 The explanatory power of QE shocks

Based on the VAR estimates, the model could be used to back out two scenarios for the evolution of the endogenous variables. In the first scenario, the QE shock is present and, together with the other shocks, drives the economy. In a counterfactual, the QE shock is switched off. The difference between both outcomes thus illustrates the impact of QE shocks over time. Figures (16) to (21) plot the QE impact (in green) together with the realization of each observable variable (in red). These historical decompositions show that QE was indeed supportive to industrial production - again with a time lag of roughly one year - in each of the QE programs. Following QE2, the effect was strongest with the entire growth in industrial production being due to QE shocks.

In all model specifications, QE shocks also account for a sizable portion of the nominal and real interest rate, respectively. During 2010 about half a percentage point is taken off the interest rate through QE shocks. Again, QE2 and QE3 seems to be more effective in this respect than QE1. QE shocks also explain a large part of equity returns, see figures (16), (17), (19), (20) and (21). Between 10 to 20 percentage points of the increase in stock prices is accounted for by QE shocks. In 2011,

almost the entire stock market development is driven by QE shocks. Throughout the sample period QE shocks contributed to a lower VIX index. In particular, in 2010 the VIX index falls by 25%, which is almost fully explained by QE shocks.

To summarize the explanatory power of QE shocks in a single number, we decompose the forecast error variance for each variable into the fraction explained by QE shocks and the remaining driving forces, respectively. The results for model I are presented in the right column of table (2). Over a horizon of 12 to 24 months, unconventional policy shocks explain between 4.6% and 6% of variation in financial variables and between 4% and 5.5% of industrial production. Below we will compare this with the role of conventional policy shocks.

6   A comparison with conventional monetary policy

In this section we assess how unconventional the effect of unconventional monetary policy is, that is, we compare unconventional with conventional monetary policy. Before 2008, the Fed's main policy instrument was the Federal Funds rate. As a consequence, we estimate our model specification I for the period 1998:1 to 2006:12 and replace the latent propensity to QE with the Federal Funds rate. All other model properties remain unchanged to facilitate a comparison of the results. In particular, the ordering of the variables is left untouched. We also leave the lag order unchanged and we do not include the inflation rate. The latter point is likely to result in an inappropriate representation of monetary policy before the crisis. Nevertheless, we leave out inflation in order to stay as close as possible to our model for QE.

The resulting impulse response functions describing the variables' adjustment after an unexpected policy easing are presented in figure (22). Most obviously, an expected policy easing results in a persistent fall in the Federal Funds rate. It can also be seen that industrial production increases reaching the peak response of 0.3% one year after the shock. Stock prices jump immediately by about 1.5 percentage points. This response, however, is likely to be misleading as in this model we neglect the inflation response. With an increase in inflation after a policy easing the real stock price movement will be more moderate. The long-term interest rate one year after the shock has fallen by 0.05 percentage points.

Comparing (22) and (8) shows that in terms of the response of industrial production an unconventional policy shock is equivalent to a cut in the Federal Funds rate of

about 50 basis points. These effects of QE are higher than those found e.g. in Rosa (2012). In another comparison, we normalize the responses by the response in bond yields. In the Qual VAR an easing shock was consistent with a reduction of long rates of about 0.075 percentage points, which is roughly 1.5 times the response of the long rate after a one standard deviation fall in the Federal Funds rate. When considering the real impact of policy, we therefore see that QE has a mildly stronger effect impact than conventional policy. A policy impulse that is equivalent in terms of the impact on bond yields would thus lead to a 0.6% increase in industrial production when policy is implemented through QE and to only a 0.45% increase if policy is implemented in the conventional way. Note that here we compare the peak responses only.

The notion that QE is more important in driving the economy than conventional monetary policy is supported by the forecast error variance decomposition of the conventional policy VAR, see the left column of table (2). For horizon of 12 and 24 months, respectively, the explanatory power of Federal Funds rate shocks is much smaller than the explanatory power of QE shocks estimated by the Qual VAR.

The comparison of unconventional and conventional policies are in line with the literature, see for example Rosa (2012), but should be taken as illustrative only. The sample used to estimate conventional policies is covering the Great Moderation episode, for which not only monetary policy was conducted conventionally, but also all other shocks haven been subdued. Put differently, the crisis period since 2008 is characterized not only by unconventional monetary policy, but at the same time also by a the Great Recession, a large fiscal stimulus package and serious concerns about financial stability.

7 Robustness

In this section we provide two alternative specifications of the model.

Including inflation

The Qual VAR presented before does not include a measure of inflation. In order to assess whether by excluding inflation we omit important information, we augment model I with core PCE inflation. We order inflation second, i.e. after real activity but before the latent variable. This is consistent with most studies on conventional monetary policy. The results are presented in figure (14). Inflation increases after a surprise easing, but this response lacks statistical significance. All other responses remain broadly unchanged.

A larger set of binary QE dates

As mentioned before, our set of binary policy dummies does not include announcements related to keeping the Federal Funds rate low, that is Forward Guidance announcements. To assess the robustness of our findings with regard of the choice of the policy announcements, we also estimate model I with the binary indicator equal to one at each of the policy events listed by Hattori et al. (2013). While most of the announcements coincide with the news included in our baseline estimation, the set includes several Forward Guidance announcements. As figure (15) shows, however, both the qualitative and the quantitative properties of the estimated impulse response functions remain unaffected.[5]

8 Conclusions

In this paper we proposed a new approach to estimate the impact of unconventional monetary policy. The aim was to provide a framework that is as close as possible to the standard VAR framework we typically use to study conventional monetary policy and at the same time able to process information on unconventional easing episodes. Our model is based on the idea of linking standard business cycle dynamics reflected in a VAR system with binary information on QE announcement days. The resulting Qual VAR is able to extract the latent propensity to unconventional policy easing. The new model proposed here has several advantages over other approaches to estimating QE. In particular, its close similarity with standard VAR models makes it an easy tool for policy analysis.

We find that a QE has significant effects on interest rates, real economic activity, stock prices and market uncertainty. We also showed that QE shocks account for a large fraction of the dynamics in stock prices and interest rates since 2008. QE is found to be even more effective in influencing real activity than conventional monetary policy. Our results thus provide empirical support for the effectiveness of unconventional policy tools. The model is unable, however, to decompose different transmission channels or to distinguish between LSAP and other tools such as a maturity transformation within the Fed's bond portfolio.

In our model we considered announcements to introduce or extend QE only. We did not, however, include announcements of exiting from QE or "tapering" unconventional measures, respectively, which emerge at the time of writing. Given the recent

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[5]The estimated latent variable for this specification as well as the list of policy announcements are available on request.

market sensitivity to tapering news, applying the model to tapering events might be an interesting way forward.

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Table 1: Important Quantitative Easing announcements

Date	Program	Event	Content
11/25/2008	QE1	FOMC statement	LSAP initially announced
12/01/2008	QE1	Bernanke speech	Suggestion of extending QE to Treasuries
01/28/2009	QE1	FOMC statement	Fed stands ready to expand QE
03/18/2009	QE1	FOMC statement	LSAP expanded
08/12/2009	QE1	FOMC statement	details about LSAP
08/27/2010	QE2	Bernanke speech	Bernanke sees role for additional QE
09/21/2010	QE2	FOMC statement	FOMC emphasizes low inflation
10/12/2010	QE2	FOMC minutes	"additional accommodation" needed
11/03/2010	QE2	FOMC statement	QE2 announced
09/21/2011	"Twist"	FOMC statement	Maturity Extension Program announced
06/20/2012	"Twist"	FOMC statement	Maturity Extension Program extended
08/22/2012	QE3	FOMC minutes	"additional accommodation ... warranted"
09/13/2012	QE3	FOMC statement	QE3 announced
12/12/2012	QE3	FOMC statement	QE3 expanded

Notes: The announcement dates are taken from Fawley and Neely (2013).

Table 2: Forecast error variance decomposition

variable	impact of policy shock (in % of total variation)					
	conventional policy			unconventional policy		
	at horizon			at horizon		
	1 month	12 months	24 months	1 month	12 months	24 months
ΔIP	0.00	1.16	3.22	0.00	4.06	5.49
Yield	0.23	1.76	1.34	2.01	4.61	6.13
$\Delta STOCKP$	6.45	1.48	1.43	1.29	6.31	5.92
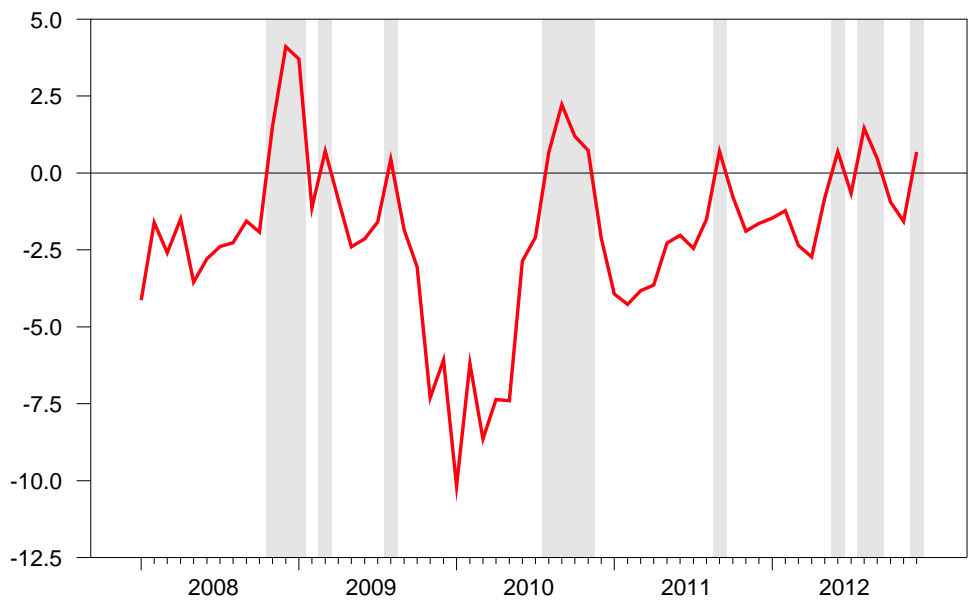
Figure 1: QE announcements (shaded) and latent propensity for QE (red) estimated in model I
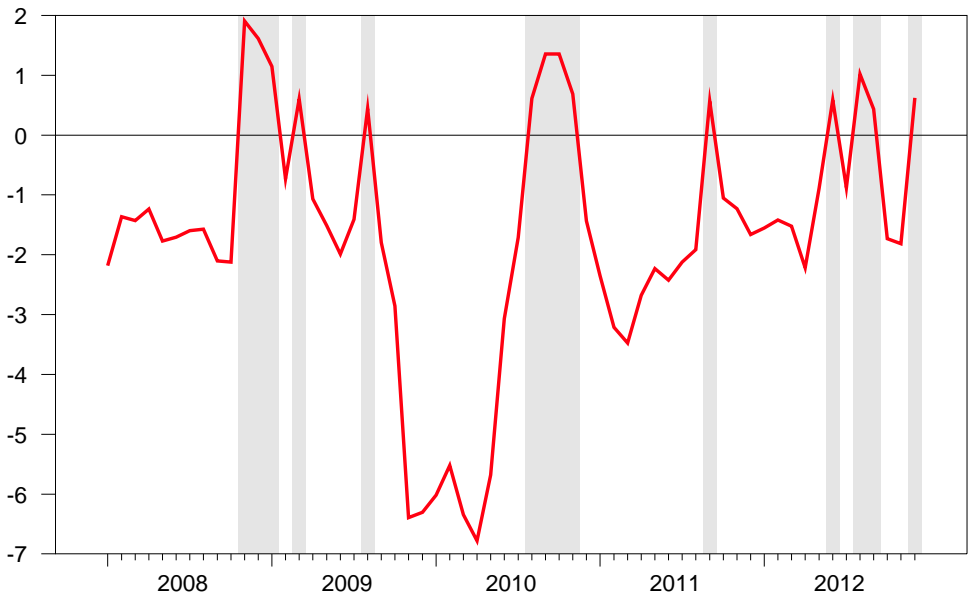
Figure 2: QE announcements (shaded) and latent propensity for QE (red) estimated in model II
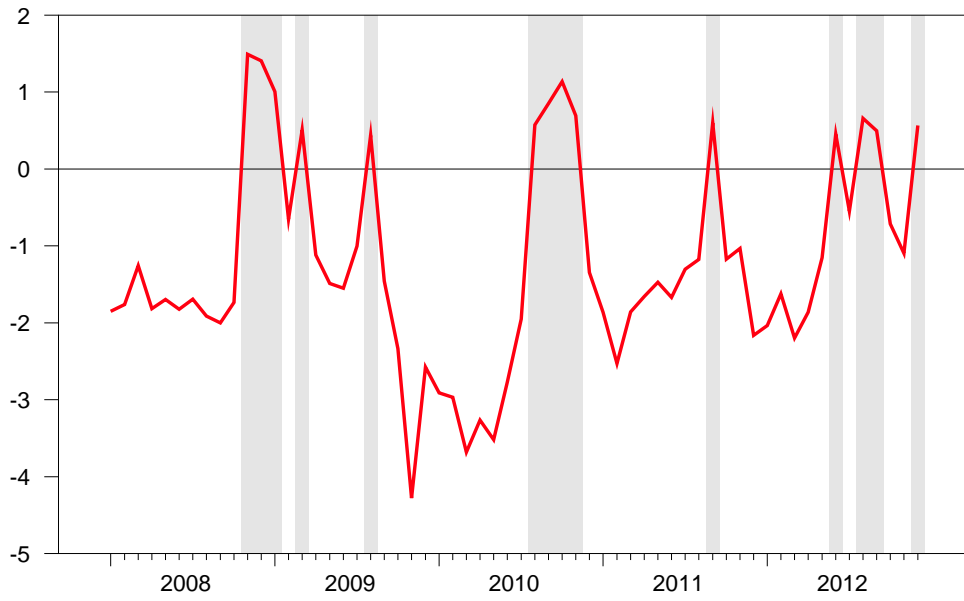
Figure 3: QE announcements (shaded) and latent propensity for QE (red) estimated in model III
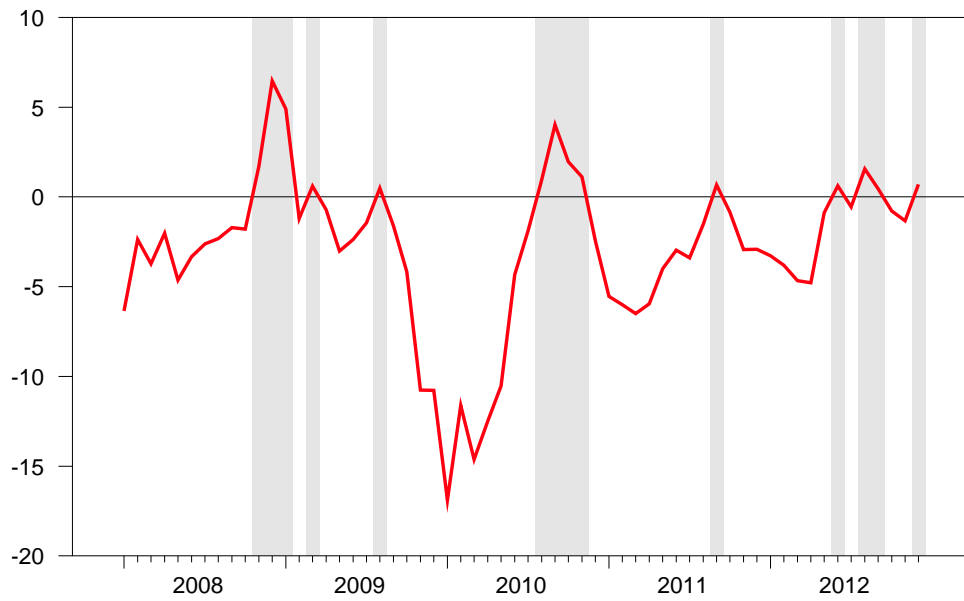
Figure 4: QE announcements (shaded) and latent propensity for QE (red) estimated in model IV

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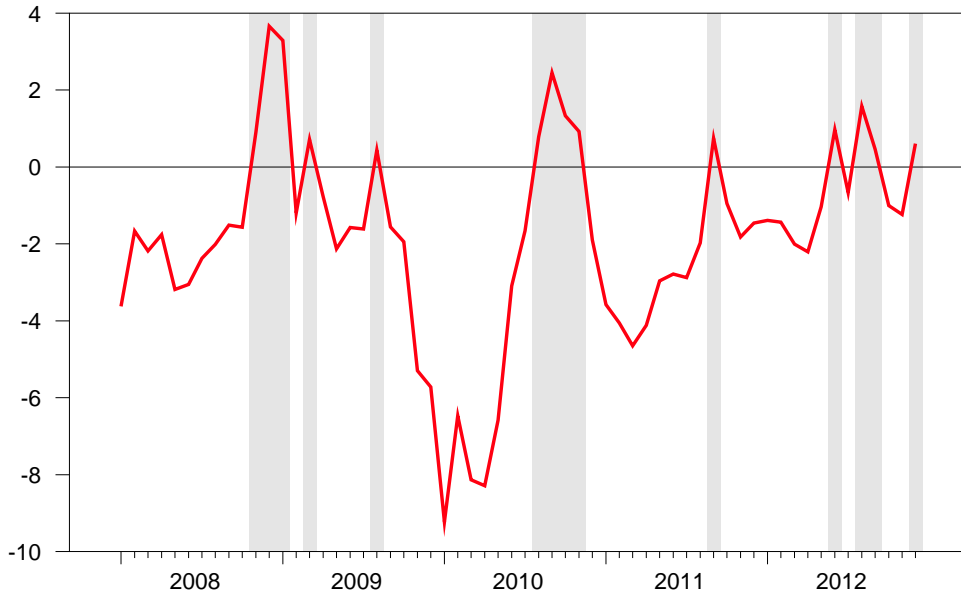
Figure 5: QE announcements (shaded) and latent propensity for QE (red) estimated in model V
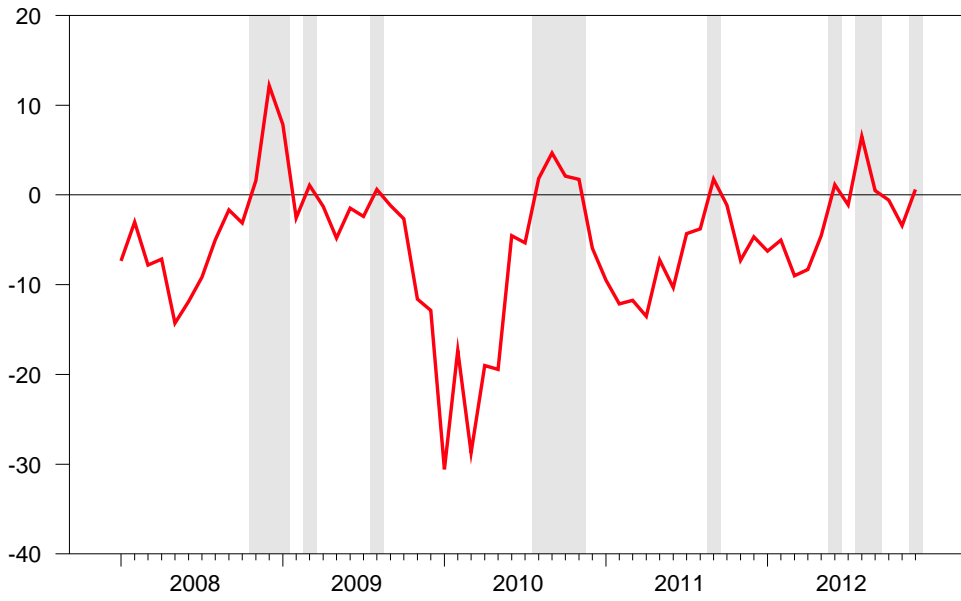
Figure 6: QE announcements (shaded) and latent propensity for QE (red) estimated in model VI

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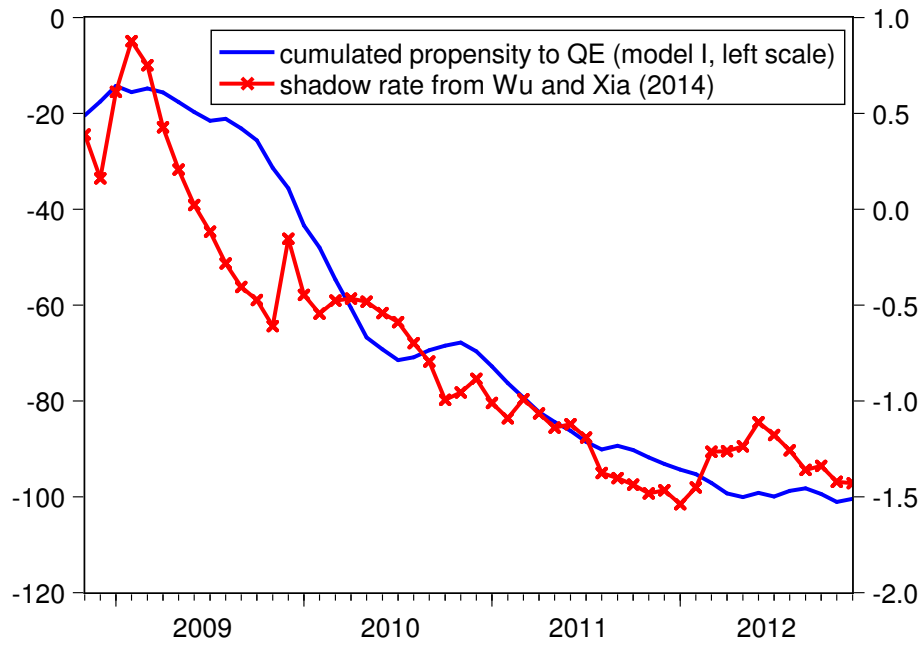
Figure 7: Cumulated latent propensity to QE and shadow rate from Wu and Xia (2014)
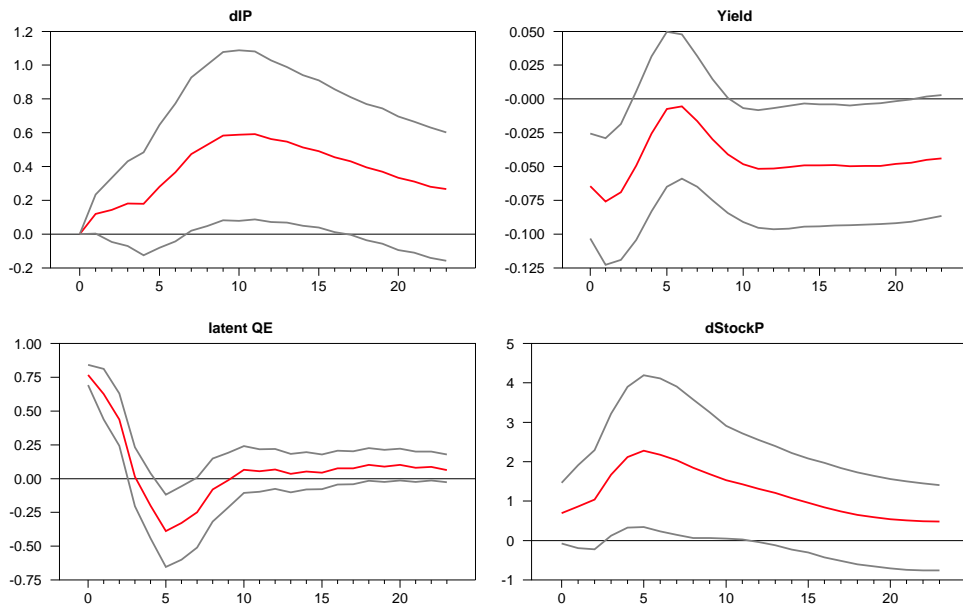
Figure 8: The effect of a shock to the latent propensity to QE in model I
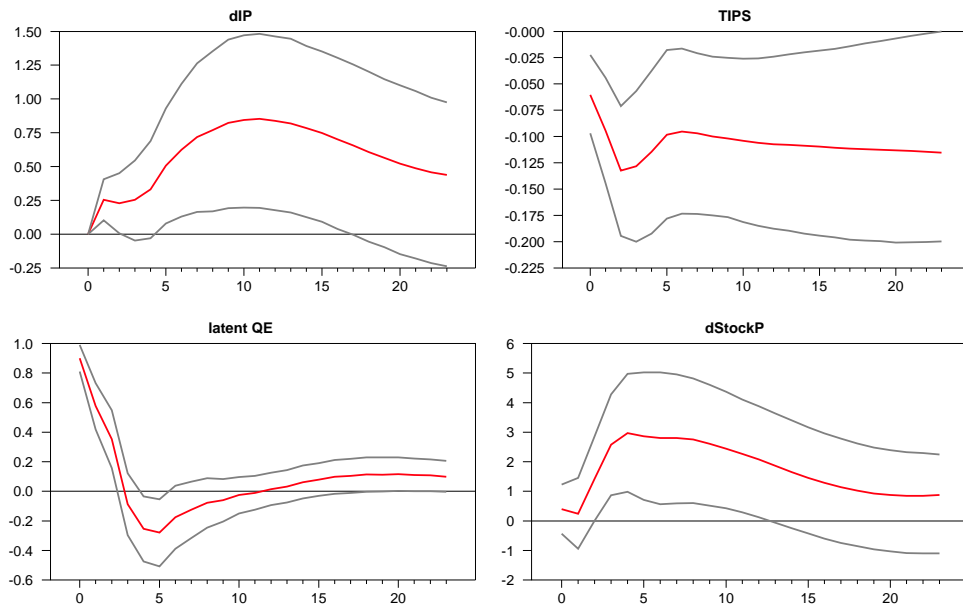
Figure 9: The effect of a shock to the latent propensity to QE in model II
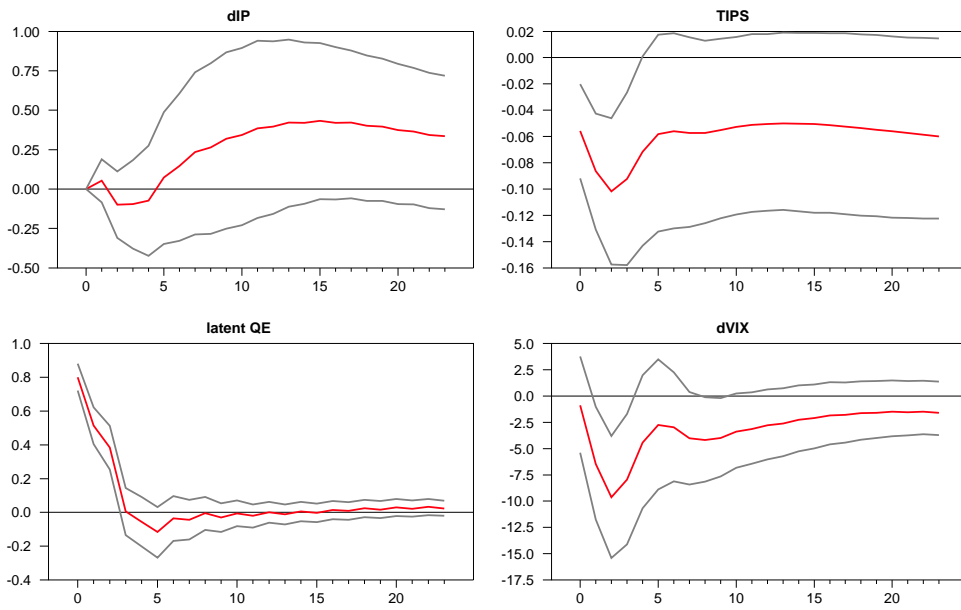
Figure 10: The effect of a shock to the latent propensity to QE in model III
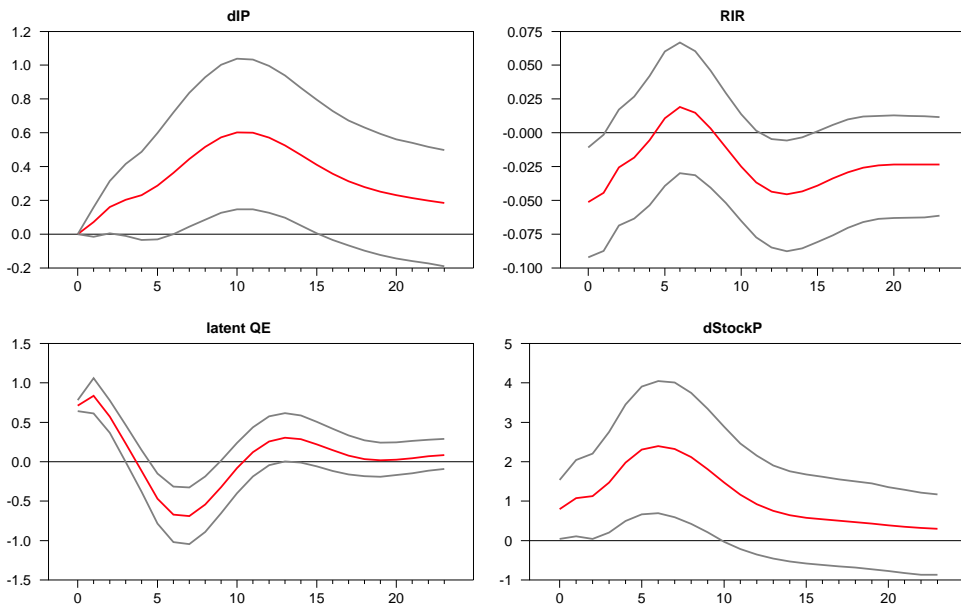
Figure 11: The effect of a shock to the latent propensity to QE in model IV
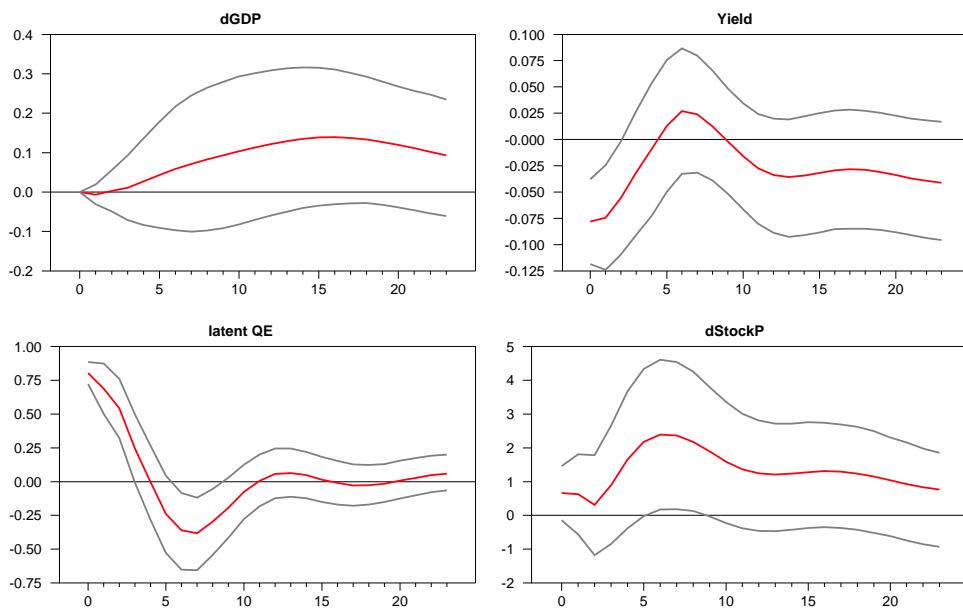
Figure 12: The effect of a shock to the latent propensity to QE in model V
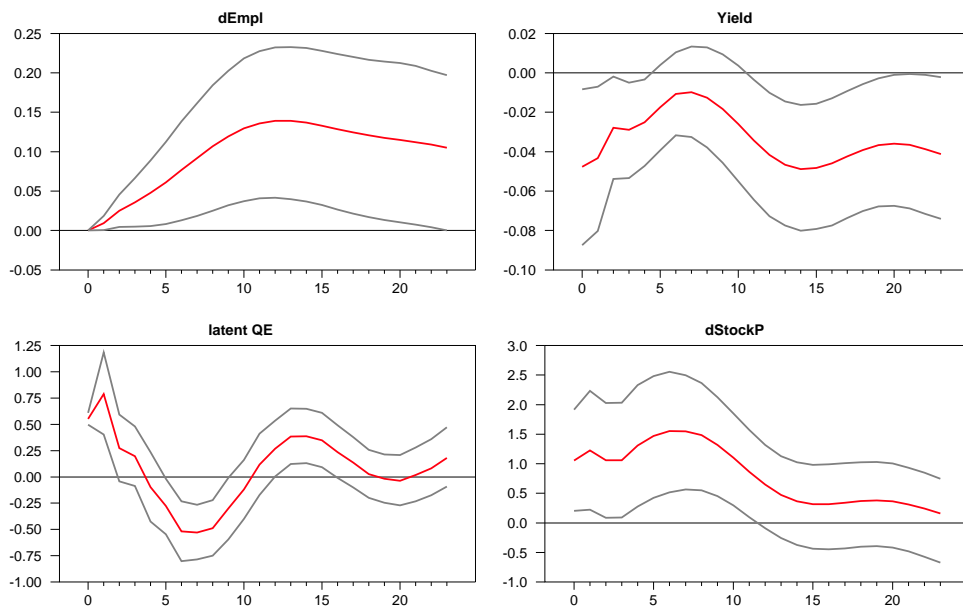
Figure 13: The effect of a shock to the latent propensity to QE in model VI
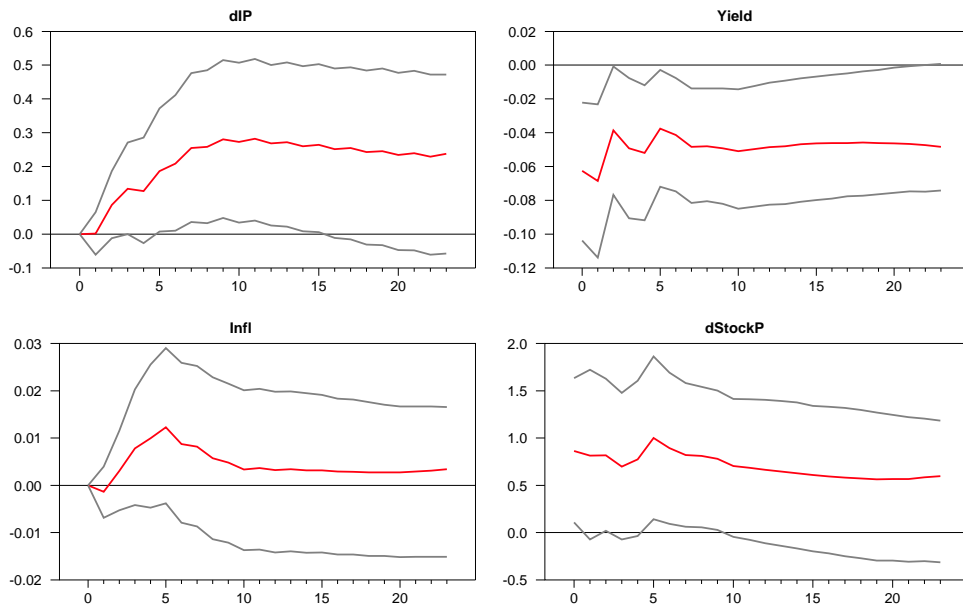
Figure 14: The effect of a shock to the latent propensity to QE in model I augmented by core PCE inflation
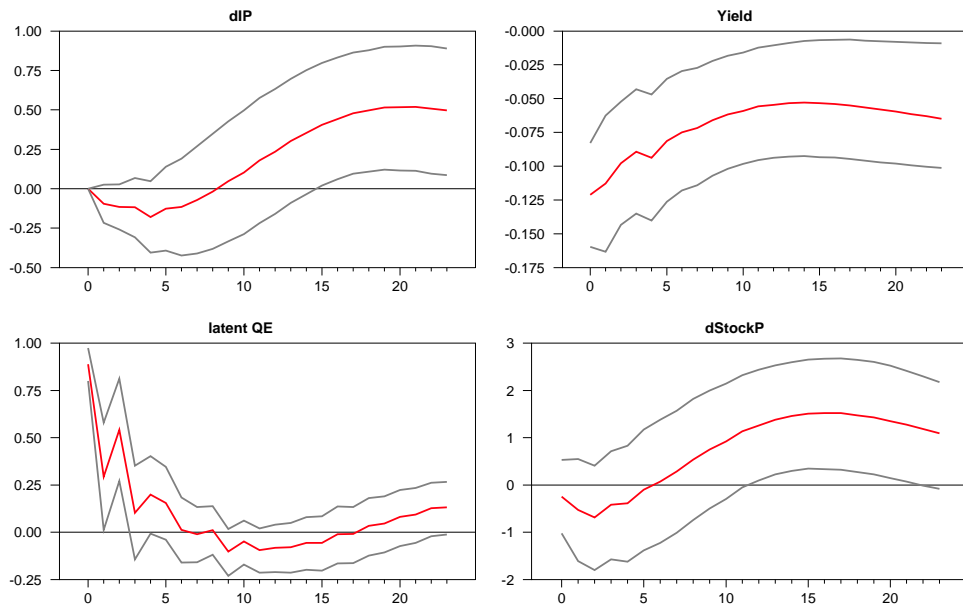
Figure 15: The effect of a shock to the latent propensity to QE in model I based on an extended set of policy actions

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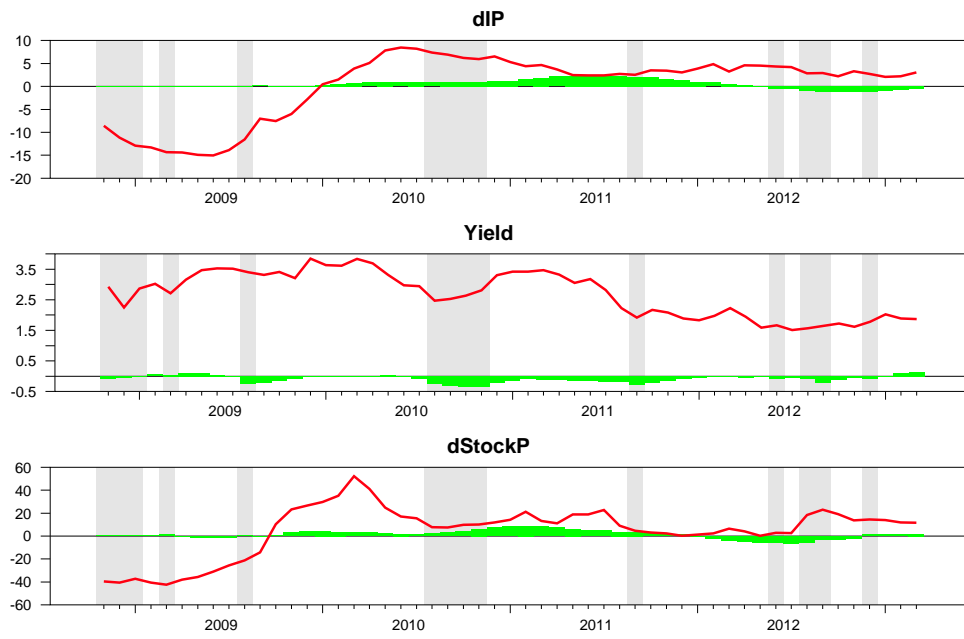
Figure 16: Non-policy variables (red) and fraction explained by QE shocks (green) in model I
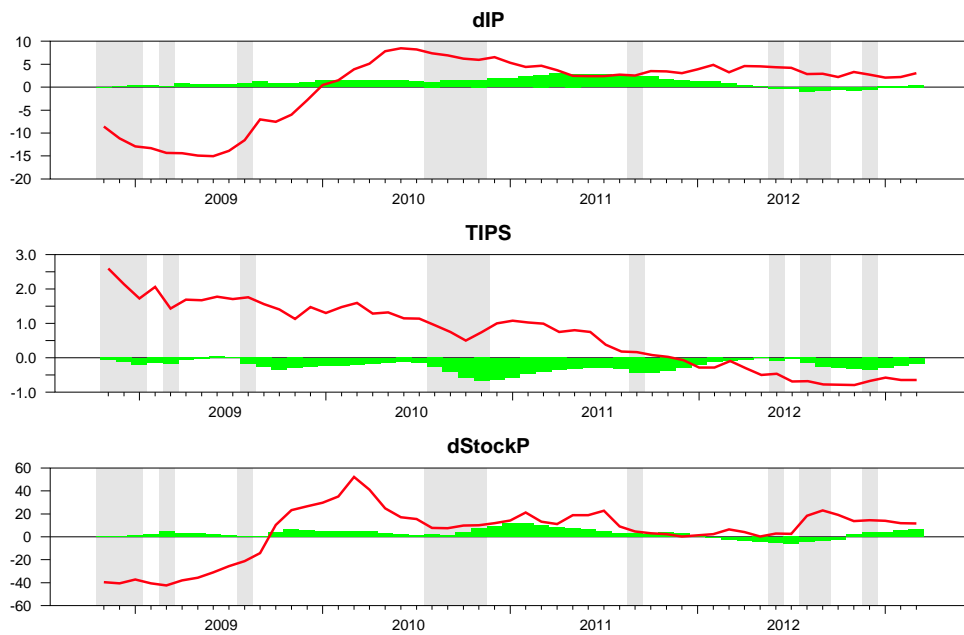
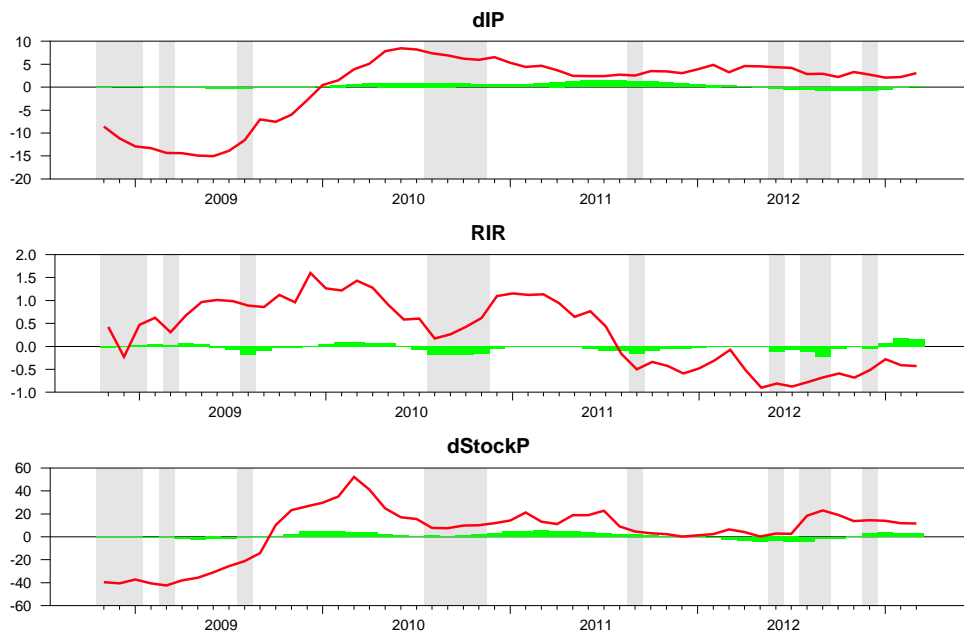Figure 17: Non-policy variables (red) and fraction explained by QE shocks (green) in model II

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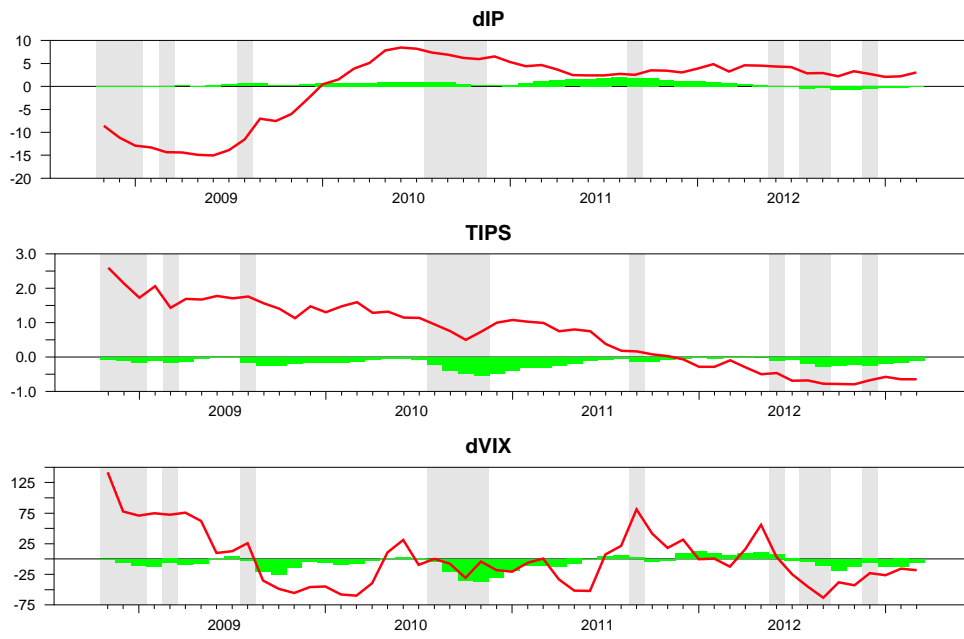
Figure 18: Non-policy variables (red) and fraction explained by QE shocks (green) in model III

Figure 19: Non-policy variables (red) and fraction explained by QE shocks (green) in model IV
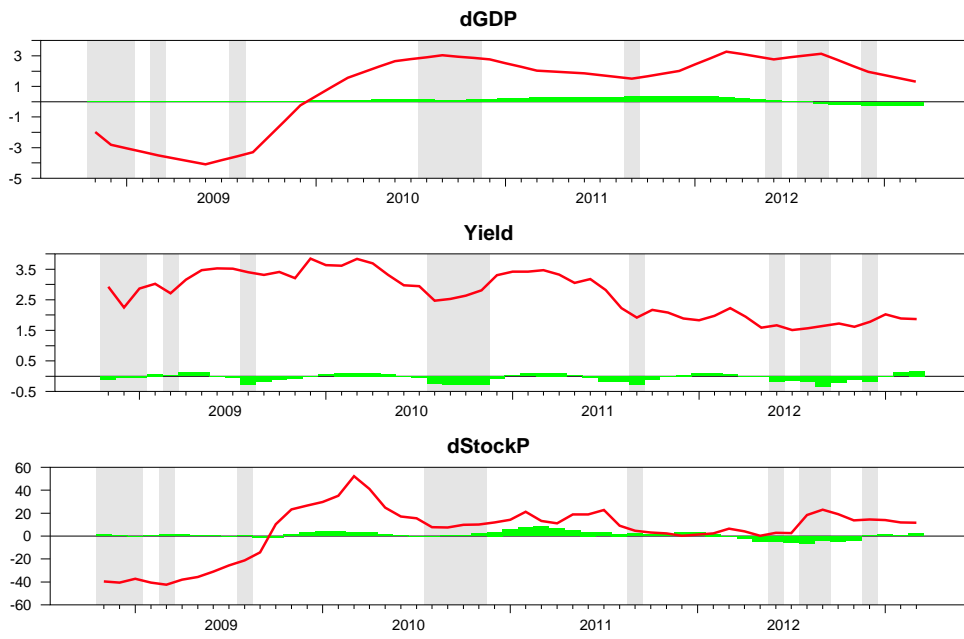
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Figure 20: Non-policy variables (red) and fraction explained by QE shocks (green) in model V

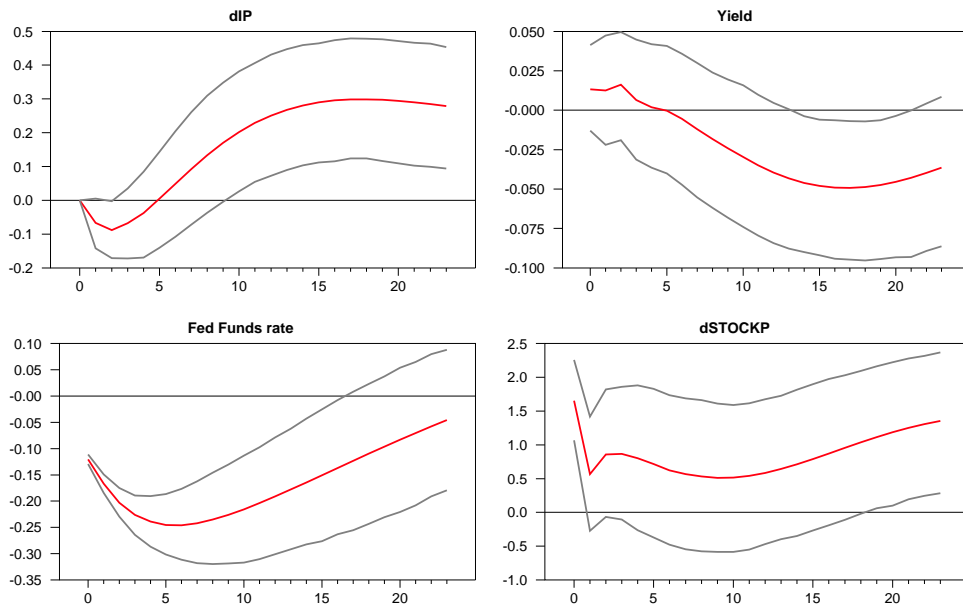Figure 21: Non-policy variables (red) and fraction explained by QE shocks (green) in model VI

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Figure 22: The effect of a conventional policy shock