Bank i Kredyt 49(3), 2018, 191-216

BANK I KREDYT
BANK & CREDIT

How far does monetary policy reach? Evidence from factor-augmented vector autoregressions for Poland

Mariusz Kapuściński*

Submitted: 14 December 2017. Accepted: 4 April 2018 r.

Abstract

This study applies factor-augmented vector autoregressions to identify the effects of monetary policy shocks in a small, open, emerging market economy. It uses data on 132 variables for Poland, 'compressing' them to either structural (having an economic interpretation) or economically uninterpretable factors, also known as diffusion indices. The tightening of monetary policy is found to have broad, contractionary effects. Among other things, production, employment, job offers, prices, loans and stock prices decrease, unemployment and non-performing loans increase. As one of extensions, the effects of changes in global and foreign factors are investigated. Domestic prices are found to respond to global prices of commodities and foreign prices. Domestic production and interest rates – to their foreign counterparts.

Keywords: factor analysis, vector autoregressions, factor-augmented vector autoregressions, high--frequency identification, monetary transmission mechanism

JEL: C38, C32, E43, E52

* Warsaw School of Economics; e-mail: mk54483@doktorant.sgh.waw.pl.

1 Introduction

In the basic new Keynesian model, as in Galí (2015), a central bank usually sets an interest rate according to a Taylor-type rule. The interest rate is changed when inflation deviates from the inflation target or/and when output deviates from potential output. In reality, central bankers make monetary policy decisions in a data-rich environment. They monitor a large number of variables. Indeed, results from a seminal study by Bernanke and Boivin (2003) for the Federal Reserve indicate that members of the Federal Open Market Committee consider more than inflation and output when they set a target for the federal funds rate. This should be taken into account in order to correctly identify an exogenous component of changes in interest rates (shocks/innovations) when investigating the effects of monetary policy.

In order to address this problem, the present study applies factor-augmented vector autoregressions (FAVARs) to identify the effects of monetary policy shocks in Poland, a small, open, emerging market economy. This framework makes it possible to implicitly use a large number of variables in one model, combining factor analysis with vector autoregressions (VARs). 132 variables are 'compressed' into structural factors (having an economic interpretation), as in Belviso and Milani (2006), or into economically uninterpretable factors, as in Bernanke, Boivin and Eliasz (2005). Factors are also known as diffusion indices (Stock, Watson 2002). Structural factors are obtained by extracting principal components from groups of variables related to economic concepts (real activity, inflation, credit, money, interest rates, financial market, expectations), economically uninterpretable factors – from all variables collected together. The study is the first to research into the monetary transmission mechanism in Poland using fully fledged FAVARs and, according to the author's knowledge, the first to compare results from FAVARs with structural versus economically uninterpretable factors. More generally, the study is one of few analysing the effects of monetary policy shocks in an emerging market economy using FAVARs (exceptions include Gupta, Jurgilas, Kabundi 2010; Rosoiu 2015a, 2015b). These are its main contributions.

Not only do FAVARs facilitate better identification of monetary policy shocks, but they also have other advantages over standard VARs which, in order to preserve the degrees of freedom, usually contain explicitly only a few variables. First, a given concept can be proxied by many variables. It is usually not entirely clear which variable exactly should be used as a measure of, for example, output or inflation. By applying factor analysis to many proxies one can get rid of measurement error. Second, impulse response functions can be calculated for all variables affected by factors. In principle, a researcher can avoid estimating many models with slightly different sets of variables (for example, replacing industrial production with its components) and risking the omitted variable bias.

Besides estimating both models with structural factors and economically uninterpretable factors, the study also carries out a thorough sensitivity analysis and makes extensions. As far as sensitivity analysis is concerned, different numbers of lags, measures of monetary policy and kinds of identification are checked. For extensions, the marginal contribution of domestic factors to standard VARs is analysed (as in Bernanke, Boivin, Eliasz 2005) and the effects of changes in global and foreign factors are investigated (as in Liu, Mumtaz, Theophilopoulou 2014).

Results indicate that the tightening of monetary policy has broad, contractionary effects. Production, employment, job offers, prices, loans and stock prices decrease, unemployment and non-performing loans increase. However, the exchange rate does not appear to immediately appreciate, as it should according to economic theory (precisely, according to economic models consistent with uncovered interest parity, UIP, see, for example, Dornbusch 1976). If anything, it depreciates. Some explanation for this result, supported by factor analysis, is that the economic contraction raises the risk premium, which compensates for higher interest on deposits. But that finding varies among studies using VARs, calling for a different strategy to identify the causal effect.

The results are robust with respect to different measures of monetary policy and identification schemes. On the other hand, 6 lags in a VAR – half of the baseline number, but at the same time a number larger than suggested by information criteria – are insufficient to adequately capture dynamic relationships between variables. A standard VAR, with differences of logarithms (logs) of industrial production, the CPI (consumer price index) and the REER (real effective exchange rate), and with the money market interest rate, gives a price puzzle (a rise in prices after an increase in the interest rate), which can be removed by the inclusion of two factors. Domestic prices respond to global prices of commodities and foreign prices. Domestic production and interest rates – to their foreign counterparts.

However, applied to data for Poland, FAVARs are no panacea. Models with structural and economically uninterpretable factors give qualitatively similar results, but the former do not appear to fully capture the effects on the labour market, and estimates from the latter in the most important cases are imprecise. Using monthly data for the period between January 2001 and March 2017 in FAVARs with 12 lags, the degrees of freedom remain a tight constraint, and only 4 factors can be included in a given model. Therefore, in models with structural factors some variables need to be introduced separately by replacing other variables. In models with commodity price and foreign factors the number of lags needs to be reduced. Furthermore, the price puzzle from the standard VAR can also be removed by using high-frequency identification instead of identification by short-run, recursive restrictions.

The article is structured as follows. The second section reviews the literature. The third section describes the models. The fourth one – data and estimation. The fifth section presents the results. The last section concludes.

2 Literature review

This study contributes to the already quite extensive literature on the effects of monetary policy in Poland. However, it is the first one to analyse it within a fully fledged FAVAR framework. In the most similar study to the one carried out here, Balabanova and Brüggemann (2017) start from a standard VAR, with logs of industrial production, CPI, the EUR/PLN exchange rate and with a money market interest rate. Then, they augment it with factors estimated either from 10 variables for 11 euro area economies or from 9 variables for the Czech Republic, Hungary and Slovakia. The authors use the factors either as endogenous or as exogenous variables. In the baseline model they find a decrease in production, an appreciation of the exchange rate and no significant response of CPI after a monetary policy shock (a rise in the interest rate). However, inclusion of factors for the Czech Republic, Hungary and Slovakia as exogenous variables makes the response of CPI significant and negative.

In comparison to that study, this one extracts factors from domestic, not only foreign variables. Furthermore, here foreign factors are economically interpretable (foreign real activity factor, foreign inflation factor, foreign interest rates factor), so meaningful impulse responses to shocks to them can be, and are, calculated. They are extracted from data for all European Union (EU) economies, as well as for the United States (US), Brazil, Russia, India and China. Also, this study uses a shorter sample – in Balabanova and Brüggemann (2017) it starts in January 1995 and ends in December 2013. On the one hand, the sample in the present study is more homogenous. On the other hand, it gives a smaller number of degrees of freedom. Therefore, as mentioned above, in models with foreign factors the number of lags needs to be reduced, and they are not fully comparable with these without foreign factors. Finally, in this study variables are differenced if non-stationary, in Balabanova and Brüggemann (2017) – they are not. It again implies some trade-off – the risk of an omitted long-run relationship, mitigated by the large number of lags, versus the risk of capturing a spurious relationship.

Factors from 170 domestic variables, as well as from 198 foreign, euro area variables, are estimated and used in a FAVAR for Poland in Benkovskis et al. (2011). However, they investigate only the effects of euro area monetary policy shocks. They find that they are associated with a decrease in GDP (gross domestic product) in Poland. In comparison to this study, their factors are based on quarterly data (for the period between the second quarter of 1999 and the second quarter of 2010). They use more variables related to external trade (which is directly connected with the aim of their study) but, for example, no variables related to credit. In a more loosely related study, Bystrov (2014) augments a VAR, containing a money market interest rate and a spread on loans for house purchases, with factors extracted from 54 domestic variables. He finds a significant relationship between the money market interest rate and the spread, indicating an incomplete interest rate pass-through. Also, his results show that the spread responds to three factors: first one with high loadings on exchange rates, stock market indices and CDS (credit default swap) spreads, second one with high loadings on industrial production, employment and wages, and a third one with high loadings on interest rates (other than the one used as a measure of monetary policy). Variables used to estimate factors in Bystrov (2014) cover similar concepts as this study, but a smaller number of variables is used for each concept. He also uses monthly data, but for a shorter period (January 2004 – June 2014).

VARs for monetary policy analysis for Poland, without factors, are used in a number of studies. They differ with respect to the sets of variables, frequency and transformations of data, samples, inference (classical or Bayesian) and identification schemes. Usually they find a decrease in measures of real activity and inflation following a monetary policy shock. Findings on the response of the exchange rate are mixed. Studies conducted at Narodowy Bank Polski constitute standard references: Kapuściński et al. (2014), Kapuściński et al. (2016), Demchuk et al. (2012), Łyziak et al. (2008), Łyziak et al. (2011), and Pawłowska and Wróbel (2002). Arratibel and Michaelis (2013), and Darvas (2013) investigate how the monetary transmission mechanism in Poland has evolved over time, estimating VARs with time-varying coefficients. Postek (2011) uses non-linear VARs. Gajewski (2015) estimates more standard VARs, but focuses on regional differences in the effects of monetary policy shocks. Haug, Jędrzejowicz and Sznajderska (2013) analyse the effects of both monetary and fiscal policy.

Andrle, Garcia-Saltos and Ho (2013) focus on variance decomposition between the effects of domestic and foreign shocks, but show responses to domestic monetary policy shocks as well. A focus on another subject, showing the effects of monetary policy shocks as an aside, can also be found in Serwa and Wdowiński (2016), Górajski and Ulrichs (2016), and Bogusz, Górajski, Ulrichs (2015) within the VAR framework, in Goczek and Partyka (2016) within the VECM (Vector Error Correction Model) framework, and in Dybka et al. (2017) within both frameworks. There is also a group of articles comparing the effects of monetary policy either within groups of post-transition economies (including

Poland) or between them and developed economies. They usually use data from more distant periods. This group includes: Jarociński (2010), Gavin and Kemme (2009), Anzuini and Levy (2007), and Creel and Levasseur (2007).

Another group of articles related to this study uses factors estimated from large numbers of variables in forecasting exercises for Poland. Baranowski, Leszczyńska and Szafrański (2010) find that economically uninterpretable factors reduce forecast errors for inflation, particularly at longer horizons. Szafrański (2011) finds a decrease in forecast errors at shorter horizons when using a structural factor related to other measures of inflation, and at longer horizons – when using a factor related to real activity. Szafranek (2017a) shows an improvement in inflation forecasts compared to a large number of benchmarks by employing machine learning, with factor analysis as one of the steps in the analysis. Brzoza-Brzezina and Kotłowski (2009) use factor analysis to calculate the pure inflation rate. They find it to improve inflation forecasts and to be more responsive to monetary policy than standard measures of inflation. These results indicate that a large number of economic variables for Poland can be usefully summarised by factors extracted from them, at least for forecasting purposes. Similar findings of Stock and Watson (2002) for the US were used by Bernanke, Boivin and Eliasz (2005) as one of the arguments for studying the monetary transmission mechanism using FAVARs.

The last group of related articles investigates the role of commodity prices and foreign variables (among other factors) in explaining real activity, inflation and interest rates in Poland. Leszkiewicz--Kędzior (2015) and Socha (2014) find a strong relationship between global and domestic energy prices. Hałka and Szafrański (2015) find that factors in inflation common to Central and Eastern European economies explain 13% of inflation in Poland. According to Hałka and Szafranek (2017) deflation in Poland between 2014 and 2016 was driven mainly by commodity prices and foreign real activity. Such a relationship in general (a significant, positive relationship between inflation, and commodity prices and foreign real activity) was found in Hałka and Kotłowski (2016). Hałka and Szafranek (2016) point to large spillovers from inflation in the euro area to inflation in Poland. A significant role of commodity prices and foreign inflation in explaining the inflation in Poland was also found in Szafranek (2017b), a role of foreign inflation – in Hałka and Kotłowski (2013). Goczek and Mycielska (2013) find that interest rates in the euro area affect interest rates in Poland (and the relationship does not go the other way round). However, as they do not control for other variables affecting interest rates, their results are difficult to interpret. Results from this group of articles motivate using commodity price and foreign factors in extensions.

3 Models

The empirical analysis in this study is conducted in two steps. In the first step, a large number of observable variables is 'compressed' into a smaller number of unobservable factors, employing factor analysis. In the second step, these factors are used, together with one or a few observable factors, as endogenous variables in VARs.

As far as the first step is concerned, a general framework is the following. Let X_t^* denote a vector of global/foreign observable variables and X_t – a vector of domestic observable variables. They consist of different measures of key economic concepts. Let F_t^* and F_t be vectors of global/foreign and domestic unobservable factors, respectively. They are supposed to summarise information from X_t^* and X_t.

Finally, let Y_t denote a vector of (domestic) observable factors. Y_t contains either variables without noise or variables in which noise might not be neglected when monetary policy decisions are made (see Amir-Ahmadi, Uhlig 2015). The relationship between observable variables and factors is the following:

$$\begin{bmatrix} X_t^* \\ X_t \\ Y_t \end{bmatrix} = \begin{bmatrix} \Lambda^* & 0 & 0 \\ 0 & \Lambda & \Lambda^Y \\ 0 & 0 & I \end{bmatrix} \begin{bmatrix} F_t^* \\ F_t \\ Y_t \end{bmatrix} + \upsilon_t \tag{1}$$

where Λ^*, Λ and Λ^Y are matrices of factor loadings, and υ_t is a vector of error terms.

According to this set of equations, global/foreign variables are restricted to be affected only by global/foreign factors, and domestic variables – by domestic factors, including observable ones.

In this study, global/foreign variables are divided into groups related to economic concepts, as in Liu, Mumtaz, Theophilopoulou (2014). Each group is allowed to be affected only by one factor with a structural interpretation. It means that the first equation from the matrix notation above can be expanded in the following way:

$$\begin{bmatrix} X_{1,t}^* \\ \vdots \\ X_{k,t}^* \end{bmatrix} = \begin{bmatrix} \Lambda_1^* & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \Lambda_k^* \end{bmatrix} \begin{bmatrix} F_{1,t}^* \\ \vdots \\ F_{k,t}^* \end{bmatrix} + \upsilon_{1,t} \tag{2}$$

where k is the number of global/foreign factors.

Domestic variables are also divided into groups connected with economic concepts. Each group is either allowed to be affected only by one structural factor, as in Belviso and Milani (2006) or by many economically uninterpretable factors, as in Bernanke, Boivin and Eliasz (2005). In the first approach, Λ^Y is restricted to 0, and the second equation from the matrix notation above has the following expansion:

$$\begin{bmatrix} X_{1,t} \\ \vdots \\ X_{l,t} \end{bmatrix} = \begin{bmatrix} \Lambda_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \Lambda_l \end{bmatrix} \begin{bmatrix} F_{1,t} \\ \vdots \\ F_{l,t} \end{bmatrix} + \upsilon_{2,t} \tag{3}$$

where l is the number of domestic factors.

Both global/foreign and domestic factors are estimated using principal components. However, the estimation of economically uninterpretable domestic factors requires additional steps. First, principal components are extracted from X_t. Let the vector C_t denote them. At this stage it is not explicitly taken into account that Y_t is observable. Nevertheless, under not very restrictive conditions, C_t includes both F_t and Y_t (see Stock, Watson 2002). Then F_t is obtained by rotating C_t to remove the effects of Y_t.

In practice, in order to be able to identify shocks by short-run, recursive restrictions in the second step of empirical analysis, variables from X_t are divided into slow-moving, which cannot be immediately affected by Y_t, and fast-moving, which can. Not only are principal components extracted from X_t, but also (separately) from slow-moving variables. Let them be denoted by the vector F_t^S. Next, C_t is regressed on F_t^S and Y_t, and factors estimated from X_t are rotated so that $F_t = C_t - \hat{\beta} Y_t$ where β is the matrix of coefficients. Finally, factor loadings are estimated by regressing X_t on F_t and Y_t.[1]

In the second step, reduced-form VARs in the following general form are estimated:

$$\begin{bmatrix} F_t^* \\ F_t \\ Y_t \end{bmatrix} = \begin{bmatrix} B_{11}(L) & 0 & 0 \\ B_{21}(L) & B_{22}(L) & B_{23}(L) \\ B_{31}(L) & B_{32}(L) & B_{33}(L) \end{bmatrix} \begin{bmatrix} F_{t-1}^* \\ F_{t-1} \\ Y_{t-1} \end{bmatrix} + \varepsilon_t \tag{4}$$

where $B_{ij}(L)$ are matrices of coefficients ($i = 1 \ldots p,\ j = 1 \ldots p,\ p$ is the number of endogenous variables in a VAR, L is a lag operator) and ε_t denotes a vector of error terms.

According to the set of equations above, domestic factors are not allowed to affect foreign ones.

In extensions with global/foreign factors a seemingly unrelated regression estimation is employed, as it is more efficient in this case (see Enders 2015). In the baseline models, sensitivity analysis and the remaining extensions $B_{11}(L)$ are restricted to 0 and VARs are estimated using ordinary least squares.

In all except two models shocks are identified by short-run, recursive restrictions. Global/foreign factors are, if included, arranged before domestic ones. Domestic, economically uninterpretable factors are arranged before Y_t. However, it should be noted that they can be affected immediately by Y_t, if they have non-zero factor loadings on it. The specifics of the ordering of domestic, structural factors will be described in the next section. Of course, a given model always contains either structural or economically uninterpretable domestic factors, never both. In the remaining two models high-frequency identification is used. Specifically, monetary policy shocks from Kapuściński (2017), estimated similarly as in Gürkaynak, Sack and Swanson (2005), are employed as a measure of monetary policy. A similar approach is used, for example, in Barakchian and Crowe (2013).

4 Data and estimation

The set of variables applied to models described in the previous section consists of 135 domestic variables, 10 commodity price indices and 102 foreign series, comprising 3 variables for 32 economies. Domestic variables include 3 measures of monetary policy. The foreign economies are the following: the EU economies, the US, Brazil, Russia, India and China. The sample starts in January 2001 and ends in March 2017.

[1] Bernanke, Boivin and Eliasz (2005) propose also an alternative approach: to extract factors from slow-moving and fast-moving variables separately, and order them in such a way that the former come before, and the latter after the observable factors in the Cholesky decomposition. However, in the present study, as in theirs, this procedure introduces collinearity between the measure of monetary policy and other interest rates in an additional robustness check (available on request), and destabilises the results. But when fast-moving interest rates and spreads are removed from the set of observable variables results are similar to using the rotation of factors. Interestingly, they can also be largely replicated employing unrotated factors, when using generalised impulse response functions (insensitive to the ordering) instead of orthogonalised ones.

Variables in X_t are chosen to be similar as in Bernanke, Boivin and Eliasz (2005), but adapted to Poland and grouped as in Belviso and Milani (2006). They are supposed to cover information available to, and monitored by, members of the Monetary Policy Council (as reflected in Inflation Reports) and by the private sector, particularly by professional forecasters (as reflected, for example, in bulletins of commercial banks). The groups of variables are related to the following concepts:

– real activity – this group consists of measures of production, building permits, domestic and external trade, employment, unemployment, and job offers,

– inflation – comprises consumer and producer prices, prices in external trade, and wages,

– credit – includes loans, non-performing loans and spreads between interest rates on loans and the overnight money market interest rate,

– money – covers money supply, including divisia indices,

– interest rates – consists of money markets interest rates, government bond yields and interest rates on loans,

– financial market – comprises bilateral exchange rates (an increase means depreciation), effective exchange rates (an increase means appreciation), stock market indices, as well as dividend yield and price/earnings ratio,

– expectations – includes confidence indicators for industry and consumers, and spreads of money market interest rates and government bond yields versus the overnight money market interest rate.

One structural factor is estimated from each of these groups. They are given the following structural interpretations: the real activity factor, the inflation factor, the credit factor, the money factor, the interest rates factor, the financial market factor and the expectations factor, respectively, with such an ordering in a Cholesky decomposition. In practice, as will be explained below in this section, only 4 factors are included in a given model. In an alternative approach, 4 economically uninterpretable factors are extracted from all variables collected together. For consistency, when economically uninterpretable factors are rotated, variables related to real activity, inflation, credit and money are used as slow-moving, variables related to interest rates, financial market and expectations – as fast-moving.

Compared to variables in Bernanke, Boivin and Eliasz (2005), data for Poland on capacity utilisation, personal income, duration of unemployment, hours of work and personal consumption expenditures are unavailable at a monthly frequency. Data on housing starts and new orders are not available for a large number of periods. Similarly for the components of the purchasing managers' index (PMI) and for government bill yields, but these can be replaced with the components of the Business Climate Indicator (BCI) and by money market interest rates, respectively. Corporate bond yields, unavailable for any period, are replaced with interest rates on loans. Data on bank reserves and the monetary base adjusted for changes in the reserve requirement, also unavailable, could have been estimated. However, its use would not have brought much information, as in Poland the demand for reserves is driven mostly by the reserve requirement, and Narodowy Bank Polski adjusts the supply of reserves to the demand. Manufacturers' shipments of mobile homes do not seem to be relevant for Poland either. Instead, the set of variables is supplemented with the following series: production in construction, retail trade, quantities and prices in exports and imports, loans in foreign currencies (exchange rate adjusted), non-performing loans and divisia indices, not used in Bernanke, Boivin and Eliasz (2005). The components of aggregate variables, if employed, are also adapted to reporting in Poland (and, more generally, in the EU). The main innovation in comparison to Belviso and Milani

(2006) is adding spreads between interest rates on loans and the overnight money market interest rate, to test for the financial accelerator.

In all except two models Y_t contains only the measure of monetary policy. The baseline measure in this study, for comparability with Bernanke, Boivin and Eliasz (2005) and Belviso and Milani (2006), is the overnight money market interest rate, WIBOR ON (Warsaw Interbank Offered Rate, Overnight). The volume-weighted overnight money market interest rate and an operating target of Narodowy Bank Polski, POLONIA (Polish Overnight Index Average), is available only since 2005. In sensitivity analysis WIBOR 1M, the 1-month money market interest rate, and monetary policy shocks from Kapuściński (2017) are checked. In the remaining two models, in the exercise analysing the marginal contribution of domestic factors to a standard VAR in extensions, Y_t consists of industrial production, CPI, WIBOR ON and REER, ordered in this way in the Cholesky decomposition. Such a set of variables in a VAR for monetary policy analysis is used, for example, in Peersman and Smets (2001).

X_t^* comprises commodity price indices calculated by the International Monetary Fund, and industrial production, CPI and 10-year government bond yields for the economies listed above. If unavailable, 10-year government bond yields are replaced with other interest rates. If missing only for some periods, the former are estimated using changes in the latter, assuming that they move proportionally.

On the one hand, the use of long-term instead of short-term interest rates in this study makes it possible to capture the effects of forward guidance and asset purchases. On the other hand, long-term interest rates reflect also other factors (for example, the risk premium). A practical motive for not using short-term interest rates is to avoid having the same interest rate for the euro area economies. Liu, Mumtaz and Theophilopoulou (2014) use short-term interest rates and more measures of real activity and inflation, but their set of economies is more global and contains only a few members of the euro area. Furthermore, the analysis of the international transmission of shocks is the very aim of their study. Here, it is only one of the extensions.

From each of these 4 groups (commodity price indices, industrial production, CPI, 10-year government bond yields) one structural factor is extracted and interpreted as the commodity price factor, the foreign real activity factor, the foreign inflation factor and the foreign interest rates factor. The ordering in the Cholesky decomposition is the same as the ordering in which they are listed. In practice, either the first factor or the next three factors are used in a given model.

In general, 247 series are used. Variables are differenced if non-stationary and expressed in percent, or log-differenced if non-stationary and expressed in units other than percent. Results from unit root tests do not help much, as in many cases different tests find different orders of integration. Furthermore, their power is low, particularly for persistent processes (see, for example, DeJong et al. 1992). Instead, transformations are applied to make economic sense. For example, the log of industrial production should trend upwards, but its growth (log-differences) should be stationary. Eventually, transformations are similar as in Bernanke, Boivin and Eliasz (2005), with a few exceptions. First, job offers divided by registered unemployed persons are not used in log, since they are in percent. Second, building permits, unemployment rates and job offers divided by registered unemployment persons require (log-)differencing, as in Poland they are very slow-moving. Variables other than interest rates, spreads and financial market series are seasonally adjusted and, if necessary, calendar adjusted. (Log-)differenced variables are winsorised (the 5% extreme observations are replaced, 2.5% from each tail). The list of variables, together with sources and transformations, is shown in Table A.1 in an online

Appendix A. The results from unit root tests and publicly available time series are provided in an online Appendix B.[2]

When applying the data to the models, even using factor analysis to 'compress' variables, the number of degrees of freedom is a tight constraint. Between January 2001 and March 2017 there are 195 periods. VARs with stationary variables usually require a large number of lags, in order to mitigate the risk of omitting long-run relationships. Bernanke, Boivin and Eliasz (2005), and Belviso and Milani (2006) use 13 lags. In this study 12 lags are used in most models, even though in baseline models information criteria suggest 2–4 lags. 6 lags are checked in the sensitivity analysis. To keep the number of parameters below the number of periods divided by 3, as suggested by one of the rules of thumb (see Ouliaris, Pagan, Restrepo 2016), only 5 variables can be used in a given model. In a FAVAR with high-frequency identification the number of lags needs to be reduced to 9 for the model to be stable. In models with the commodity price factor and in models with foreign factors 9 and 6 lags are used, respectively.[3]

Summing up and supplementing the information above, endogenous variables in the first of baseline models with structural factors (FAVAR-BM, as Belviso and Milani) are the following: the real activity factor, the inflation factor, the credit factor, WIBOR ON and the financial market factor. In the remaining 3 models, the credit factor is replaced with the money factor, the interest rates factor and the expectations factor, respectively. The baseline model with economically uninterpretable factors (FAVAR-BBE, as Bernanke, Boivin and Eliasz) uses 4 factors and WIBOR ON. In these models the number of lags is 12. Sensitivity analysis is conducted on the FAVAR-BM. First, the number of lags is reduced to 6. Second, WIBOR ON is replaced with either WIBOR 1M or monetary policy shocks (models with 12 and 9 lags, respectively). In the first extension, a standard VAR with log-differences of industrial production, the CPI and the REER, and with WIBOR ON is estimated, and then (1) extended with 2 factors, (2) WIBOR ON is replaced with monetary policy shocks. These models use respectively 12, 9 and 12 lags. Finally, in the second extension, the FAVAR-BM is extended with (1) the commodity price factor (9 lags), (2) the foreign factors (6 lags). In all except two models only the effects of monetary policy shocks are analysed. In models with global/foreign factors the focus is on the effects of commodity price, foreign real activity, foreign inflation and foreign interest rates shocks.

5 Results

5.1 Baseline results

Factor analysis

Starting with results from factor analysis, which are important for the interpretation of results from VARs, Figures A.1–A.3 in the online Appendix A show factor loadings. Bars are ordered as variables in

[2] Appendices are available at: https://figshare.com/s/e3c93125786cea2e24ad.

[3] It should be noted that, as long as the number of parameters to estimate remains below some reasonable benchmark, problems related to an insufficient number of lags are more serious than these related to an overparametrized model (except for forecasting, in which this study is not interested). One of the justifications for the use of VAR models, the Wold theorem, says that any vector of time series has a VAR representation, but the lag length of the model should go to infinity for the approximation to be 'good' (see, for example, Canova 2007).

Table A.1. Because series are standardised, loadings equal correlations between observable variables and unobservable factors. Usually they are considered to be significant if their absolute values are above 0.3–0.5.

In Figure A.1 there are loadings on domestic, structural factors. The real activity factor positively affects measures of production, building permits, domestic and external trade, employment and job offers, and negatively affects unemployment. However, only absolute values of loadings of industrial production are above 0.5. The inflation factor is positively correlated with prices, particularly strongly with consumer prices, less with producer prices and much less with prices in external trade. Its correlation with wages is close to 0. Loadings of loans on the credit factor are positive, loadings of non-performing loans and loan spreads – negative, but absolute values of the negative ones are somewhat below 0.5. Money, interest rates and expectations factors correlate positively with all variables from which they are estimated.[4] The financial market factor negatively affects bilateral exchange rates, and positively affects effective exchange rates and stock market indices. It is also, respectively, positively and negatively correlated with dividend yield and price/earnings ratio, though these relationships are relatively weak.

Interestingly, the financial market factor explains as much as 3/4 of the variability of the NEER and 2/3 of the variability of the WIG (Warszawski Indeks Gieldowy), a stock market index. Since it is associated with simultaneous appreciations of the former and increases in the latter (or depreciations and decreases, respectively), it might be related to the risk premium. If the exchange rate is driven mostly by the risk premium, that would explain a frequent finding that it depreciates after the tightening of monetary policy. This is because it is followed by economic contraction, which should increase the risk premium.[5] It does not necessarily mean that monetary policy does not affect the exchange rate also through different channels, possibly working in the opposite direction (as UIP or carry trade). However, a more careful identification strategy might be required for them not to be overshadowed by the effects through the risk premium.[6]

Figure A.2 shows loadings on domestic, economically uninterpretable factors after a rotation. Loadings on an observable factor, the WIBOR ON, are shown as well. Variables do not appear to endogenously group themselves in 'entering' factors. That would have made the latter de facto structural. If anything, the first two factors affect the most the variables related to credit. The first factor is negatively correlated with domestic currency loans and positively correlated with foreign currency loans, the second one is positively correlated with both. However, absolute values of loadings of domestic currency loans on the first factor are below 0.5. The third factor correlates the most with variables connected with the financial market – positively with bilateral exchange rates, negatively with effective exchange rates and stock market indices. Loadings on the fourth factor are the highest and negative for measures of money supply. WIBOR ON contemporaneously affects other interest rates (positively), but also variables related to expectations (negatively).

---

[4] The extraction of only one factor from the credit and money groups is sufficient to obtain high loadings on variables related to both concepts. On the other hand, in this approach confidence intervals for the responses of credit-related variables to a monetary policy impulse from the FAVAR-BM with the joint credit-money factor are wider than in the original one (otherwise being similar).

[5] An alternative interpretation is that not only income earned on deposits but also on equities affects the exchange rate. The economic contraction lowers profits and returns on equity, which compensates for higher interest on deposits.

[6] For example, Kapuściński (2017) finds an appreciation of the exchange rate following a surprise rise in the interest rate in Poland, focusing on responses in 30- and 60-minute windows around announcements of Monetary Policy Council's decisions.

In Figure A.3 there are loadings on global/foreign factors. All except one commodity price index, connected with prices of beverages, have loadings on the commodity price factor above 0.5. Almost all loadings of foreign industrial production, CPI and 10-year government bond yields on foreign real activity, inflation and interest rates factors, respectively, are positive. Foreign factors have relatively weak effects on Brazil, Russia, India and China.

Figures A.4–A.6 in the online Appendix A show factor scores with 68% confidence intervals. They were calculated using a delete-*d* jackknife, with d equal to $\sqrt{n}$, where n is the number of observations. 1000 samples of d observations were randomly drawn and removed from all observations, and factors were extracted and scores were made using the remaining observations. Confidence intervals are practically invisible.[7] It suggests that uncertainty related to the estimation of factors can be ignored. Therefore, standard analytical confidence intervals are used in VAR analysis.

Figure A.7 in the online Appendix A compares shares of the variability of each domestic variable explained by structural and economically uninterpretable factors. Structural factors (specifically, the real activity factor in this case) explain a much larger share of the variability of industrial production. On the other hand, economically uninterpretable factors are much better in explaining employment and unemployment. There are also significant differences for money supply in favour of structural factors, and for the PPI, foreign currency loans, loan spreads and confidence indicators in favour of economically uninterpretable factors.

At this point an important caveat should be made. FAVARs enables the analysis of the effects of shocks on observable variables only through unobservable factors included in VARs. Their maximal number for a given number of observations and lags might be insufficient to capture some important relationships. Even for a ‘right’ (according to some criterion) number of factors some information is lost. It might be a measurement error, but also information measured reliably in a given variable, though not in any of the remaining variables. However, these components matter only when they are necessary to identify shocks or when shocks affect them, which does not seem very likely. In this study, results from factor analysis suggest that particularly the variability of employment and unemployment might be insufficiently explained by structural factors, and the variability of industrial production – by economically uninterpretable factors.

Vector autoregressions

Moving to results from VARs, Figure 1 shows responses of structural factors to a monetary policy impulse from the baseline FAVARs-BM, with 68% confidence intervals. Interpreting the results it should be noted that these factors have the mean 0, the standard deviation 1 and correspond to transformed variables. Following an increase in WIBOR ON, the interest rates factor increases, and the financial market and expectations factors decrease. Their responses are very quick, reaching peaks/troughs as early as immediately or after 1 month. There is also a decline in real activity, inflation and credit factors. The maximal effect on the first one occurs after 3 months, on the second and on the third one – after 15 months. The response of the money factor is less well-behaved. *A* trough negative response

[7] For foreign factors, when the delete-*d* jackknife is used with respect to economies, factor scores are also similar between draws.

after 3 months is followed by an increase after 6 months and a more persistent decrease in the second year after the shock.[8]

Figure A.8 in the online Appendix A presents the responses of economically uninterpretable factors to a monetary policy shock from the baseline FAVAR-BBE. These factors have standard deviations different from 1 (although, loadings shown in Figure A.2 were computed for standardised factors). Factor 1 increases, contributing to (among other things) an increase in foreign currency loans and a decrease in domestic currency loans. There is also a decline in factor 2, which lowers both domestic and foreign currency loans. After an increase in WIBOR ON the response of factor 3 (correlating positively with bilateral exchange rates, negatively with effective exchange rates and stock market indices) switches signs for 2 years. The effect on factor 4 is positive, contributing to a decrease in money supply. However, in this model each variable is affected by many factors and the net effects will be known only after calculating impulse responses of the former (see below).

Figures 2–3 and 4–5 show responses of 30 (out of 132) variables to a monetary policy impulse, derived from responses of factors, from the baseline FAVARs-BM and the baseline FAVAR-BBE, respectively. Each response is computed as a sum of responses of factors 'entering' a given variable, multiplied by factor loadings (see equations 1–4). Furthermore, in order to restore original units, responses are multiplied by standard deviations of variables. Finally, responses of (log-)differenced variables are cumulated, so they are comparable with these from VARs using non-stationary variables in (log-)levels, a common practice in the literature. On the other hand, they are neither explicitly comparable with results from Bernanke, Boivin and Eliasz (2005), who go with responses of variables in logs further to levels, nor to these from Belviso and Milani (2006), who do not restore original units and do not cumulate responses of variables in differences. The online Appendix B provides also non-cumulative impulse responses of differenced variables and responses of the remaining 102 variables.

According to the results from FAVAR-BM, following a 0.20 percentage point (1 standard deviation) increase in WIBOR ON, industrial production decreases (or increases after a decrease – models are linear). After 14 months it is lower by 0.81% (confidence interval between -1.60 and -0.01%), compared to a counterfactual without a shock. There is also a decline in production in construction, building permits and retail trade. Point estimates from FAVAR-BBE have the same sign, but are less precise. In both models employment decreases and unemployment increases. However, the effects according to the results from FAVAR-BBE are much stronger. Job offers decline, with more precise estimates from FAVAR-BM. Differences in estimates appear to be related to differences in the shares of the variability of variables attributable to factors in the two approaches.

The point impulse response function for the CPI is negative in both models. After 40 months consumer prices are lower by 0.21% (-0.47–0.05%), according to estimates from FAVAR-BM, which also in this case are more precise. In both models confidence intervals are on both sides of 0 for all horizons, though they are close to 0 from above in the model with structural factors, and responses of growth in prices are clearly statistically significant for many horizons. The annualised trough effect on growth in prices is at -0.17 percentage point (between -0.26 and -0.08 percentage point) after 15 months. The response of PPI is similar as the response of CPI in FAVAR-BM, in FAVAR-BBE confidence intervals

[8] As mentioned, in FAVARs-BM real activity, inflation and financial market factors, and WIBOR ON are the 'core' variables, while credit, money, interest rates and expectations factors are introduced separately. Figure 1 shows impulse response functions of the 'core' variables from a model with the credit factor. However, their responses in the remaining models are similar.

are very wide. On the other hand, FAVAR-BBE better capturing the effects on the labour market indicates a decrease in wages, while their response in FAVAR-BM is economically insignificant.

An increase in WIBOR ON is also associated with a decrease in loans. The effects arising from a decline in demand appear to be amplified by the supply-side effects through the financial accelerator – non-performing loans and loan spreads increase. Results from FAVAR-BBE, in contrast to these from FAVAR-BM, indicate some delay in the interest rate pass through (an initial negative response of spreads).

Estimates for responses of the measures of money supply are imprecise. Point impulse response functions are negative. Changes in WIBOR ON are transmitted to other money market interest rates, government bond yields and loan rates. However, point estimates differ between models. In FAVAR-BM they appear to be underestimated.

A monetary policy impulse depreciates the NEER and lowers the WIG index. As far as the response of the exchange rate is concerned, it might be that the effects through UIP are overshadowed by the effect through the risk premium, as discussed above.[9] But this result is not robust among studies using VARs, which calls for a different strategy to identify the causal effect.[10] There is also a rise in dividend yield and a decline in price/earnings ratio. In FAVAR-BBE the effects are more persistent. But it should be noted that factors in both models explain only a small share of the variability of these 2 variables, except for dividend yield in FAVAR-BM.

Finally, the PMI, the consumer confidence indicator, as well as spreads of longer money market interest rates and government bond yields versus WIBOR ON decrease. The decrease in spreads is less persistent according to the results from FAVAR-BBE.

In general, both FAVAR-BM and FAVAR-BBE indicate that the tightening of monetary policy has broad, contractionary effects. An increase in WIBOR is transmitted to other interest rates. Financial asset prices decrease, but, at a monthly frequency, the exchange rate does not appear to appreciate, as it should according to economic theory (specifically, according to UIP). If anything, it depreciates. The effects of the shock are amplified through the financial accelerator. In effect, measures of (current and expected) real economic activity and inflation decrease. It is associated with a decrease in credit and money, with more uncertainty related to the response of the latter. Results from models with structural and economically uninterpretable factors differ somewhat in the estimated strength of the effects and in the precision of the estimates.

5.2 Sensitivity analysis

Figures A.9–A.11 in the online Appendix A show results from sensitivity analysis, in which FAVAR-BM is modified in 3 ways. In order to preserve space, only the responses of 16 observable variables/factors to a monetary policy impulse are shown. Results from similar exercises on FAVAR-BBE (with similar conclusions) are available in the online Appendix B.

[9] The result is insensitive to the addition of commodity price and foreign factors in the Bayesian estimation of the FAVAR-BM with 12 lags and the Litterman/Minnesota prior.

[10] For example, Kapuściński et al. (2016) also find a depreciation in some models, but in other they do not. In Darvas (2013) there is a depreciation at the beginning and then an appreciation. Arratibel and Michaelis (2013) and Jarocinski (2010) impose an appreciation by sign restrictions, hardly solving the problem.

When the original number of lags is reduced to 6, by as much as half but to a number still higher than the one suggested by information criteria, in most cases estimates are very imprecise (Figure A.9). On the other hand, point impulse response functions have the same signs, though for consumer and producer prices these functions take much more time to decrease. It appears that 6 lags are insufficient to capture dynamic relationships between variables adequately. However, taking into account that models use differenced variables if they are non-stationary (a long-run relationship is not explicitly modelled), this is not very surprising and should not be interpreted as invalidating baseline results.

Baseline results do not change qualitatively when WIBOR 1M is used instead of WIBOR ON as a measure of monetary policy (Figure A.10). When monetary policy shocks are identified using high-frequency identification instead of short-run, recursive restrictions (WIBOR ON is replaced with externally identified cumulative series of shocks, residuals are still orthogonalised by a Cholesky decomposition, though), changes in results are minor (Figure A.11). Estimates of responses of variables affected by the real activity factor are less precise. A decrease in prices starts later.

Summing up, baseline results appear to be robust to reasonable changes in original models. However, some subjective choices related to their specification affect the precision of estimates.[11]

5.3 Extensions

Figure 6 shows results from the first extension, which analyses a marginal contribution of domestic factors to standard VARs. It compares responses of production in industry, the CPI, the measure of monetary policy and the REER to a monetary policy impulse from 4 models: the FAVAR-BM, a standard VAR (with production in industry, CPI, WIBOR ON and REER as endogenous variables, transformed for stationarity) and the standard VAR supplemented with 2 economically uninterpretable factors, or with high-frequency identification. Impulse response functions with confidence intervals are available in the online Appendix B.

Results from the standard VAR indicate a price puzzle (a rise in prices after an increase in the interest rate, see, for example, Sims 1992). It can be removed by the inclusion of 2 economically uninterpretable factors. Inclusion of only 1 is insufficient, inclusion of as many as 3 does not change much. It might indicate that additional information, compared to the standard 4-variable VAR for monetary policy analysis in an open economy, is required to correctly identify monetary policy shocks.[12] Responses of the remaining variables are qualitatively similar for FAVAR-BM, the standard VAR and the standard VAR supplemented with 2 factors.

However, the price puzzle can also be removed by using high-frequency identification instead of identification by short-run, recursive restrictions. It requires less effort related to data processing. Furthermore, if it properly removes the endogenous component of changes in interest rates, there is no

[11] Additional robustness checks on the FAVAR-BM, outcomes from which are shown in the online Appendix B, are the following: the Bayesian estimation of the model with commodity price and foreign factors, 12 lags and the Litterman/Minnesota prior, estimation using quarterly data, the delete-*d* jackknife with respect to economies for foreign factors, the replacement of credit and money factors with a joint credit-money factor, estimation using Hodrick-Prescott-filtered and Hamilton-filtered data, the identification of shocks with Kim-Roubini and sign restrictions, and the Bayesian estimation of the model with all foreign factors, 12 lags and the Litterman/Minnesota prior.

[12] But the validity of such an interpretation is not clear-cut. Structural residuals from the 4-variable VAR are more correlated with high-frequency identified monetary policy shocks, which can serve as a benchmark (see Rudebusch 1998), than these from the VAR containing two additional factors.

threat of omitted variable bias (see Bishop, Tulip 2017 for a formal derivation of this argument). On the other hand, impulse response functions from the model with high-frequency identification (including a response of the measure of monetary policy) are worryingly persistent. Externally identified series of shocks might need to be cleaned further, for example, as in Miranda-Agrippino and Ricco (2017).

Figures A.12–A.15 in the online Appendix A show results from the second extension. The set of variables in FAVAR-BM is extended either with the commodity price factor or with foreign real activity, inflation and interest rates factors. The effects of shocks to these variables are investigated. Again, only responses of 16 observable variables/factors are shown, and responses from FAVAR-BBE (with similar conclusions) are available in the online Appendix B. It should be noted that these results are from models with probably an insufficient number of lags and should be treated with caution. In future research, their sensitivity can be analysed either using a larger number of lags when a sufficient number of observations is available or dropping the variables unavailable before 2001 and extending the sample backwards.

It might be argued (rightly) that if global/foreign factors are significant, they should be included in baseline models, used to identify the effects of monetary policy shocks. However, sensitivity analysis shows that 6 lags, the maximum for a given number of observations and variables while keeping the number of degrees of freedom reasonable, are insufficient to this end. Fortunately, results from models with high-frequency identification, robust to an omission of variables in the information set of the central bank, are similar. But their sensitivity should be analysed having a sufficient number of additional observations. Furthermore, the results are qualitatively similar when commodity price and foreign factors are added in the Bayesian estimation of the FAVAR-BM with 12 lags and the Litterman/Minnesota prior.

After an increase in commodity prices, domestic prices rise (Figure A.12). In response, monetary policy is tightened. Similarly, there is an increase in domestic production following an increase in foreign real activity (Figure A.13) and domestic prices rise after a rise in foreign prices (Figure A.14). In these two cases the domestic interest rate also increases. It goes up after an increase in foreign interest rates as well (Figure A.15). However, at least to some extent, this is due to a (rather puzzling) rise in domestic prices following the shock. The latter phenomenon might arise because the shock is not clean from anticipatory changes in foreign interest rates related to expected inflation, which materialises (put differently, a foreign interest rates shock might not be correctly identified).

6 Conclusions

This study applies FAVARs to identify the effects of monetary policy shocks on 132 variables in Poland. Compared to the existing studies, it does so using a fully fledged version of this framework, and 'compressing' variables (separately) to both structural factors (as in Belviso, Milani 2006) and economically uninterpretable factors (as in Bernanke, Boivin, Eliasz 2005). Sensitivity with respect to the specification of models is analysed, and the analysis is extended to check the marginal contribution of factors to standard VARs and the effects of changes in global/foreign factors.

The tightening of monetary policy is found to have broad, contractionary effects on different measures of real activity, inflation, credit and stock prices, among other things. However, the exchange rate does not appreciate. This might be due to the prevailing effects brought about through the risk premium, as suggested by results from factor analysis. But this finding varies among studies using VARs, which calls for a different strategy to identify the causal effect.

The results are robust, but some subjective choices related to the specification of models affect the precision of estimates. Information from two factors is sufficient to remove the price puzzle from standard VARs. Domestic prices respond to global prices of commodities and foreign prices. Domestic production and interest rates – to their foreign counterparts.

However, results differ somewhat depending on whether structural or economically uninterpretable factors are applied. The discrepancies are limited, though, mainly to the precision of estimates and the strength of the effects. Furthermore, even when factor analysis is used to 'compress' variables, the small number of observations remains constraining. If the aim is to remove the price puzzle from the model with stationary variables by better identifying monetary policy shocks, it can also be achieved by using high-frequency identification.[13] This approach requires less data processing without running the risk of omitted variable bias. On the other hand, FAVARs also have other advantages (as listed in the Introduction).

As far as policy implications are concerned, the study confirms an earlier finding that monetary policy does affect inflation in Poland. However, it should be noted that the quantitative effects are uncertain, as reflected by wide confidence intervals for the response of prices to a monetary policy impulse. For example, according to a point estimate, lowering inflation from 5 to 2.5% would require increasing the interest rate by 2.94 percentage points (more than 11 rises of 0.25 percentage point). But 68% confidence intervals span from 1.92 to 6.25 percentage points. Furthermore, the maximum effect of each interest rate rise would come after 15 months. Therefore, on the one hand gradualism (see Bernanke 2004), on the other hand forward-lookingness appear to be required when making monetary policy decisions.

In future research, the set of variables can be extended with some important and interesting variables available only at a quarterly frequency, at least for some periods. They include GDP, house prices, bank profits, capital buffers and lending policy. Then, an expectation maximisation algorithm can be used to estimate factors. Variables can be grouped differently in structural factors, especially that, for example, labour market variables share only a limited part of their variability with measures of production. It could also be interesting to combine FAVARs with high-frequency identification and the approach of Romer and Romer (2004) to identify monetary policy shocks by adding a forecast factor. A larger number of observations should also allow to estimate FAVARs with time-varying coefficients. Borio and Hofmann (2017) show that the effects of monetary shocks might differ depending on the initial level of interest rates. According to Auer, Borio and Filardo (2017) the role of global factors in explaining domestic inflation is increasing.

References

Amir-Ahmadi P., Uhlig H. (2015), *Sign restrictions in Bayesian FaVARs with an application to monetary policy shocks*, NBER Working Papers, 21738, National Bureau of Economic Research.

Andrle M., Garcia-Saltos R., Ho G. (2013), *The role of domestic and external shocks in Poland. Results from an agnostic estimation procedure,* IMF Working Papers, 13/220, International Monetary Fund.

[13] In models with non-stationary variables, as in Kapuściński et al. (2016), the price puzzle rarely occurs.

Anzuini A., Levy A. (2007), Monetary policy shocks in the new EU members: a VAR approach, *Applied Economics*, 39(9), 1147–1161.

Arratibel O., Michaelis H. (2013), *The impact of monetary policy and exchange rate shocks in Poland: evidence from a time-varying VAR*, Munich Discussion Papers in Economics, 2013-36, Department of Economics, University of Munich.

Auer R., Borio C., Filardo A. (2017), *The globalisation of inflation: the growing importance of global value chains*, BIS Working Paper, 602, Bank for International Settlements.

Balabanova Z., Brüggemann R. (2017), External information and monetary policy transmission in new EU member states: results from FAVAR models, *Macroeconomic Dynamics*, 21(2), 311–335.

Barakchian S.M., Crowe C. (2013), Monetary policy matters: evidence from new shocks data, *Journal of Monetary Economics*, 60(8), 950–966.

Baranowski P., Leszczyńska A., Szafrański G. (2010), Krótkookresowe prognozowanie inflacji z użyciem modeli czynnikowych, *Bank i Kredyt*, 41(4), 23–44.

Belviso F., Milani F. (2006), Structural factor-augmented VARs (SFAVARs) and the effects of monetary policy, *The B.E. Journal of Macroeconomics*, 6(3), 1–46.

Benkovskis K., Bessonovs A., Feldkircher M., Wörz J. (2011), The transmission of euro area monetary shocks to the Czech Republic, Poland and Hungary: evidence from a FAVAR model, *Focus on European Economic Integration*, (3), 8–36.

Bernanke B. (2004), *Gradualism*, Speech 540, Board of Governors of the Federal Reserve System, https://www.federalreserve.gov/boarddocs/speeches/2004/200405202/default.htm.

Bernanke B., Boivin J. (2003), Monetary policy in a data-rich environment, *Journal of Monetary Economics*, 50(3), 525–546.

Bernanke B.S., Boivin J., Eliasz P. (2005), Measuring the effects of monetary policy: a Factor-Augmented Vector Autoregressive (FAVAR) approach, *The Quarterly Journal of Economics*, 120(1), 387–422.

Bishop J., Tulip P. (2017), *Anticipatory monetary policy and the 'price puzzle'*, RBA Research Discussion Papers, 2017-02, Reserve Bank of Australia.

Bogusz D., Górajski M., Ulrichs M. (2015), *Optymalne strategie polityki pieniężnej dla Polski uwzględniające wrażliwość banku na ryzyko nieosiągnięcia założonego celu*, Materiały i Studia, 317, Narodowy Bank Polski.

Borio C., Hofmann B. (2017), *Is monetary policy less effective when interest rates are persistently low?*, BIS Working Paper, 628, Bank for International Settlements.

Brzoza-Brzezina M., Kotłowski J. (2009), Bezwzględna stopa inflacji w gospodarce polskiej, *Gospodarka Narodowa*, 9(217), 1–21.

Bystrov V. (2014), A factor-augmented model of markup on mortgage loans in Poland, *Bank i Kredyt*, 45(6), 491–512.

Canova F. (2007), *Methods for Applied Macroeconomic Research*, Princeton University Press.

Creel J., Levasseur S. (2007), Monetary policy transmission mechanisms in the CEECs: How important are the differences with the euro area?, *The IUP Journal of Monetary Economics,* 5(1), 30–59.

Darvas Z. (2013), Monetary transmission in three central European economies: evidence from time--varying coefficient vector autoregressions, *Empirica*, 40(2), 363–390.

DeJong D., Nankervis J., Savin N., Whiteman C. (1992), The power problems of unit root tests in time series with autoregressive errors, *Journal of Econometrics*, 5(1–3), 323–343.

Demchuk O., Łyziak T., Przystupa J., Sznajderska A., Wróbel E. (2012), *Monetary policy transmission mechanism in Poland. What do we know in 2011?*, NBP Working Paper, 116, Narodowy Bank Polski.

Dornbusch R. (1976), Expectations and exchange rate dynamics, *Journal of Political Economy*, 84, 1161–1176.

Dybka P., Olesiński B., Pękała P., Torój A. (2017), To SVAR or to SVEC? On the transmission of capital buffer shocks to the real economy, *Bank i Kredyt*, 48(2), 119–148.

Enders W. (2015), *Applied Econometric Time Series*, John Wiley & Sons.

Gajewski P. (2015), Regionalne zróżnicowanie efektów impulsu polityki pieniężnej w Polsce, *Gospodarka Narodowa*, 4, 27–47.

Galí J. (2015), *Monetary Policy, Inflation, and the Business Cycle: an Introduction to the New Keynesian Framework and Its Applications*, Princeton University Press.

Gavin W., Kemme D. (2009), Using extraneous information to analyze monetary policy in transition economies, *Journal of International Money and Finance*, 28(5), 868–879.

Goczek L., Mycielska D. (2013), Gotowi na euro? Badanie empiryczne faktycznej swobody polskiej polityki pieniężnej, *Bank i Kredyt*, 45(3), 267–290.

Goczek L., Partyka K. (2016), Reakcja polityki pieniężnej na wydarzenia giełdowe, *Gospodarka Narodowa*, 5, 27–50.

Górajski M., Ulrichs M. (2016), Optymalne wrażliwe na ryzyko strategie polityki pieniężnej dla Polski, *Bank i Kredyt*, 47(1), 1–32.

Gupta R., Jurgilas M., Kabundi A. (2010), The effect of monetary policy on real house price growth in South Africa: a factor-augmented vector autoregression (FAVAR) approach, *Economic Modelling*, 27, 315–323.

Gürkaynak R., Sack B., Swanson E. (2005), Do actions speak louder than words? The response of asset prices to monetary policy actions and statements, *International Journal of Central Banking*, 1(1), 55-93.

Hałka A., Kotłowski J. (2013), *Does domestic output gap matter for inflation in a small open economy?*, NBP Working Paper, 152, Narodowy Bank Polski.

Hałka A., Kotłowski J. (2016), *Global or domestic? Which shocks drive inflation in European small open economies?*, NBP Working Paper, 232, Narodowy Bank Polski.

Hałka A., Szafranek K. (2016), Whose inflation is it anyway? Inflation spillovers between the euro area and small open economies, *Eastern European Economics*, 54(2), 109–132.

Hałka A., Szafrański G. (2015), *What common factors are driving inflation in CEE countries?*, NBP Working Paper, 225, Narodowy Bank Polski.

Haug A., Jędrzejowicz T., Sznajderska A. (2013), *Combining monetary and fiscal policy in an SVAR for a small open economy*, NBP Working Paper, 168, Narodowy Bank Polski.

Jarociński M. (2010), Responses to monetary policy shocks in the east and the west of Europe: a comparison, *Journal of Applied Econometrics*, 25(5), 833–868.

Kapuściński M. (2017), Monetary policy and fiancial asset prices in Poland, *Bank i Kredyt*, 48(3), 263–294.

Kapuściński M., Kocięcki A., Kowalczyk H., Łyziak T., Przystupa J., Stanisławska E., Sznajderska A., Wróbel E. (2016), *Monetary policy transmission mechanism in Poland. What do we know in 2015?*, NBP Working Paper, 249, Narodowy Bank Polski.

Kapuściński M., Łyziak T., Przystupa J., Stanisławska E., Sznajderska A., Wróbel E. (2014), *Monetary policy transmission mechanism in Poland. What do we know in 2013?*, NBP Working Paper, 180, Narodowy Bank Polski.

Leszkiewicz-Kędzior K. (2015), Wpływ cen paliw na procesy inflacyjne w polskiej gospodarce, *Bank i Kredyt*, 46(4), 357–392.

Liu P., Mumtaz H., Theophilopoulou A. (2014), The transmission of international shocks to the UK. Estimates based on a time-varying factor augmented VAR, *Journal of International Money and Finance*, 46(C), 1–15.

Łyziak T., Przystupa J., Stanisławska E., Wróbel E. (2011), Monetary policy transmission disturbances during the financial crisis, *Eastern European Economics*, 49(5), 75–96.

Łyziak T., Przystupa J., Wróbel E. (2008), *Monetary policy transmission in Poland: a study of the importance of interest rate and credit channels*, SUERF – The European Money and Finance Forum.

Miranda-Agrippino S., Ricco G. (2017), *The transmission of monetary policy shocks*, Bank of England Working Papers, 657.

Ouliaris S., Pagan A., Restrepo J. (2016), *Quantitative macroeconomic modeling with structural vector autoregressions – an EViews implementation*, IHS Global.

Pawłowska M., Wróbel E. (2002), *Monetary transmission in Poland: some evidence on interest rate and credit channels*, NBP Working Paper, 24, Narodowy Bank Polski.

Peersman G., Smets F. (2001), *The monetary transmission mechanism in the euro area: more evidence from VAR analysis*, Working Paper Series, 0091, European Central Bank.

Postek Ł. (2011), *Nieliniowy model mechanizmu transmisji monetarnej w Polsce w latach 1999–2009. Podejście empiryczne*, Materiały i Studia, 253, Narodowy Bank Polski.

Romer C., Romer D. (2004), A new measure of monetary shocks: derivation and implications, *American Economic Review*, 94(4), 1055–1084.

Rosoiu A. (2015a), Monetary policy and factor-augmented VAR model, *Procedia Economics and Finance*, 32, 400–407.

Rosoiu A. (2015b), Monetary policy and time varying parameter vector autoregression model, *Procedia Economics and Finance,* 32, 496–502.

Rudebusch G. (1998), Do measures of monetary policy in a VAR make sense?, *International Economic Review*, 39(4), 907–931.

Serwa D., Wdowiński P. (2016), *Macro-financial linkages in the Polish economy: combined impulse-response functions in SVAR models*, NBP Working Paper, 246, Narodowy Bank Polski.

Sims C. (1992), Interpreting the macroeconomic time series facts: the effects of monetary policy, *European Economic Review*, 36, 975–1000.

Socha R. (2014), Asymetria relacji cen paliw płynnych w Polsce i cen ropy naftowej, *Gospodarka Narodowa*, 5, 133–160.

Stock J., Watson M. (2002), Macroeconomic forecasting using diffusion indexes, *Journal of Business & Economic Statistics*, 20(2), 147–162.

Szafranek K. (2017a), *Bagged artificial neural networks in forecasting inflation: an extensive comparison with current modelling frameworks*, NBP Working Paper, 262, Narodowy Bank Polski.

Szafranek K. (2017b), Flattening of the New Keynesian Phillips curve: evidence for an emerging, small open economy, *Economic Modelling*, 63, 334–348.

Szafranek K., Hałka A. (2017), *Determinants of low inflation in an emerging, small open economy. A comparison of aggregated and disaggregated approaches*, NBP Working Paper, 267, Narodowy Bank Polski.

Szafrański G. (2011), *Krótkoterminowe prognozy polskiej inflacji w oparciu o wskaźniki wyprzedzające*, Materiały i Studia, 263, Narodowy Bank Polski.

Acknowledgements

I would like to thank Marta Korczak, Tomasz Łyziak, Ilona Pietryka, Małgorzata Skibińska, Andrzej Sławiński, Dorota Ścibisz, Ewa Wróbel, two Referees and the participants of the NBP seminar for their useful comments. Any remaining errors are mine.

Appendix

Figure 1

Responses to a monetary policy impulse and 68% confidence intervals, FAVAR-BM

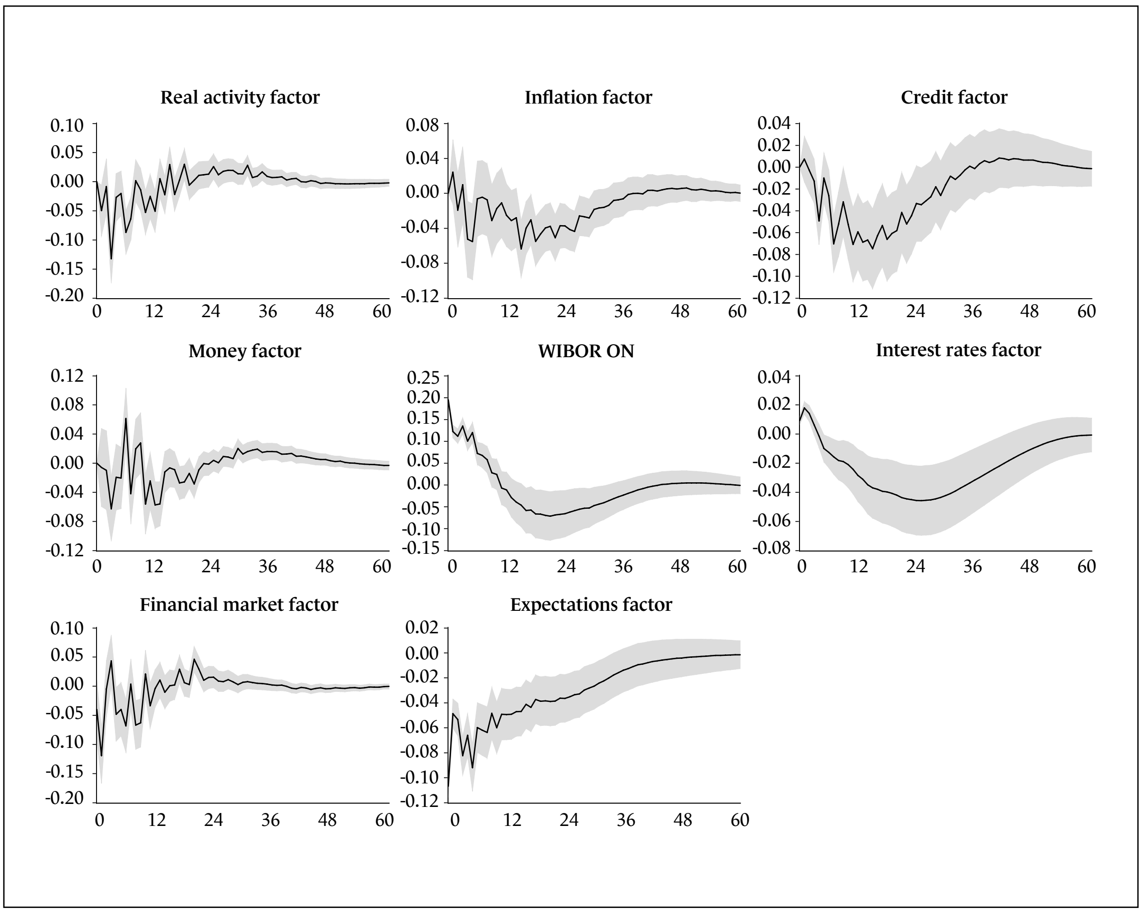

Figure 2

Responses to a monetary policy impulse and 68% confidence intervals, FAVAR-BM

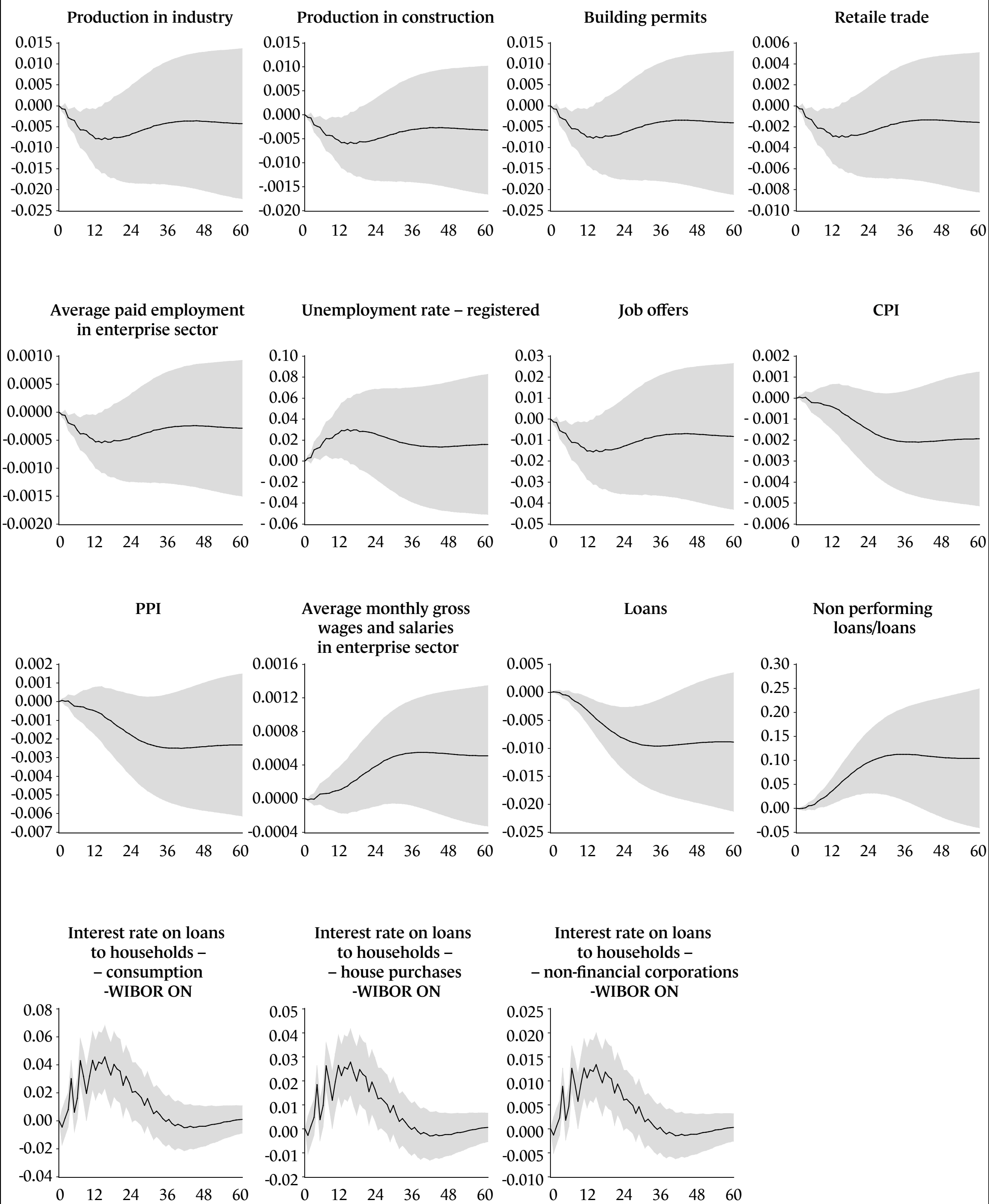

Figure 3

Responses to a monetary policy impulse and 68% confidence intervals, FAVAR-BM

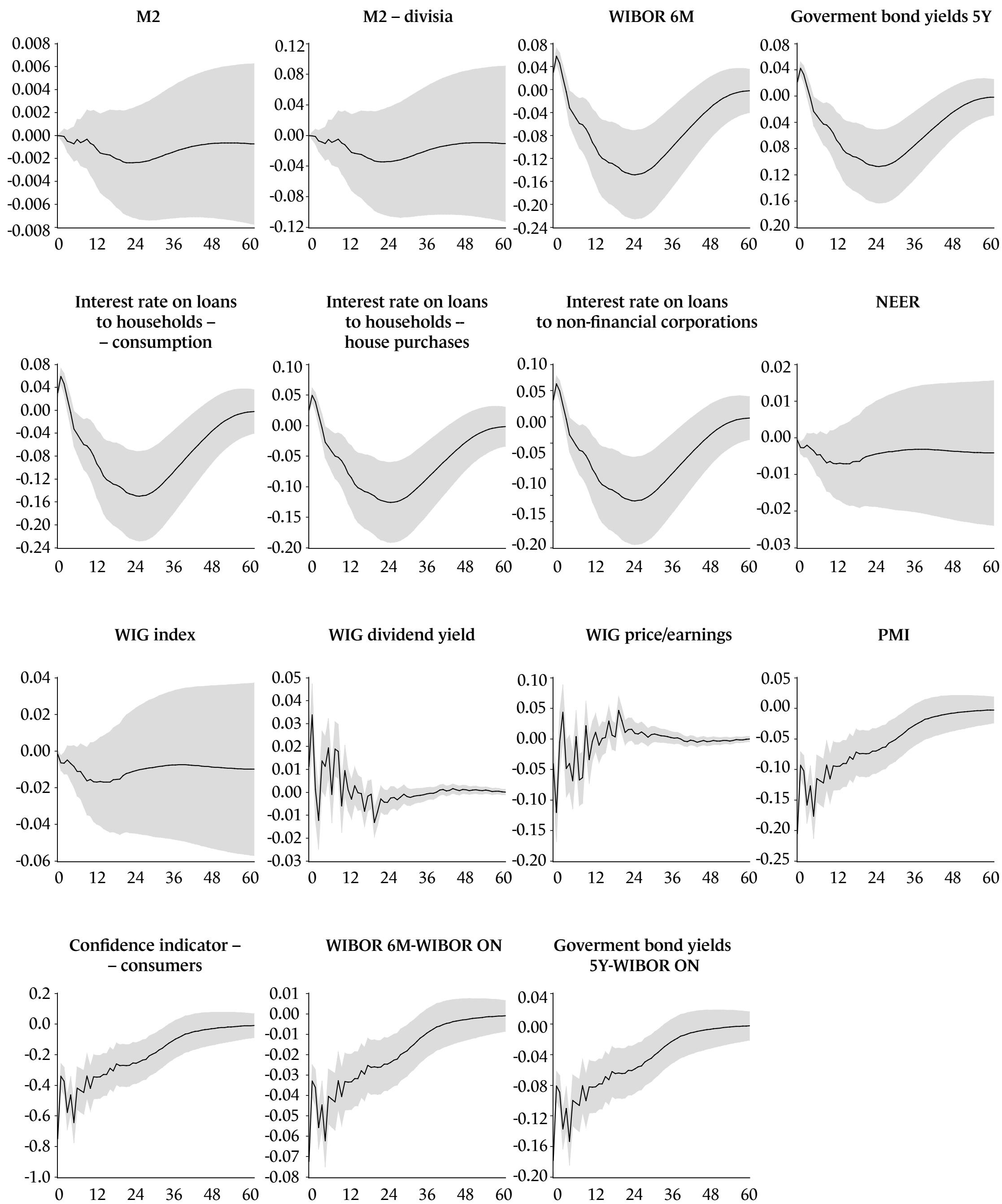

Figure 4

Responses to a monetary policy impulse and 68% confidence intervals, FAVAR-BBE

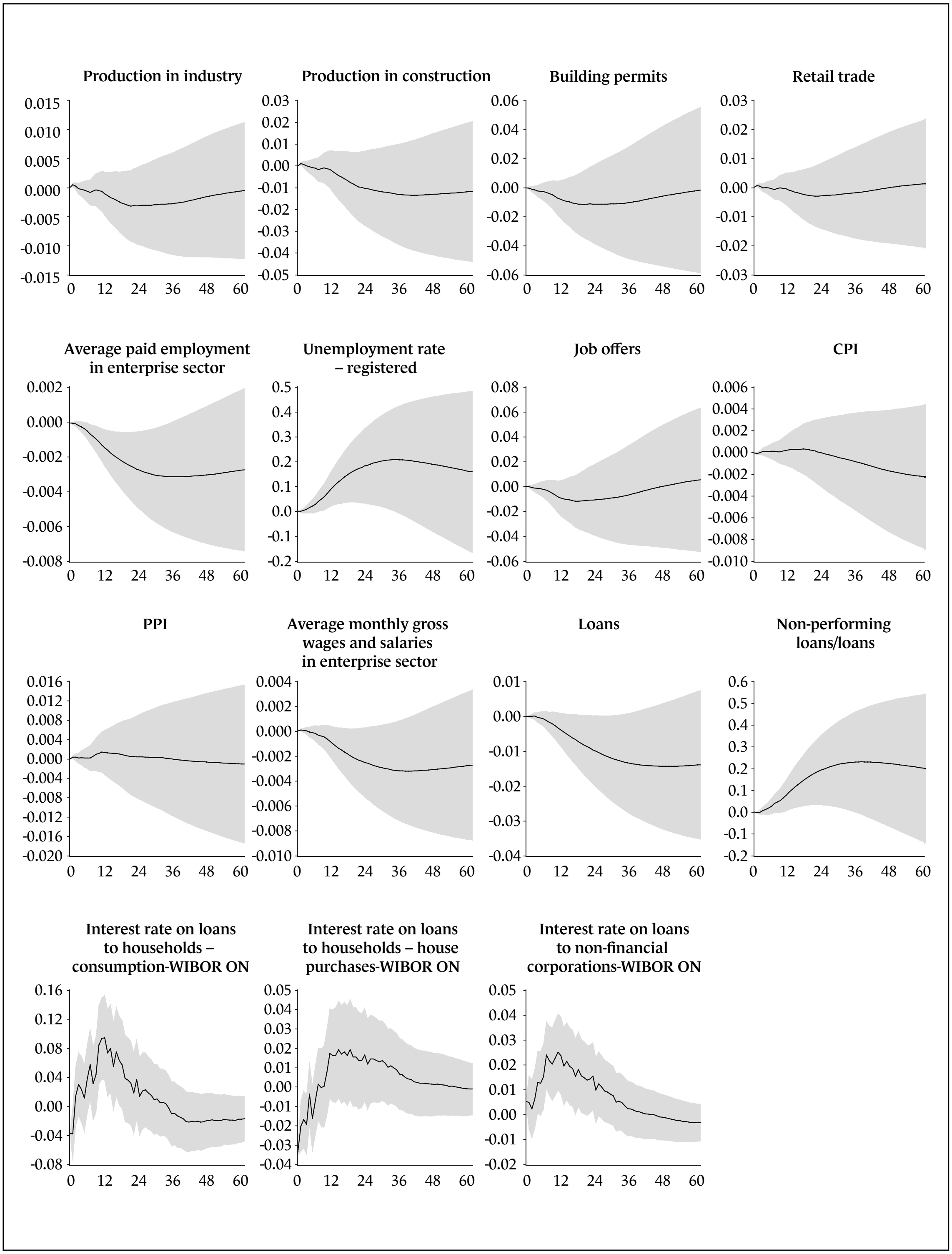

Figure 5

Responses to a monetary policy impulse and 68% confidence intervals, FAVAR-BBE

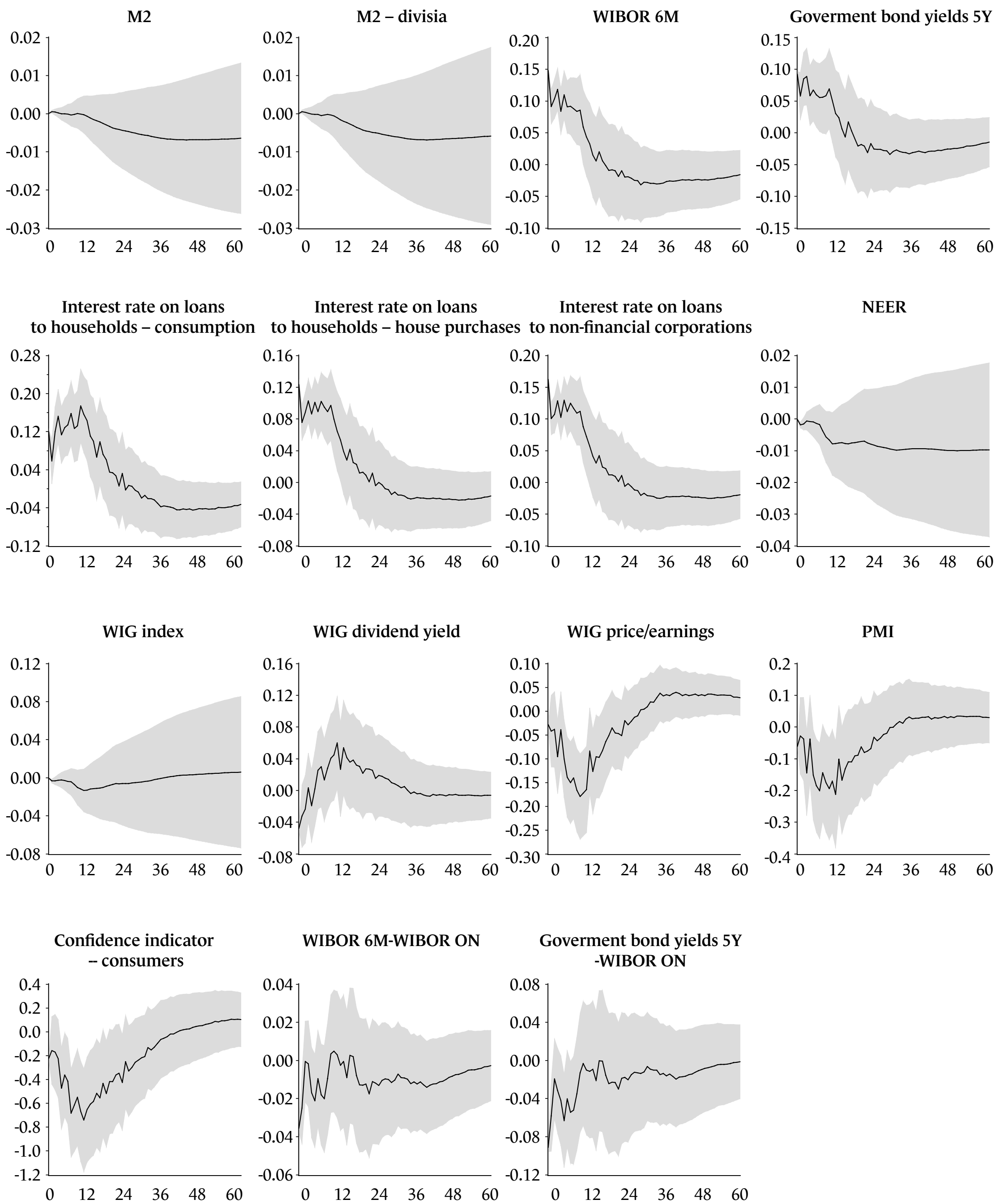

Figure 6
Responses to a monetary policy impulse