

BEAR 5.0

A. DIEPPE (ECB) B. VAN ROYE (Bloomberg L.P.)

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WITH CONTRIBUTIONS FROM:

B. BLAGOV, M. SCHULTE AND B. SCHUMANN

<https://github.com/european-central-bank/BEAR-toolbox>

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BEAR 5.0: what's new?

- 1 Factor-augmented VARs, Bernanke et al. (2005)
- 2 (Bayesian) Proxy SVARs, Caldara and Herbst (2019)
- 3 Trend-cycle VARs, Banbura and Van Vlodrop (2019)
- 4 Mixed Frequency Bayesian VARs, Schorfheide and Song (2015)
- 5 More
 - Git (frequent updates)
 - New interface
 - New identification techniques



Gary Koop, Professor University Strathclyde

- Bayesian VAR analysis is made easy using the BEAR toolbox. It is a powerful tool for academics, central bankers and policymakers.

Fabio Canova, Professor Norwegian Business School

- A toolbox built by policymakers for policymakers. A must!

Giorgio E Primiceri, Professor Northwestern

- BEAR is an invaluable, user-friendly toolbox for the Bayesian estimation of state-of-the-art multivariate time-series models. Not only it is accessible to less-technical users, but also extremely useful to more advanced researchers.



Outline

- 1 Summary of BEAR
- 2 (Bayesian) Proxy SVARs
- 3 Trend-Cycle Bayesian VARs
- 4 Mixed-Frequency Bayesian VARs
- 5 BEAR 5.0 More features
- 6 BEAR 4 Recap
- 7 Using BEAR: interfaces, outputs and documentation
- 8 Stochastic Volatility
- 9 Time Varying Parameters
- 10 Equilibrium VARs
- 11 Priors for the long-run
- 12 Forecast evaluation procedures
- 13 Other improvements in BEAR 4.2



Short recap of BEAR

BEAR is a comprehensive (Bayesian) VAR toolbox for Research and Policy analysis.

Aim to satisfy 3 main objectives:

- 1 Easy to understand, augment and adapt. Constantly developed further to always be at the frontier of economic research.
- 2 Comprehensive: all applications (basic and advanced) gathered in one single application.
- 3 Easy to use for desk economists and non-technical users thanks to a user-friendly graphical interface and user's guide.



5 estimation types of VAR models

- 1 Standard OLS VAR
- 2 Bayesian VAR: many prior distributions
- 3 Mean-adjusted Bayesian VAR
- 4 Panel VAR: 6 types
- 5 Time Varying Parameters & Stochastic Volatility

Identifications and applications

- Sign and magnitude restrictions
- Conditional forecasts
- Historical decompositions and FEVD



Factor Augmented VARs

Motivation

- "... small number of variables is unlikely to span the information sets used by actual central banks, which are known to follow literally hundreds of data series..." Bernanke et al. 2005
- Extract factors from (very) large "information" data sets

Pro

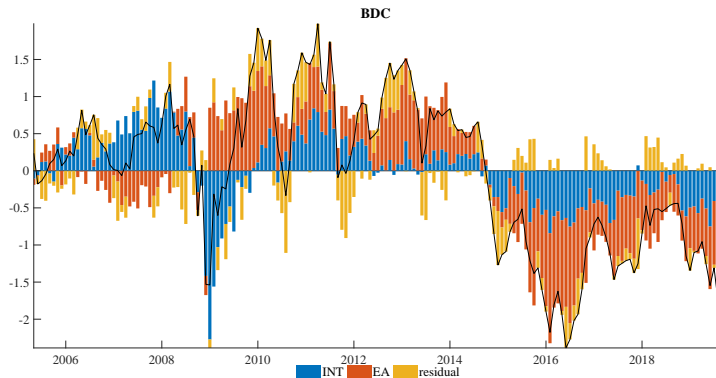
- Few factors summarise a large amount of information
- Better representation of economic concepts (e.g. price pressure, trade tensions, uncertainty)

Con

- Factors are hard to interpret

Factor Augmented VARs

Example output: What is driving long-term inflation expectations?



(Bayesian) Proxy SVARs

Motivation

- "... the instrument is constructed as a partial measure of the shock of interest: [...] the part of a monetary shock revealed during a monetary policy announcement window." Stock & Watson (2018)
- Identifies the shock based on covariance restrictions with a suitable proxy variable.

Pro

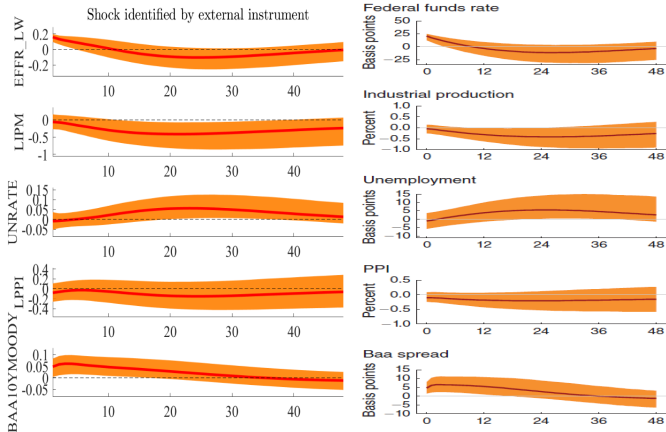
- Identifies the shock without imposing any theoretical structure
- Avoids drawbacks of conventional identification schemes
- Combination with sign/magnitude restrictions

Con

- Limited amount of suitable proxy variables

(Bayesian) Proxy SVARs

Example output: Replication of Caldara and Herbst (2019)



Motivation

- "The slowly changing mean can account for a number of secular developments such as changing inflation expectations, slowing productivity growth or demographics." Banbura, Van Vlodrop (2018)
- time-varying unconditional mean is anchored to off-model information, i.e. survey forecasts

Pro

- Increased forecasting performance by reducing uncertainty about the uncond. mean

Con

- Suitable survey forecast not available for all variables of interest

Trend-Cycle Bayesian VARs

Example output Banbura and Van Vlodrop (2018)

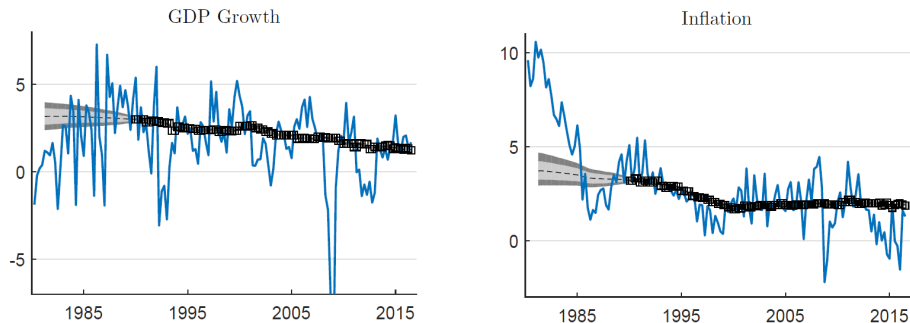


Figure 1: Posterior distributions for the end-of-sample local and unconditional means



Motivation

- ”Modern Big Data analytics, often referred to as the three “Vs”: the large number of time series continuously released (Volume), the complexity of the data covering various sectors of the economy, published in an asynchronous way and with different frequencies and precision (Variety), and the need to incorporate new information within minutes of their release (Velocity). ... BVARs are able to effectively handle the three Vs ...”, (Cimadomo et al. 2020).

Pro

- Flexible to use big data in real time for nowcasting

Con

- Computationally intensive

Mixed-Frequency Bayesian VARs

Example output

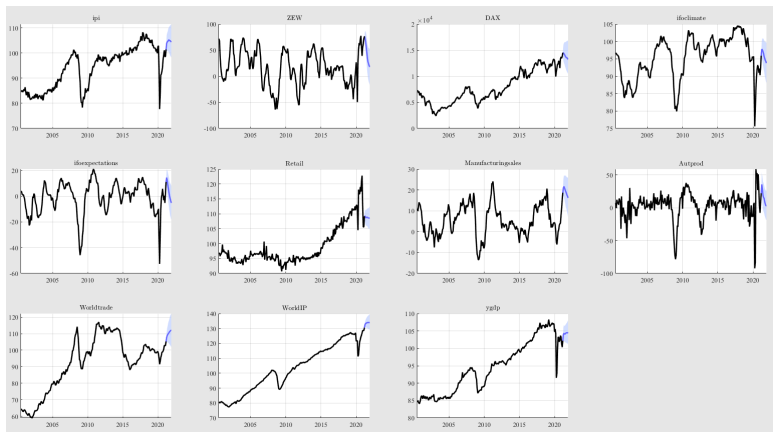


Figure 2: Nowcasting German GDP with a MF Bayesian VAR



BEAR 5.0 More features

More identification approaches

Long run zero restrictions (Blanchard and Quah 1989)

- In BEAR, enter '1000 1000' in the periods for the zero restrictions

Correlation restrictions (Ludvigson et al. 2017)

- In BEAR, enter the external variable in the sheet 'IV' and specify the name of the shock to be correlated.

Relative magnitude restrictions (Caldara et al. 2016)

- In BEAR, enter S1 for stronger and W1 for weaker in sheet 'relmagn res value'.

FEVD restrictions (Weale and Wieladek 2016)

- In BEAR, enter .Absolute or .Relative in sheet 'FEVD res value'.

BEAR 5.0 More features

More

Variable specific priors for the AR coefficient

- In BEAR, enter the values in sheet 'AR priors' and select in interface.

Priors for exogenous variables

- In BEAR, enter the prior value in sheet 'exo priors' and select in interface.



BEAR 5.0 More features

Moved to Github and has replications

BEAR 5.0 is open source

- BEAR will be regularly updated on Github:
<https://github.com/european-central-bank/BEAR-toolbox>
- Also available from ECB website:
<https://www.ecb.europa.eu/pub/research/working-papers/html/bear-toolbox.en.html>

BEAR 5.0 has 5 replication files

- Banbura and van Vlodrop (2018)
- Caldara and Herbst (2019)
- Amir-Ahmadi and Uhlig (2015)
- Bernanke, Boivin and Eliasch (2004)
- Wieladek and Garcia Pascual (2016)

BEAR 5.0 More features

New interface

The screenshot displays the BEAR 5.0 software interface, specifically the 'SPECIFICATION' tab. The window title is 'BEAR'. The interface is divided into several sections:

- REPLICATIONS:** Shows 'Bayesian VAR' selected in a dropdown menu. A 'RUN' button with a bear icon is visible.
- DATA:** 'Data Frequency' is set to 'Quarterly'. 'Estimation Start date' is '1974q1' and 'Estimation End date' is '2014q4'. There are input fields for 'Enter the list of endogenous variables' (containing 'DOM_GDP', 'DOM_CPI', 'STN') and 'Enter the list of exogenous variables' (empty).
- OUTPUT:** 'Lags' is set to 4. 'Include constant' is turned 'Off'. 'Output in excel' and 'Produce figures' are checked. 'Set results file' is 'test'.
- APPLICATIONS:** 'Set path to data' is 'C:\Dropbox\BEAR\BEAR-toolbox'. Below this, 'Bayesian VAR Priors' is set to 'NormalWishart'. 'OLS' is unchecked, 'FAVAR' is checked, and 'Mixed Frequency' (with 'MFVAR' sub-option) is unchecked.
- HYPERPARAMETERS:** Includes sliders for 'Autoregressive coefficient' (with 'Excel' checkbox), 'Overall tightness', 'Cross-variable weighting', 'Lag decay', 'Exogenous variables' (with 'Excel' and 'Default' checkboxes), 'Block exogeneity shrinkage', 'Sum of coefficients tightness', 'Dummy initial observation tightness', and 'Long-run prior tightness'.
- ITERATIONS:** 'Total number of iterations' and 'Number of burn-in iterations' are both set to 0.
- FAVAR OPTIONS:** 'Transformation' is 'No'. 'Tcodes endo' is empty. 'Onestep', 'slowfast', and 'Blocks' are all set to 'No'. 'No. factors', 'Block names', and 'Block no. factors' are empty input fields.

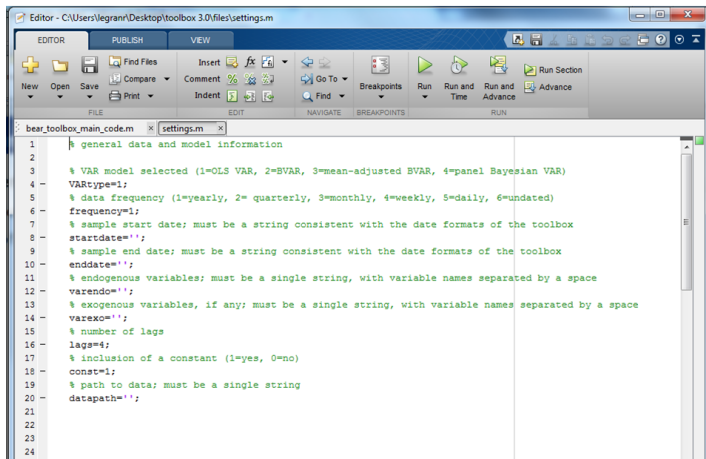


- Developers version
- Stochastic Volatility
- Time Varying Parameters
- Forecast evaluation



Developer's version

- Less restrictive than the interface for potential customised use
- Example: implementation of automatic loop



The screenshot shows a MATLAB editor window titled "Editor - C:\Users\legran\Desktop\toolbox 3.0\files\settings.m". The window has a menu bar with "EDITOR", "PUBLISH", and "VIEW" tabs. Below the menu bar is a toolbar with various icons for file operations (New, Open, Save, Compare, Print), editing (Insert, Comment, Indent), navigation (Go To, Find), and execution (Breakpoints, Run, Run and Time, Run and Advance). The main area displays the code for "settings.m" with line numbers 1 through 24. The code is as follows:

```
1 | % general data and model information
2 |
3 | % VAR model selected (1=OLS VAR, 2=BVAR, 3=mean-adjusted BVAR, 4=panel Bayesian VAR)
4 | VARTYPE=1;
5 | % data frequency (1=yearly, 2= quarterly, 3=monthly, 4=weekly, 5=daily, 6=undated)
6 | frequency=1;
7 | % sample start date; must be a string consistent with the date formats of the toolbox
8 | startdate='';
9 | % sample end date; must be a string consistent with the date formats of the toolbox
10 | enddate='';
11 | % endogenous variables; must be a single string, with variable names separated by a space
12 | varendo='';
13 | % exogenous variables, if any; must be a single string, with variable names separated by a space
14 | varexo='';
15 | % number of lags
16 | lags=4;
17 | % inclusion of a constant (1=yes, 0=no)
18 | const=1;
19 | % path to data; must be a single string
20 | datapath='';
21 |
22 |
23 |
24 |
```

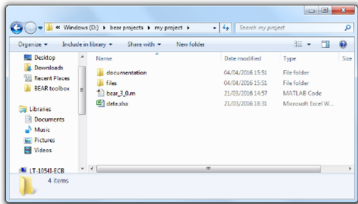


guide providing the mathematical derivations for the models and applications implemented by the toolbox.

- the 'files' folder. This folder contains the set of matlab functions run by the code. Except in a few specific cases indicated in this guide, you should not alter nor delete any elements in this folder. Doing so may result in the code not working properly anymore.
- the 'bear_3_0.m' matlab file. This file is used to start the toolbox and run the estimation. Further details can be found in [chapter 3](#). Running your project.
- the 'data.xlsx' Excel file. This file contains the data that will be used by the toolbox to run the estimation.

By default, the toolbox folder is called 'bear toolbox 3.0'. However, it is possible to rename the folder to suit your particular project, for instance 'project Japan', or 'BVAR US'. You may then place the folder in any directory of your choice. For example, you may create a new project, and for this project change the folder name from 'bear toolbox 3.0' to 'my project'. Assume that for convenience you also create a new folder on your D drive called 'bear projects' that gathers all your different projects. You may then move 'my project' into 'bear projects'. Your project folder will then look as follows:

Figure 2.2.: Project folder



6

A.3. Derivations of the posterior distribution with a Minnesota prior

The derivation of the posterior distribution with a Minnesota prior remains relatively simple. It starts with equation 1.3.15:

$$\pi(\beta|y) \propto \exp\left[-\frac{1}{2}\left\{(y - \bar{X}\beta)\Sigma^{-1}(y - \bar{X}\beta) + (\beta - \beta_0)\Omega_0^{-1}(\beta - \beta_0)\right\}\right] \quad (\text{A.3.1})$$

To transform this expression, consider only the exponential part in the curly brackets and develop it:

$$\begin{aligned} & (y - \bar{X}\beta)\Sigma^{-1}(y - \bar{X}\beta) + (\beta - \beta_0)\Omega_0^{-1}(\beta - \beta_0) \\ &= y\Sigma^{-1}y + \beta\bar{X}\Sigma^{-1}\bar{X}\beta - 2\beta\bar{X}\Sigma^{-1}y + \beta_0\Omega_0^{-1}\beta + \beta_0\Omega_0^{-1}\beta_0 - 2\beta_0(\Omega_0^{-1})\beta \\ &= y\Sigma^{-1}y + \beta(\Omega_0^{-1} + \bar{X}\Sigma^{-1}\bar{X})\beta - 2\beta_0(\Omega_0^{-1}\beta_0 + \bar{X}\Sigma^{-1}y) + \beta_0\Omega_0^{-1}\beta_0 \end{aligned} \quad (\text{A.3.2})$$

Notice that A.3.1 resembles the kernel of a normal distribution, but with a sum of squares rather than a single square term within the exponential part. It would therefore be nice to replace this sum by a single square, to obtain the kernel of a normal distribution. This can be done by applying the manipulations known as "completing the square". This most of the time amounts to adding and subtracting an additional matrix term, and inserting the product of a matrix with its inverse. After factoring, this will eventually lead to a single squared form, while the additional terms created will be independent of β and will hence be relegated to the proportionality constant. Hence, complete the squares in A.3.2:

$$= y\Sigma^{-1}y + \beta(\Omega_0^{-1} + \bar{X}\Sigma^{-1}\bar{X})\beta - 2\beta_0\bar{\Omega}^{-1}\bar{\Omega}(\Omega_0^{-1}\beta_0 + \bar{X}\Sigma^{-1}y) + \beta_0\Omega_0^{-1}\beta_0 + \bar{\beta}\bar{\Omega}^{-1}\bar{\beta} - \bar{\beta}\bar{\Omega}^{-1}\bar{\beta} \quad (\text{A.3.3})$$

Note that A.3.3 holds whatever the definition of $\bar{\Omega}$ and $\bar{\beta}$ (as long as dimensions agree). Nevertheless, one may obtain the desired squared form from A.3.3 by defining:

$$\bar{\Omega} = (\Omega_0^{-1} + \bar{X}\Sigma^{-1}\bar{X})^{-1} \quad (\text{A.3.4})$$

and

$$\bar{\beta} = \bar{\Omega}(\Omega_0^{-1}\beta_0 + \bar{X}\Sigma^{-1}y) \quad (\text{A.3.5})$$

For then, A.3.3 rewrites:



Input: Excel data file

The screenshot displays an Excel spreadsheet with the following data:

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		rgdp	inf	un	exdoll								
2	1999q1	0.84	0.25	10.10	1.12								
3	1999q2	0.71	0.76	9.90	1.06								
4	1999q3	1.06	0.25	9.70	1.05								
5	1999q4	1.28	0.38	9.50	1.04								
6	2000q1	1.15	0.75	9.30	0.99								
7	2000q2	0.91	0.50	9.00	0.93								
8	2000q3	0.56	0.49	8.80	0.91								
9	2000q4	0.78	0.74	8.50	0.87								
10	2001q1	0.89	0.24	8.30	0.92								
11	2001q2	0.00	1.70	8.30	0.87								
12	2001q3	0.11	-0.24	8.30	0.89								
13	2001q4	0.11	0.24	8.40	0.90								
14	2002q1	0.22	0.72	8.50	0.88								
15	2002q2	0.55	1.30	8.60	0.92								
16	2002q3	0.44	-0.12	8.70	0.98								
17	2002q4	0.00	0.35	8.80	1.00								
18	2003q1	-0.22	0.93	9.00	1.07								
19	2003q2	0.11	0.58	9.10	1.14								
20	2003q3	0.54	0.23	9.10	1.12								
21	2003q4	0.76	0.57	9.10	1.19								
22	2004q1	0.54	0.23	9.30	1.25								
23	2004q2	0.53	1.48	9.20	1.20								
24	2004q3	0.32	0.11	9.20	1.22								
25	2004q4	0.32	0.34	9.20	1.30								
26	2005q1	0.21	0.11	9.20	1.31								
27	2005q2	0.63	1.34	9.20	1.26								
28	2005q3	0.73	0.33	9.10	1.22								
29	2005q4	0.62	0.55	8.90	1.19								



Stochastic Volatility

Motivation

Motivation

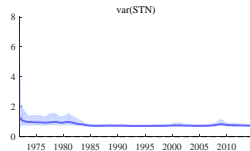
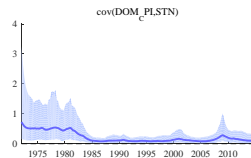
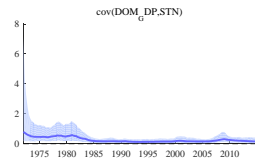
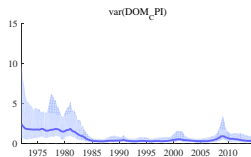
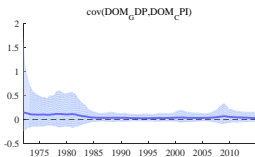
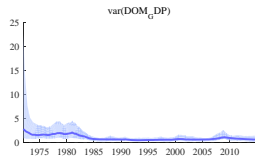
- A data-generating process of economic variables often seems to have drifting coefficients and shocks of stochastic volatility.
- In particular, VAR innovation variances change over time (Bernanke and Mihov 1998, Kim and Nelson 1999, MacConnell and Perez Quiros 2000).

Setup in BEAR

- Cogley and Sargent (2005)
- Sparse matrix approach (Chan and Jeliazkov 2009)
- Three options: 1.) Standard, 2.) Random inertia, 3.) Large BVARs (Carriero, Clark and Marcellino 2012)

Stochastic Volatility

Example output



Time Varying Parameters

Motivation and setup in BEAR

Motivation

- "There is strong evidence that U.S. unemployment and inflation were higher and more volatile in the period between 1965 and 1980 than in the last 20 years." (Primiceri 2005, RES).
- Typical questions in ECB policy analysis: Has the Phillips curve flattened? Has the monetary policy transmission channel changed?

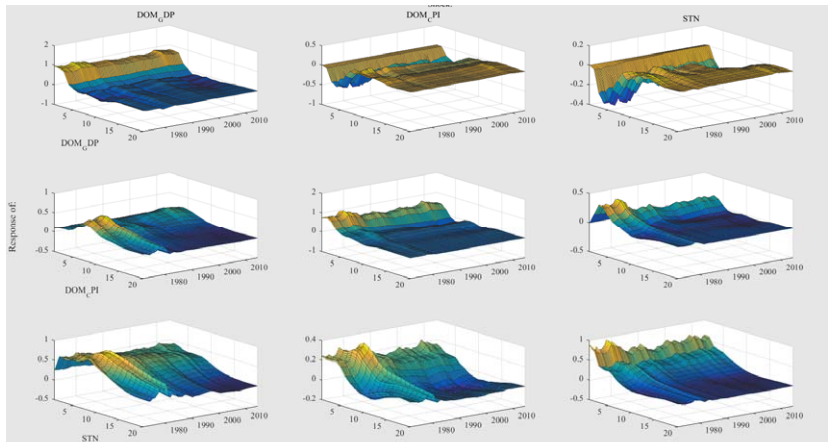
Set-up in BEAR

- Sparse matrix approach (Chan and Jeliazkov 2009)
- Two options: 1.) Time varying VAR coefficients 2.) General (Time varying VAR coefficients and Stochastic Volatility)



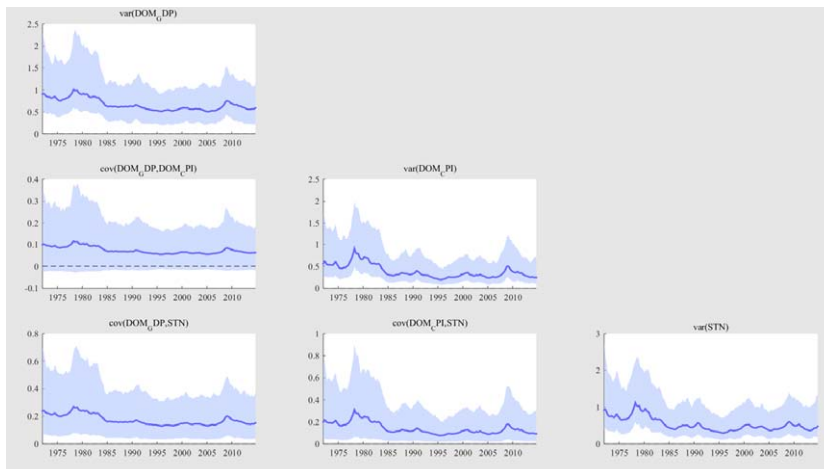
Time Varying Parameters

Example output



Time Varying Parameters

Example output



Equilibrium VARs

Motivation and setup in BEAR

Motivation

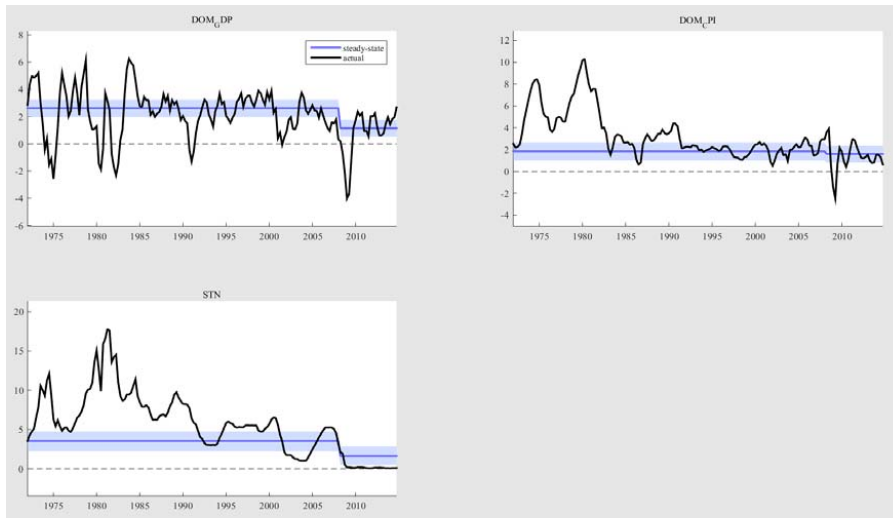
- Usually we are interested in trend-cycle decompositions.
- For historical decompositions we want to calculate deviations from "steady-state".
- So we have to take into account the "long-run", the "equilibrium", "steady-state", "trends" or "fundamentals".

Set-up in BEAR

- We extend the methodology of Villani (2009).
- In Version 4.0 it is possible to have a prior on the deterministic part (constant, linear trend, quadratic trend).
- A generalization to stochastic trends will be part of the next version.

Equilibrium VARs

Example output



Priors for the long-run

Motivation and setup in BEAR

Motivation

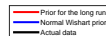
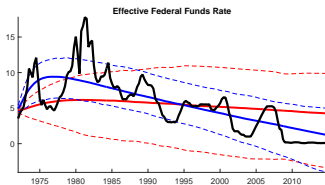
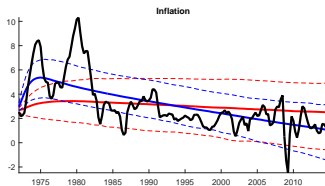
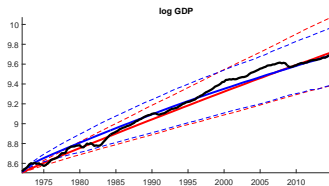
- Disciplination the long-run predictions of VARs.
- "Flat-prior VARs tend to attribute an implausibly large share of the variation in observed time series to a deterministic—and thus entirely predictable—component." (Giannone et al. 2017)
- Priors can be naturally elicited using economic theory, which provides guidance on the joint dynamics of macroeconomic time series in the long run.

Set-up in BEAR

- Giannone, Lenza and Primiceri (2017).
- Conjugate prior, easily implemented using dummy observations and combined with other popular priors.

Priors for the long-run

Example output



Forecasting evaluation procedures

Motivation and setup in BEAR

Motivation

- Assess forecasting performance of our VAR.
- Large literature has provided important insights on how to test whether forecasts are optimal / rational.
- Traditional tests that are based on stationarity assumptions should not be used in the presence of instabilities.

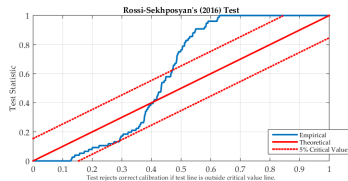
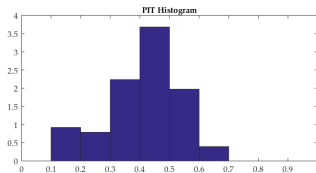
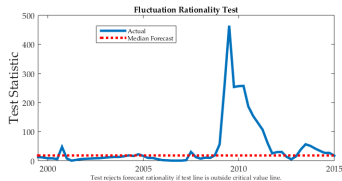
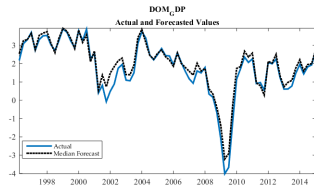
Set-up in BEAR

- Rossi and Sekhposyan (2016, 2017) and Loria and Rossi (2017).
- Rolling window estimations with density and forecast evaluation.



Forecasting evaluation procedures

Example Output



- Sign restrictions for panel VAR models (pooled and hierarchical models)
- Introduced the DIC criterion
- IRFs to exogenous variables
- Parallelisation for some procedures (sign restrictions, tilting)
- Option to suppress figures and excel output (efficiency gains)

