OESTERREICHISCHE NATIONALBANK
EUROSYSTEM

US Monetary Policy in a Globalized World

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Workshop on Global Spillovers – How much do we really know?
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Motivation

1. **Globalization**
   - *"... effective monetary policy making now requires taking into account a diverse set of global influences, many of which are not fully understood"* Ben Bernanke, Stanford, 2007.
   - *"Monetary policy settings in major countries should continue to be carefully calibrated and clearly communicated, with cooperation among policymakers to help manage spillovers and spillbacks"*, IMF, 2014.
2. **Time variation**
   - Broad consensus that US monetary policy transmission has changed over time (Sims and Zha, 2006)
   - Primiceri (2005), Boivin (2006), Boivin et al. (2010) find evidence for gradual variation in parameters and volatility over time. What does this imply for spillovers?

Agenda

- **Research questions:**
  1. Does the global economy respond to US monetary policy shocks?
  2. Variation over time?
  3. Do US interest rates react to foreign shocks?

- **Econometrics:** Time-varying parameter global vector autoregression with stochastic volatility (TVP-SV-GVAR).

- **Results:**
  1. We find significant spillovers from US monetary policy.
  2. Strength of spillovers increased over the recent years, peaked around the global financial crisis.
  3. US rates respond to foreign shocks.

The linear GVAR model

Ingredients: N countries, a vector $\boldsymbol{x}_{i,t}$ of macroeconomic time series, a link matrix $\boldsymbol{W}_i$, $\boldsymbol{x}^*_{i,t}$, to approximate global factors

1. For each country i, specify a VARX*(1,1) model:

$$\boldsymbol{x}_{i,t} = \underbrace{c_{i0} + c_{i1}\boldsymbol{t}}_{deterministics} + \underbrace{\boldsymbol{\Phi}_{i1}\boldsymbol{x}_{i,t-1}}_{domestic} + \underbrace{\boldsymbol{\Lambda}_{i0}\boldsymbol{x}^*_{i,t} + \boldsymbol{\Lambda}_{i1}\boldsymbol{x}^*_{i,t-1}}_{international} + \varepsilon_{i,t}$$

where $\boldsymbol{x}^*_{i,t} := \sum_{j=0}^{N} \omega_{ij}\boldsymbol{x}_{j,t}$ and $\varepsilon_{i,t} \sim \mathcal{N}(0, \boldsymbol{\Sigma}_i)$

2. After some straightforward algebra it is possible to rewrite the GVAR in a standard VAR form

$$\boldsymbol{x}_t = \boldsymbol{b}_0 + \boldsymbol{b}_1\boldsymbol{t} + \boldsymbol{F}\boldsymbol{x}_{t-1} + \boldsymbol{e}_t,$$

$\boldsymbol{x}_t = (\boldsymbol{x}_{0,t}, \boldsymbol{x}_{1,t}, ..., \boldsymbol{x}_{N,t})$ denotes the global vector and $\boldsymbol{b}_0$, $\boldsymbol{b}_1$, $\boldsymbol{F}$ stack the parameter vectors of the country-specific specifications

From linear to TVP GVARs: Road map

The TVP-SV-GVAR model with a Cholesky structure

Estimate structural / Cholesky form of the model (Lopes et al., 2013)

+ equation-by-equation estimation, exploits parallel computing

⇒ allows estimation of medium- to large scale TVP-SV-VARs

Bayesian estimation

- Specify law of motions and priors for all parameters

Identification

1. Use a recursive structure to identify monetary policy (MP) shocks in the USA and in three regions.
2. Use generalized impulse response functions (GIRFs) to calculate further regional shocks.

The observation equation of the TVP-GVAR

For country model i we have

$$\boldsymbol{A}_{i0,t}\boldsymbol{x}_{i,t} = \sum_{p=1}^{P} \boldsymbol{B}_{ip,t}\boldsymbol{x}_{i,t-p} + \sum_{q=0}^{Q} \boldsymbol{\Lambda}_{iq,t}\boldsymbol{x}^{*}_{i,t-q} + \varepsilon_{it}, \tag{1}$$

- $\boldsymbol{A}_{i0,t}$ is a $k_i \times k_i$ matrix of structural coefficients
- $\boldsymbol{B}_{ip,t}$ $(p = 1, \ldots, P)$ is a $k_i \times k_i$ matrix of coefficients associated with the lagged endogenous variables
- $\boldsymbol{\Lambda}_{iq,t}$ $(q = 0, \ldots, Q)$ denotes a $k_i \times k_i^*$ dimensional coefficient matrix corresponding to the k_i^* weakly exogenous variables in $\boldsymbol{x}^*_{it}$
- $\varepsilon_{it} \sim \mathcal{N}(0, \boldsymbol{D}_t)$ is a heteroskedastic vector error term with $\boldsymbol{D}_t = \mathrm{diag}(\lambda_{i0,t}, \ldots, \lambda_{ik_i,t})$

The state equations of the TVP-SV-VAR

For country model i we have

$$
\begin{aligned}
\boldsymbol{a}_{i,t} &= \boldsymbol{a}_{i,t-1} + \varepsilon_{i,t} & \varepsilon_{i,t} &\sim \mathcal{N}(\mathbf{0}, \boldsymbol{V_i}) & (2)\\
\text{vec}(\boldsymbol{\Psi}_{i,t}) &= \text{vec}(\boldsymbol{\Psi}_{i,t-1}) + \boldsymbol{\eta}_{i,t} & \boldsymbol{\eta}_{i,t} &\sim \mathcal{N}(\mathbf{0}, \boldsymbol{S_i}) & (3)\\
h_{il,t} &= \mu_{il} + \rho_{il}(h_{il,t-1} - \mu_{il}) + \nu_{il,t} & \nu_{il,t} &\sim \mathcal{N}(0, \varsigma_{il}^2) & (4)
\end{aligned}
$$

with $\boldsymbol{a}_t$ collecting the free elements of $\boldsymbol{A}_t$, and $\boldsymbol{\Psi}_{i,t}$ collecting the elements of $\boldsymbol{B}_{ip,t}$ and $\boldsymbol{\Lambda}_{iq,t}$. Finally $h_{il,t} = \log(\lambda_{il,t})$ denotes the log-volatility of the lth equation in country model i.

Bayesian inference: Prior setup

Priors on the initial state:

$$\begin{aligned} \boldsymbol{a}_{i0} &\sim \mathcal{N}(\mathbf{0}, \underline{\boldsymbol{V}}_{ai}) \\ \text{vec}(\boldsymbol{\Psi}_{i0}) &\sim \mathcal{N}(\mathbf{0}, \underline{\boldsymbol{V}}_{\Psi_i}) \end{aligned}$$

with $\underline{\boldsymbol{V}}_{ai}$ and $\underline{\boldsymbol{V}}_{\Psi_i}$ diagonal prior variance-covariance matrices.

Priors on the variances of the state equations, $\boldsymbol{V}_i$ and $\boldsymbol{S}_i$:

$$\begin{aligned} \nu_{i,rr}^2 &\sim \mathcal{G}\left(\frac{1}{2}, \frac{1}{2B_\nu}\right), \quad r = 1, \ldots, l_i \\ s_{i,jj}^2 &\sim \mathcal{G}\left(\frac{1}{2}, \frac{1}{2B_s}\right), \quad j = 1, \ldots, K_i \end{aligned}$$

where B_s and B_ν denote scalars that control the tightness of the prior and $l_i = k_i(k_i - 1)/2$.

Bayesian inference: Prior setup II

Prior for the volatility equation:

Normal prior on μ_{il},

$$\mu_{il} \sim \mathcal{N}(\underline{\mu}_i, \underline{V}_{\mu_i}).$$

Beta prior on the persistence parameter ρ,

$$\frac{\rho_{il} + 1}{2} \sim \text{Beta}(e_0, f_0),$$

Gamma prior on ς_{il},

$$\varsigma_{il} \sim \mathcal{G}(0.5, 1/(2B_\sigma)).$$

Bayesian inference: Estimation of country model i

MCMC=function(X){

For equation $l = 1, \ldots, k_i$ {

Initialize $\boldsymbol{V}_{il}$, $\boldsymbol{S}_{il}$ and $\boldsymbol{h}_{il} = (h_{il,0}, \ldots, h_{il,T})'$

For irep =1,...,ntot{

1. Sample $\boldsymbol{a}_{il}^T = (\boldsymbol{a}_{il,0}, \ldots, \boldsymbol{a}_{il,T})'$ and $\text{vec}(\boldsymbol{\Psi}_{il})^T = (\text{vec}(\boldsymbol{\Psi}_{il,0}), \ldots, \text{vec}(\boldsymbol{\Psi}_{il,T}))'$ using the Carter & Kohn (1994) algorithm
2. Sample the variances of Eqs. (2) and (3) using Gibbs steps by noting that the conditional posteriors are of generalized inverse Gaussian form
3. Sample $\boldsymbol{h}_{il}^T = (h_{il,1}, \ldots, h_{il,T})'$ through the algorithm put forth in Kastner & Fruehwirth-Schnatter (2014)

}

}

Collect the parameter draws for all k_i equations and construct the TVP-SV-VAR

}

Note that the first for-loop can easily be parallelized!

Data & country coverage

Country coverage (36 countries)

Western Europe: AT, BE, DE, ES, FI, FR, GR, IT, NL, PT, DK, GB, CH, NO, SE.

Other developed economies: AU, CA, JP, NZ, US.

Emerging Asia: CN, IN, ID, MY, KR, PH, SG, TH.

Latin America: AR, BR, CL, MX, PE.

Mid-East and Africa: TR, SA, ZA.

Data (1979Q4-2013Q4)

Δy_{it}: Real GDP growth.

Δp_{it}: CPI inflation.

Δe_{it}: Change in the real exchange rate vis-a-vis the US dollar.

i_{it}: Short-term interest rate.

s_{it}: Term spread.

$\Delta poil_t$: Change in oil price, endogenous in US model.

Identification

- First, we assess US and regional monetary policy shocks by assuming the following ordering (Christiano et al., 1996, 1999):

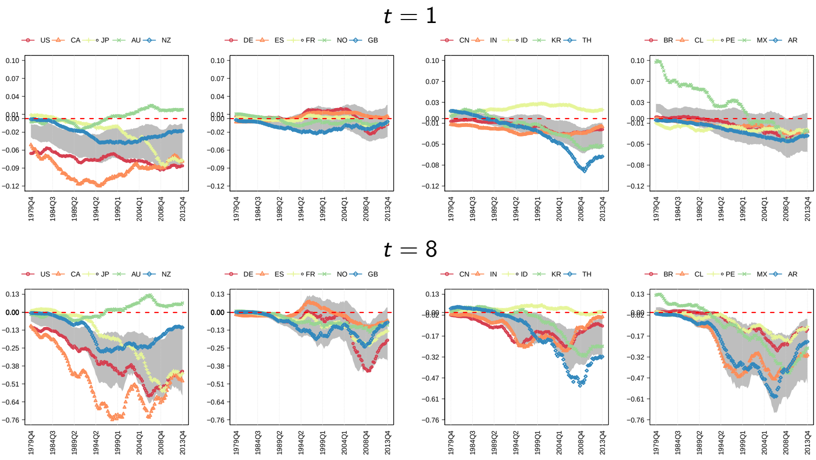
$$\boldsymbol{x}_{0t} = (\Delta poil_t, \Delta y_{0t}, \Delta p_{0t}, i_{0t}, s_{0t})'$$

  This is the same ordering as used in the estimation stage of the local TVP-SV models.

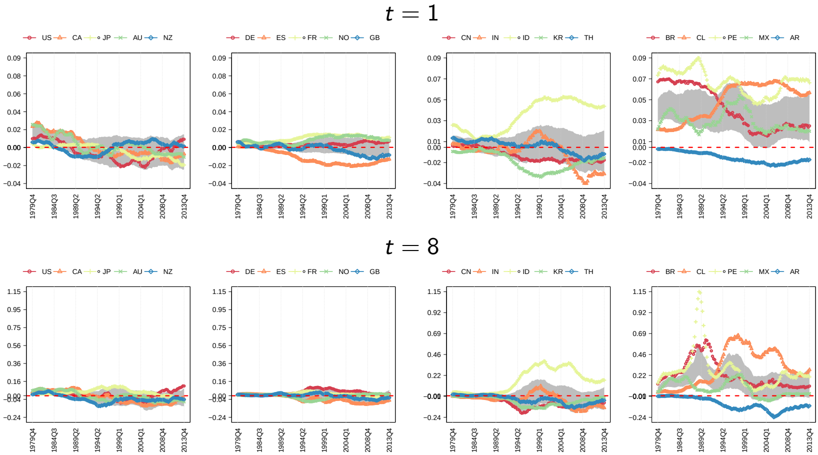
- Second we assess the US response to additional regional shocks using generalized impulse response functions:
  1. A positive shock to inflation by around one percentage point, on average, in Western Europe, Asia and Latin America,
  2. A negative output growth shock by around one percentage point, on average, in Western Europe, Asia and Latin America,
  3. A one percent real appreciation shock of the US dollar against currencies in Western Europe, Asia and Latin America.

RESULTS I: International responses to $+100$ bp US MP shock

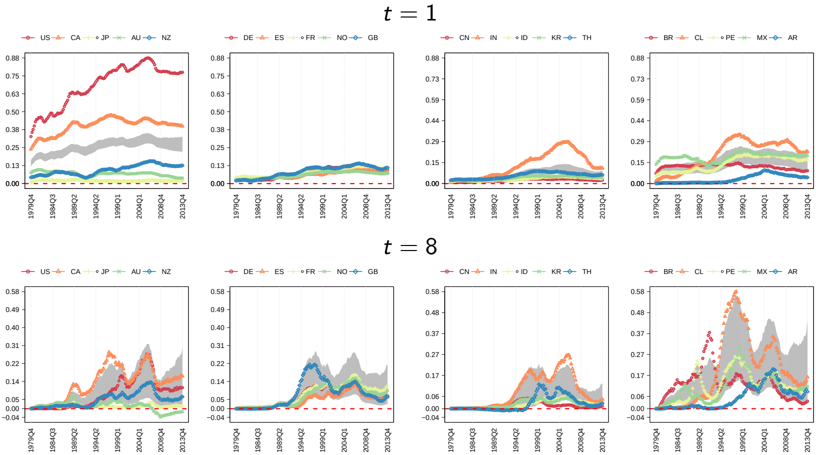
Real GDP growth (cumulative response)



Inflation (cumulative response)



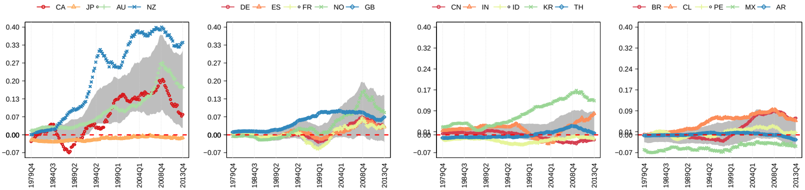
Short-term interest rates



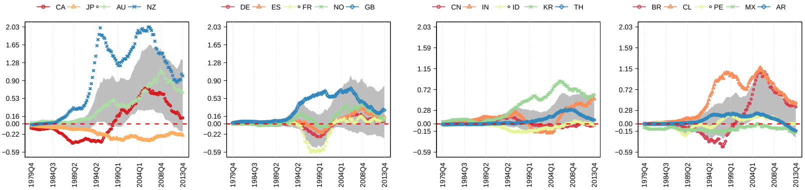
International response of real exchange rate

+ denotes real appreciation of US dollar, cumulative response

$t = 1$



$t = 8$



Remarks

A US monetary tightening leads to . . .

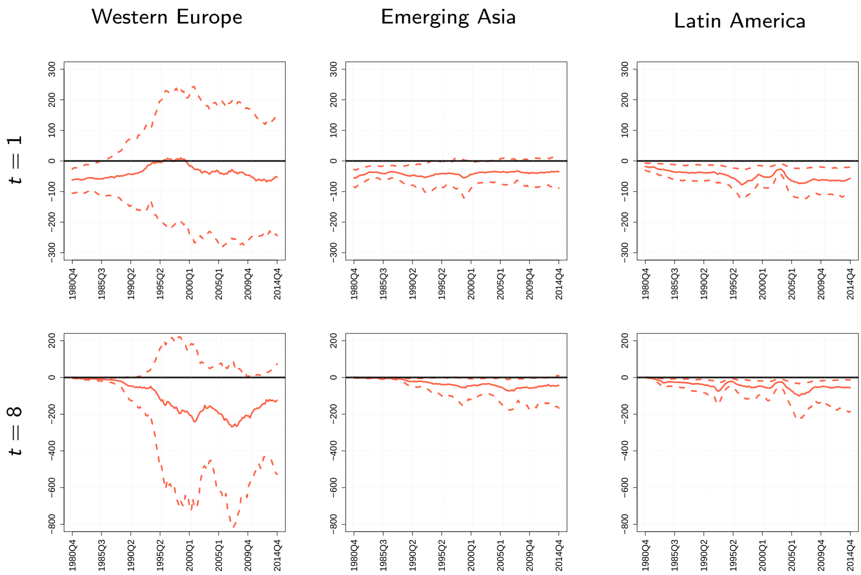
1. A decrease international output (even after eight quarters)
2. A decrease in prices in the short-term (exception Latin America)
3. An increase of international interest rates.
4. A weakening of most currencies against the US dollar.

We also find

- Cross-country heterogeneity of spillovers, especially among emerging economies.
- Considerable time variation in international spillovers.

RESULTS II: Responses of US interest rates to regional shocks

US interest rate response to regional MP shocks



US interest rate response to other regional shocks

Shock to		"Volcker" regime 1979 - 1987 Low$_{0.25}$	Median	High$_{0.75}$	"Greenspan" regime 1987 - 2006 Low$_{0.25}$	Median	High$_{0.75}$	"Bernanke" regime 2006 - 2013 Low$_{0.25}$	Median	High$_{0.75}$
Inflation in	$t = 1$	**12.9**	**43.9**	**79.6**	**33.3**	**73.7**	**120.6**	**5.6**	**35.9**	**65.1**
Western Europe	$t = 8$	-168.7	-54.2	78.1	-228.8	-85.7	50.8	-182.4	-76.8	12.7
Real GDP growth	$t = 1$	**-165.8**	**-122.0**	**-79.0**	**-134.1**	**-97.1**	**-64.3**	**-126.6**	**-91.1**	**-58.2**
in Western Europe	$t = 8$	**-214.5**	**-107.2**	**-38.4**	**-156.0**	**-79.0**	**-20.7**	**-138.8**	**-62.6**	**-15.8**
Exchange rate	$t = 1$	-0.5	4.0	8.2	-0.0	3.9	7.3	-0.0	4.0	7.4
in Western Europe	$t = 8$	-9.8	-2.2	5.8	-8.0	-1.6	4.4	-6.8	-0.4	5.7
Inflation	$t = 1$	**20.0**	**42.1**	**66.0**	**18.0**	**36.3**	**59.2**	**17.3**	**32.8**	**52.8**
in Asia	$t = 8$	**-106.2**	**-54.8**	**-3.4**	**-107.8**	**-59.0**	**-9.4**	**-85.6**	**-43.8**	**-6.1**
Real GDP growth	$t = 1$	**-120.6**	**-87.9**	**-58.5**	**-132.2**	**-95.8**	**-59.4**	**-125.9**	**-91.6**	**-56.2**
in Asia	$t = 8$	**-174.6**	**-106.6**	**-59.2**	**-209.4**	**-132.2**	**-70.7**	**-210.3**	**-127.8**	**-67.4**
Exchange rate	$t = 1$	**-10.5**	**-5.0**	**-0.1**	**-10.1**	**-5.0**	**-0.5**	**-12.9**	**-6.5**	**-1.8**
in Asia	$t = 8$	-23.0	-9.4	0.6	-16.2	-5.0	4.7	-11.2	-0.4	10.8
Inflation	$t = 1$	-9.8	3.8	19.0	-3.8	9.1	22.0	-3.8	15.0	34.9
in Latin America	$t = 8$	-40.9	-1.9	25.5	-34.0	2.6	28.9	-45.4	0.9	40.4
Real GDP growth	$t = 1$	**-60.1**	**-44.5**	**-28.7**	**-67.4**	**-50.1**	**-32.1**	**-78.1**	**-56.5**	**-36.8**
in Latin America	$t = 8$	**-91.0**	**-56.5**	**-30.9**	**-99.6**	**-63.3**	**-33.6**	**-111.3**	**-67.7**	**-34.6**
Exchange rate	$t = 1$	-2.8	0.8	5.1	-3.6	0.3	3.8	-1.5	2.1	6.5
in Latin America	$t = 8$	-14.7	-6.4	2.1	**-19.2**	**-9.2**	**-1.9**	**-22.3**	**-11.2**	**-4.7**

Notes: The table presents the posterior distribution of generalized impulse response functions (GIRFs) associated with a regional rise in inflation, a reduction of regional real GDP growth and an appreciation of the US dollar against regional currency baskets. Responses are based on 1,500 posterior draws from a total chain of 30,000 iterations and in basis points. Responses for which credible sets do not include a zero value in bold.

Conclusions I

- We developed a **new framework** for global macroeconomic analysis (TVP-SV-GVAR) which allows **for time-varying parameters and residual variances**

1. A **US monetary policy tightening** triggers **significant spillovers**
   - Global real activity contracts and rather persistently.
   - International prices fall immediately, but adjust quickly.
   - Global nominal interest rates follow the US rate hike.
   - The US dollar tends to appreciate in real terms.
   - **Cross-country heterogeneity:** countries highly integrated with USA (e.g., Canada), emerging economies (e.g., Brazil, Chile, India) show strongest response
   - **Variation over time:** Strength of output and interest rate spillovers increased from the 1980s and peaked in 2008; afterwards extent of spillovers declined.

Conclusions II

2. **US interest rates respond to foreign regional shocks:**

   - In the medium term, **US short-term rates decrease** when either **foreign monetary policy is tightened or foreign real GDP growth decreases**.
   - Domestic rates decreased to boost economic growth in the USA $\Rightarrow$ **US rates do not follow international rates**
   - **For other shocks, less compelling evidence** of US interest rate reaction.
   - Exception: **shocks from Asia including China**. Here, **US rates** also **respond to an exchange rate shock** in the short-run and to **an inflation shock** in the medium-term.

Work in progress: A BGVAR Toolbox

- Toolbox for linear Bayesian GVARs in `R`.
- Two priors:
  1. Stochastic search variable selection (SSVS) as in Feldkircher and Huber (2016)
  2. Combination of sum of coefficients, initial dummy observations and Minnesota prior as in Crespo Cuaresma et al. (2016)
- Parallel computing (via `snowfall`)
- Impulse response analysis:
  1. Orthogonalized IRFs
  2. Generalized IRFs
  3. Sign restrictions
- Forecasting
- **Release date: This summer.**

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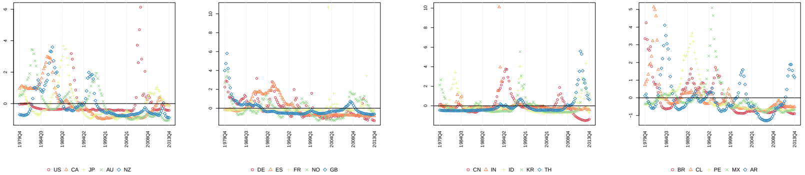
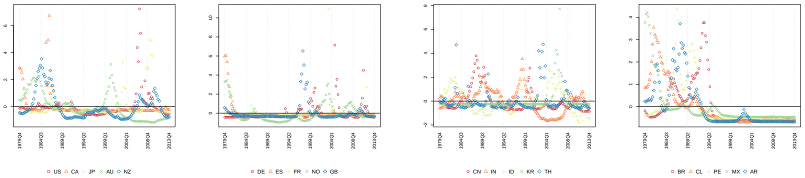
Backup slides

Stochastic volatility over time

Real GDP growth

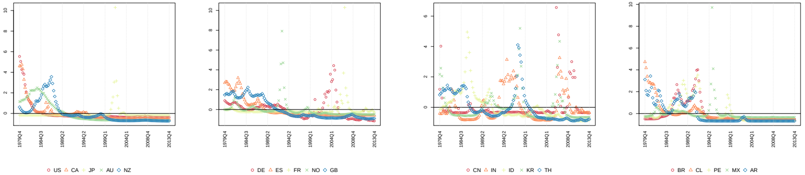


Inflation



Stochastic volatility over time

Short-term interest rate



Real exchange rate