OESTERREICHISCHE NATIONALBANK
EUROSYSTEM

US Monetary Policy in a Globalized World

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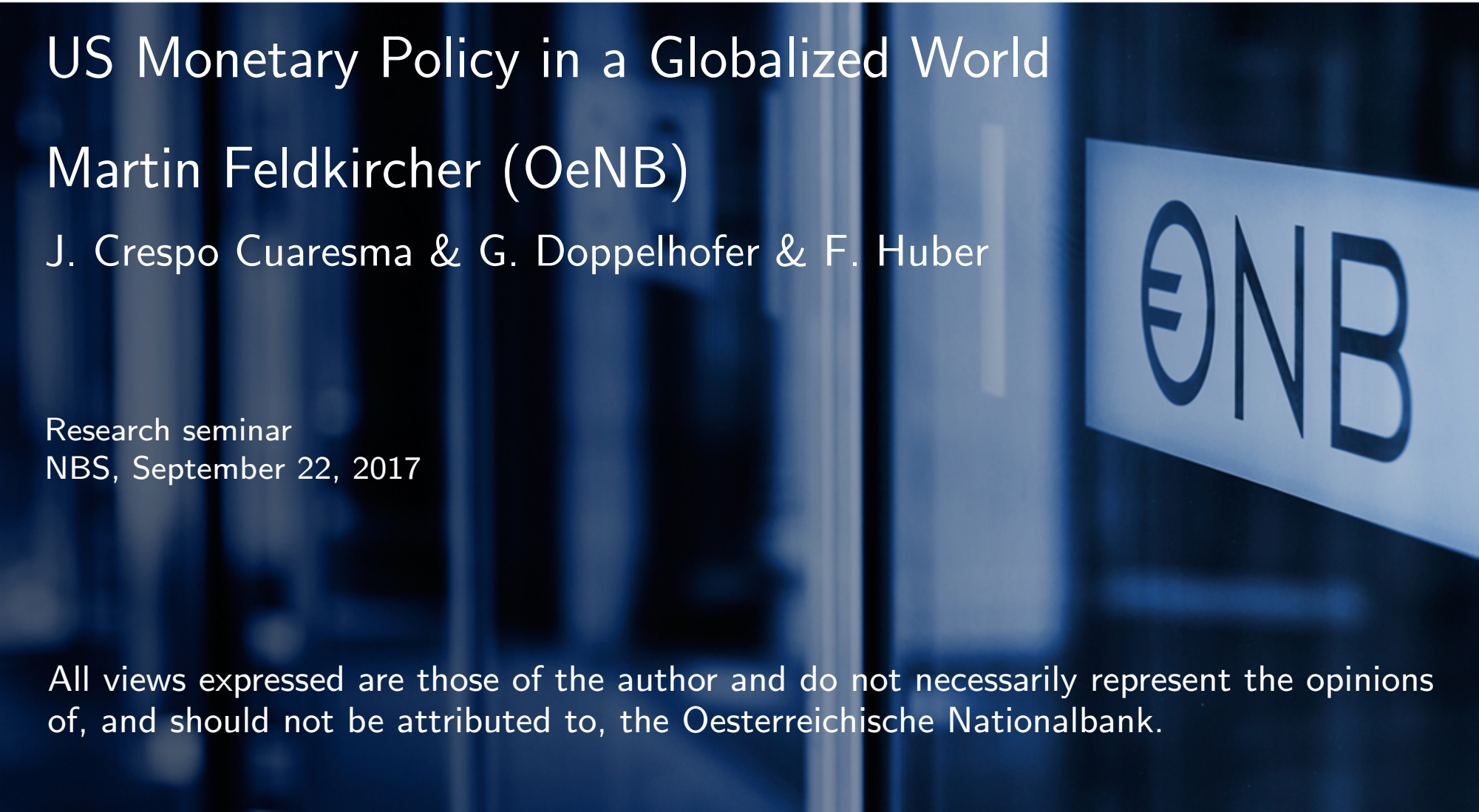


Research seminar
NBS, September 22, 2017

Motivation - 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.

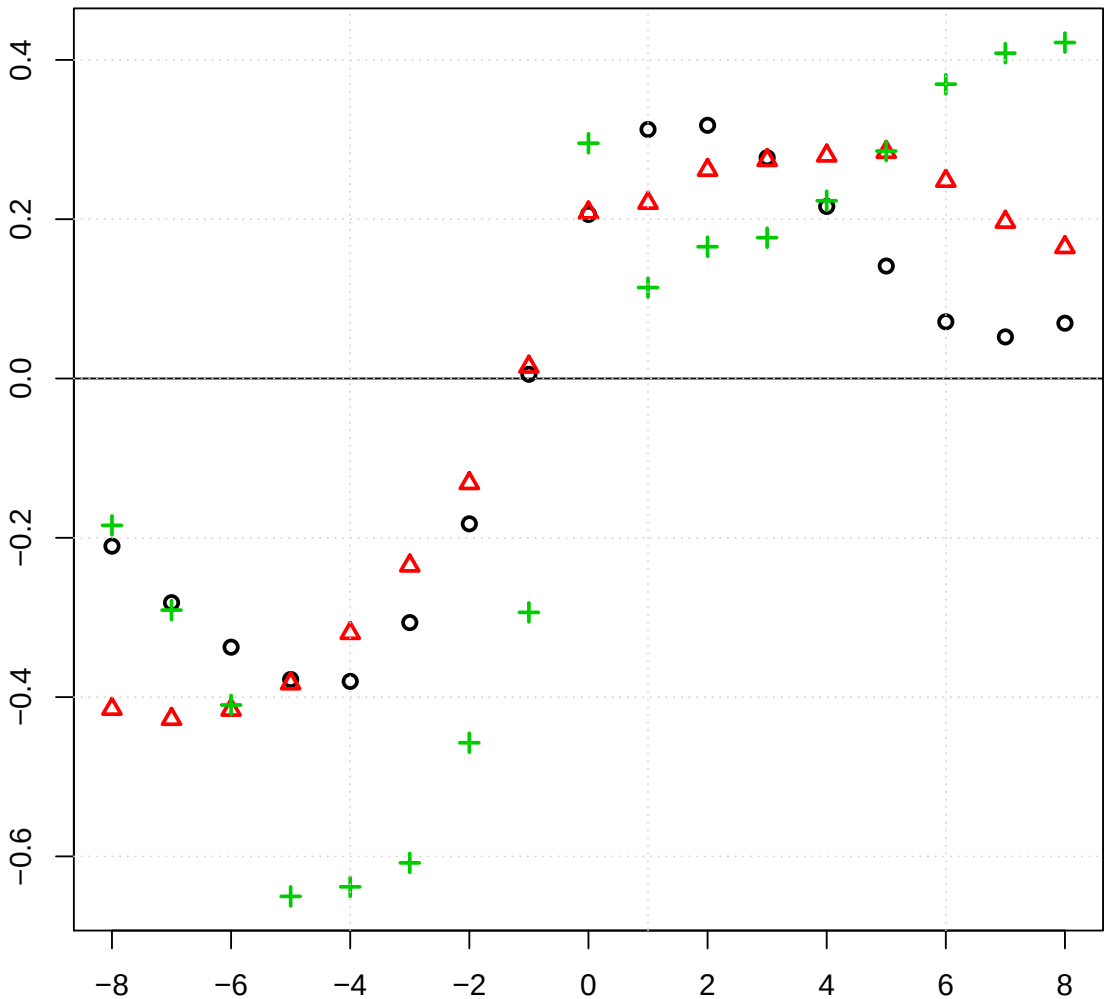
- *"International spillovers from the monetary policy of one country to other economies are a corollary of globalisation. ... policymakers, have to rise to the challenge of conducting monetary policy in the presence of these unintended side-effects."*
  Vítor Constâncio, Hong Kong, October 2015.

- *"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."*
  International Monetary Fund, 2014.

Global factors more important for Fed policy?

Motivation - Time variation

Correlation of de-trended US real GDP with lags and leads of Federal Funds Rate



1. Bretton Woods
2. Great moderation
3. Unconventional MP

Broad consensus that US **monetary policy transmission changes over time** (Sims and Zha, 2006, Primiceri, 2005, Boivin, 2006, Boivin et al., 2010). **Spillovers**?

Agenda

- **Research questions:**
  1. Does the global economy respond to US monetary policy shocks?
  2. Variation over time?
  3. Why are some countries more strongly affected, others less?
  4. Do US interest rates react to foreign shocks?

- **Econometrics:** **T**ime-**V**arying parameter **G**lobal **V**ector **A**uto**R**egression with **S**tochastic **V**olatility (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. In general, size of spillovers related to macroeconomic vulnerabilities, the exchange rate, FX exposure and capital account restrictions in the receiving economy
  4. 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:

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

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-SV-GVARs: Road map

The TVP-SV-GVAR model with a Cholesky structure

Estimate structural / Cholesky form of the model (Carriero et al., 2017, Lopes et al., 2013)

$+$ equation-by-equation estimation, exploits parallel computing

$\Rightarrow$ 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-SV-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 $\boldsymbol{D}_t = \text{diag}(\lambda_{i0,t}, \ldots, \lambda_{ik_i,t})$

The state equations of the TVP-SV-GVAR

For country model i we have

$$\boldsymbol{a}_{i,t} = \boldsymbol{a}_{i,t-1} + \varepsilon_{i,t} \qquad \varepsilon_{i,t} \sim \mathcal{N}(\mathbf{0}, \boldsymbol{V_i}) \tag{2}$$

$$\text{vec}(\boldsymbol{\Psi}_{i,t}) = \text{vec}(\boldsymbol{\Psi}_{i,t-1}) + \boldsymbol{\eta}_{i,t} \qquad \boldsymbol{\eta}_{i,t} \sim \mathcal{N}(\mathbf{0}, \boldsymbol{S_i}) \tag{3}$$

$$h_{il,t} = \mu_{il} + \rho_{il}(h_{il,t-1} - \mu_{il}) + \nu_{il,t} \qquad \nu_{il,t} \sim \mathcal{N}(0, \varsigma_{il}^2) \tag{4}$$

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:

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

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 $\boldsymbol{S}_i$:

$$\nu^2_{i,rr} \sim \mathcal{G}\left(\frac{1}{2}, \frac{1}{2B_\nu}\right), \quad r = 1, \ldots, l_i$$
$$s^2_{i,jj} \sim \mathcal{G}\left(\frac{1}{2}, \frac{1}{2B_s}\right), \quad j = 1, \ldots, K_i$$

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):

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

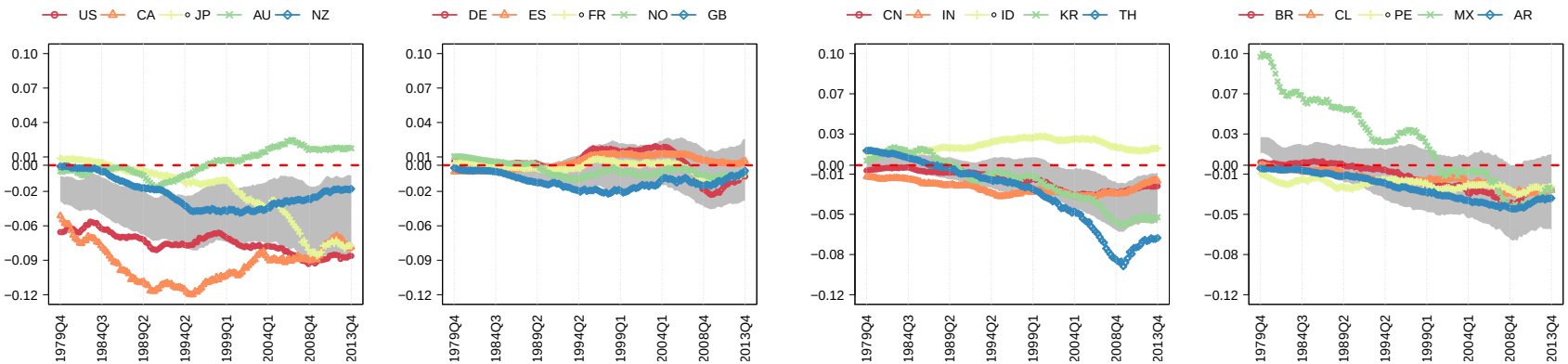
  This is the same ordering as used in the estimation stage of the local TVP-SV models.

- 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.

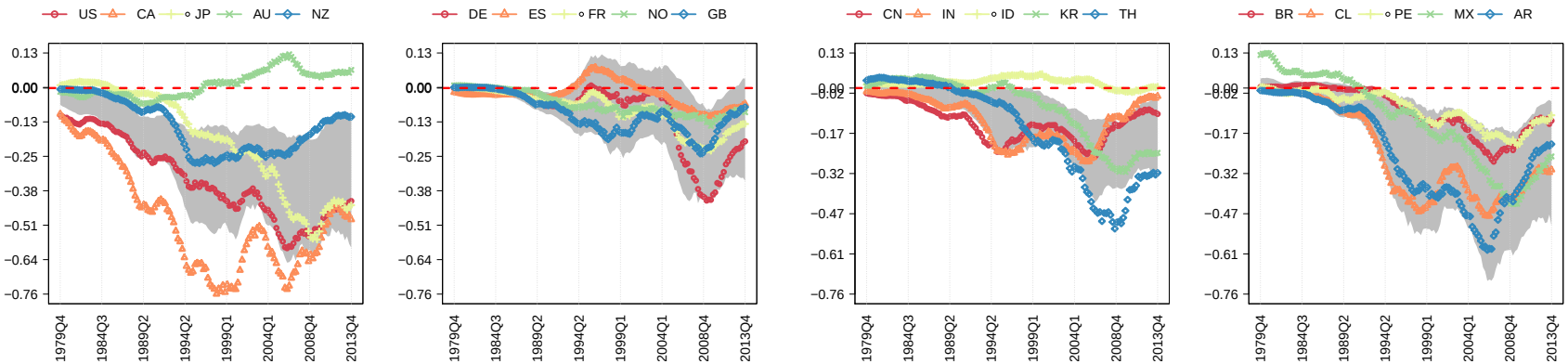
RESULTS I: International responses to +100 bp US MP shock

Real GDP growth (cumulative response)

$t = 1$

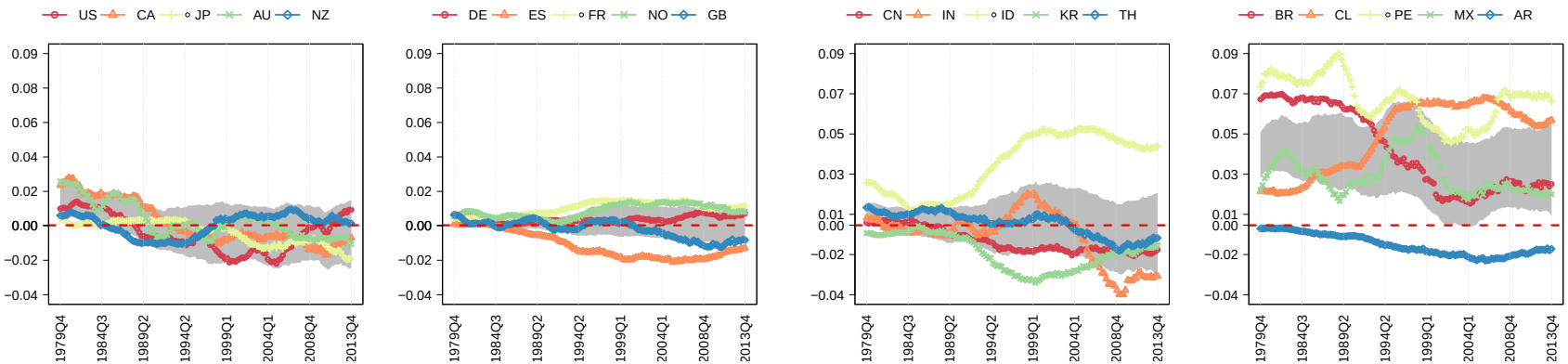


$t = 8$

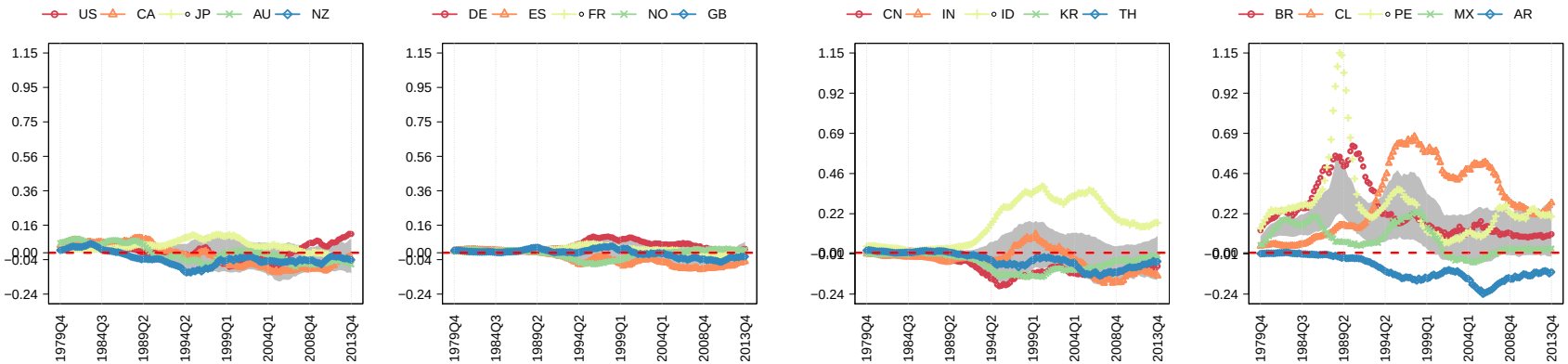


Inflation (cumulative response)

$t = 1$

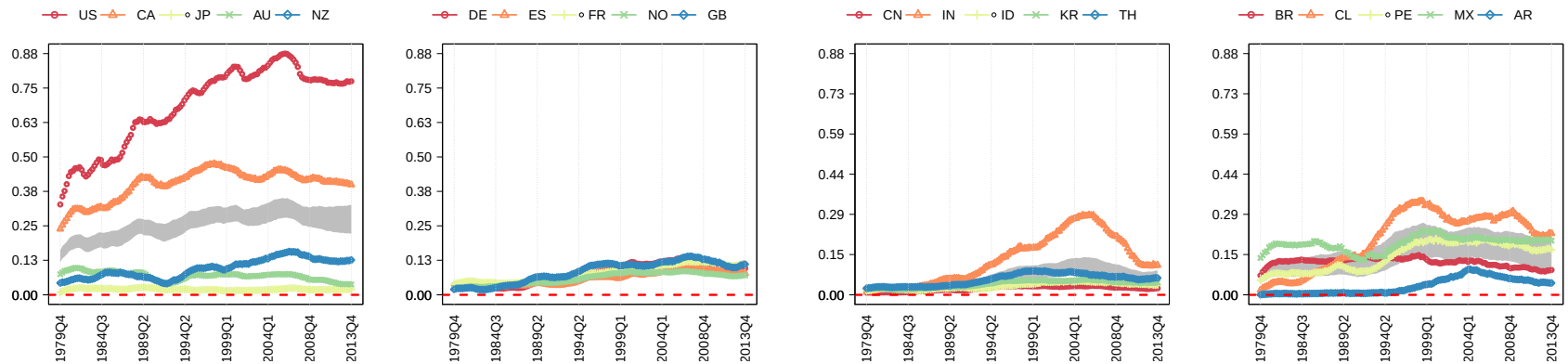


$t = 8$

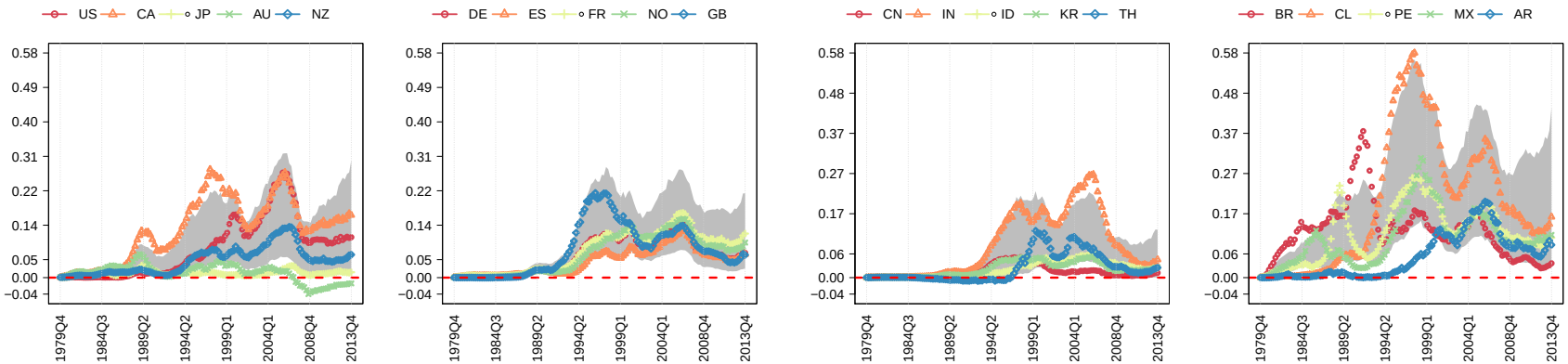


Short-term interest rates

$t = 1$



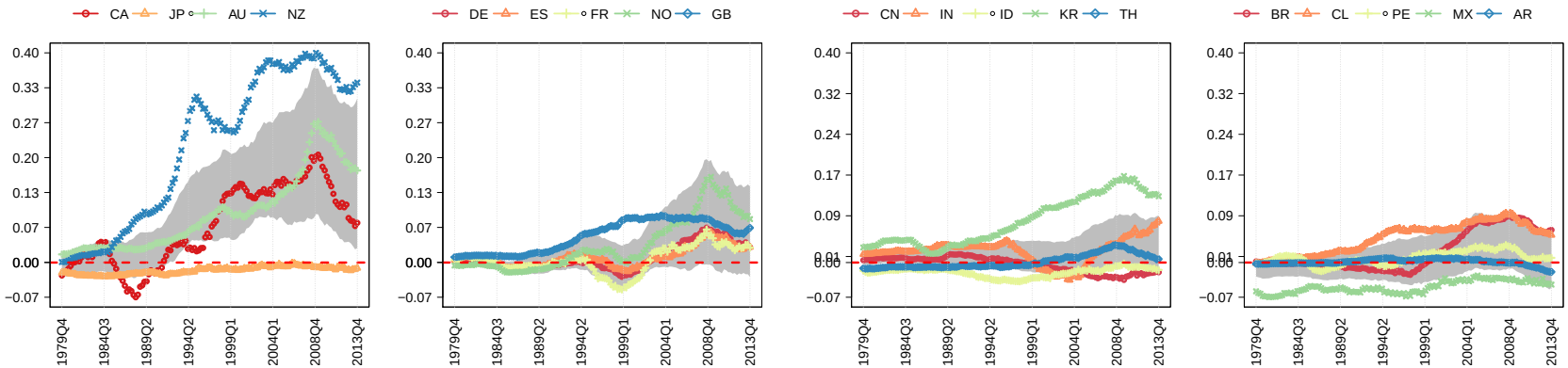
$t = 8$



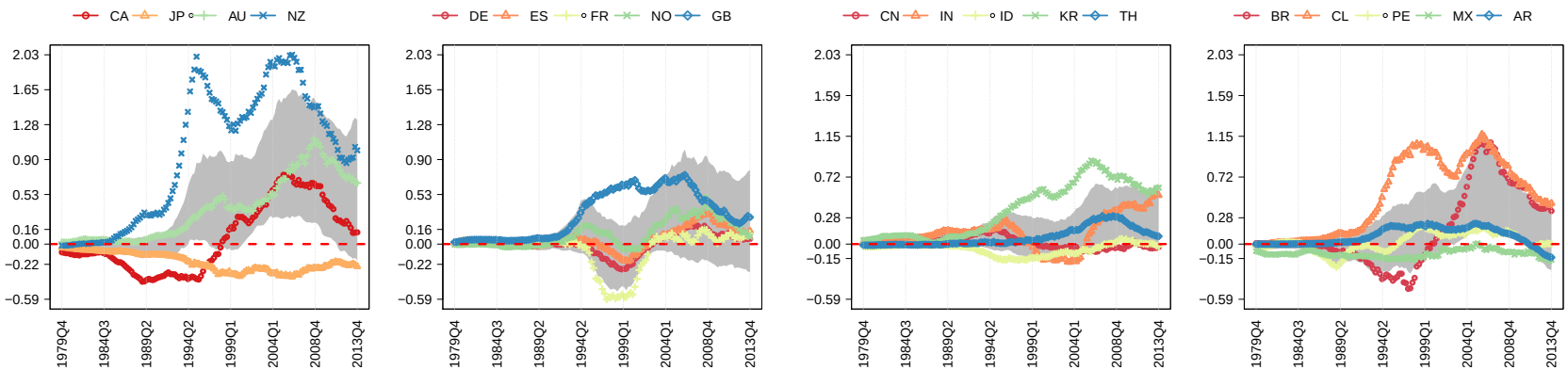
International response of real exchange rate

+ 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: Determinants of spillovers

Determinants of spillovers

Linear panel regression with country and time fixed effects

$$z_{it} = \alpha_t + \gamma_i + \beta_s X_{si,t} + u_{it},$$

z_{it} ... yearly averages of **absolute** cumulative spillovers to
$z_{it} \in \{\Delta y_{it}, \Delta p_{it}, \Delta e_{it}, i_{it}, s_{it}\}$

α_t and γ_i are time and country fixed effects, respectively.

$X_{si,t}$ a matrix containing s explanatory variables

Potential determinants (Georgiadis, 2016)

We collect annual data for 27 variables:

Exchange rate stability (10): Exchange rate (vis-a-vis US dollar), ER Volatility, Min Deviation, Max Deviation, Zero Change, Base Exchange Rate, Range, FX Exposure, FX Reserves, Asset Exposure

Macroeconomic and fiscal vulnerabilities (4): Current Account, Fiscal Deficit, Government Debt, Gross Savings

Financial depth and stability (6): Bank Credit to Deposits, Liquid Liabilities, Deposit Money, Financial Deposits, Private Credit

Financial and trade openness (7): Portfolio Assets, Portfolio Liability, Foreign Liabilities, FDI Assets, Foreign Assets, Capital Restrictions (inflow/outflow), Trade Openness

Bayesian model averaging (BMA)

- **Challenge:** For $K = 27$ covariates, 2^K different model specifications
- **Bayesian approach:** Average over models, any posterior statistic θ (e.g., regression coefficient, forecast, etc.):

$$E(\theta|D) = \sum_{s}^{2^K} E(\theta|D, M_s)\ p(M_s|D)$$

Weights via Bayes Rule $\Rightarrow$ **Posterior Model Probability** (PMP):

$$p(M_s|D) = \frac{p(D|M_s)p(M_s)}{p(D)} \propto \underbrace{p(D|M_s)}_{\text{marginal lik.}} \quad \underbrace{p(M_s)}_{\text{model prior}}$$

Posterior Inclusion Probabilities (PIP) for regressor i:
$p(x_i|D) = \sum_{s}^{2^K} \mathbf{1}(x_i \in M_s)p(M_s|D) \quad i \in \{1, \ldots, K\}$

BMA - prior setup

Zellner's g prior on slope coefficients (Fernández et al, 2001):

$$\beta_s|g,\sigma^2 \sim N(0, g\sigma^2(X_s'X_s)^{-1})$$

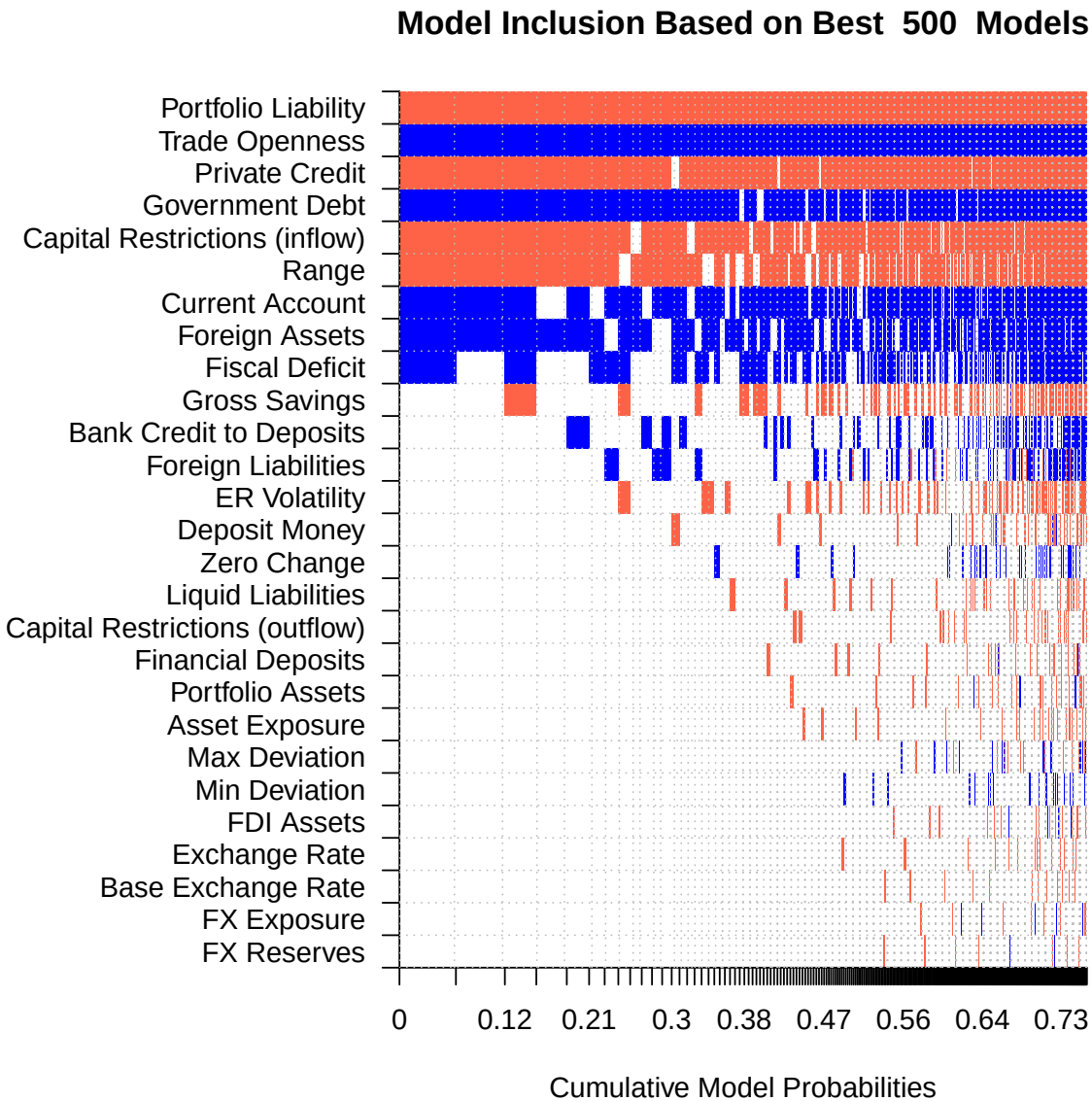
Binomial-beta prior on the model space (Ley and Steel, 2009):

$$p(M_s) = \theta^{k_s}(1-\theta)^{K-k_s}, \theta = \bar{m}/K$$

Estimated using `R` package `bms` (Zeugner and Feldkircher, 2015):
`https://cran.r-project.org/web/packages/BMS/index.html`

Illustration - Spillovers to real GDP growth

Blue positive and red negative coefficient



GDP growth & inflation

Spillovers to	*GDP growth*		*Inflation*	
	PIP	PM	PIP	PM
ER Volatility	0.0311	-0.0191	**1.0000**	-0.5593*
Range	**0.7588**	-0.0175*	**1.0000**	0.1016*
...	...	...	...	...
Current account def.	**0.8143**	0.0588*	0.0547	-0.0019
Fiscal deficit	**0.5312**	0.0005	0.3945	-0.0003
Gov. Debt	**0.9121**	0.0002*	0.0232	0.0000
Gross Savings	0.2829	-0.0002	**1.0000**	0.0013*
...	...	...	...	...
Deposit Money	0.0678	0.0000	**1.0000**	-0.0004*
Financial Deposits	0.045	0.0000	**0.8740**	0.0002*
Private Credit	**0.9517**	-0.0002*	**0.9989**	0.0004*
...	...	...	...	...
Capital restrictions (inflows)	**0.8696**	-0.0165*	0.0570	-0.0005
Portfolio Liability	**0.9997**	-0.0347*	0.0301	0.0002
Foreign Assets	**0.7272**	0.0033	0.1411	0.0004
Trade Openness	**0.9999**	0.0003*	**0.5359**	0.0001
...	...	...	...	...

Note: PIP=posterior inclusion probability, PM=posterior mean.

Real exchange rate & short-term int. rate

Spillovers to	*Real exchange rate*		*Short-term interest rate*	
	PIP	PM	PIP	PM
ER Volatility	0.0643	-0.0117	**1.0000**	-0.5821*
FX Exposure	**0.6979**	0.0414*	0.0812	0.0004
Min Deviation (appr. LC)	0.0196	0.0007	**0.9559**	-0.0694*
Max Deviation (depr. LC)	0.0423	-0.0019	**0.9985**	0.0972*
Asset Exposure	0.0663	0.0006	**0.5920**	-0.0021
Range	**0.7704**	0.0368*	**1.0000**	0.0481*
...	...	...	...	...
Fiscal Deficit	0.2650	0.0004	**0.9611**	-0.0004*
Government Debt	0.0177	0.0000	**0.9090**	0.0001*
Gross Savings	0.0695	-0.0001	**0.9904**	0.0004*
...	...	...	...	...
Deposit Money	0.0638	0.0000	**0.6039**	-0.0001
Financial Deposits	**1.0000**	0.0013*	0.1376	0.0000
Liquid Liabilities	**0.9833**	-0.0008*	0.1066	0.0000
Private Credit	0.1205	0.0000	**0.7169**	0.0001
...	...	...	...	...
Capital Restrictions (inflow)	**0.9631**	-0.0454*	0.1788	0.0008
...	...	...	...	...

Remarks – General patterns

Factors that **amplify** spillovers

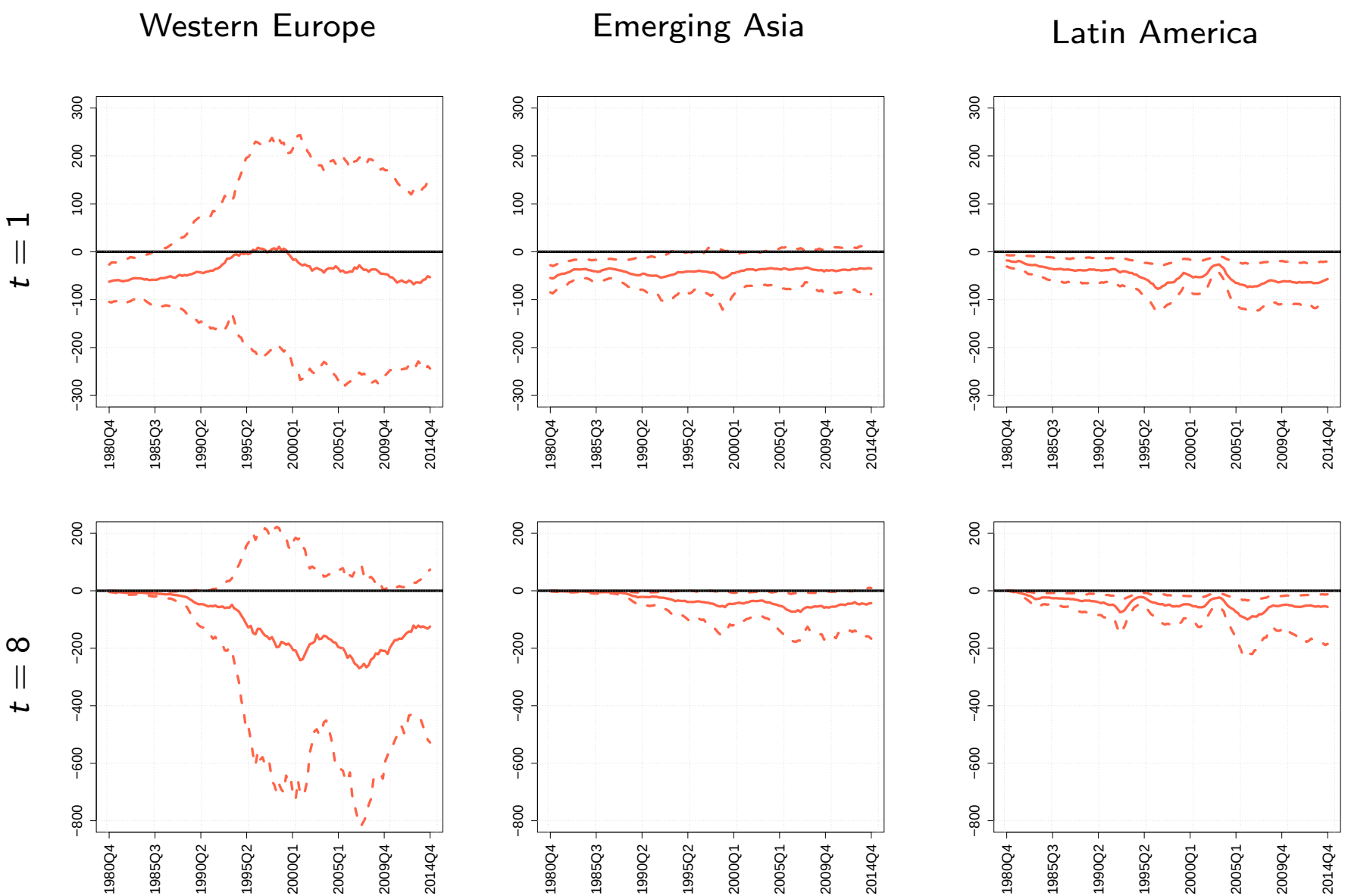
- trade openness
- gross savings (proxy for oil / gas exporters)
- macroeconomic vulnerabilities (gov. debt, current account balance)
- share of international reserves / FX exposure
- the range of exchange rate movements

Factors that **cushion** spillovers

- volatility of the exchange rate against the base country
- capital account restrictions

RESULTS III: 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			"Greenspan" regime 1987 - 2006			"Bernanke" regime 2006 - 2013		
		$Low_{0.25}$	Median	$High_{0.75}$	$Low_{0.25}$	Median	$High_{0.75}$	$Low_{0.25}$	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 develop 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.

2. **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

3. **Cross-country heterogeneity**
   No single determinant that explains spillovers to all variables equally well; some **general patterns** that emerge from the data

   Size of spillovers from US monetary policy **robustly related** to

   - the extent of **macroeconomic vulnerabilities** (gov. debt, current account balance, gross savings
   - **exchange rate** (exchange rate regime, exchange rate volatility)
   - **FX exposure** (FX reserves, FX exposure)
   - **capital account restrictions**
   - degree of **trade integration**

   Mixed results regarding **financial depth** and **financial stability**

Conclusions III

4. **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 decrease 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 Bayesian GVARs in `R`.
- Three 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)
  3. Normal-Gamma prior with stochastic volatility (Huber and Feldkircher, 2016)
- Parallel computing (via `snowfall`) and triangularization (Carriero et al., 2015)
- Impulse response analysis:
  1. Orthogonalized IRFs
  2. Generalized IRFs
  3. Sign restrictions
- Historical / forecast error variance decomposition
- Unconditional and conditional forecasts

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Backup slides

First layer: Estimation of country models

- Each country is modeled as a country-specific VAR augmented with the foreign variables (VARX)

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

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

Second layer: Stacking the single models

- After the country-by-country estimation of the VECMX we can proceed to the second step of the GVAR modelling strategy

  1. Recover the parameters of the VARX models
  2. Combine the VARX into a global model

- The resulting model will have the form of a standard VAR where all variables will be "endogenous"

- This is a purely mechanical step: **no estimation is involved!**

Second layer: Stacking the single models

- VARX(1,1): $x_{it} = \Phi_{i1} x_{i,t-1} + \Lambda_{i0} x^*_{it} + \Lambda_{i1} x^*_{i,t-1} + \varepsilon_{it}$
- Use link matrix $\mathcal{W}_i$ and selection matrix S_i

$$S_i x_t = \Phi_{i1} S_i x_{t-1} + \Lambda_{i0} \mathcal{W}_i x_t + \Lambda_{i1} \mathcal{W}_i x_{t-1} + \varepsilon_{it}$$

$$\underbrace{(S_i - \Lambda_{i0} \mathcal{W}_i)}_{G_i} x_t = \underbrace{(\Phi_{i1} S_i + \Lambda_{i1} \mathcal{W}_i)}_{H_i} x_{t-1} + \varepsilon_{it}$$

$$G_i x_t = H_i x_{t-1} + \varepsilon_{it}$$

- Stack all country-specific models

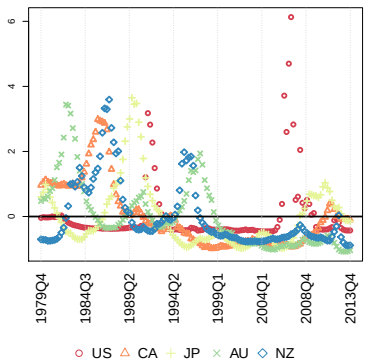
$$G x_t = H x_{t-1} + e_t$$

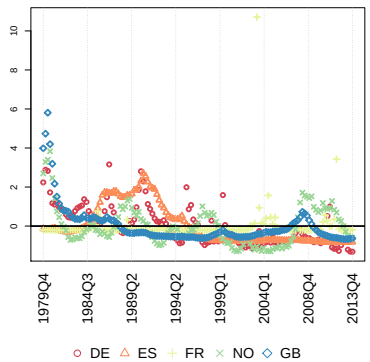
- The **GVAR** model

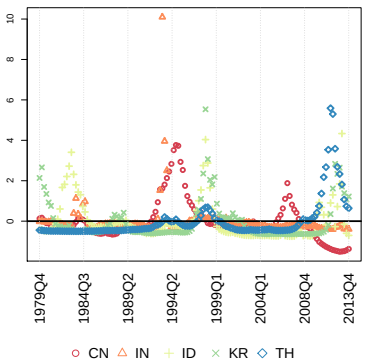
$$x_t = \underbrace{F x_{t-1}}_{F = G^{-1} H} + \underbrace{\tilde{e}_t}_{G^{-1} e_t}$$

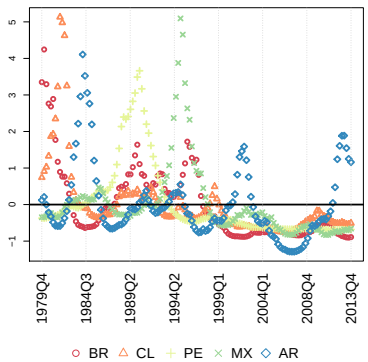
Stochastic volatility over time

Real GDP growth

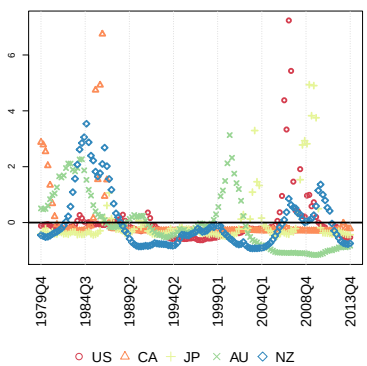


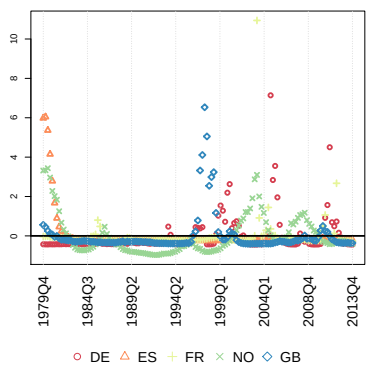


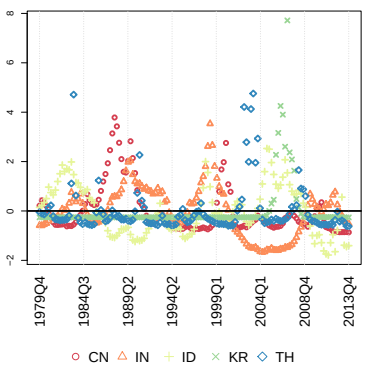


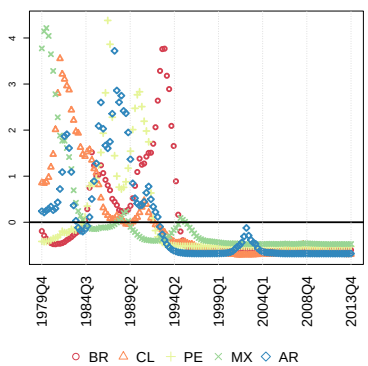


Inflation



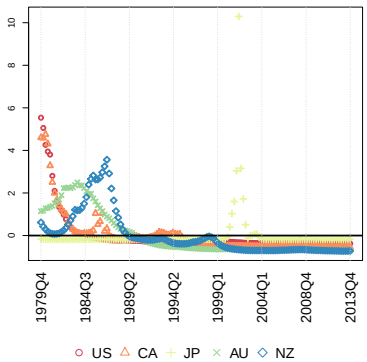


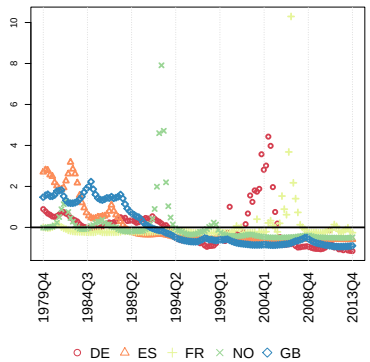


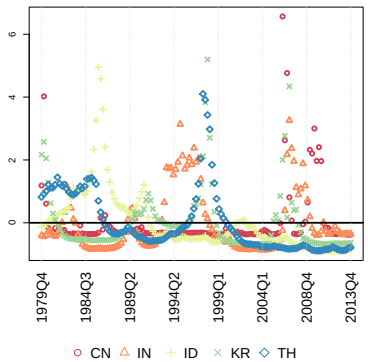


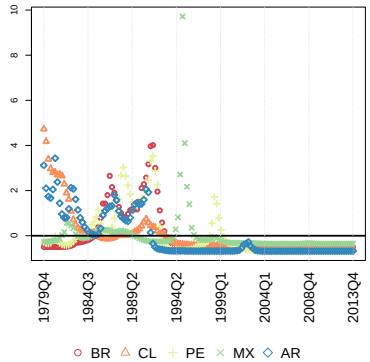
Stochastic volatility over time

Short-term interest rate









Real exchange rate