Assessing the effect of US Monetary Policy Normalization on Latin American Economies

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The views expressed are those of the author and do not necessarily reflect those of the Central Bank of Peru.

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This paper in a nutshell

1. **Main purpose:** Estimate the spillover effects of US policy tightening after the end of the Great Financial Crisis (GFC) in a sample of Latin American Countries (some ITers): Chile, Colombia, Mexico and Peru.
2. **Empirical strategy:** Hierarchical Panel VAR with an exogenous block that considers the US and Global variables. Model estimated with Bayesian MCMC methods for the sample 2001-2018. Structural shocks (FFR and demand) identified through zero and sign restrictions.
3. **Main results/contribution:** US policy tightening produces on average a rise in domestic interest rates, the EMBI spread, an increase in the growth rate of the monetary base and a higher depreciation that leads to a fall in Central Bank Reserves. After that, we observe a fall in domestic credit and the trade balance. Finally, we observe an ambiguous effect in activity and rise in inflation.

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Motivation(1)

- As a response of the Financial Crisis of 2008, the Federal Reserve of the United States (Fed) lowered the Federal Funds Rate (FFR) until reaching the Zero Lower Bound (ZLB).

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- The Fed started using alternative instruments in order to get a looser monetary policy. In particular, the Fed started increasing the size of its balance sheet (Cúrdia and Woodford, 2011) and lowering long term interest rates (Baumeister and Benati, 2013).
- The Quantitative Easing (QE) produced significant nominal and real effects over several macroeconomic variables around the globe, both in advanced economies (Baumeister and Benati, 2013) and also in emerging economies (see e.g. Carrera *et al.* (2015), among others).

Motivation(2)

- After seven years of the application of the Quantitative Easing, the Fed has started removing the monetary stimulus, first with the *Tapering Talk* in May of 2013, and then raising the FFR since December 2015.

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- Monetary Policy normalization actions are centered in i) Raising short-term interest rates, ii) Raising the *spread* between long and short-term interest rates, and iii) Reducing the size of the Fed's Balance Sheet (Williamson, 2015).
- It is important to isolate the surprise component of this policy action: make the difference between the systematic and non-systematic component.

Motivation(3)

- The main purpose of this paper is to identify the dynamic effects of changing the monetary stance, which is different than the systematic reaction of the Fed after demand shocks, i.e. the typical Taylor rule that can be found in popular textbooks related with monetary policy (see e.g. Woodford (2003) and Gali (2015)).

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- We focus our attention on LATAM countries that apply the Inflation Targeting scheme (see e.g. Pérez Forero (2015)).

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- Shocks affecting the US can be transmitted to the Latin American Countries through an exogenous block (Cushman and Zha, 1997; Zha, 1999; Canova, 2005) in a Panel VAR setup (Gondo and Pérez Forero, 2018).
- Estimation is performed using Bayesian Methods via Gibbs sampling (Zellner, 1971; Koop, 2003; Canova, 2007; Koop and Korobilis, 2010).

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- An identified US interest rate shock produces a typical textbook effect, i.e. an increase in the FFR is followed by a fall in money growth, output and inflation. In addition, this shock is transmitted to the small open economy and produces a nominal depreciation and a positive reaction of the domestic interest rate.

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- An identified US interest rate shock produces a typical textbook effect, i.e. an increase in the FFR is followed by a fall in money growth, output and inflation. In addition, this shock is transmitted to the small open economy and produces a nominal depreciation and a positive reaction of the domestic interest rate.
- Moreover, the tighter external monetary policy produces, a negative effect in aggregate credit, and a positive effect in inflation. Our results are in line with Canova (2005) and, we take into account the Unconventional Monetary Policy (UMP) period when performing the estimation by introducing the yield curve spread.

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The model

Consider the set of countries $n = 1, \ldots, N$, where each country n is represented by a VAR model with exogenous variables:

$$y_{n,t} = \sum_{l=1}^{p} B'_{n,l} y_{n,t-l} + \sum_{l=0}^{p} B^{*\prime}_{n,l} y^{*}_{t-l} + \Delta_n z_t + u_{n,t} \tag{1}$$

where $y_{n,t}$ is a $M_1 \times 1$ vector of endogenous domestic variables, y^*_t is a $M_2 \times 1$ vector of endogenous domestic variables, z_t is a $W \times 1$ vector of exogenous variables common to all countries, $u_{n,t}$ is a $M_1 \times 1$ vector of reduced form shocks such that $u_{n,t} \sim N\left(\mathbf{0}, \Sigma_n\right)$, $E\left(u_{n,t} u'_{m,t}\right) = \mathbf{0}, n \neq m$ $\in \{1, \ldots, N\}$, p is the lag length and T_n is the sample size for each country $n \in \{1, \ldots, N\}$.

The model

At the same time, there exists an exogenous block that evolves independently and is common for all countries $n = 1, \ldots, N$, such that

$$y_t^* = \sum_{l=1}^{p} \Phi_l^{*\prime} y_{t-l}^* + \Delta^* z_t + u_t^* \tag{2}$$

with $u_t^* \sim N\left(\mathbf{0}, \Sigma^*\right)$ and $E\left(u_t^* u_{n,t}^\prime\right) = \mathbf{0}$.

A more compact form

For each country $n \in \{1, \ldots, N\}$ such that:

$$\begin{bmatrix} \mathbf{I}_{M_1} & -B^{*\prime}_{n,0} \\ \mathbf{0} & \mathbf{I}_{M2} \end{bmatrix} \begin{bmatrix} y_{n,t} \\ y^*_t \end{bmatrix} = \sum_{i=1}^{p} \begin{bmatrix} B'_{n,l} & B^{*\prime}_{n,l} \\ \mathbf{0} & \Phi^{*\prime}_l \end{bmatrix} \begin{bmatrix} y_{n,t} \\ y^*_t \end{bmatrix} + \begin{bmatrix} \Delta_n \\ \Delta^* \end{bmatrix} z_t + \begin{bmatrix} \Sigma_n & \mathbf{0} \\ \mathbf{0} & \Sigma^* \end{bmatrix} \begin{bmatrix} u_{n,t} \\ u^*_t \end{bmatrix},$$

System (1) represents the small open economy (SOE) in which its dynamics are influenced by the big economy block (2), but (2) is independent of block (1). This type of *Block Exogeneity* has been applied in the context of SVARs by Cushman and Zha (1997), Zha (1999) and Canova (2005), among others.

Priors I

We assume a normal prior for β_n in order get a posterior distribution that is also normal, i.e. a conjugated prior:

$$p\left(\beta_n \mid \overline{\beta}, O_n, \tau\right) = N\left(\overline{\beta}, \tau O_n\right) \tag{3}$$

with $\overline{\beta}$ as the common mean and τ as the overall tightness parameter. The covariance matrix O_n takes the form of the typical Minnesota prior (Litterman, 1986), i.e. $O_n = diag\left(o_{ij,l}\right)$ such that

$$o_{ij,l} = \begin{cases} \frac{1}{l^{\phi_3}} & , i = j \\ \frac{\phi_1}{l^{\phi_3}}\left(\frac{\widehat{\sigma}_j^2}{\widehat{\sigma}_i^2}\right) & , i \neq j \\ \phi_2 & , exogenous \end{cases}$$

where

$$i, j \in \{1, \ldots, M_1\} \text{ and } l = 1, \ldots, p$$

Priors II

and where $\widehat{\sigma}_j^2$ is the variance of the residuals from an estimated $AR(p)$ model for each variable $j \in \{1, \ldots, M_1\}$. In addition, we assume the non-informative priors:

$$p\left(\Sigma_n\right) \propto \left|\Sigma_n\right|^{-\frac{1}{2}(M_1+1)} \tag{4}$$

that are supposed to be calibrated. In turn, in a Hierarchical context (Gelman *et al.*, 2003), it is possible to estimate the posterior distribution of hyper-parameters $\overline{\beta}$ and τ. We assume an inverse-gamma prior distribution for τ (Gelman, 2006; Jarociński, 2010).

$$p\left(\tau\right) = IG\left(\frac{\upsilon}{2}, \frac{s}{2}\right) \propto \tau^{-\frac{\upsilon+2}{2}} \exp\left(-\frac{1}{2}\frac{s}{\tau}\right) \tag{5}$$

Finally, we assume the non-informative prior:

$$p\left(\overline{\beta}\right) \propto 1 \tag{6}$$

Priors III

In addition, coefficients of the exogenous block have a traditional Litterman prior with

$$p\left(\beta^{*}\right)=N\left(\overline{\beta^{*}},\tau_{X}O_{X}\right) \tag{7}$$

where $\overline{\beta^{*}}$ assumes a random walk for each variable and $O_X = diag\left(o^{*}_{ij,l}\right)$ such that

$$o^{*}_{ij,l}=\begin{cases}\frac{1}{l^{\phi_3}} & ,i=j\\ \frac{\phi_1}{l^{\phi_3}}\left(\frac{\widehat{\sigma}^2_j}{\widehat{\sigma}^2_i}\right) & ,i\neq j\\ \phi_2 & ,exogenous\end{cases}$$

where

$$i,j\in\{1,\ldots,M_2\} \text{ and } l=1,\ldots,p$$

Priors IV

and similarly $\widehat{\sigma}_j^2$ is the variance of the residuals from an estimated $AR(p)$ model for each variable $j \in \{1, \ldots, M_2\}$. As in the domestic block, we assume the non-informative priors:

$$p\left(\Sigma^*\right) \propto \left|\Sigma^*\right|^{-\frac{1}{2}(M_2+1)} \tag{8}$$

We also estimate the overall tightness parameter as in the domestic block, so that

$$p\left(\tau_X\right) = IG\left(\frac{\upsilon_X}{2}, \frac{s_X}{2}\right) \propto \tau_X^{-\frac{\upsilon_X+2}{2}} \exp\left(-\frac{1}{2}\frac{s_X}{\tau_X}\right) \tag{9}$$

As a result of the hierarchical structure, our statistical model presented has several parameter blocks, so that

$$\Theta = \left\{\{\beta_n, \Sigma_n\}_{n=1}^{N}, \beta^*, \Sigma^*, \tau, \overline{\beta}, \tau_X\right\}$$

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Bayesian Estimation

Given the specified priors and the joint likelihood function (30) - (32), we combine efficiently these two pieces of information in order to get the estimated parameters included in Θ. Using the Bayes' theorem we have that:

$$p\left(\Theta \mid Y\right) \propto p\left(Y \mid \Theta\right) p\left(\Theta\right) \tag{10}$$

Gibbs Sampling

Recall that $\Theta = \left\{ \{\beta_n, \Sigma_n\}_{n=1}^{N}, \beta^*, \Sigma^*, \tau, \overline{\beta}, \tau_X \right\}$. Set $k = 1$ and denote K as the total number of draws. Then follow the steps below:

1. Draw $p\left(\beta^* \mid \Theta/\beta^*, \mathbf{y}^*, \mathbf{y}_n\right)$. If the candidate draw is stable keep it, otherwise discard it.
2. For $n = 1, \ldots, N$ draw $p\left(\beta_n \mid \Theta/\beta_n, \mathbf{y}^*, \mathbf{y}_n\right)$. If the candidate draw is stable keep it, otherwise discard it.
3. Draw $p\left(\Sigma^* \mid \Theta/\Sigma^*, \mathbf{y}^*, \mathbf{y}_n\right)$.
4. For $n = 1, \ldots, N$ draw $p\left(\Sigma_n \mid \Theta/\Sigma_n, \mathbf{y}^*, \mathbf{y}_n\right)$.
5. Draw $p\left(\tau_X \mid \Theta/\tau_X, Y\right)$.
6. Draw $p\left(\overline{\beta} \mid \Theta/\overline{\beta}, Y\right)$. If the candidate draw is stable keep it, otherwise discard it.
7. Draw $p\left(\tau \mid \Theta/\tau, Y\right)$.
8. If $k < K$ set $k = k + 1$ and return to Step 1. Otherwise stop.

Estimation Setup

1. We run the Gibbs sampler for $K = 1,050,000$, discard the first $50,000$ draws and set a thinning factor of $1,000$. As a result, we have $1,000$ draws for conducting inference.
2. Following Gelman (2006) and Jarociński (2010), we assume a uniform prior for the standard deviation, which translates into

$$p(\tau) \propto \tau^{-1/2} \quad (11)$$

   by setting $v = -1$ and $s = 0$ in (5).
3. Regarding the Minnesota-stye prior, we set a conservative $\phi_1 = \phi_2 = \phi_3 = 1$.

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Identification

We impose the following restrictions:

- The first group is related with zero restrictions in the contemporaneous coefficients matrix, as in the old literature of Structural VARs, i.e. Sims (1980) and Sims (1986).

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- The first group is related with zero restrictions in the contemporaneous coefficients matrix, as in the old literature of Structural VARs, i.e. Sims (1980) and Sims (1986).
- The second group are the sign restrictions as in Canova and De Nicoló (2002) and Uhlig (2005), where we set a horizon of three months.

Identification

Var / Shock	Name	FFR shock	Demand shock
Domestic Block	$\mathbf{y}$	?	?
EPU index	EPU_{US}	?	?
IP growth	IP_{US}	$\leqslant 0$	$\geqslant 0$
CPI Inflation Rate	CPI_{US}	$\leqslant 0$	$\geqslant 0$
Federal Funds Rate	FFR	$\geqslant 0$	$\geqslant 0$
M1 Growth	$M1_{US}$	$\leqslant 0$	?
SPREAD	$SPREAD_{LT-ST}$	$\geqslant 0$	?
Commodity prices	$Pcom$	?	?
Oil prices	WTI	?	?

Table: Identifying Restrictions

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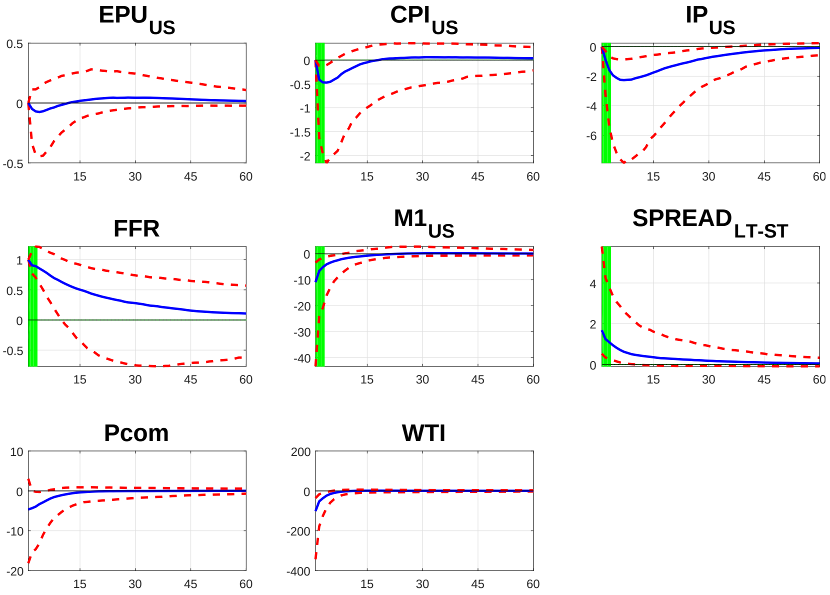

Figure: Response of U.S. variables after a Monetary policy shock; median value (solid line) and 68% bands (dotted lines)

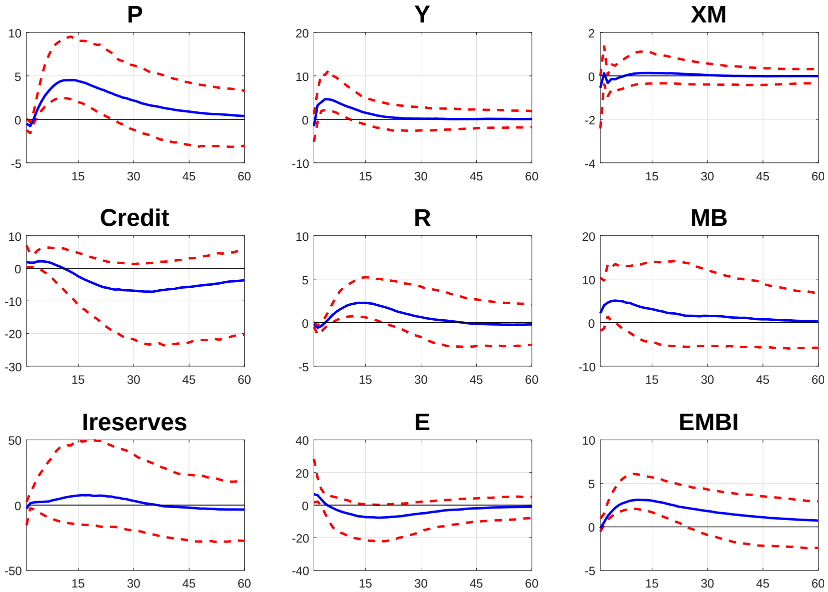

Figure: Average Response of LATAM variables after a US Monetary Policy shock; median value and 68% bands

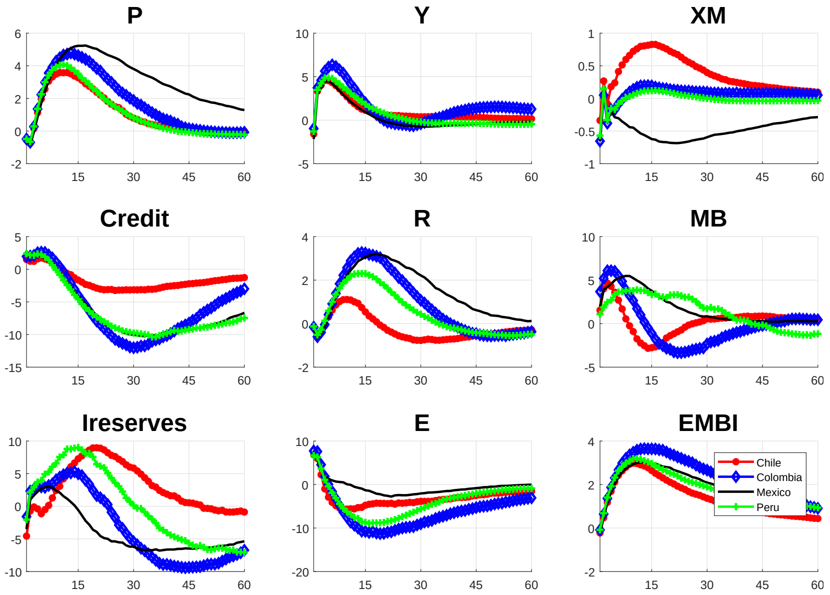

Figure: Response of LATAM variables after a US Monetary policy shock; median values

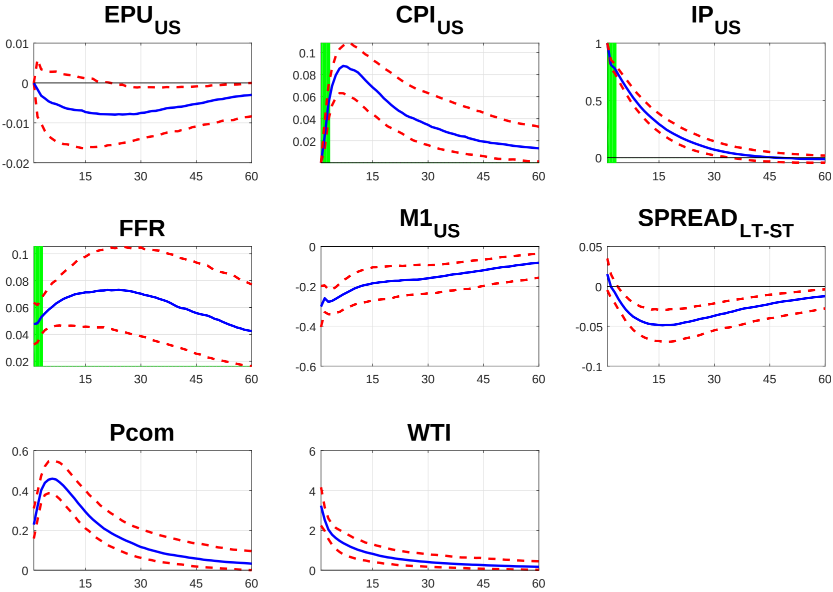

Figure: Response of U.S. variables after a demand shock; median value (solid line) and 68% bands (dotted lines)

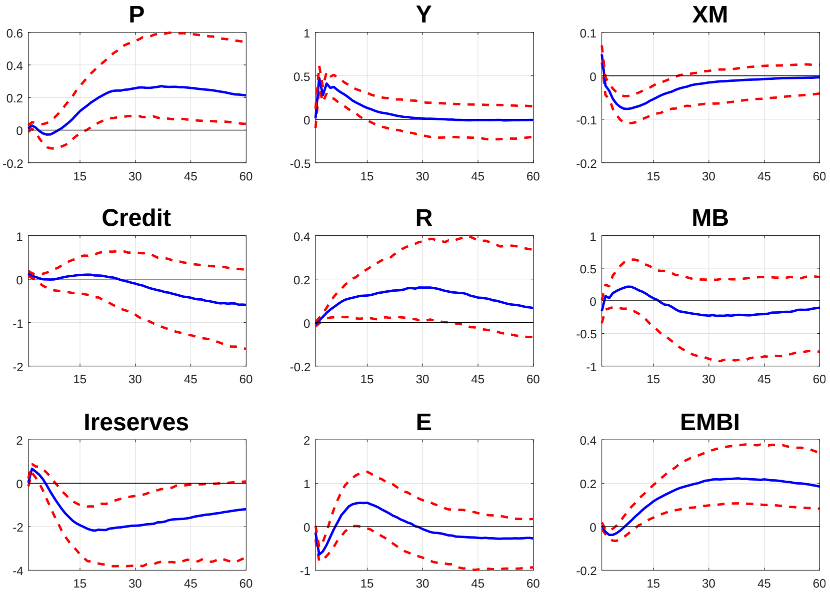

Figure: Average Response of LATAM variables after a demand shock; median value (solid line) and 68% bands (dotted lines)

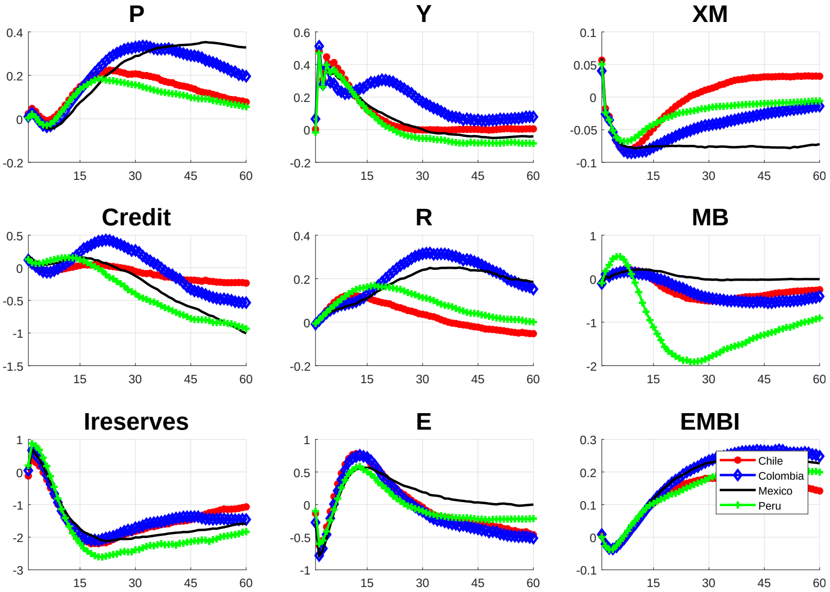

Figure: Response of LATAM variables after a US demand shock; median values

Concluding Remarks (1)

- We have estimated the potential effect in Latin American Economies of a normalization in the US monetary policy with a Panel Vector Autorregressive model.

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- Results are similar across different economies and must be taken with caution, since they are preliminary. The increase in the FFR is very persistent, and this is because the initial point is very close to zero. Moreover, it produces the usual liquidity effect, a contraction in US economic activity and a decrease in the CPI inflation. Second, demand shocks trigger a rise in US interest rate, and this is in line with a predictable monetary policy.

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- Results are similar across different economies and must be taken with caution, since they are preliminary. The increase in the FFR is very persistent, and this is because the initial point is very close to zero. Moreover, it produces the usual liquidity effect, a contraction in US economic activity and a decrease in the CPI inflation. Second, demand shocks trigger a rise in US interest rate, and this is in line with a predictable monetary policy.
- Regarding Latin American economies, we study the case of Chile, Colombia, Mexico and Peru. Given the considerable amount of uncertainty regarding the effect these shocks, we use Bayesian techniques in order to properly assess the confidence intervals of the associated impulse responses.

Concluding Remarks (2)

- Results show that a US normalization shock (either through the interest rate of a demand shock) produces a nominal depreciation and a positive reaction of the domestic interest rate and the risk premium. Furthermore, in most cases the identified external monetary shock produces a negative effect in the aggregate credit and the trade balance, and a positive effect in inflation.

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- On the other hand, given the reduced span of data (2001-2018), it is natural to observe a considerable amount of uncertainty in the estimated dynamic effect.
- Overall, in terms of the the contribution of the paper, we use an efficient approach in order to assess the spillover effects of US Monetary Policy Normalization in LATAM economies from the data, an event that is still a current issue for Latin American Policy makers, especially for Central Banks. This is not an easy task and deserves more attention in the literature.

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- Nevertheless, so far we consider that we have imposed enough restrictions in order to properly identify and isolate the two structural shocks mentioned in this document.

Reduced-form estimation

Assuming that we have a sample $t = 1, \ldots, T$, the regression model for the domestic block can be re-expressed as

$$Y_n = X_n B_n + U_n \tag{12}$$

Where we have the data matrices $Y_n \, (T_n \times M_1)$, $X_n \, (T_n \times K)$, $U_n \, (T_n \times M_1)$, with $K = M_1 p + W$ and the corresponding parameter matrix $B_n \, (K \times M_1)$. In particular

$$B_n = \begin{bmatrix} B'_{n,1} & B'_{n,2} & \cdots & B'_{n,p} & B^{*\prime}_{n,1} & B^{*\prime}_{n,2} & \cdots & B^{*\prime}_{n,p} & \Delta'_n \end{bmatrix}'$$

Reduced-form estimation

The model in equation (12) can be re-written such that

$$\mathbf{y}_n = \left(I_{M_1} \otimes X_n\right) \beta_n + \mathbf{u}_n$$

where $\mathbf{y}_n = vec\left(Y_n\right)$, $\beta_n = vec\left(B_n\right)$ and $\mathbf{u}_n = vec\left(U_n\right)$ with

$$\mathbf{u}_n \sim N\left(0, \Sigma_n \otimes I_{T_n - p}\right)$$

Under the normality assumption of the error terms, we have the likelihood function for each country

$$p\left(\mathbf{y}_n \mid \beta_n, \Sigma_n\right) = N\left(\left(I_{M_1} \otimes X_n\right) \beta_n, \Sigma_n \otimes I_{T_n - p}\right)$$

which is

$$p\left(\mathbf{y}_n \mid \beta_n, \Sigma_n\right) = \left(2\pi\right)^{-M_1\left(T_n - p\right)/2} \left|\Sigma_n \otimes I_{T_n - p}\right|^{-1/2} \times$$
$$\exp\left(-\frac{1}{2}\left(\mathbf{y}_n - \left(I_{M_1} \otimes X_n\right)\beta_n\right)' \left(\Sigma_n \otimes I_{T_n - p}\right)^{-1} \left(\mathbf{y}_n - \left(I_{M_1} \otimes X_n\right)\beta_n\right)\right) \tag{13}$$

where $n = 1, \ldots, N$.

Reduced-form estimation

In order to estimate the exogenous block, rewrite equation (2) as a regression model

$$Y^* = X^*\Phi^* + U^*$$

Where we have the data matrices $Y^*\,(T^* \times M_2)$, $X^*\,(T^* \times K^*)$, $U^*\,(T^* \times M_2)$, with $K^* = M_2 p + W$ and the corresponding parameter matrix $\Phi^*\,(K^* \times M_2)$. In particular

$$\Phi^* = \left[\begin{array}{cccccc} \Phi_1^{*\prime} & \Phi_2^{*\prime} & \cdots & \Phi_p^{*\prime} & \Delta^{*\prime} \end{array}\right]'$$

The model in equation (2) can be re-written such that

$$\mathbf{y}^* = \left(I_{M_2} \otimes X^*\right)\beta^* + \mathbf{u}^*$$

where $\mathbf{y}^* = vec\,(Y^*)$, $\beta^* = vec\,(\Phi^*)$ and $\mathbf{u}^* = vec\,(U^*)$ with

$$\mathbf{u}^* \sim N\left(0, \Sigma^* \otimes I_{T^*-p}\right)$$

Reduced-form estimation

Under the normality assumption of the error terms, we have the likelihood function for the exogenous block

$$p\left(\mathbf{y}^* \mid \beta^*, \Sigma^*\right) = N\left(\left(I_{M_2} \otimes X^*\right)\beta^*, \Sigma^* \otimes I_{T^*-p}\right)$$

which is

$$\begin{array}{c} p\left(\mathbf{y}^* \mid \beta^*, \Sigma^*\right) = (2\pi)^{-M_2(T^*-p)/2}\left|\Sigma^* \otimes I_{T^*-p}\right|^{-1/2} \times \\ \exp\left(\begin{array}{c} -\frac{1}{2}\left(\mathbf{y}^* - \left(I_{M_2} \otimes X^*\right)\beta^*\right)'\left(\Sigma^* \otimes I_{T^*-p}\right)^{-1} \\ \left(\mathbf{y}_n - \left(I_{M_2} \otimes X^*\right)\beta^*\right) \end{array}\right) \end{array} \tag{14}$$

Reduced-form estimation

The statistical model described by (30) and (32) has a joint likelihood function. Denote $\Theta = \left\{ \{\beta_n, \Sigma_n\}_{n=1}^{N}, \beta^*, \Sigma^* \right\}$ as the set of parameters, then the likelihood function is

$$p(\mathbf{y}, \mathbf{y}^* \mid \Theta) \propto |\Sigma^*|^{-T^*/2} \prod_{n=1}^{N} |\Sigma_n|^{-T_n/2} \times$$

$$\exp\left(\begin{array}{c} -\frac{1}{2} \sum_{n=1}^{N} (\mathbf{y}_n - (I_{M_1} \otimes X_n)\beta_n)' (\Sigma_n \otimes I_{T_n - p})^{-1} \times \\ (\mathbf{y}_n - (I_{M_1} \otimes X_n)\beta_n) \\ -\frac{1}{2} (\mathbf{y}^* - (I_{M_2} \otimes X^*)\beta^*)' (\Sigma^* \otimes I_{T^* - p})^{-1} \times \\ (\mathbf{y}_n - (I_{M_2} \otimes X^*)\beta^*) \end{array} \right) \quad (15)$$

Priors

The joint prior is given by (3), (4), (5), (6), (7), (8) and (9), so that

$$
\begin{aligned}
p(\Theta) \propto & \prod_{n=1}^{N} p(\Sigma_n)\, p\left(\beta_n \mid \overline{\beta}, O_n, \tau\right) p(\tau) \\
= & \prod_{n=1}^{N} |\Sigma_n|^{-\frac{1}{2}(M_1+1)} \times \\
& \tau^{-\frac{NM_1K}{2}} \exp\left(-\frac{1}{2}\sum_{n=1}^{N}\left(\beta_n - \overline{\beta}\right)'\left(\tau^{-1}O_n\right)^{-1}\left(\beta_n - \overline{\beta}\right)\right) \times \\
& \tau^{-\frac{\upsilon+2}{2}} \exp\left(-\frac{1}{2}\frac{s}{\tau}\right) \times \\
& |\Sigma^*|^{-\frac{1}{2}(M_2+1)} \times \\
& \tau_X^{-\frac{M_2K^*}{2}} \exp\left(-\frac{1}{2}\left(\beta^* - \overline{\beta^*}\right)'\left(\tau_X^{-1}O_X\right)^{-1}\left(\beta^* - \overline{\beta^*}\right)\right) \times \\
& \tau_X^{-\frac{\upsilon_X+2}{2}} \exp\left(-\frac{1}{2}\frac{s_X}{\tau_X}\right)
\end{aligned} \tag{16}
$$

Gibbs sampling details I

The algorithm described in subsection **??** uses a set of conditional distributions for each parameter block. Here we provide specific details about the form that these distributions take and how they are constructed.

1. Block 1: $p\left(\beta^* \mid \Theta/\beta^*, \mathbf{y}^*\right)$: Given the likelihood (32) and the prior

$$p\left(\beta^* \mid \overline{\beta^*}, \tau\right) = N\left(\overline{\beta^*}, \tau_X O_X\right)$$

then the posterior is Normal

$$p\left(\beta^* \mid \Theta/\beta^*, \mathbf{y}^*\right) = N\left(\widetilde{\beta}^*, \widetilde{\Delta}^*\right)$$

with

$$\widetilde{\Delta}^* = \left(\left(\Sigma^*\right)^{-1} \otimes \left(X^*\right)' X^* + \tau_X^{-1} O_X^{-1}\right)^{-1}$$

$$\widetilde{\beta}^* = \widetilde{\Delta}^* \left(\left(\left(\Sigma^*\right)^{-1} \otimes \left(X^*\right)'\right)\left(\mathbf{y}^*\right) + \tau_X^{-1} O_X^{-1} \overline{\beta^*}\right)$$

Gibbs sampling details II

2. Block 2: $p\left(\beta_n \mid \Theta/\beta_n, \mathbf{y}_n\right)$: Given the likelihood (30) and the prior

$$p\left(\beta_n \mid \overline{\beta}, \tau\right) = N\left(\overline{\beta}, \tau O_n\right)$$

then the posterior is Normal

$$p\left(\beta_n \mid \Theta/\beta_n, \mathbf{y}_n\right) = N\left(\widetilde{\beta}_n, \widetilde{\Delta}_n\right)$$

with

$$\widetilde{\Delta}_n = \left(\Sigma_n^{-1} \otimes X_n' X_n + \tau^{-1} O_n^{-1}\right)^{-1}$$

$$\widetilde{\beta}_n = \widetilde{\Delta}_n \left(\left(\Sigma_n^{-1} \otimes X_n'\right)\left(\mathbf{y}_n\right) + \tau^{-1} O_n^{-1} \overline{\beta}\right)$$

Gibbs sampling details III

3. Block 3: $p\left(\Sigma^* \mid \Theta/\Sigma^*, \mathbf{y}^*\right)$: Given the likelihood (32) and the prior

$$p\left(\Sigma^*\right) \propto \left|\Sigma^*\right|^{-\frac{1}{2}(M_2+1)}$$

Denote the residuals

$$U^* = Y^* - X^* B^*$$

as in equation (12). Then the posterior variance term is Inverted-Wishart centered at the sum of squared residuals:

$$p\left(\Sigma^* \mid \Theta/\Sigma^*, \mathbf{y}^*\right) = IW\left(U^{*\prime}U^*, T^*\right)$$

Gibbs sampling details IV

4. Block 4: $p\left(\Sigma_n \mid \Theta/\Sigma_n, \mathbf{y}_n\right)$: Given the likelihood (30) and the prior

   $$p\left(\Sigma_n\right) \propto \left|\Sigma_n\right|^{-\frac{1}{2}(M_1+1)}$$

   Denote the residuals

   $$U_n = Y_n - X_n B_n$$

   as in equation (12). Then the posterior variance term is Inverted-Wishart centered at the sum of squared residuals:

   $$p\left(\Sigma_n \mid \Theta/\Sigma_n, \mathbf{y}_n\right) = IW\left(U_n' U_n, T_n\right)$$

Gibbs sampling details V

5. Block 5: $p\left(\tau_X \mid \Theta/\tau_X, Y\right)$: Given the priors

$$p\left(\tau_X\right) = IG\left(s, \upsilon\right) \propto \tau_X^{-\frac{\upsilon_X+2}{2}} \exp\left(-\frac{1}{2}\frac{s_X}{\tau_X}\right)$$

$$p\left(\beta_n \mid \overline{\beta}, O_n, \tau\right) = N\left(\overline{\beta}, \tau O_n\right)$$

then the posterior is

$$p\left(\tau_X \mid \Theta/\tau_X, Y\right) = IG\left(\frac{M_2 K + \upsilon_X}{2}, \frac{\sum_{n=1}^{N}\left(\beta_n - \overline{\beta}\right)' O_n^{-1}\left(\beta_n - \overline{\beta}\right) + s_X}{2}\right.$$

Gibbs sampling details VI

6. Block 6: $p\left(\overline{\beta} \mid \Theta/\overline{\beta}, Y\right)$: Given the prior

$$p\left(\beta_n \mid \overline{\beta}, O_n, \tau\right) = N\left(\overline{\beta}, \tau O_n\right)$$

by symmetry

$$p\left(\overline{\beta} \mid \beta_n, O_n, \tau\right) = N\left(\overline{\beta}, \tau O_n\right)$$

Then taking a weighted average across $n = 1, \ldots, N$:

$$p\left(\overline{\beta} \mid \{\beta_n\}_{n=1}^{N}, \tau\right) = N\left(\overline{\overline{\beta}}, \overline{\Delta}\right)$$

with

$$\overline{\Delta} = \left(\sum_{n=1}^{N} \tau^{-1} O_n^{-1}\right)^{-1}$$

$$\overline{\overline{\beta}} = \overline{\Delta}\left[\sum_{n=1}^{N} \tau^{-1} O_n^{-1} \beta_n\right]$$

Gibbs sampling details VII

7. Block 7: $p(\tau \mid \Theta/\tau, Y)$: Given the priors

$$p(\tau) = IG(s, \upsilon) \propto \tau^{-\frac{\upsilon+2}{2}} \exp\left(-\frac{1}{2}\frac{s}{\tau}\right)$$

$$p\left(\beta_n \mid \overline{\beta}, O_n, \tau\right) = N\left(\overline{\beta}, \tau O_n\right)$$

then the posterior is

$$p(\tau \mid \Theta/\tau, Y) = IG\left(\frac{NM_1K + \upsilon}{2}, \frac{\sum_{n=1}^{N}\left(\beta_n - \overline{\beta}\right)' O_n^{-1}\left(\beta_n - \overline{\beta}\right) + s}{2}\right)$$

A complete cycle around these seven blocks produces a draw of Θ from $p(\Theta \mid Y)$.

Data Description (Exogenous block)

We include the following variables for the exogenous block:

- Economic Policy Uncertainty index from the U.S. (EPU_{US}).
- Consumer Price Index for All Urban Consumers: All Items (1982-84=100), not seasonally adjusted.
- Industrial Production Index (2007=100), seasonally adjusted.
- Federal Funds Rate (FFR)[1].
- M1 Money Stock, not seasonally adjusted.
- Producer Price Index (All Commodities).
- Crude Oil Prices: West Texas Intermediate (WTI) - Cushing, Oklahoma.

Data is in monthly frequency (2001:12-2018:06) and it was taken from the Federal Reserve Bank of Saint Louis website (FRED database).

[1] We include the Shadow Interest Rate as in Wu and Xia (2015) starting in 2008.

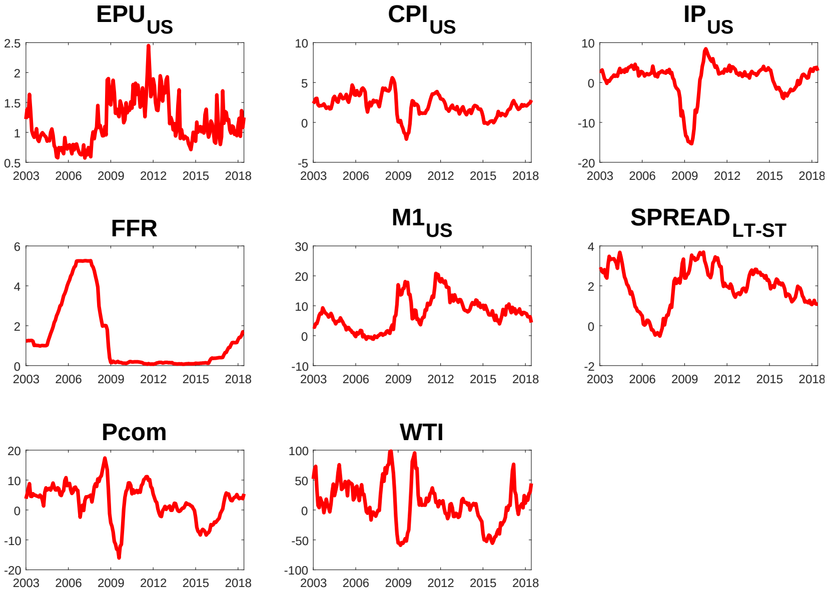

Figure: US data

Data Description (Chile)

We include the following variables from the Chilean economy:

- Nominal exchange rate.
- Interbank interest rate in Chilean pesos.
- Aggregated credit of the banking system in U.S. Dollars (Foreign Currency).
- Aggregated credit of the banking system in Chilean pesos (Domestic Currency).
- Consumer price index (2008=100).
- IMACEC Monthly indicator of economic activity (2008=100), not seasonally adjusted.

Data is in monthly frequency (2001:12-2018:05) and it was taken from the Central Bank of Chile website. All variables except interest rates are included as year-to-year growth rates.

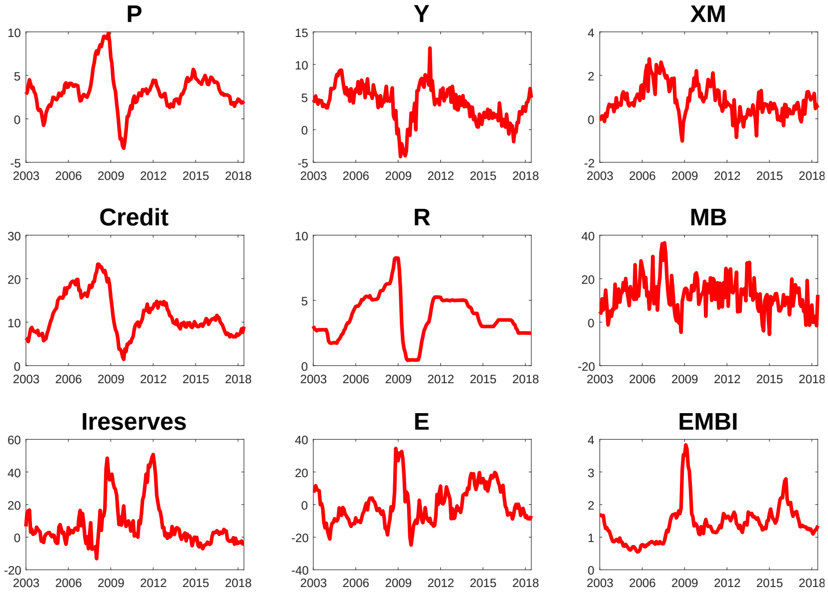

Figure: Chilean data

Data Description (Colombia)

We include the following variables from the Colombian economy:

- Nominal exchange rate.
- Interbank interest rate in Colombian pesos.
- Aggregated credit of the banking system in U.S. Dollars (Foreign Currency).
- Aggregated credit of the banking system in Colombian pesos (Domestic Currency).
- Consumer price index (December 2008=100).
- Real industrial production index (1990=100), seasonally adjusted with TRAMO-SEATS.

Data is in monthly frequency (2001:12-2018:06) and it was taken from the Banco de la República website. All variables except interest rates are included as year-to-year growth rates.

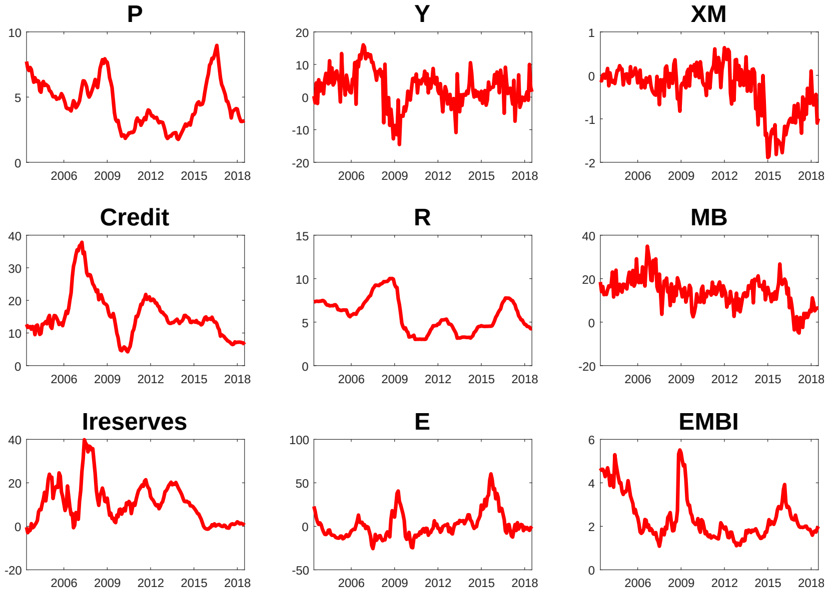

Figure: Colombian data

Data Description (Mexico)

We include the following variables from the Mexican economy:

- Nominal exchange rate.
- Interbank interest rate (at 28 days) in Mexican pesos.
- Aggregated credit of the banking system commercial banks) in U.S. Dollars expressed in Mexican pesos (Foreign Currency).
- Aggregated credit of the banking system (commercial banks) in Mexican pesos (Domestic Currency).
- Consumer price index (December 2010=100).
- IGAE Global economic activity index (2008=100), seasonally adjusted with TRAMO-SEATS.

Data is in monthly frequency (2001:12-2018:06) and it was taken from the Banco de México website. All variables except interest rates are included as year-to-year growth rates.

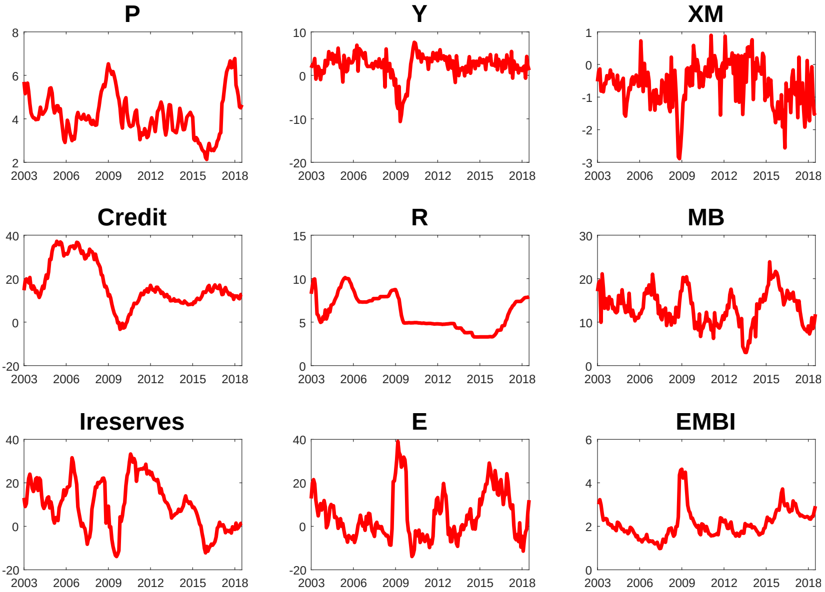

Figure: Mexican data

Data Description (Peru)

We include the following variables from the Peruvian economy:

- Nominal exchange rate index.
- Interbank interest rate in Soles (in percentages).
- Aggregated credit of the banking system in U.S. Dollars (Foreign Currency).
- Aggregated credit of the banking system in Soles (Domestic Currency).
- Consumer price index for Lima (2009=100).
- Real Gross Domestic Product index (2007=100), seasonally adjusted with TRAMO-SEATS.

Data is in monthly frequency (2001:12-2018:06) and it was taken from the Central Reserve Bank of Peru website. All variables except interest rates are included as year-to-year growth rates.

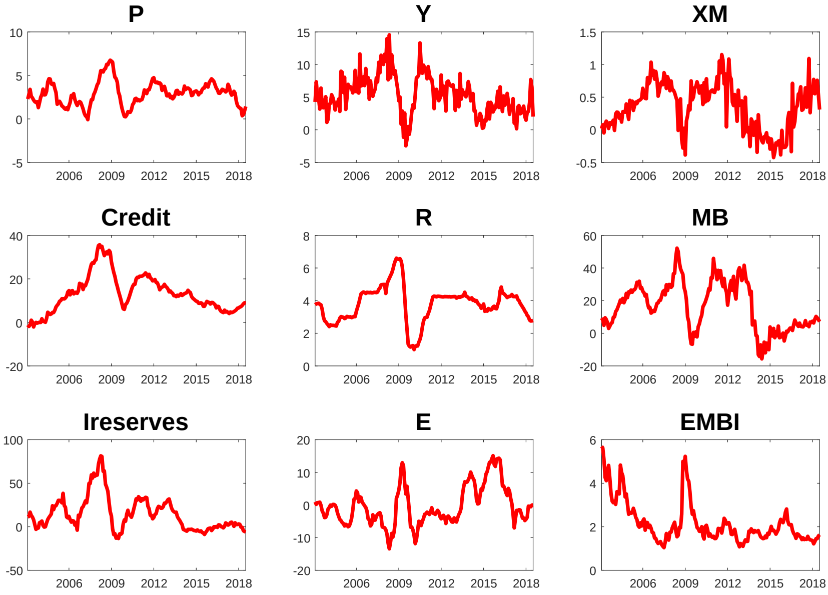

Figure: Peruvian data

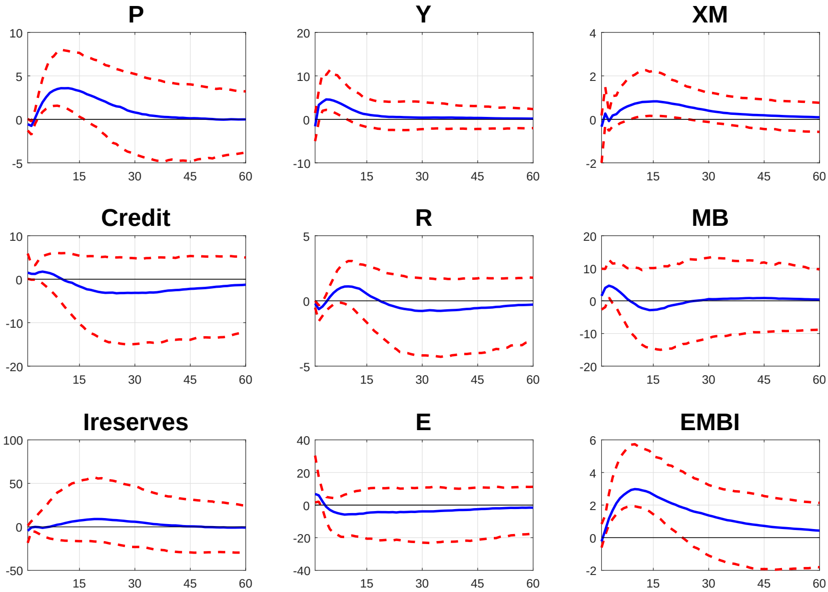

Figure: Response of Chilean variables after a US Monetary Policy shock; median value and 68% bands

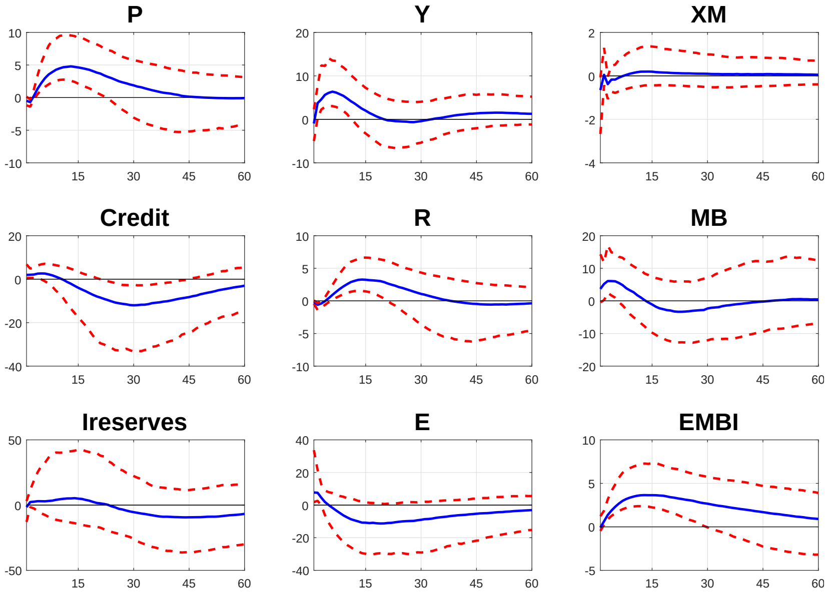

Figure: Response of Colombian variables after a US Monetary Policy shock; median value and 68% bands

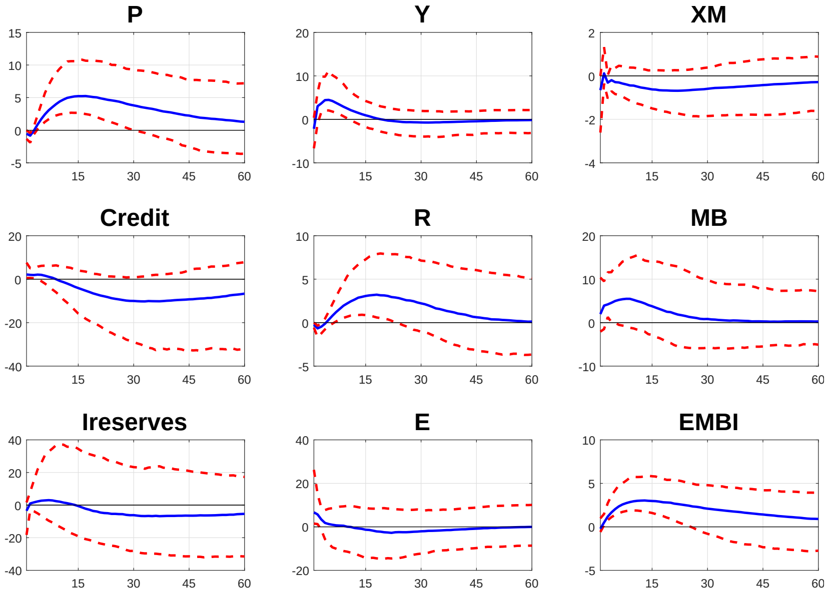

Figure: Response of Mexican variables after a US Monetary Policy shock; median value and 68% bands

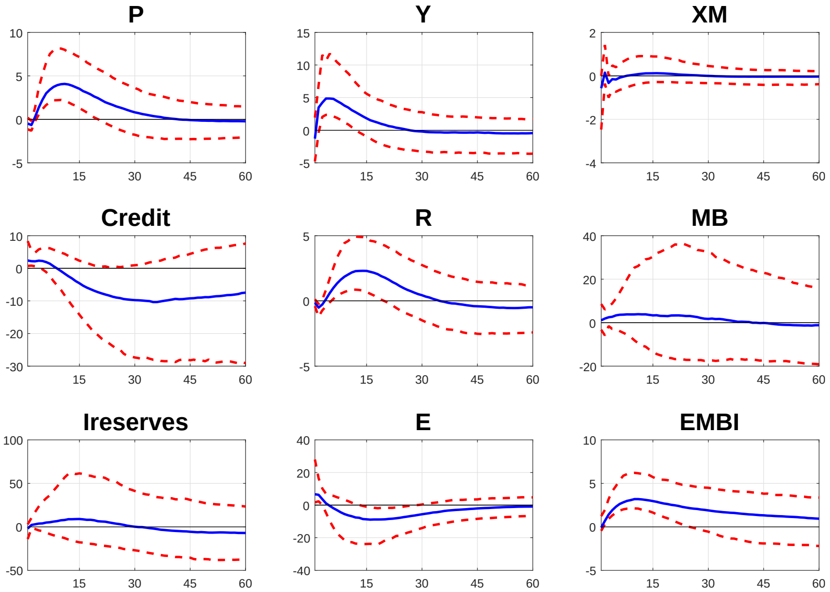

Figure: Response of Peruvian variables after a US Monetary Policy shock; median value and 68% bands

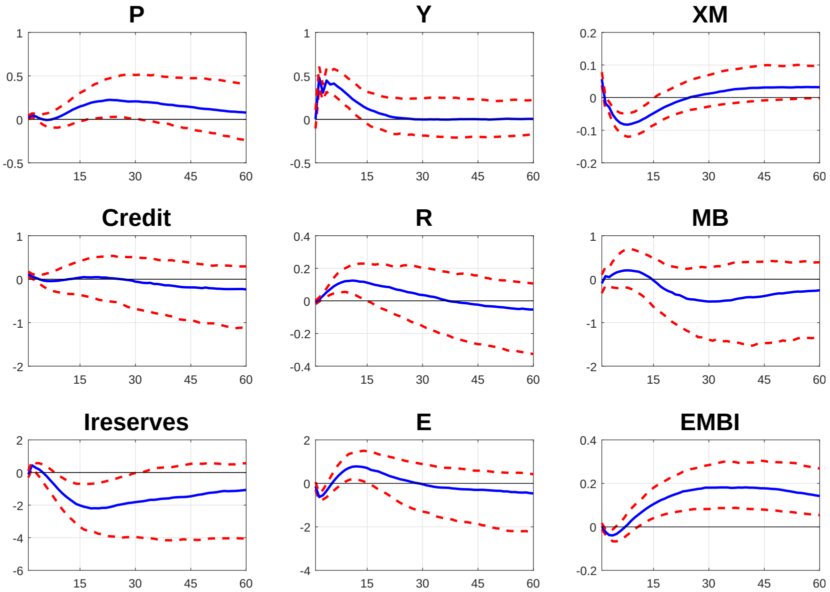

Figure: Response of Chilean variables after a US demand shock; median value and 68% bands

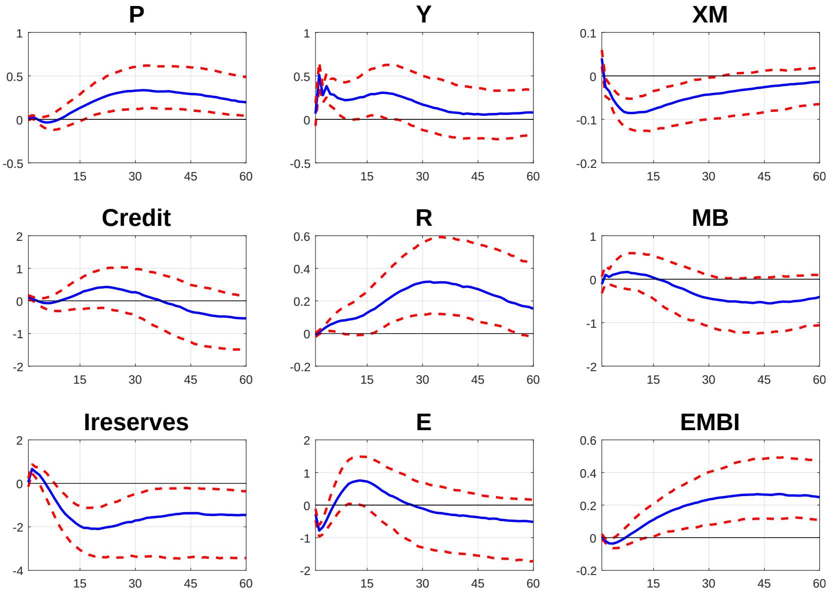

Figure: Response of Colombian variables after a US demand shock; median value and 68% bands

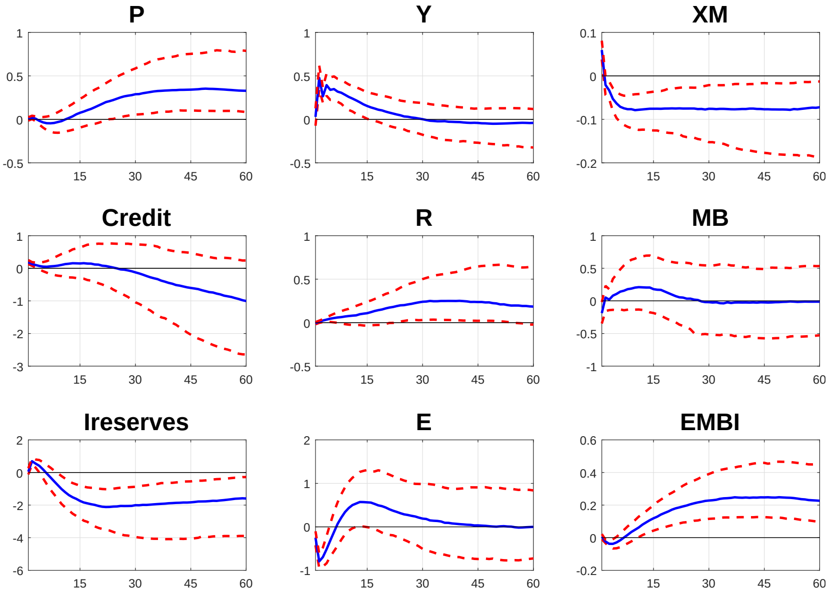

Figure: Response of Mexican variables after a US demand shock; median value and 68% bands

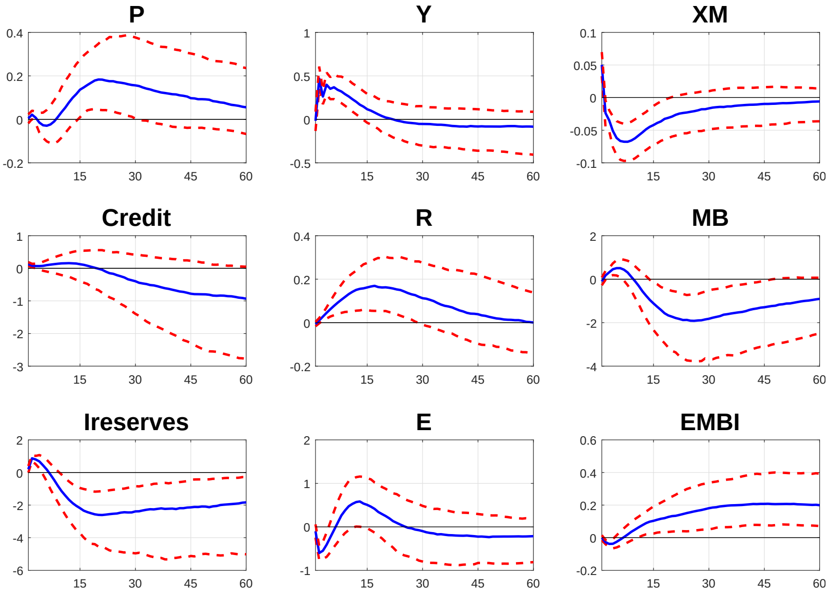

Figure: Response of Peruvian variables after a US demand shock; median value and 68% bands

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