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

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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).
- 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.
- Monetary Policy normalization actions are centered in i) Raising short-term interest rates, ii) Raising the sprrad bewtween 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)).
- Monetary policy normalization will have a direct impact on Latin American Economies. The question is then how is the transmission mechanism of these policy actions from the US and what are the spillover macroeconomic effects over Latin American Economies.
- We focus our attention on countries that apply the Inflation Targeting scheme (see e.g. Pérez Forero (2015)).

This paper(1)

- I estimate the potential spillover effects of normalization through a Bayesian Hierarchical Panel VAR (see Ciccarelli and Rebucci (2006), Jarociński (2010), Canova and Pappa (2011) and Pérez Forero (2015)).
- I consider a small open economy setup, where the big economy is the United States (US) and the Small economy is the Latin American One (e.g. Chile, Colombia, Mexico or Peru).
- Shocks affecting the US can be transmitted to the Latin American Countries, but not the other way around, i.e. we use the extended approach suggested by Gondo and Pérez Forero (2018) in order to consider an exogenous block (see also Cushman and Zha (1997), Zha (1999) and Canova (2005)) in a Panel VAR setup, i.e. the exogenous block is common to all countries.
- The statistical model is estimated using Bayesian Methods via Gibbs sampling (see Zellner (1971), Koop (2003), Canova (2007) and Koop and Korobilis (2010)).

This paper(2)

- Monetary policy shocks are identified through sign restrictions as in Canova and De Nicoló (2002) and Uhlig (2005) and recently by Arias *et al.* (2014).
- An identified US interest rate shock through sign and zero restrictions 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, in most cases, a negative effect in aggregate credit, economic activity and a positive effect in inflation. Our results are in line with Canova (2005) and, more importantly, we take into account the Unconventional Monetary Policy (UMP) period when performing the estimation by introducing the yield curve spread. Therefore, our results are not biased, in sense that the identified shocks are easy to interpret.

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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:

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

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 $u_{n,t} \sim N(\mathbf{0}, \Sigma_n)$, $E\left(u_{n,t} u'_{m,t}\right) = \mathbf{0}, n \neq m \in \{1, \ldots, N\}$, 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, such that

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

with $u_t^* \sim N\left(\mathbf{0}, \Sigma^*\right)$ and $E\left(u_t^* u_{n,t}'\right) = \mathbf{0}$.

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). Even though block (2) has effects over block (1), we assume that the block (2) is independent of block (1), and thus it will keep the same coefficients for each country model. 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. This is a plausible strategy for representing SOEs such as the Latin American ones, since they are influenced by external shocks such as commodity prices.

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

$$Y_n = X_n B_n + U_n \tag{3}$$

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 (3) can be re-written such that

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

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

$$p\left(\mathbf{y}_n \mid \beta_n, \Sigma_n\right) = (2\pi)^{-M_1(T_n - p)/2} \left|\Sigma_n \otimes I_{T_n - p}\right|^{-1/2} \times \exp\left(-\frac{1}{2}\left(\mathbf{y}_n - \left(I_{M_1} \otimes X_n\right)\beta_n\right)' \left(\Sigma_n \otimes I_{T_n - p}\right)^{-1} \left(\mathbf{y}_n - \left(I_{M_1} \otimes X_n\right)\beta_n\right)\right) \tag{4}$$

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

$$\Phi^* = \begin{bmatrix} \Phi_1^{*\prime} & \Phi_2^{*\prime} & \cdots & \Phi_p^{*\prime} & \Delta^{*\prime} \end{bmatrix}^\prime$$

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

$$\begin{gathered} p\left(\mathbf{y}^* \mid \beta^*, \Sigma^*\right) = (2\pi)^{-M_2(T^*-p)/2}\left|\Sigma^* \otimes I_{T^*-p}\right|^{-1/2} \times \\ \exp\left(\begin{array}{c} -\frac{1}{2}\left(\mathbf{y}^* - \left(I_{M_2} \otimes X^*\right)\beta^*\right)'\left(\Sigma^* \otimes I_{T^*-p}\right)^{-1} \\ \left(\mathbf{y}_n - \left(I_{M_2} \otimes X^*\right)\beta^*\right) \end{array}\right) \end{gathered} \tag{5}$$

Reduced-form estimation

The statistical model described by (11) and (13) 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

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

$$\exp \left(\begin{array}{c} -\frac{1}{2} \sum_{n=1}^{N} (\mathbf{y}_n - (I_{M_1} \otimes X_n) \beta_n)' (\Sigma_n \otimes I_{T_n - p})^{-1} \times \\ (\mathbf{y}_n - (I_{M_1} \otimes X_n) \beta_n) \\ -\frac{1}{2} (\mathbf{y}^* - (I_{M_2} \otimes X^*) \beta^*)' (\Sigma^* \otimes I_{T^* - p})^{-1} \times \\ (\mathbf{y}_n - (I_{M_2} \otimes X^*) \beta^*) \end{array} \right) \quad (6)$$

Priors I

Given the normality assumption of the error terms, it follows that each country coefficients vector is normally distributed. As a result, we assume a normal prior for them in order get a posterior distribution that is also normal, i.e. a conjugated prior:

$$p\left(\beta_n \mid \overline{\beta}, O_n, \tau\right) = N\left(\overline{\beta}, \tau O_n\right) \tag{7}$$

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:

$$p\left(\Sigma_n\right) \propto \left|\Sigma_n\right|^{-\frac{1}{2}(M_1+1)} \tag{8}$$

In a standard Bayesian context, $\overline{\beta}$ and τ would be hyper-parameters that are supposed to be calibrated. In turn, in a Hierarchical context (see e.g. Gelman *et al.* (2003)), it is possible to derive a posterior distribution for both and and therefore estimate them. That is, we do not want to impose any particular tightness for the prior distribution of coefficients, we want to get it from the data. Following Gelman (2006) and Jarociński (2010)[1] we assume an inverse-gamma prior distribution for τ, so that

$$p\left(\tau\right) = IG\left(\frac{\upsilon}{2}, \frac{s}{2}\right) \propto \tau^{-\frac{\upsilon+2}{2}} \exp\left(-\frac{1}{2}\frac{s}{\tau}\right) \tag{9}$$

Priors III

Finally, we assume the non-informative prior:

$$p\left(\overline{\beta}\right) \propto 1 \tag{10}$$

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

$$p\left(\beta^{*}\right) = N\left(\overline{\beta^{*}}, \tau_X O_X\right) \tag{11}$$

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:

$$p\left(\Sigma^*\right) \propto \left|\Sigma^*\right|^{-\frac{1}{2}(M_2+1)} \tag{12}$$

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

$$p\left(\tau_X\right) = IG\left(\frac{\upsilon_X}{2}, \frac{s_X}{2}\right) \propto \tau_X^{-\frac{\upsilon_X+2}{2}} \exp\left(-\frac{1}{2}\frac{s_X}{\tau_X}\right) \tag{13}$$

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

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

Priors V

and the joint prior is given by (7), (8), (9), (10), (11), (12) and (13), so that

$$
\begin{aligned}
p(\Theta) &\propto \prod_{n=1}^{N} p(\Sigma_n)\, p\left(\beta_n \mid \overline{\beta}, O_n, \tau\right) p(\tau) \\
&= \prod_{n=1}^{N} |\Sigma_n|^{-\frac{1}{2}(M_1+1)} \times \\
&\tau^{-\frac{N M_1 K}{2}} \exp\left(-\frac{1}{2}\sum_{n=1}^{N}\left(\beta_n - \overline{\beta}\right)'\left(\tau^{-1} O_n\right)^{-1}\left(\beta_n - \overline{\beta}\right)\right) \times \\
&\tau^{-\frac{\upsilon+2}{2}} \exp\left(-\frac{1}{2}\frac{s}{\tau}\right) \times \\
&|\Sigma^*|^{-\frac{1}{2}(M_2+1)} \times \\
&\tau_X^{-\frac{M_2 K^*}{2}} \exp\left(-\frac{1}{2}\left(\beta^* - \overline{\beta^*}\right)'\left(\tau_X^{-1} O_X\right)^{-1}\left(\beta^* - \overline{\beta^*}\right)\right) \times \\
&\tau_X^{-\frac{\upsilon_X+2}{2}} \exp\left(-\frac{1}{2}\frac{s_X}{\tau_X}\right)
\end{aligned}
\qquad (14)
$$

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Bayesian Estimation

Given the specified priors and the joint likelihood function (11) - (13), 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:

$$p(\Theta \mid Y) \propto p(Y \mid \Theta)\, p(\Theta) \tag{15}$$

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

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. Following Gelman (2006) and Jarociński (2010), we assume a uniform prior for the standard deviation, which translates into

$$p(\tau) \propto \tau^{-1/2} \tag{16}$$

by setting $v = -1$ and $s = 0$ in (9).
Regarding the Minnesota-stye prior, we set a conservative $\phi_1 = \phi_2 = \phi_3 = 1$. More specifically, $\phi_1 = 1$ means that there is no a priori difference between own lags and lags of other variables; $\phi_2 = 1$ means that there is no a priori heteroskedasticity coming from exogenous variables; and $\phi_3 = 1$ means that the shrinking pattern of coefficients is linear.

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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).
- 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}	?	$\geqslant 0$
CPI Inflation Rate	CPI_{US}	$\leqslant 0$	$\geqslant 0$
Federal Funds Rate	FFR	$\geqslant 0$	?
M1 Growth	$M1_{US}$	?	?
SPREAD	$SPREAD_{LT-ST}$	$\geqslant 0$	?
Commodity prices	$Pcom$	?	?
Oil prices	WTI	?	?

Table: Identifying Restrictions

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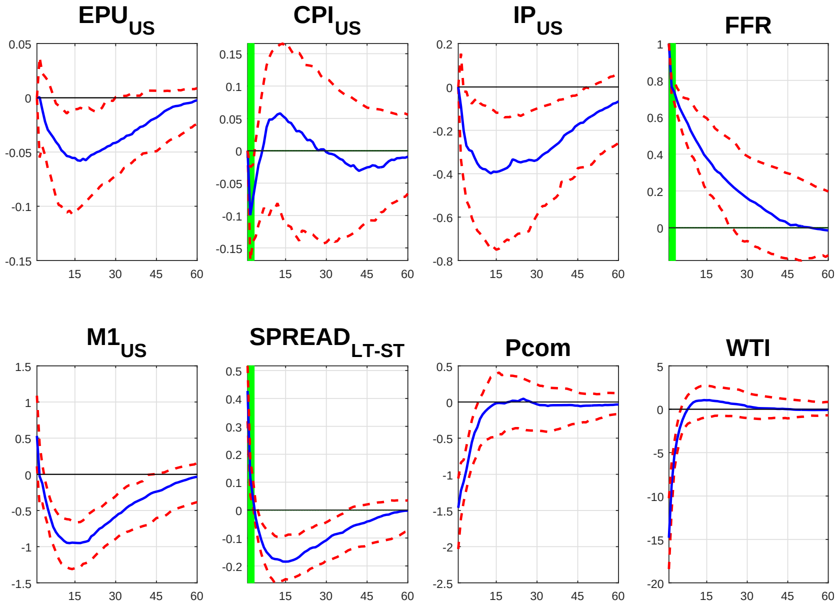

Figure: Response of U.S. variables after a Monetary policy shock; median value (solid line) and 68% bands (dotted lines)

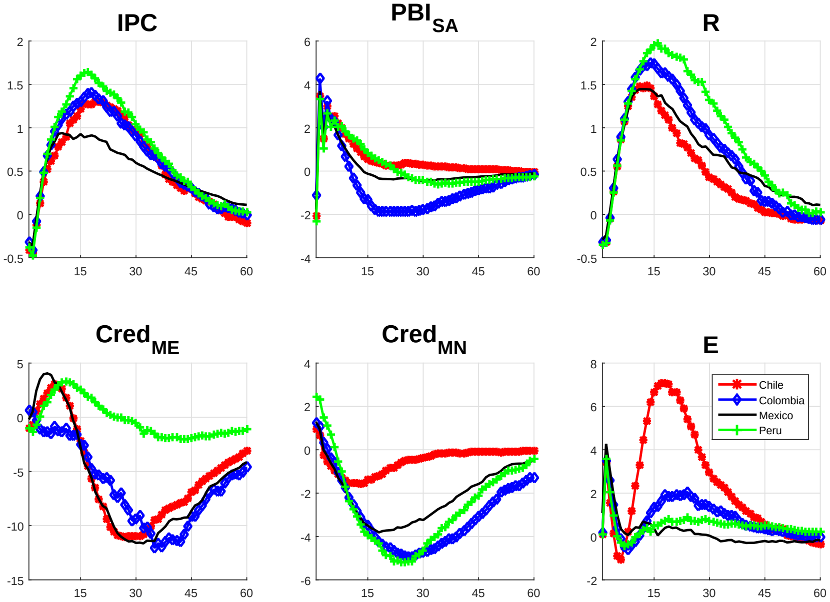

Figure: Response of LATAM variables after a US Monetary policy shock; median values

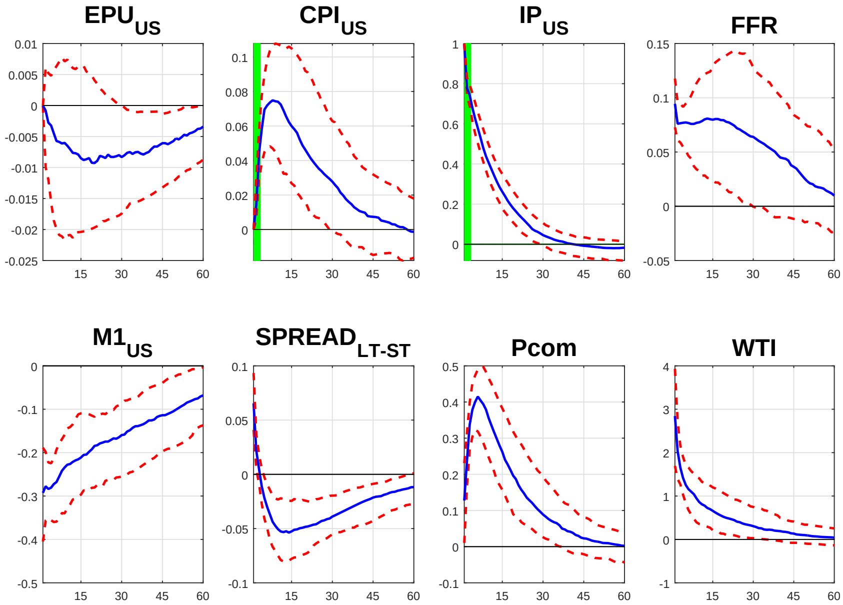

Figure: Response of U.S. variables after a demand shock; median value (solid line) and 68% bands (dotted lines)

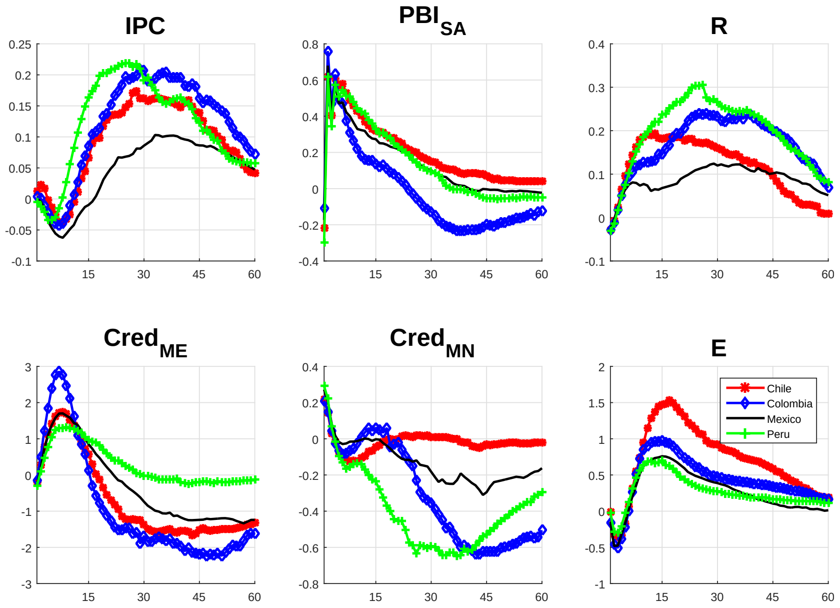

Figure: Response of LATAM variables after a US demand shock; median values

Concluding Remarks I

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

- Results show that a US interest rate shock produces a nominal depreciation and a positive reaction of the domestic interest rate. Furthermore, in most cases the identified external monetary shock affects negatively in aggregate credit (in both currencies), economic activity and inflation.
- On the other hand, demand and supply shocks have mixed and uncertain effects across LATAM economies. Perhaps more work is needed in terms of imposing more restrictions to properly identify demand shocks, since it is widely accepted in the literature that sign restrictions are relatively weak. On the other hand, given the reduced span of data (2002-2016), it is natural to observe a considerable amount of uncertainty.

Concluding Remarks III

- 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.
- Our approach is flexible relative to a stylized dynamic macroeconomic model, and this is why there exists some space to do some refinements. This could take the direction of expanding the information set and also considering additional plausible restrictions.
- Nevertheless, so far we consider that we have imposed enough restrictions in order to properly identify and isolate the three structural shocks mentioned in this document.

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 (13) 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 (11) 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 (13) 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 (3). 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 (11) 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 (3). 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 $n = 1, \ldots, N$:

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

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)[2].
- 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 (2002:01-2016:09) and it was taken from the Federal Reserve Bank of Saint Louis website (FRED database).

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

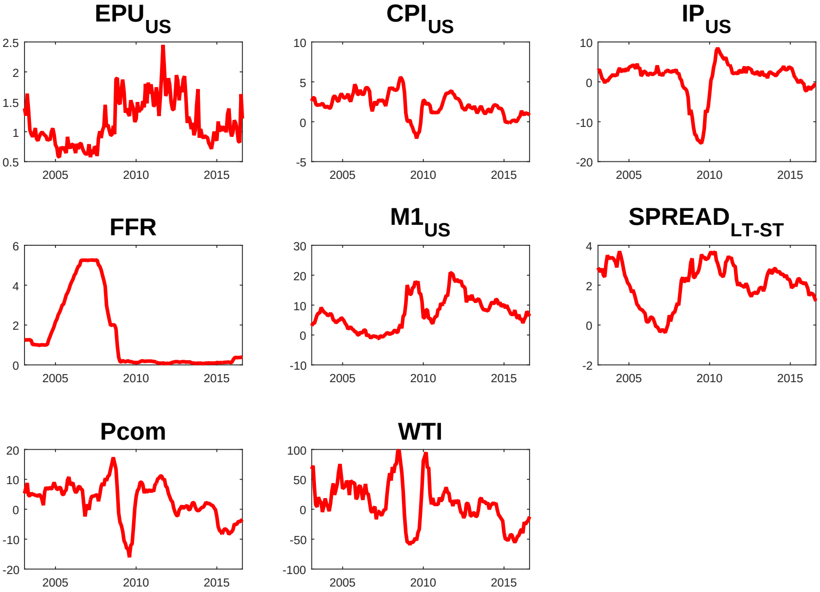

Figure: US data

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 (2002:01-2016:09) and it was taken from the Central Bank of Chile website. All variables except interest rates are included as year-to-year growth rates.

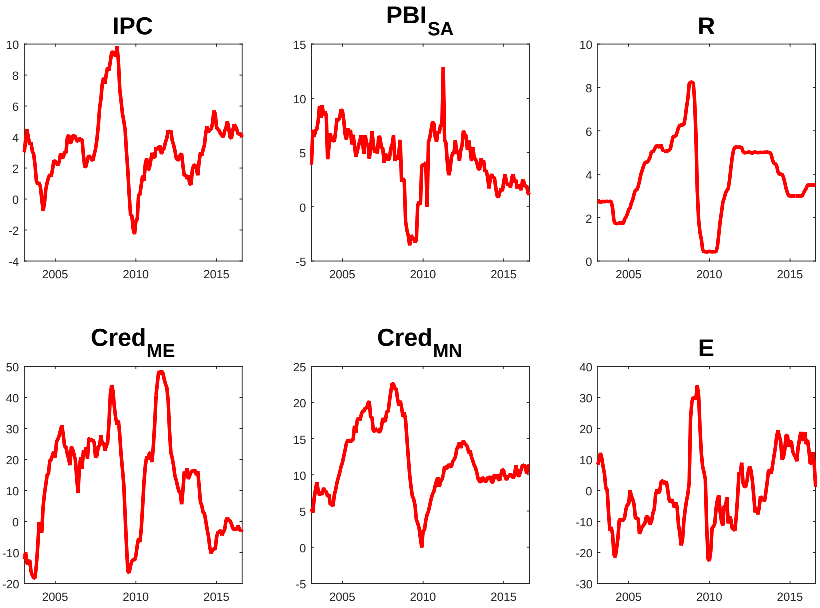

Figure: Chilean data

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 (2002:01-2014:06) and it was taken from the Banco de la República website. All variables except interest rates are included as year-to-year growth rates.

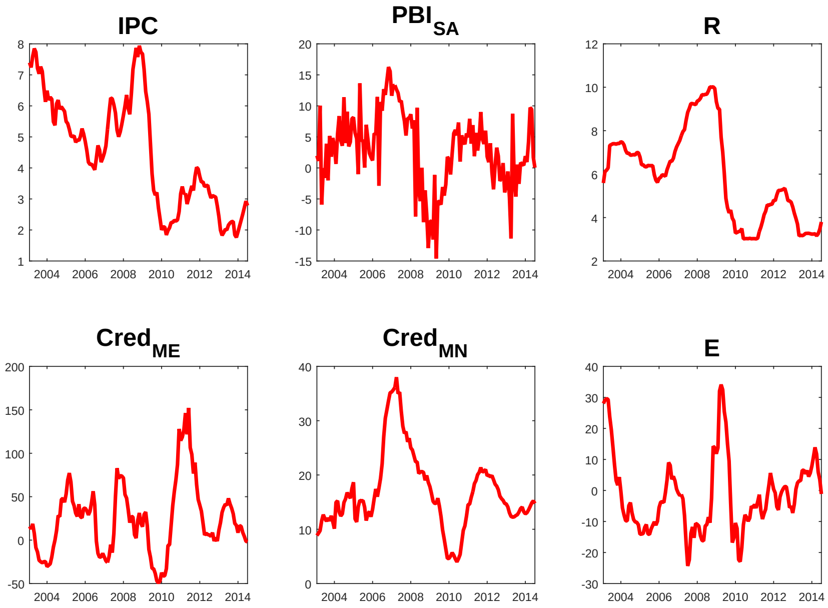

Figure: Colombian data

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 (2002:01-2016:09) and it was taken from the Banco de México website. All variables except interest rates are included as year-to-year growth rates.

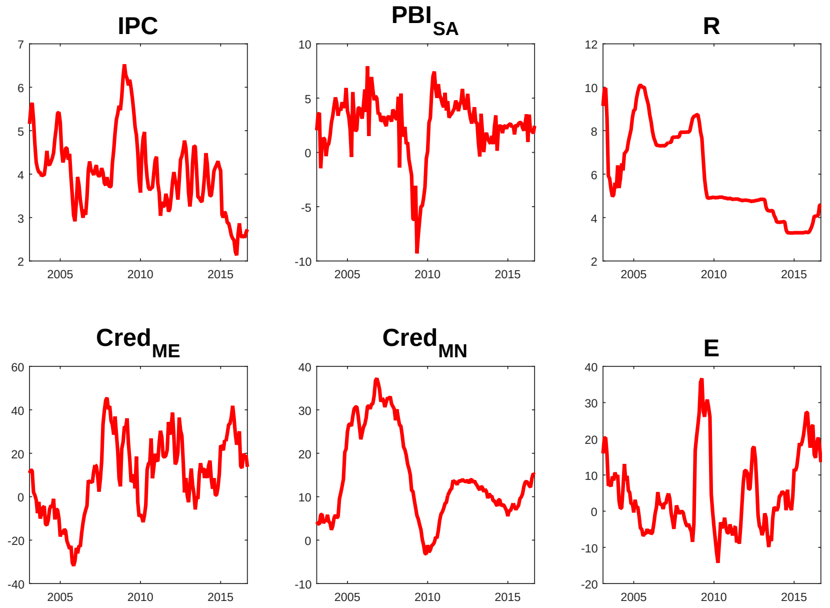

Figure: Mexican data

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 (2002:01-2016:09) 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.

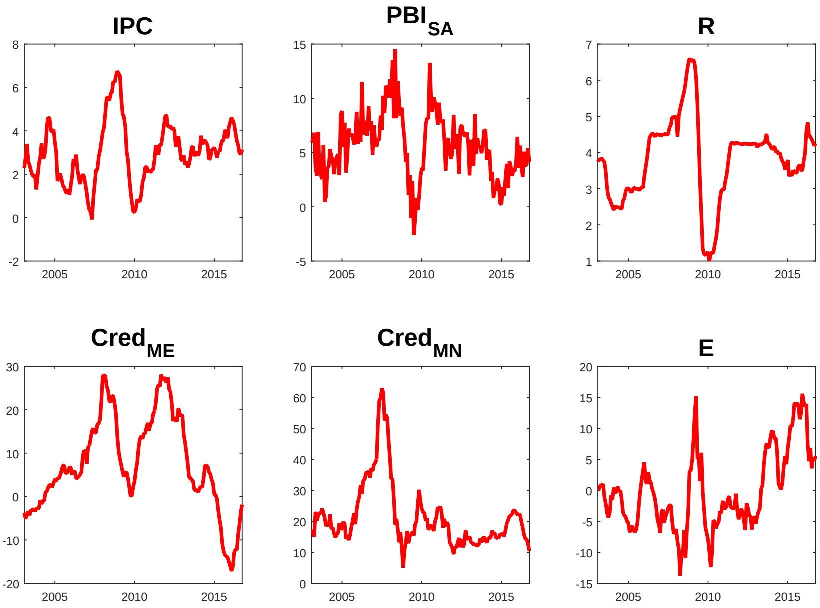

Figure: Peruvian data

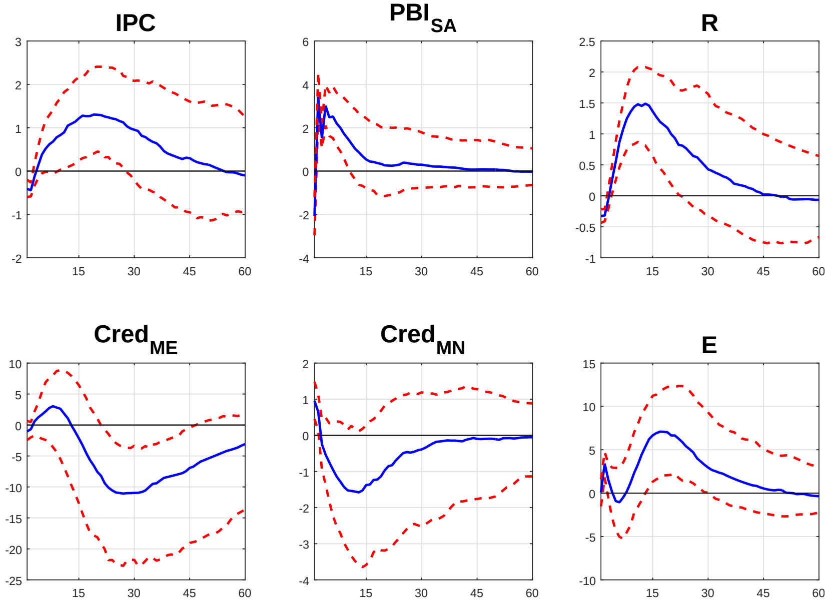

Figure: Response of Chilean variables after a US Monetary Policy shock; median value and 68% bands

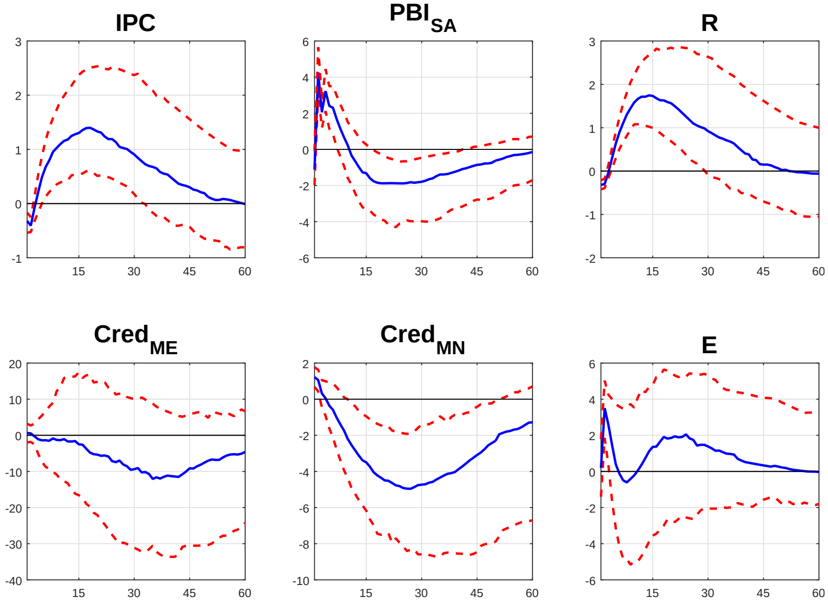

Figure: Response of Colombian variables after a US Monetary Policy shock; median value and 68% bands

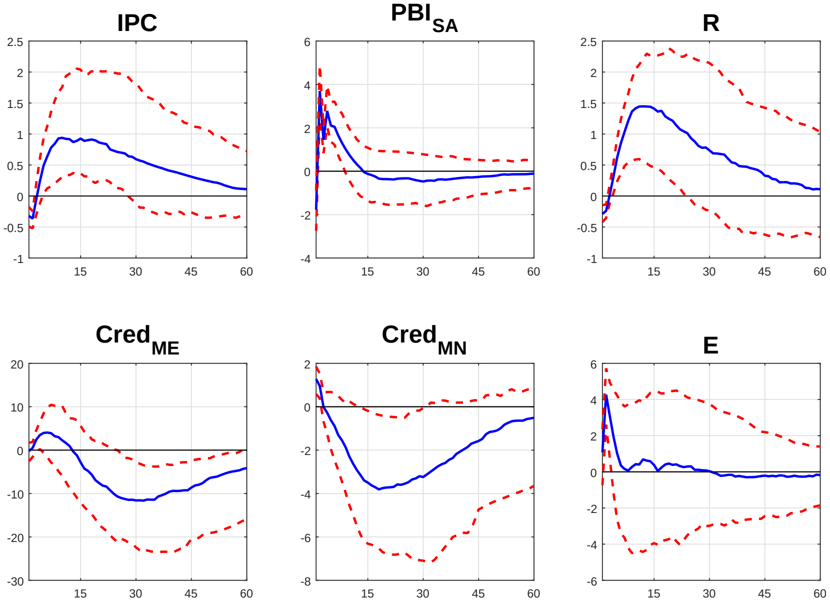

Figure: Response of Mexican variables after a US Monetary Policy shock; median value and 68% bands

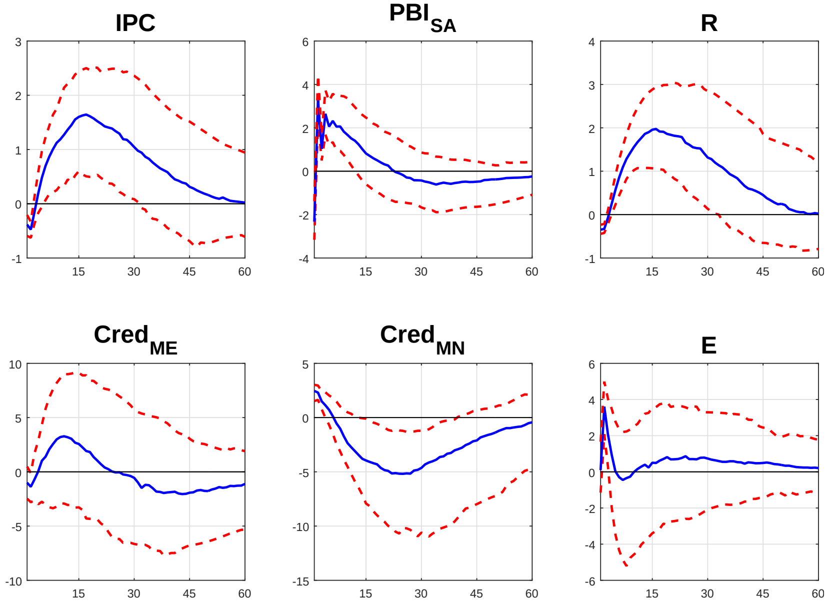

Figure: Response of Peruvian variables after a US Monetary Policy shock; median value and 68% bands

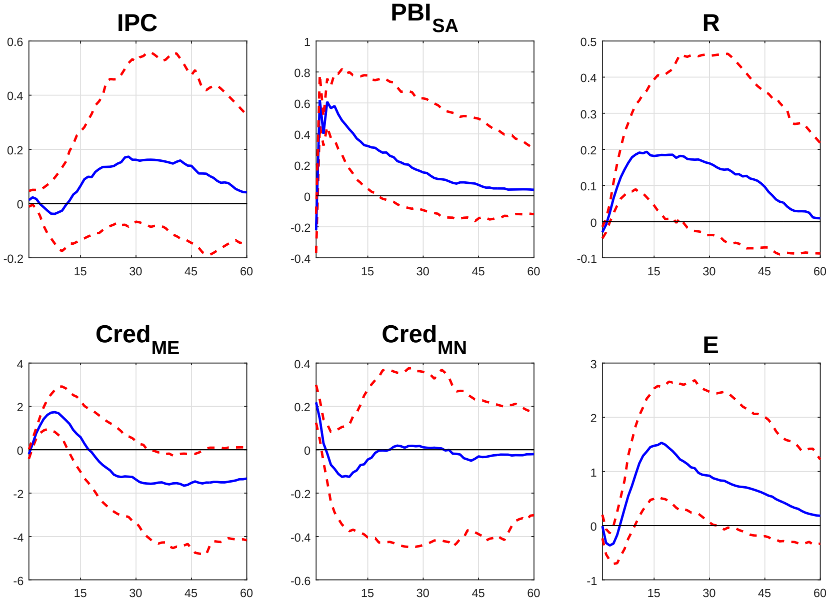

Figure: Response of Chilean variables after a US demand shock; median value and 68% bands

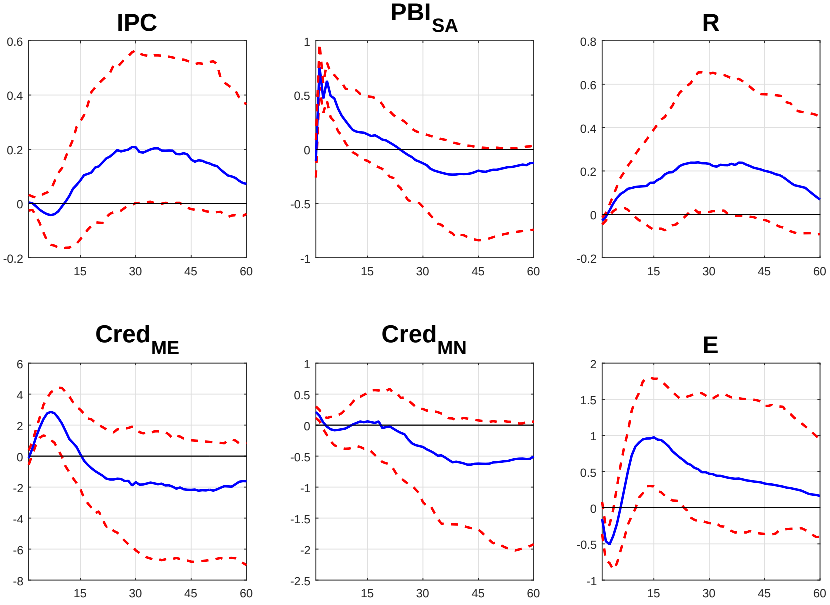

Figure: Response of Colombian variables after a US demand shock; median value and 68% bands

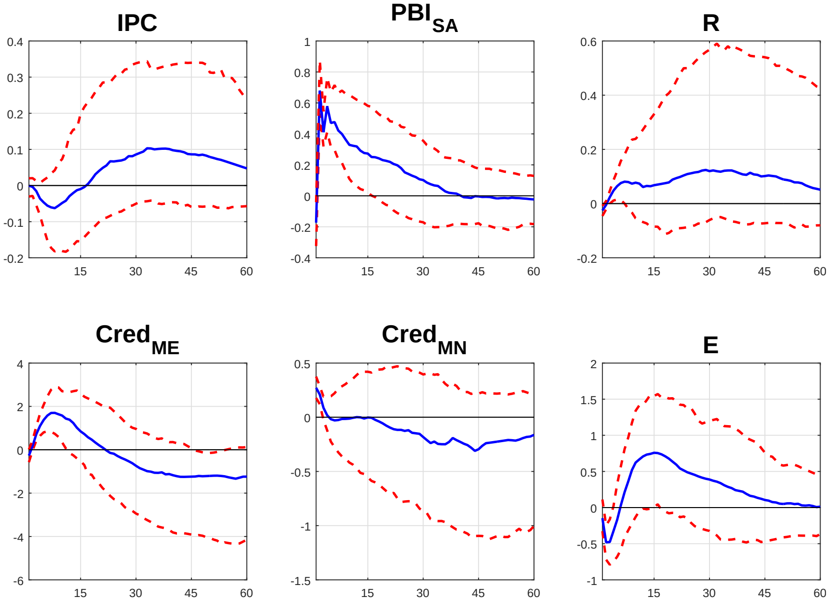

Figure: Response of Mexican variables after a US demand shock; median value and 68% bands

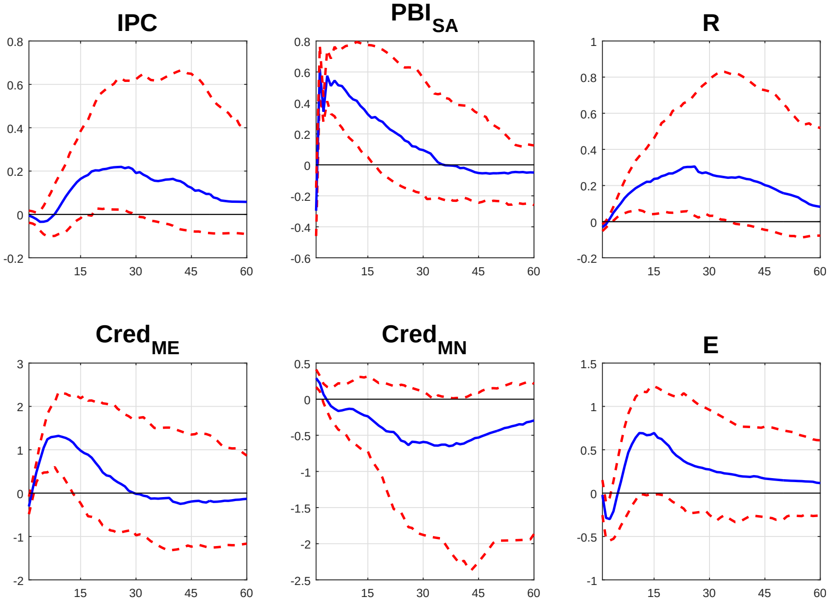

Figure: Response of Peruvian variables after a US demand shock; median value and 68% bands

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