Aggregate Dynamics after a Shock to Monetary Policy in Developing Countries*

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This paper investigates the effects from a shock to monetary policy in developing economies under an inflation-targeting regime. We find that price adjustment is fast in these economies, causing the monetary policy shock to have less persistent effects on output compared with those in advanced economies. We show that a small open-economy model featuring staggered wage setting with incomplete financial markets is largely able to explain our findings.

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1. Introduction

There are many developing countries that have been exploring alternative monetary regimes after years of high and variable inflation. However, there remains considerable debate regarding the

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appropriate framework for analyzing monetary policy in such an environment. Our goal in this paper is to develop a model which is appropriate for monetary policy analysis in developing economies. When developing such a model, Christiano, Eichenbaum, and Evans (1998) suggest applying the Lucas program. In our paper, we follow this advice and apply the Lucas program using monetary policy shocks. This involves three steps.

In the first step, when isolating monetary policy shocks in developing economies which adopted an inflation-targeting regime, we use the methodology pursued by Arias, Caldara, and Rubio-Ramirez (2015). Indeed, we identify sets of structural parameters in our vector autoregressive (VAR) model which are coherent with imposed sign and zero restrictions on the systematic component of monetary policy and on impulse response functions (IRFs) to a tightening monetary policy shock.

Having isolated monetary policy shocks in developing economies this way, in the second step of the Lucas program, we characterize our experiment. We study the dynamic behavior of output, consumer prices, nominal exchange rates with the United States, M1, and monetary-policy-related interest rates in developing economies following a tightening shock to monetary policy. We find that this shock is characterized by a temporary fall in output, inverted hump-shaped dynamics in the price level, strong appreciation in nominal exchange rates, a persistent liquidity effect on M1, and a transient rise in policy-related interest rates in these economies.

In the last step of the Lucas program, we develop a dynamic stochastic sticky-price small open-economy model and assess its success by comparing the outcomes from a shock to monetary policy in this model with those in actual developing economies. There are several features of our model which are worth mentioning. First, there are Calvo-type nominal price contracts. Second, the frequency of price changes differs between the home and foreign countries. Third, regardless of being domestic or foreign, if a firm sets prices in the home (foreign) currency, it is subject to the price rigidity in the home (foreign) country. Fourth, insurance is incomplete, as households in the home country only have access to the non-state-contingent domestic asset. Fifth, in regards to the real side, our model maintains that capacity utilization can be variable. Lastly, it incorporates a novel method of staggered wage setting which we discuss in detail in the wage-setting problem of households in our model.[1] After a brief discussion of our model, we compare the outcomes in this model with those in actual developing economies following an unanticipated change in policy stance. We find that our model is largely able to account for the movements in the key variables following such a change in the developing economies included in our sample.

Are our findings regarding the dynamic effects from a tightening shock to monetary policy in developing economies under inflation targeting similar to those in the United States? Two differences are noteworthy: First, while the initial effects from the shock on output are strong in the former, they are negligible in the latter. Second, the dynamic response of the price level to the shock is different between developing economies and the United States. In fact, while the price level exhibits inverted hump-shaped dynamics in the former, it falls smoothly and steadily in the latter.[2] In addition, owing to strong inertia of the price level, a shock to monetary policy in the United States causes a small contemporaneous effect on the price level. Yet, more frequent price adjustment results in a monetary policy shock in developing economies having a sizable contemporaneous effect on

[1]Since it is standard practice in the literature to assume that wages in developing economies quickly respond to shocks, our staggered wage-setting assumption may invoke debate. In this regard, it is useful to discuss some evidence which supports the staggered wage-setting assumption in developing economies. For example, in Turkey, half of the workers with social security benefits are paid the minimum wage, which remains unchanged over a quarter. Similarly, in Hungary, Kézdi and Kónya (2009) note that 70 percent of wages are reset in a specific month of a year, suggesting that these wages are unchanged over a one-year duration. Such evidence supports our assumption that wages in developing economies have some rigidity.

Besides being more in line with wage-setting practices in developing economies, the staggered wage-setting assumption also helps our model account for the findings in Li (2011) that developing economies have an average contemporaneous correlation of 0.41 between detrended real wages and real GDP and that real wages are responsive to business cycles and lag the cycle by an average of one quarter. As a matter of fact, dropping the staggered wage-setting assumption and instead assuming that wages are flexible results in the model predicting that real wages and real GDP have an almost perfect correlation and that real wages closely follow business cycles without any lag.

[2]See Leeper, Sims, and Zha (1996), Arias, Caldara, and Rubio-Ramirez (2015), Christiano, Eichenbaum, and Evans (2005), and Uhlig (2005).

the price level, suggesting that the extent to which the price level has inertia is more limited in these economies.

Our paper is related to a number of papers in the literature. In a recent survey, Mishra and Montiel (2013) report that a wide range of empirical approaches fails to yield consistent and convincing evidence of large real effects from monetary policy shocks in low-income countries. Berument (2007) and Berument, Denaux, and Yalcin (2012) study innovations to monetary policy in Turkey and find that a tightening monetary policy shock results in a fall in both output and prices. While our findings are similar to the findings in these studies, the adopted empirical methodology is different. Indeed, Berument (2007) identifies policy innovations with the recursive identification, where the ordering of variables included in estimating VAR models is important and often debatable, as we discuss in subsection 2.1.6. Similar to our study, Berument, Denaux, and Yalcin (2012) also use an agnostic identification procedure, albeit without taking into account the systematic component of monetary policy, which can drastically change inferences from the effects of monetary policy shocks, as discussed in Arias, Caldara, and Rubio-Ramirez (2015).

The organization of the paper is as follows: Section 2 presents our empirical strategy for isolating monetary policy shocks in developing economies under an inflation-targeting regime and reports our findings on the consequences of these shocks. Section 3 develops a dynamic stochastic sticky-price small open-economy model. Section 4 describes the estimation and calibration of the model's parameters. Section 5 evaluates the success of the model in accounting for the outcomes of a domestic monetary policy shock in the developing economies reported in section 2. The last section concludes.

2. Empirical Section

In this section, we discuss our methodology for identifying monetary policy shocks in developing economies that adopted an inflation-targeting regime. Our method for isolating monetary policy shocks in these economies is based on Arias, Caldara, and Rubio-Ramirez (2015), which elaborates on the agnostic identification procedure in

Uhlig (2005) by taking into account the systematic component of monetary policy in structural vector autoregressions (SVARs).[3]

2.1 Methodology

We consider the following panel SVAR:

$$Y'_{it}A_{Y0} = \sum_{j=1}^{p} Y'_{it-j}A_{Yj} + \sum_{j=0}^{p} X'_{it-j}A_{Xj} + \mu_i + \varepsilon'_{it} \quad \text{for} \quad 1 \leq t \leq T, \tag{1}$$

where Y_{it} is an $n_Y \times 1$ vector of endogenous variables and X_{it} is an $n_X \times 1$ vector of exogenous variables in the panel SVAR. While A_{Y0} and A_{Yj} are $n_Y \times n_Y$ matrices of structural parameters for $1 \leq j \leq p$, A_{Xj} is an $n_X \times n_Y$ matrix of structural parameters for $0 \leq j \leq p$, where p denotes the number of lags included in the panel SVAR. We require A_{Y_0} to be non-singular. Lastly, μ_i and ε_{it} denote the time-invariant country-specific fixed-effect term and an $n_Y \times 1$ vector of structural shocks, respectively. Conditional on past and initial observations of Y_{it} and on contemporaneous, past, and initial observations of X_{it}, ε_{it} is Gaussian with mean zero and covariance equal to an identity matrix of I_{n_Y}. The reduced-form panel VAR implied by (1) is

$$Y'_{it} = \sum_{j=1}^{p} Y'_{it-j}B_{Yj} + \sum_{j=0}^{p} X'_{it-j}B_{Xj} + \mu_i A_{Y0}^{-1} + u'_{it} \quad \text{for} \quad 1 \leq t \leq T, \tag{2}$$

where $B_{Yj} = A_{Yj}A_{Y0}^{-1}$ for $1 \leq j \leq p, B_{Xj} = A_{Xj}A_{Y0}^{-1}$ for $0 \leq j \leq p$, $u'_{it} = \varepsilon'_{it}A_{Y0}^{-1}$, and $\mathbb{E}(u_{it}u'_{it}) = (A_{Y0}A'_{Y0})^{-1} = \Sigma$. B_{Yj}, $B_{Xj}, \mu_i A_{Y0}^{-1}$, and Σ are reduced-form parameters. Following Arias, Caldara, and Rubio-Ramirez (2015), we identify a monetary policy shock in developing economies under inflation targeting using both sign and zero restrictions on the systematic component of monetary policy and

[3]Arias, Caldara, and Rubio-Ramirez (2015) find that a tightening monetary policy shock has a persistent negative effect on output in the United States when the systematic component of monetary policy is taken into account. Otherwise, they find that this shock leads to a rise in output.

only sign restrictions on impulse response functions (IRFs) of the variables.

The endogenous variables in our panel SVAR system of (1), Y_{it}, consist of five variables:

$$Y_{it} = \begin{bmatrix} \mathcal{Y}_{it} & P_{it} & \mathcal{E}_{it} & M1_{it} & R_{\mathcal{H},it} \end{bmatrix}', \tag{3}$$

where $\mathcal{Y}_{it}$ refers to country i's seasonally adjusted real GDP.[4] P_{it}, $\mathcal{E}_{it}$, and $M1_{it}$ are country i's CPI, the local currency price of a U.S. dollar, and M1, respectively.[5] Lastly, $R_{\mathcal{H},it}$ represents country i's monetary-policy-related interest rate, which is presumably controlled by its monetary authority.

The exogenous variables included in (1), which are common among developing countries, are given by

$$X_{it} = \begin{bmatrix} P_t^{com.} & \mathcal{Y}_t^{U.S.} & P_t^{U.S.} & M1_t^{U.S.} & R_t^{U.S.} \end{bmatrix}', \tag{4}$$

where $P_t^{com.}$ denotes commodity prices denominated in dollars, and $\mathcal{Y}_t^{U.S.}, P_t^{U.S.}, M1_t^{U.S.}$, and $R_t^{U.S.}$ stand for seasonally adjusted real GDP, CPI, M1, and the monetary-policy-related interest rate in the United States, respectively. In order to consistently estimate the parameters included in (2), we assume that developing economies are small, resulting in domestic structural shocks in these economies having no contemporaneous effect on $P_{it}^{com.}$ and on the variables from the United States.[6] In econometric terms, we assume $E(X_{it}u_{it}') = 0_{5\times 5}$, where $0_{5\times 5}$ is a 5×5 matrix of zeros.

2.1.1 Data

Table 1 reports the adoption dates of inflation targeting in the developing countries contained in our sample for which we have quarterly data. It is notable that since the adoption dates of the inflation-targeting regime were not the same among the countries in our sample, we have unbalanced panel data. As stated in Arellano and

[4]Where data for seasonally adjusted series are not available, we obtain seasonally adjusted series using the Demetra+ program from Eurostat.

[5]$M1_{it}$ is seasonally adjusted using the Demetra+ program from Eurostat.

[6]This assumption is also consistent with the common practice of modeling the United States as a closed economy.

Table 1. Adoption Dates of Inflation Targeting in Developing Economies

Country	Effective IT Adoption Date
Brazil	1999:Q2
Chile	1999:Q3
Colombia	1999:Q3
Guatemala	2005:Q1
Indonesia	2005:Q3
Mexico	2001:Q1
South Africa	2000:Q1
Turkey	2006:Q1

Source: Roger (2009).

Bond (1991), this does not fundamentally change our analysis since we only require the assumption that observations are independently distributed in the initial cross-section and that subsequent additions and deletions occur randomly.

Our source of data is the International Monetary Fund's (IMF's) International Financial Statistics. We use quarterly data which spans the post-inflation-targeting period for each country until 2013:Q1.[7]

2.1.2 Sign Restrictions on IRFs

Uhlig (2005) suggests remaining agnostic about the question of interest and discarding all structural parameters that are not consistent with a priori theorizing. Following his approach, we remain agnostic on the dynamic effects of a tightening shock to monetary policy on output but restrict the initial dynamic effects from this shock on the price level, the nominal exchange rate, M1, and the monetary-policy-related interest rate.

RESTRICTION 1. *A tightening monetary policy shock contemporaneously results in a fall in the price level and M1, an appreciation in*

[7]Commodity prices in dollars are available from the IMF's International Financial Statistics only at a monthly frequency. We convert these statistics to a quarterly frequency by taking a three-month average of the monthly commodity prices.

the nominal exchange rate, and an increase in the short-term interest rate.

Restriction 1 ensures that the price and liquidity puzzles are eliminated and that the bilateral nominal exchange rate with the United States appreciates following a positive innovation in the domestic short-term rate.[8]

2.1.3 Systematic Portion of Monetary Policy

In this section, we discuss the specification of the monetary policy equation in developing economies under inflation targeting. The set of structural parameters was constrained by restriction 1. To identify monetary policy shocks, we further constrain the set by disciplining the systematic portion of monetary policy, as suggested by Arias, Caldara, and Rubio-Ramirez (2015). As a matter of fact, we assume that a monetary-policy-related interest rate is a key measure of monetary policy.

Furthermore, we also assume that while it can contemporaneously respond to unanticipated changes in output, consumer prices, nominal exchange rates, and domestic-currency-denominated commodity prices, it responds with a one-quarter lag to innovations in M1. A short-term interest rate can be a good measure of monetary policy only if there is a one-quarter delay in its response to M1.[9] However, this assumption should be tested. In order to do this, we follow Bernanke and Blinder (1992) and estimate the slope of the supply curve of reserves. They show that if a central bank follows an interest rate targeting rule, the supply curve approximately has a zero slope, leading an unanticipated change in demand for reserves to have either no or, at most, a negligible effect on interest rates.

[8]The price puzzle refers to the finding that a tightening monetary policy shock leads to an increase in inflation. The liquidity puzzle refers to the finding that the same type of shock results in an increase in monetary aggregates. Since the supply of monetary aggregates shrinks and holding domestic financial assets becomes more attractive, a tightening shock results in nominal appreciation.

[9]Otherwise, the ensuing correlation between innovations in short-term interest rates and those in M1 would make interpreting innovations in the former as shocks to monetary policy impossible since these innovations would reflect not only the monetary policy stance but also a reaction of central banks to changes in the economy, causing short-term interest rates to be an invalid measure of policy.

On the other hand, if the central bank follows a reserves-targeting regime, reserves are supplied inelastically, resulting in the supply curve of reserves having a large slope.

We have monthly data for Turkey to test this hypothesis. Following Bernanke and Blinder (1992), we run a three-variable VAR that includes the logs of non-borrowed and required reserves of deposit money banks (denoted by nbr_t and rr_t, respectively), and a simple weighted average of overnight interest rates ($R_{\mathcal{H},it}$). For our monthly data, 6 is chosen to be the lag length.[10] Next, we estimate the following equation:

$$\boldsymbol{u}_t^{R_{\mathcal{H}}} = b \times \boldsymbol{u}_t^{nbr} + e_t, \tag{5}$$

where $\boldsymbol{u}_t^{R_{\mathcal{H}}}$ and $\boldsymbol{u}_t^{nbr}$ are innovations to $R_{\mathcal{H},it}$ and nbr_t, respectively, and can be interpreted as shocks to these variables. The slope of the supply of reserves is given by b in (5). Similar to Bernanke and Blinder (1992), we estimate b using innovations to RR_t (denoted by $\boldsymbol{u}_t^{rr}$) as an instrument for $\boldsymbol{u}_t^{nbr}$. This estimate is consistent since the error terms in $R_{\mathcal{H},t}$ have no contemporaneous effect on innovations to rr_t owing to a fourteen-day delay between calculation and maintenance periods of required reserves in Turkey.[11] In addition, one would expect innovations to rr_t to be a good instrument for innovations to nbr_t under a regime of short-term interest rate targeting since they should be strongly correlated under this regime.

Table 2 reports the slope estimates from (5), the correlation between $\boldsymbol{u}_t^{rr}$ and $\boldsymbol{u}_t^{nbr}$ (denoted by $\rho_{rr,nbr}$), the correlation between $\boldsymbol{u}_t^{nbr}$ and $\boldsymbol{u}_t^{R_{\mathcal{H}}}$ (denoted by $\rho_{nbr,R_{\mathcal{H}}}$), and the correlation between $\boldsymbol{u}_t^{rr}$ and $\boldsymbol{u}_t^{R_{\mathcal{H}}}$ (denoted by $\rho_{rr,R_{\mathcal{H}}}$) over the different regimes of monetary policy implemented in Turkey between 1990:M1 and 2013:M3.

[10]For all the series, we use the last observations from each month. Our source of data for the series is Interbank Money Market Transactions Summary and Deposit Money Banks Balance Sheet from the Central Bank of the Republic of Turkey's Electronic Data Delivery System. We define the total reserves of deposit money banks (denoted by tr_t) as the sum of claims on central bank (code number: TP.PB.K07) and required reserves (code number: TP.PB.K23). Next, we define nbr_t as the difference between tr_t and loans used from the central bank whose code is TP.PB.S08.

[11]$\mathbb{E}(\boldsymbol{u}_t^{rr} e_t) = 0$. This assumption would not have been justified if we had used the monthly averages for $R_{\mathcal{H},t}$. Yet, for $R_{\mathcal{H},t}$, we use the series from the end of each month, which results in shocks to this variable having no effect on rr_t due to the lagged reserve accounting system in Turkey.

Table 2. The Slope Estimates of the Supply Curve of Reserves in Turkey

Regime	**Pre-Implicit Inflation Targeting (1990:M1–2001:M12)**	**Implicit Inflation Targeting (2002:M1–2005:M12)**	**Explicit Inflation Targeting (2006:M1–2013:M3)**
b	4.354	0.093	−0.010
	(1.004)	(0.037)	(0.016)
$\rho_{rr,nbr}$	0.65	0.73	0.41
$\rho_{nbr,R_{\mathcal{H}}}$	0.31	0.45	0.06
$\rho_{rr,R_{\mathcal{H}}}$	0.36	0.34	−0.07

Note: The numbers in parentheses indicate standard errors.

The last column of this table indicates a small and insignificant slope of the supply curve of reserves under the explicit inflation-targeting regime in Turkey; it also indicates that while innovations to $R_{\mathcal{H},t}$ are almost uncorrelated with those to either nbr_t or rr_t, innovations to nbr_t have a large correlation with rr_t. Therefore, we conclude that the explicit inflation-targeting regime in Turkey can be characterized by short-term interest rate targeting.

The findings under an explicit inflation-targeting regime sharply contrast with those in the period when an implicit inflation-targeting regime was in effect and with those in the previous period, the first four years of which were characterized by base money targeting and the rest by crawling band regimes in Turkey. Indeed, innovations to $R_{\mathcal{H},t}$ have a large correlation with nbr_t and rr_t, and the slope of the supply curve is estimated to be larger in these periods compared with that in the period when explicit inflation targeting was in effect. These findings are not compatible with short-term interest rate targeting in the period before the explicit inflation-targeting regime in Turkey.

Our conjecture is that this finding holds generally for the developing countries in our sample. Consequently, we specify the monetary policy equation in developing countries under inflation targeting as an interest rate rule.

The Specification of the Monetary Policy Equation. Letting the first structural shock be the monetary policy shock, the monetary policy equation can be written from (1) as

$$Y'_{it} a_{Y0,c_1} = \sum_{j=1}^{p} Y'_{it-j} a_{Yj,c_1} + \sum_{j=0}^{p} X'_{it-j} a_{Xj,c_1} + \varepsilon_{1,it} \quad \text{for} \quad 1 \leq t \leq T, \tag{6}$$

where a_{Y0,c_1} is the first column of A_{Y0}, a_{Yj,c_1} is the first column of A_{Yj} for $j \in \{1, 2, \ldots, p\}$, and a_{Xj,c_1} is the first column of A_{Xj} for $j \in \{0, c_1, \ldots, p\}$. $\varepsilon_{1,it}$ denotes the period-t monetary policy shock in country i and is the first element of ε_{it}.

Now, we turn to the discussion of the systematic portion of monetary policy in developing countries.

RESTRICTION 2. *A monetary-policy-related interest rate is the key instrument of monetary policy in developing countries which adopted* *an inflation-targeting regime. The monetary authorities in these economies contemporaneously react to an increase in output and consumer prices, a nominal exchange rate depreciation, and an increase in commodity prices in the national currencies ($P_{it}^{com.} \times \mathcal{E}_{it}$) by increasing the policy rate. Yet, they can only react to innovations in monetary aggregates with a one-quarter delay.*

Restriction 2 is similar to the restrictions imposed in Arias, Caldara, and Rubio-Ramirez (2015) in their benchmark specification of the systematic portion of monetary policy for the United States. Our discussion in subsections 2.1.2 and 2.1.3 suggests the policy rates are the key instruments of monetary policy in our sample of countries. We assume that central banks in developing countries aim at keeping the economy at its full employment level and respond to an increase in output by increasing policy-related rates to prevent the economy from overheating. In addition, since their main goal is price stability, they increase policy-related interest rates if consumer and commodity prices increase. However, the timing of the central banks' reaction to an unanticipated increase in consumer prices may differ from that in commodity prices. This is implicitly assumed in restriction 2. Further, differently from Arias, Caldara, and Rubio-Ramirez (2015), we also assume that central banks in developing economies increase short-term interest rates if a nominal exchange rate depreciation occurs mainly due to a delayed effect on consumer prices from shocks to the exchange rate.[12] This assumption is also in harmony with the finding in Calvo and Reinhart (2002) that the weight attached by the monetary authorities in developing economies to the stabilization of the exchange rate in setting interest rates is much larger than that in developed economies. Finally, we assume that short-term interest rates are unresponsive to shocks to monetary aggregates.

Using restriction 2, one can rewrite (6) as

$$\begin{aligned} R_{\mathcal{H},it} = &-a^{-1}_{Y0,c_{51}} \left\{ a_{Y0,c_{11}} \mathcal{Y}_{it} + a_{Y0,c_{21}} P_{it} + a_{Y0,c_{31}} \mathcal{E}_{it} + a_{Y0,c_{41}} M1_{it} \right\} \\ &+ a^{-1}_{Y0,c_{51}} a_{X0,c_{11}} P_{it}^{com.} + D'_{it} A_D + a^{-1}_{Y0,c_{51}} \varepsilon_{1,it}, \qquad (7) \end{aligned}$$

[12] See Frankel, Parsley, and Wei (2005) for a discussion of a partial short-term exchange rate pass-through on consumer prices in developing economies.

where $a_{_{Y0,c_{k1}}}$ and $a_{_{X0,c_{k1}}}$ are the k^{th} elements of the first column of the corresponding matrices and D_{it} is a matrix of variables which enter into the monetary policy equation but are unconstrained by restriction 2. D_{it} may contain the lags of both endogenous and exogenous variables in addition to the current exogenous variables.

Next, we present a matrix characterization of both restrictions 1 and 2. This requires some definitions.

DEFINITION. *The IRF of the i^{th} variable to the j^{th} shock at finite horizon h is given by the i^{th} row and j^{th} column of the matrix:*

$$L_h(A_{_{Y0}}, B_{_{Y1}}, \ldots, B_{_{Yp}}) = (A_{_{Y0}}^{-1} J' F^h J)',$$

where

$$F = \begin{vmatrix} B_{_{Y1}} & I_{n_Y} & 0_{n_Y \times n_Y} & \cdots & 0_{n_Y \times n_Y} \\ B_{_{Y2}} & 0_{n_Y \times n_Y} & I_{n_Y} & \cdots & 0_{n_Y \times n_Y} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ B_{_{Yp-1}} & 0_{n_Y \times n_Y} & 0_{n_Y \times n_Y} & \cdots & I_{n_Y} \\ B_{_{Yp}} & 0_{n_Y \times n_Y} & 0_{n_Y \times n_Y} & \cdots & 0_{n_Y \times n_Y} \end{vmatrix},$$

$$J = \begin{vmatrix} I_{n_Y} \\ 0_{n_Y \times n_Y} \\ 0_{n_Y \times n_Y} \\ \vdots \\ 0_{n_Y \times n_Y} \end{vmatrix}. \tag{8}$$

We define the matrices $S_{1A_{_{Y0}}}$, $S_{1A_{_{X0}}}$, S_{1L_0}, and $Z_{1A_{_{Y0}}}$, which characterize sign and zero restrictions, as

$$S_{1A_{_{Y0}}} = \begin{vmatrix} -1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix}, \quad S_{1A_{_{X0}}} = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{vmatrix} \tag{9}$$

$$S_{1L_0} = \begin{vmatrix} 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{vmatrix}, \quad Z_{1A_{Y0}} = \begin{vmatrix} 0 & 0 & 0 & 1 & 0 \end{vmatrix}. \tag{10}$$

Restrictions 1 and 2 can be summarized with the following matrices:

$$S_1 = \begin{vmatrix} S_{1A_{Y0}} & S_{1A_{X0}} & 0_{5\times n_Y} \\ 0_{4\times n_Y} & 0_{4\times n_X} & S_{1L_0} \end{vmatrix} \begin{vmatrix} A_{Y0} \\ A_{X0} \\ L_0 \end{vmatrix} e_1 > 0 \tag{11}$$

$$Z_1 = \begin{vmatrix} Z_{1A_{Y0}} & 0_{1\times n_X} & 0_{1\times n_Y} \end{vmatrix} \begin{vmatrix} A_{Y0} \\ A_{X0} \\ L_0 \end{vmatrix} e_1 = 0. \tag{12}$$

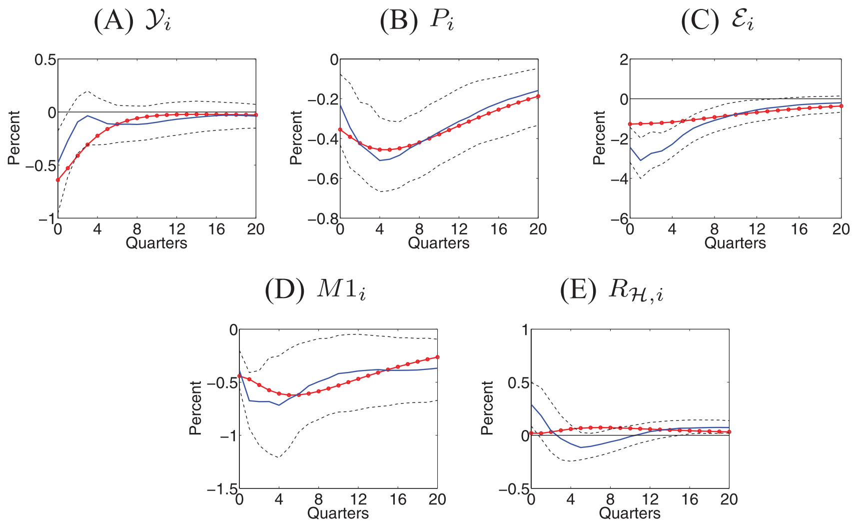
S_1 in (11) is a matrix of 9×1. Its first five elements characterize the sign restrictions from the systematic component of monetary policy on output, the price level, the nominal exchange rate, the monetary-policy-related interest rate, and commodity prices, respectively. The last four elements correspond to the sign restrictions on the contemporaneous response to a tightening monetary policy shock of the price level, the nominal exchange rate, M1, and the monetary-policy-related interest rate. Z_1 in (12) characterizes a zero restriction on M1 from the systematic component of monetary policy.

2.1.4 Estimation and Inference

All the variables that are used to estimate (2) are in logs except $R_{\mathcal{H},it}$ and $R_t^{U.S.}$, which are in levels. For our quarterly data, 4 is chosen to be the lag length. To draw inferences from the posterior, we employ Bayesian methods with a normal-Wishart prior, as in Uhlig (2005). In particular, we take 15,000 draws from the panel VAR posterior, and for each draw, we verify if the draw is consistent with the sign and zero restrictions.[13] We discard all the draws that do not

[13] We use the algorithm suggested by Arias, Rubio-Ramirez, and Waggoner (2014) to verify whether the sign and zero restrictions hold for a particular draw.

Figure 1. IRFs to Monetary Policy Shocks



Notes: Our calculations are based on the IMF's International Finance Statistics. The solid lines indicate the estimated pointwise impulse responses. The area between the dashed lines shows the 68 percent confidence interval estimated using algorithms in Arias, Rubio-Ramirez, and Waggoner (2014). The solid lines with circles indicate the model-based impulse responses.

satisfy these restrictions and keep the remaining ones. In figure 1, we provide the 68 percent confidence bands as well as the median IRFs.

2.1.5 Results

Figure 1 illustrates the IRFs of output ($\mathcal{Y}_i$), the price level (P_i), the nominal exchange rate ($\mathcal{E}_i$), M1, and the monetary-policy-related interest rate ($R_{\mathcal{H},i}$) to a 1 percent innovation in $R_{\mathcal{H},i}$ in developing economies when restrictions 1 and 2 are imposed. With this specification, a tightening monetary policy shock in these economies

- induces a decrease in $\mathcal{Y}_i$ relative to its undistorted path which is not significant after two quarters;
- results in a fall in P_i in the impact period, followed by an inverted hump-shaped dynamics thereafter;

- leads to a much larger fall in $\mathcal{E}_i$ than P_i in the impact period, implying that the real exchange rate with the United States appreciates in developing economies;
- causes a sizable and persistent fall in the $M1_i$, suggesting large liquidity effects; and
- gives rise to a short-lived increase in $R_{\mathcal{H},i}$.

How do our findings from a tightening shock to monetary policy in developing economies compare with those in the United States? Since we use a methodology similar to Arias, Caldara, and Rubio-Ramirez (2015), it is a useful exercise to compare our findings with theirs. We note two differences regarding the price-level dynamics. First, following this shock, while we find that the price level exhibits inverted hump-shaped dynamics in developing economies (see panel B in figure 1), Arias, Caldara, and Rubio-Ramirez (2015) find that it falls steadily in the United States.[14] Second, while we find that the response of the price level in developing economies is initially large, Arias, Caldara, and Rubio-Ramirez (2015) indicate that it is initially small in the United States. These findings imply a more rapid price adjustment in developing economies compared with that in the United States, which can be traced mainly to two characteristics of developing economies: the high pass-through of exchange rates into import prices, and frequent price changes. Furthermore, the dynamic response of output in developing economies differs from that in the United States. Specifically, while the initial response of output from the shock is large in the former, it is small in the latter.[15]

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[14]Similarly, Christiano, Eichenbaum, and Evans (1996, 1998), Leeper, Sims, and Zha (1996), Bernanke, Boivin, and Eliasz (2005), and Boivin, Giannoni, and Mihov (2009) find either a smooth and steady decline or first a negligible increase and then a steady decline in the price level in the United States after a tightening monetary policy shock.

[15]In section A.1 of online appendices to this paper (available at http://www.ijcb.org), we do three robustness checks. First, we consider an alternative specification of the monetary policy equation. This alternative specification is the same as the benchmark specification except that monetary authorities are assumed to contemporaneously react to price inflation, the rate of change in the nominal exchange rate, and commodity price inflation rather than the *levels* of these variables, as assumed in the benchmark specification. In the second robustness check, we replace restriction 1 with a weaker restriction that a tightening shock results in a contemporaneous increase in the policy rate, leaving the IRFs of the other endogenous variables unconstrained. Third, we enlarge our sample

2.1.6 A Critique of the Recursive Assumption

Before concluding our empirical section, it is useful to discuss the recursive assumption, which is widely used in the literature for isolating monetary policy shocks. The recursive assumption identifies monetary policy shocks with short-run restrictions on the contemporaneous response of variables. In this method, the monetary authority is assumed to set its operating instrument by observing the movements in two different sets of variables. The first set of variables contains variables that may respond only with a lag to monetary policy shocks and whose current values are known to the central bank before a decision on its operating instrument is made. The second set of variables, on the other hand, consists of variables that may contemporaneously respond to monetary policy shocks and whose current values are unknown to the central bank before setting its operating instrument. The necessity of including variables in one of these sets lies at the root of the controversy over the recursive assumption for identifying shocks to monetary policy in developing economies. For example, in which set should the price level be included? Including it in the first set implies that prices are sluggish in responding to monetary policy shocks. Such an assumption would be in conflict with the fact that a considerable share of prices change in a typical quarter in developing economies. Additionally, because of the fast response of exchange rates to monetary policy shocks and a stronger pass-through of exchange rates into import prices in developing countries than in advanced countries, it is plausible to assume that monetary policy shocks affect prices contemporaneously through their effect on exchange rates. Consequently, including the

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of countries by using the money-market rate as a measure of a short-term interest rate in developing economies if the monetary-policy-related interest rate is unavailable. With this larger sample, we study the effects from the monetary policy shocks using both the benchmark and the alternative specification of the systematic portion of monetary policy. We find little difference in our results from these cases compared with our main estimation.

In online appendix A.2, we also look at the outcomes from the identification where, differently from the benchmark identification, the systematic component of monetary policy is not disciplined, and we find that a tightening shock no longer causes output to contract. Consequently, taking into account the systematic component of monetary policy in the agnostic identification of monetary policy shocks in developing economies drastically changes the outcomes.

price level in the first set of variables is questionable. Including the price level in the second set of variables is also questionable since including it in this set implies that central banks set their operating instrument without knowing what the current price level is. However, they collect data on a large volume of prices and are likely to predict the general trend in prices over any period. In our view, the price level in developing economies belongs to neither the first nor the second set of variables. Yet, since the recursive assumption requires it to be included in either of the two sets, we have abandoned this strategy.

Our method for isolating monetary policy shocks in developing economies can be regarded as free of our criticism of the recursive assumption.[16] In particular, in our identification scheme, monetary authorities can contemporaneously observe general fluctuations in consumer prices and respond to them if they deem necessary. At the same time, prices are free to respond contemporaneously to shocks in monetary policy stance.

3. Theoretical Model

In this section, we briefly present a small open-economy DSGE model and leave the discussion of its first-order conditions and its log-linear approximation around some positive inflation steady state to online appendix B. We start with the problem of home and foreign households.

3.1 The Problem of Home and Foreign Households

There is a continuum of infinitely lived households in each country with a mass of one and indexed with h. Each household comprises two members. Their aim is to maximize their joint lifetime discounted utility with the discount factor given by β. In period t, the members of the h^{th} household in the home country have to make a sequence of decisions. First, they have to choose how much to consume from the non-traded final consumption good (C_t). Second, they optimally choose how intensively they supply their capital (u_t)

[16] We owe thanks to the anonymous referee for the suggestion regarding identification strategy for isolating monetary policy shocks in developing countries.

in each period. Third, they decide on the amount of investment (I_t) and, therefore, on the next period's capital stock (K_{t+1}). Fourth, they have to decide on the amount of optimal holdings of a one-period risk-free domestic bond (B_{t+1}) which pays a nominal return of $R_{\mathcal{H},t}$. Fifth, they choose the amount of optimal holdings of real money balances (M_t/P_t). Lastly, only one member of the household obtains a chance to renegotiate his wage contract in each period. The wage contract, made in any period, lasts for two periods and has to be signed one period before observing the shock. It is noteworthy that staggered wage setting helps our model account for the findings in Li (2011) that real wages follow business cycles with a one-quarter lag in developing economies and that their correlation with output is moderate.[17] The problem of the home household can be put more compactly as follows:

$$\max_{C_t,u_t,I_t,K_{t+1},B_{t+1},x_t,M_t} E_t \sum_{s=0}^{\infty} \beta^{t+s} \times \left(\frac{C_{t+s}^{1-\sigma_c}-1}{1-\sigma_c} - \frac{\tilde{n}_{t+s,i}^{1+\sigma_n}}{1+\sigma_n} - \frac{n_{t+s,i}^{1+\sigma_n}}{1+\sigma_n} + \frac{\left(\frac{M_{t+s}}{P_{t+s}}\right)^{1-\sigma_m}-1}{1-\sigma_m} \right), \quad (13)$$

where $\tilde{n}_{t,i}$ and $n_{t,i}$ are the hours worked by household members whose wage contracts are signed in period t and $t-1$, respectively. σ_c^{-1}, σ_n^{-1}, and $\sigma_m^{-1}(\bar{R}_{\mathcal{H},t}-1)^{-1}$ stand for the intertemporal elasticity of substitution, the Frisch elasticity of labor supply, and the interest semi-elasticity of money demand, respectively.[18] In solving (13), the household has the following budget constraint:

$$\begin{aligned} P_{t+s}\left(C_{t+s}+I_{t+s}+a(u_{t+s})K_{t+s}+B_{t+1+s}\right)+M_t &= M_{t-1}+M_t^a \\ &- M_{t-1}^a + x_{t+s,i}\tilde{n}_{t+s,i} + x_{t-1+s,i}n_{t+s,i} + R_{t+s}^k u_{t+s}K_{t+s} \\ &+ R_{\mathcal{H},t-1+s}P_{t-1+s}B_{t+s} + \Pi_{t+s}, \end{aligned} \quad (14)$$

[17] See online appendix C for a detailed discussion of the model-based real wage dynamics.

[18] The steady-state values of variables are denoted by the bar symbol over these variables.

where M_t^a denotes the economy-wide stock of money in the home country. We assume that monetary seignorage, $M_t^a - M_{t-1}^a$, is transferred back to home households by the home monetary authority as lump-sum transfers. In writing (14), we follow Christiano, Eichenbaum, and Evans (2005) and assume that increasing capacity utilization (u_t) involves real costs in units of the final good denoted by $a(u_t)$.[19] The price of the home non-traded final good is denoted by P_t. R_t^k denotes the rental rate of capital paid to the owners of capital stock. The nominal return on the holdings of last period's risk-free domestic bonds is shown with $R_{\mathcal{H},t-1}$. $x_{t,i}$ and $x_{t-1,i}$ in (14) represent the hourly wage earnings of the household member who negotiates his wage in period t and $t-1$, respectively. Lastly, Π_t shows the profits of firms which belong to the household. In sum, the representative household earns wage, capital, profit, and interest income. The household uses its resources to finance purchases of the final consumption good, investment, the cost associated with varying u_t, and purchases of domestic risk-free bonds.

The law of motion for capital in the home country is given as

$$K_{t+1} = (1-\delta)K_t + \phi\left(\frac{I_t}{K_t}\right)K_t, \tag{15}$$

where $\phi\left(\frac{I_t}{K_t}\right)K_t$ shows the additional capital stock which new investment in the current period makes available for the next period.[20]

The problem of the foreign household is similar and is discussed in detail in online appendix B.

[19] Christiano, Eichenbaum, and Evans (2005) find that this feature plays a central role in explaining inflation inertia and output persistence after a monetary policy shock in the United States. Indeed, when they include variable capacity utilization in their model, households lower the supply of capital services after a tightening shock. This limits the fall of the rental rate of capital in response to this shock and helps their model explain inflation inertia in the United States. It should be noted that at the steady state, capital is fully utilized, $\bar{u} = 1$, and the function $a(u)$ has the following properties: $a(1) = 0$, $a'(u) > 0$, and $a''(u) > 0$.

[20] At the steady state, $\bar{I} = \delta\bar{K}$. The function $\phi\left(\frac{I_t}{K_t}\right)$ has the following properties: $\phi\left(\delta\right) = \delta$, $\phi'\left(\delta\right) = 1$, $\phi'\left(.\right) > 0$, and $\phi''\left(.\right) < 0$. The last assumption implies that $\phi''\left(.\right)$ is concave, emanating from the fact that new investment is subject to adjustment costs.

3.1.1 Aggregate Wage Equation

It is notable that the existing models of staggered wage setting, such as the Erceg, Henderson, and Levin (2000) and Huang and Liu (2002) models, are not particularly suitable for studying developing countries. The reason is that these models require the assumption of complete financial markets, whereas financial markets in developing economies are in the infant stage and lack sophistication.[21] For this reason, we develop a novel structural staggered-wage-setting model with incomplete insurance. To explain the difficulty of incorporating staggered wages with incomplete insurance, suppose households hold only non-state-contingent bonds. Since workers renew their wage contracts in different periods under staggered wage setting, their wage income must differ after a monetary shock. This, together with the absence of state-contingent bonds with incomplete insurance, results in budget constraints being different among households. Consequently, the problem of households in the economy with incomplete insurance might not be reduced to that of the "representative household" since households' budget constraints would not be alike after the shock. Solving such a model involves the difficult task of following the non-degenerate income distribution period by period, which can be computationally demanding.

Both Erceg, Henderson, and Levin (2000) and Huang and Liu (2002) circumvent this problem by assuming complete financial markets. Under complete insurance, state-contingent assets are traded to eliminate idiosyncratic risks among households. In staggered wage-setting environments, these risks are associated with uncertainty about the timing of wage contract renewals. For example, when a tightening monetary policy shock happens, in the absence of full insurance, workers whose contracts are renewed soon may be in a disadvantageous position compared with workers whose contracts are renewed late. However, under complete financial markets, these

[21] When formal financial markets are unavailable, informal institutions in developing economies can partly fill the role played by formal financial markets in advanced countries (see Wang 2014). However, informal institutions in developing countries do not provide the same amount of insurance as would formal financial markets in advanced countries. This is evident from the finding that consumption fluctuates more than output in developing economies, which is largely the result of less sophisticated financial markets in developing economies (see International Monetary Fund 2001).

idiosyncratic risks are eliminated since income transfers through state-contingent bonds exactly offset wage income differences among households so that they have the same income in all periods. In other words, there is a single budget constraint among households and income distribution is degenerate with complete insurance.

To the best of our knowledge, what is left unexplored in the literature is that idiosyncratic risks under staggered wage setting can be eliminated even when insurance is incomplete. This can be explained as follows: in our DSGE model, households contain two members, the wife and the husband, who negotiate their wages with employers in even and odd periods, respectively. Since some wages may not be recontracted immediately after a monetary shock, wage adjustment in our model is staggered. Despite this, households' budget constraints in our model will be identical after a monetary shock. To explain this, firstly note that since wives in all households recontract their wages in the same period, their wage income will be alike after this shock. By the same logic, the wage income of husbands in all households will also be the same. Since households' total wage income is equal to the sum of wives' and husbands' wages, even in the absence of income transfers through financial assets, households' total income will be alike in all periods after the monetary shock. Consequently, there is a single budget constraint among households and the income distribution of households is degenerate since they all have the same income. This allows us to consider only the problem of the "representative household" instead of considering household-specific maximization problems. Achieving staggered wage setting without sacrificing the incomplete financial market assumption in developing countries adds realism to our model.

For reasons of brevity, we leave a detailed discussion of the home and foreign wage-setting environment to online appendix B.

3.2 The Objective of Firms in Home and Foreign Countries

3.2.1 Firms Producing Final Goods in Home and Foreign Countries

The non-traded final goods in both countries are produced by a continuum of perfectly competitive firms. Home-country firms producing final goods combine domestic goods ($Y_{\mathcal{H},t}$) and import goods ($Y_{\mathcal{F},t}$) to produce final goods (Y_t) with the following technology:

$$Y_t = \left((1-\psi)^{\frac{1}{\rho}} Y_{\mathcal{H},t}^{(\rho-1)/\rho} + \psi^{\frac{1}{\rho}} Y_{\mathcal{F},t}^{(\rho-1)/\rho}\right)^{\frac{\rho}{\rho-1}}, \tag{16}$$

where ψ and ρ represent the steady-state weight of the import good in the home country and the elasticity of substitution between the domestic and import goods, respectively.

The final good in the foreign country is again produced by perfectly competitive firms. Yet, the technology combining home and foreign goods to produce its output may involve a lower steady-state share of imports in the foreign country than in the home country. Indeed, the foreign technology is given by

$$Y_t^* = \left(\left(1-\frac{\psi}{\tau}\right)^{\frac{1}{\rho}} Y_{\mathcal{F},t}^{*(\rho-1)/\rho} + \left(\frac{\psi}{\tau}\right)^{\frac{1}{\rho}} Y_{\mathcal{H},t}^{*(\rho-1)/\rho}\right)^{\frac{\rho}{\rho-1}}, \tag{17}$$

where the variables denoted with asterisks ($*$) represent the foreign counterparts of home variables. It is clear from (17) that the steady-state import share in the foreign country is $\left(\frac{\psi}{\tau}\right)$, which is smaller than the steady-state import share in the home country ψ if $\tau \geq 1$. This assumption is convenient since it allows us to study small and large open economies within the same model. Indeed, for a large economy, one can take $\tau = 1$. For a small economy, on the other hand, one can assume τ is *arbitrarily large*, as the size of its trading partners is much larger than its size.

3.2.2 Invoice Currency and the Pricing of Internationally Traded Goods

The home-import good ($Y_{\mathcal{F},t}$) is produced by perfectly competitive home-import firms. Producing the home-import good involves combining intermediate foreign goods which are invoiced in different currencies. Indeed, while some intermediate goods are invoiced in the home currency (¢), others are invoiced in the foreign currency (¢*). In producing the home-import good, the home-import firm combines output from the foreign firms which set prices either in the home currency or in the foreign currency (denoted by $Y_{F,¢,t}$ and $Y_{F,¢^*,t}$, respectively) with the following technology:

$$Y_{\mathcal{F},t} = \left((1-\omega^*_{¢^*})^{\frac{1}{\theta_p}} Y_{F,¢,t}^{(\theta_p-1)/\theta_p} + \omega^{*\frac{1}{\theta_p}}_{¢^*} Y_{F,¢^*,t}^{(\theta_p-1)/\theta_p} \right)^{\frac{\theta_p}{\theta_p-1}}, \quad (18)$$

where θ_p stands for the elasticity of substitution between intermediate foreign goods invoiced in different currencies and $\omega^*_{¢^*}$ denotes the steady-state weight of the foreign-currency-invoiced intermediate foreign goods in the home-import price index.

The home-export good is produced similarly. Indeed, perfectly competitive foreign importers combine output from the home firms which set prices in the home and foreign currencies (denoted by $Y^*_{\mathcal{H},¢,t}$ and $Y^*_{\mathcal{H},¢^*,t}$, respectively) with the following technology:

$$Y^*_{\mathcal{H},t} = \left(\omega_{¢}^{\frac{1}{\theta_p}} {Y^*_{\mathcal{H},¢,t}}^{(\theta_p-1)/\theta_p} + (1-\omega_{¢})^{\frac{1}{\theta_p}} {Y^*_{\mathcal{H},¢^*,t}}^{(\theta_p-1)/\theta_p} \right)^{\frac{\theta_p}{\theta_p-1}}, \quad (19)$$

where $\omega_{¢}$ is the steady-state share in the foreign-import price index of the home-currency-priced intermediate home-export goods.

3.2.3 Home and Foreign Firms Producing Varieties for Intermediate Goods

The intermediate domestic and import goods in both the home and foreign countries are composite goods composed of a variety of goods produced by firms engaging in monopolistic competition. The production technology used in the production of intermediate domestic goods is given as

$$Y_{\mathcal{H},t} = \left(\int_0^1 {Y_{\mathcal{H},j,t}}^{(\theta_p-1)/\theta_p} dj \right)^{\frac{\theta_p}{\theta_p-1}}, \quad (20)$$

where $Y_{\mathcal{H},j,t}$ denotes demand for variety j of the firm producing the domestic intermediate good in the home country.

When producing variety j, the firm employs the composite labor ($N_{\mathcal{H},j,t}$) together with capital ($K_{\mathcal{H},j,t}$) and uses the following production function:

$$Y_{\mathcal{H},j,t} = K^{1-\chi}_{\mathcal{H},j,t} N^{\chi}_{\mathcal{H},j,t}, \quad (21)$$

where χ is the steady-state share of labor in the home country. In each period, only a fraction of firms producing different varieties obtain a price-change signal (denoted by $1-\alpha$). When firms obtain such a signal, they set prices with their intermediate domestic-good suppliers. These prices remain constant until a new price-change signal is obtained. During this time, firms are obliged to supply any quantity demanded of their varieties.

Similar to the domestic intermediate good, the home-export goods are composite goods made up of a continuum of varieties produced by monopolistically competitive firms, as discussed in online appendix B.

3.3 Monetary Policy

We assume monetary policy in the home country is represented by the following interest rate rule:

$$\hat{R}_{\mathcal{H},t} = \Phi_{\mathcal{Y}}\hat{\mathcal{Y}}_t + \Phi_P \hat{P}_t + e_t^r, \tag{22}$$

where e_t^r represents a shock to monetary policy in the home country, which follows an exogenous AR(1) process given by

$$e_t^r = \rho_e e_{t-1}^r + \varepsilon_t^r, \tag{23}$$

where ε_t^r is Gaussian with mean zero and variance equal to $\sigma_{\varepsilon^r}^2$.[22] Lastly, monetary policy in the foreign country is represented by a Taylor-type rule, as discussed in online appendix B.18.2.

4. Calibration and Estimation

This section discusses our methodology for estimating our model. The parameters in our model are either calibrated or estimated. We start with a discussion of the calibrated parameters whose

[22]It is notable that we also experimented with an interest rate rule in the home country where, besides output and the price level, the authorities also respond to a depreciation in the nominal exchange rate. However, the estimated value of the coefficient on the price level in this policy equation is almost zero. Since this is an implausible value, we dropped the nominal exchange rate from the policy equation in (22).

set contains $\alpha, \alpha^*, \beta, \chi, \delta, \omega_{¢}, \bar{\pi}, \bar{\pi}^*, \psi, \rho, s_c, s_i, \sigma_c^{-1}, \sigma_n^{-1}, \sigma_\phi^{-1}, \tau, \Theta'\bar{Y}$, and θ_w.[23]

Table 3 presents calibrated parameter values along with the source upon which we base our calibration for these parameters. We start with α. It is taken to be equal to 51 percent, implying that 49 percent of prices in developing countries change in a typical quarter. At the monthly frequency, this suggests a 27.2 percent frequency of price changes, which is in line with the estimates of the mean frequency of price changes in Mexico when inflation remained between 4 percent and 14 percent, as discussed in Gagnon (2009). The price stickiness in the foreign country, α^*, on the other hand, is taken as 59 percent, implying that the average *quarterly* frequency of price changes is 41 percent. This calibrated value for α^* is based on Carvalho and Nechio (2011), who report the weighted average of the *monthly* frequency of price adjustments in the United States as 21 percent. β is set to $1.03^{\frac{-1}{4}}$, which implies an annual real interest rate of 3 percent. The steady-state share of wages in output, χ, is taken as 0.66. We set δ to 0.025, implying an annual rate of depreciation of 10 percent, which is the estimated annual rate of depreciation in the United States in Christiano and Eichenbaum (1992).

The value of the steady-state share of home exports invoiced in the home currency, $\omega_{¢}$, is chosen to be zero, reflecting that exports of developing countries are priced in the core currencies rather than in their own currencies. The share of home imports invoiced in the foreign currency, on the other hand, is denoted by $\omega^*_{¢^*}$. It is remarkable that the value of $\omega^*_{¢^*}$ plays an important role in the extent of exchange rate pass-through to imported good prices in our model. When its value is close to one, it suggests that the practice of producer-currency pricing prevails among importers and the pass-through is complete. Based on the average share of foreign-currency-invoiced imports at the dock in Turkey over the period of 1996–2013, $\omega^*_{¢^*}$ is set to 0.97.[24]

To study monetary policy shocks in developing countries, we log-linearize our model around a positive-inflation and zero-debt steady

[23] σ_ϕ^{-1} is defined as $\frac{\phi'(\bullet)}{\phi''(\bullet)\bullet}$. $\Theta'\bar{Y}$ is defined in online appendix B.10.1.

[24] See online appendix D. Cook and Devereux (2006) also report similar shares of imports invoiced in the foreign currencies among some East Asian countries.

Table 3. Calibrated Parameter Values

Parameters	Description	Values	Source
α	Price stickiness in the home country	0.51	Gagnon (2009)
α^*	Price stickiness in the foreign country	0.59	Carvalho and Nechio (2011)
β	Discount factor	$1.03^{\frac{-1}{4}}$	Christiano, Eichenbaum, and Evans (2005)
χ	Labor share in GDP	0.66	Christiano, Eichenbaum, and Evans (2005)
δ	Quarterly rate of depreciation on capital	0.025	Christiano and Eichenbaum (1992)
$\omega_{¢}$	Share of home exports invoiced in the home currency	0	See text
$\omega^*_{¢*}$	Share of home imports priced in the foreign currency	0.97	Our estimate
$\bar{\pi}$	Annual steady-state inflation in the home country	0.05	See text
$\bar{\pi}^*$	Annual steady-state inflation in the foreign country	0.02	See text
ψ	Share of imports in GDP	0.25	See text
ρ	Elasticity of substitution between the domestic and imported goods	1.5	Carvalho and Nechio (2011)
s_c	% share of final consumption expenditure in GDP	68	See text
s_i	% share of investment in GDP	19	See text
σ_c^{-1}	Intertemporal elasticity of substitution	1/3	Carvalho and Nechio (2011)
σ_n^{-1}	Frisch elasticity of labor supply	1	Kimball and Shapiro (2008)
σ_ϕ^{-1}	Elasticity of aggregate investment with respect to the user cost of capital	–0.66	Cummins, Hassett, and Hubbard (1994)
τ	Relative size of the foreign country	1,000	See text
$\Theta'\bar{Y}$	Elasticity of interest rate to the net domestic risk-free asset	–0.01	Devereux and Smith (2005)

state. Let $\bar{\pi}$ and $\bar{\pi}^*$ denote annual steady-state inflation in developing and advanced economies, respectively.[25] We set $\bar{\pi}$ and $\bar{\pi}^*$ to 5 percent and 2 percent, respectively. These values are in line with annual inflation targets in these economies.

In calibrating the shares of final consumption (s_c), investment (s_m), and home imports (ψ) in GDP, we use data from the World Bank's World Development Indicators in 2002. s_c, s_m, and ψ are taken as the simple average values for the developing countries in our sample. We set σ_c^{-1} to 1/3 based on Carvalho and Nechio (2011). Similar to Christiano, Eichenbaum, and Evans (2005), σ_n^{-1} is taken as one, based on the estimate of Kimball and Shapiro (2008). We set ρ to 1.5, based on Carvalho and Nechio (2011), implying that the elasticity of substitution between the home and foreign goods is low. The elasticity of investment with respect to the user cost of capital, σ_ϕ^{-1}, is chosen to be 0.66, which is the average estimate of this elasticity in Cummins, Hassett, and Hubbard (1994). τ, which denotes the economic size of the foreign country relative to that of the home country, is taken as 1,000. τ is set to be very high for the developing countries in our sample, in line with the common small-country assumption made in the literature for these countries. It is notable that setting τ to a large value for developing economies, together with the assumption of no international borrowing at the steady state, requires that the steady-state shares of exports and imports in the foreign country be only $\frac{1}{\tau}$ as big as those in the home country. This is the essence of the small-country assumption in our model. $\Theta'\bar{Y}$ is set to a very low value so that it has no important effect on the dynamics of our model.[26]

The remaining parameters in our model are estimated. Let $\mathcal{P}$ denote this group consisting of

$$\mathcal{P} = \left[\begin{array}{ccccccc} \rho_e & \Phi_P & \Phi_{\mathcal{Y}} & \sigma_a^{-1} & \sigma_m & \theta_p & \theta_w \end{array} \right],$$

[25] $\bar{\pi}$ is defined as

$$4 \times \left(ln\bar{P}_t - ln\bar{P}_{t-1} \right).$$

[26] This parameter should not be central to our results since it is included only for a technical reason, to avoid multiple steady states in our model. See online appendix B.10.1.

where $\sigma_a^{-1} = \frac{a'(\bullet)}{a''(\bullet)\bullet}$ denotes the elasticity of capacity utilization with respect to the rental rate of capital. Let $f(\mathcal{P})$ denote the model-based IRFs of output, the price level, the nominal exchange rate, the monetary aggregate, and the policy-related interest rate for some $\mathcal{P}$ between the zeroth and twentieth quarters to a 1 percent innovation in the policy rate. Let also $\rho_{w,\mathcal{Y}}$ denote the model-based correlation of the real wage with output in the home country. We estimate $\mathcal{P}$ as the classical minimum distance estimator and denote it with $\hat{\mathcal{P}}(\hat{A}_T)$:

$$\hat{\mathcal{P}}(\hat{A}_T) = \arg\min_{\mathcal{P}} \left(\begin{bmatrix} \hat{h}_T \\ \hat{\rho}_{w,\mathcal{Y}} \end{bmatrix} - \begin{bmatrix} f(\mathcal{P}) \\ \rho_{w,\mathcal{Y}} \end{bmatrix} \right)' \times \hat{A}_T' \hat{A}_T \times \left(\begin{bmatrix} \hat{h}_T \\ \hat{\rho}_{w,\mathcal{Y}} \end{bmatrix} - \begin{bmatrix} f(\mathcal{P}) \\ \rho_{w,\mathcal{Y}} \end{bmatrix} \right), \tag{24}$$

where $\hat{h}_T$ shows the IRFs of output, the price level, the nominal exchange rate, M1, and the policy-related interest rate in *actual* developing economies between the zeroth and twentieth quarters. $\hat{\rho}_{w,\mathcal{Y}}$ is the average contemporaneous correlation of real manufacturing wages with output in emerging economies, estimated by Li (2011) to be 0.41.[27] $\hat{A}_T$ is the weighting matrix used. Lastly, T stands for the sample size of the data used for estimating the panel VAR-based IRFs. Since using different weighting matrices would yield different estimators, $\hat{\mathcal{P}}$ is written as a function of $\hat{A}_T$. As a weighting matrix, we choose the diagonal matrix, where all but the last diagonal elements are given as the inverse of standard deviations of the empirical IRFs and where the last diagonal element is equal to 4.[28] This weighting matrix ensures that more precisely estimated IRFs are given more importance than less precisely estimated ones.

[27] Since we lack data on wages for most of the countries in our sample, we are unable to study real wage dynamics in developing economies with our empirical model. Instead, we rely on the estimate of the average correlation of real wages with output at the quarterly frequency reported in Li (2011) for ten emerging economies.

[28] The last diagonal element is pertinent to the weight which we use to match $\hat{\rho}_{w,\mathcal{Y}}$ with our model. Choosing this weight to be 4 ensures that our estimation strategy attempts to keep the model-based correlation within the 95 percent confidence bands for $\hat{\rho}_{w,\mathcal{Y}}$, as reported in Li (2011).

Table 4. Estimated Parameter Values

Parameters	Description	Values
ρ_e	Persistence in a monetary policy shock in the home country	0.94 (0.01)
Φ_P	The coefficient on the price level in the home monetary policy equation	1.10 (0.15)
Φ_y	The coefficient on real expenditure in the home monetary policy equation	0.92 (0.14)
σ_α^{-1}	The elasticity of capacity utilization with respect to the rental rate of capital	0.01*
σ_m	$4 \times \sigma_m(\bar{R}_{\mathcal{H},t} - 1)$ stands for the *reciprocal* of the semi-elasticity of money demand with respect to the annualized rate of interest	26.1 (20.6)
θ_p	Price elasticity of demand for varieties within the same sector	49.6 (1.0)
θ_w	Wage elasticity of labor demand	8.5 (1.5)

Notes: The numbers in parentheses are standard errors. The asterisks next to the reported parameter values indicate that the estimated parameter values are close to their theoretical limits, and thus their standard errors are not reported.

5. Model-Based Results

In this section, we report the parameter estimates and discuss the model-based IRFs to a 1 percent monetary policy innovation in (23) and assess our model's ability and limitations to account for the IRFs in actual developing economies, as displayed in figure 1.

5.1 Estimated Parameter Values

Table 4 reports the parameter values estimated from (24). First, we discuss the parameters pertinent to the monetary policy equation in the home country. The model needs very persistent shocks to explain the IRFs in actual developing economies ($\rho_r = 0.94$). Indeed, when ρ_r is set to zero, the model has limited ability to explain the IRFs in actual developing economies and predicts that output and the price level return to their undistorted path one period after the shock. The model-based estimate of Φ_P is 1.10. This value suggests that the monetary authorities in developing economies are not very aggressive in fighting increases in the price level compared with the Volcker-Greenspan period in the United States (see, e.g., Clarida, Gali, and Gertler 2000 for the estimates of the policy equation in the United States). Our estimate of $\Phi_{\mathcal{Y}}$ is 0.94, implying that monetary authorities' response to a 1 percent deviation from potential output in developing economies is not much lower than their response to an unexpected 1 percent increase in the price level.

Second, we discuss our estimate of σ_a^{-1}. It is evident from (25) that this parameter gives the elasticity of capacity utilization with respect to the real rental rate of capital (r_t^k):

$$\frac{1}{\sigma_a}\hat{r}_t^k = \hat{u}_t. \tag{25}$$

Our estimate of σ_a^{-1} is small, suggesting that capacity utilization in developing economies is largely unresponsive to a change in r_t^k. In sharp contrast to our finding, Christiano, Eichenbaum, and Evans (2005) require this elasticity to be very large for their model to account for inflation inertia and output persistence in the United States. Indeed, a responsive capacity utilization limits the response of r_t^k after the shock since the supply of capital services can be varied even in the impact period under variable capacity utilization. This results in a smaller change in the price level in the impact period, and therefore helps their model explain inflation inertia in the United States. In contrast, as is evident from figure 1, there is no inflation inertia in developing economies. Consequently, our model does not require a greatly responsive capacity utilization to r_t^k.

Third, our estimate of σ_m implies that the semi-elasticity of money demand with respect to the annualized rate of interest is 0.48, which is half the model-based estimate of this elasticity in Christiano, Eichenbaum, and Evans (2005). This value implies that a 1 percent increase in the annualized rate of interest leads to about a 1/2 percent reduction in the real money holdings of households. Fourth, the estimated values of θ_p and θ_w imply a steady-state markup of about 2 and 14 percent in the goods and labor markets in developing economies, respectively. This suggests that our model needs a larger markup in the labor market than in the goods market to match a moderate correlation between real wages and output in developing economies, as reported in Li (2011).

5.2 The Model-Based IRFs

In this section, we discuss the model-based IRFs. As is evident from figure 1, the model-based IRFs of output are largely in line with the IRFs in the developing economies considered in this paper. In our model, output falls immediately after a tightening shock mainly due to a rise in the real interest rate. It then increases smoothly but does not return to its undistorted path for five years since shocks are greatly persistent.

Next, we discuss the model-based IRFs of the price level. Our model is quite successful in accounting for the fact that the largest price response to the shock does not occur in the impact period. Three features of our model play a pivotal role in these inverted hump-shaped dynamics of the price level following the shock. First, due to the Calvo-type price contracts, some prices remain unchanged in the impact period and can only change in subsequent periods. Second, a greatly persistent monetary policy shock in our model leads to a larger price response in the periods following the shock compared with the one that would have occurred if this shock had been transitory. Third, since wages are predetermined in the impact period and can only change in the first and second periods following the shock in our model, our model predicts a weaker price response in the impact period than in later periods.

Regarding exchange rate dynamics, a tightening shock to monetary policy is associated with nominal appreciation in our model since this shock results in a higher real rate of interest on the domestic bond. Yet, the magnitude of initial nominal appreciation in our model is not as strong as that in actual developing economies, as displayed in panel C of figure 1. Indeed, in the initial periods after the shock, the model-based IRFs remain outside the 68 percent confidence interval bands, suggesting that our model has limited ability to predict the initial effects from a monetary shock on the nominal exchange rate. In subsequent periods, however, the model-based IRFs are in line with the IRFs in actual developing economies.

Now, we turn to the model-based IRFs of money. Since the opportunity cost of holding money increases after a tightening shock, our model predicts a fall in money demand. The liquidity effect of a monetary policy shock is persistent in our model mainly because the shock is itself greatly persistent. It is also notable that our model's fit of money is quite good.

Next, we explain the response of the monetary-policy-related interest rate in our model. Despite a 1 percent innovation in the interest rate, the contemporaneous response of the interest rate in our model is less than 0.1 percent. This weak contemporaneous response results from a large output contraction and a fall in the price level accompanying the shock, which lead monetary authorities to bring the interest rate close to its pre-shock level soon after they cause it to rise unexpectedly. It is also worth emphasizing that while the model-based IRFs of the policy rate stay inside the 68 percent confidence interval bands in most of the periods, our model has limitations in explaining the response of the policy rate in developing economies.

It also bears emphasizing that responses of variables to the shock in the model, which is log-linearized around the steady state featuring annualized inflation of 5 percent, are broadly similar to those in the case where the model is log-linearized around a zero steady-state inflation. However, the model-based correlation of output with the real wage is different. Indeed, the correlation is 0.46 in the former case and –0.37 in the latter case, suggesting that the model is less successful in explaining the moderate estimate of correlation in the data—0.41—if it is log-linearized around a zero-inflation steady state.

6. Conclusion

In this paper, we have studied what happens to output, the price level, the nominal exchange rate, M1, and the monetary-policy-related interest rate following a tightening monetary policy shock in developing economies under an inflation-targeting regime. We have found that such a shock causes an output contraction; a fall in the price level, with its minimum occurring in the fourth quarter following the shock; a sizable appreciation of the nominal exchange rate; and a small increase in the policy rate in these countries. Then, we compare these findings with the outcomes in our model which features staggered wage setting under incomplete financial markets. We have found that our model is largely able to account for the aggregate dynamics following domestic monetary policy shocks in developing economies.

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