Systematic Foreign Exchange Intervention and Macroeconomic Stability: A Bayesian DSGE Approach*

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Abstract

This study quantitatively assesses the role of foreign exchange interventions (FXIs) by introducing a systematic FXI policy that follows a feedback rule into a small open economy DSGE model. While the systematic FXI policy can either dampen or amplify economic fluctuations depending on the type of shock (productivity, external, or monetary), a quantitative analysis of Vietnamese data using a Bayesian method reveals that FXIs significantly contribute to macroeconomic stability. With FXIs that insulate an economy from the external shock, the Vietnamese real FX rate is mainly accounted for by productivity shocks, consistent with the Balassa–Samuelson relationship.

Keywords: Foreign exchange intervention; Small open economy DSGE model; Bayesian estimation; Balassa–Samuelson relationship

JEL Classification: F31, F41, E58

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1 Introduction

The role of foreign exchange interventions (FXIs) in stabilizing the foreign exchange (FX) rate as a nominal anchor is a recurrent and controversial policy issue. In practice, while most advanced economies have stopped intervening in the FX market except under extreme circumstances, many emerging market economies (EMEs) adopt a "systematic managed floating" system, wherein a central bank *systematically* uses FXIs as policy tools to smooth out the FX rate volatility by leaning against abrupt movements in the FX market (Frankel, 2019). In the academic literature, many empirical studies examine the efficacy of FXIs by conducting reduced-form estimations. However, those empirical studies alone may not suffice to explain the role of a systematic FXI policy because a significant fraction of the effects of any systematic policy is a consequence of changing the endogenous behavior or expectation formation of economic agents (i.e., the Lucas critique). Hence, quantitative studies based on a structural model are necessary to further investigate the effects of a systematic FXI policy and its role in achieving macroeconomic stability.

This paper contributes to the literature by introducing a systematic FXI policy into a small open economy dynamic stochastic general equilibrium (DSGE) model and quantitatively investigating its contribution to macroeconomic stability using a Bayesian method. Specifically, the central bank is assumed to conduct FXIs that follow a systematic feedback rule, as suggested by the practices under the systematic managed floating system, in addition to conducting monetary policy that follows a feedback rule of the nominal interest rate. To quantitatively assess the efficacy of systematic FXIs, the model assumes that the FX rate deviates from uncovered interest rate parity (UIP) due to the time-varying risk premium for external debt and that FXIs can possibly affect the risk premium.[1] While this approach relies on a somewhat ad-hoc assumption to make FXIs potentially effective, whether FXIs are *quantitatively* effective is an empirical question in the quantitative analysis, given that a Bayesian estimation in the empirical exercise may find the FXI policy effects are quantitatively negligible.

While a Bayesian DSGE approach is currently one of the standard approaches for policy analysis in many fields of macroeconomic study, a relatively small number of empirical anal-

[1] Note that a standard form of FXIs, namely, the selling and buying of foreign currencies in the FX market by the central bank, has no effects on the FX rate in a conventional DSGE model without specific frictions because the FX rate is determined solely by the optimal condition with respect to interest rate parity.

yses on EMEs take this approach. Among several reasons, a technical but difficult challenge in applying this approach to the analysis of FXIs in EMEs is that the real FX rate seems to follow a non-stationary process in many EMEs. As the Bayesian DSGE approach must assume all variables to be stationary, a common methodology in the literature is to remove trends from data before an empirical analysis, using a filtering method such as the HP filter. However, given that many empirical studies on the determinants of the FX rate point to a cointegration relationship between the real FX rate and the relative productivity growth of tradable goods (i.e., the Balassa–Samuelson relationship), removing any non-stationary trends before an analysis is subject to the risk of missing important determinants of the FX rate.[2] An understanding of the underlying drivers of the FX rate is a prerequisite for investigating the effects of FXIs; therefore, the real FX rate in this study is modeled as a non-stationary variable characterized by the Balassa–Samuelson relationship, rather than a stationary variable—as in a standard model—and detrended on the balanced-growth path.

In the quantitative analysis, I focus on the role of FXIs in Vietnam, which is a typical managed floating regime country, and examine the drivers of the FX rate and the extent to which FXIs have contributed to macroeconomic stability in the country. To examine the role of FXIs in achieving macroeconomic stability, I adopt a two-step approach: First, I use Vietnamese data to estimate parameters using a Bayesian method, and decompose the variance of output growth, inflation rate, and FX rates into several structural shocks. Second, by changing the parameters for the systematic FX policy rule while keeping other estimated structural parameters unchanged, I examine how the variance decomposition results would change in the counterfactual case without FXIs. The quantitative analysis reveals that, first, in the baseline case where FXIs reasonably insulate an economy from the external shock, the real FX rate is mostly accounted for by productivity shocks. This result implies that the real FX rate in Vietnam is basically determined in a way that is consistent with the Balassa–Samuelson relationship. Second, FXIs significantly contribute to macroeconomic stability in Vietnam. Given that the impulse-response analysis shows that a systematic FXI policy amplifies the macroeconomic fluctuations caused by productivity shocks while it dampens those caused by external and monetary policy shocks, FXIs can either amplify or dampen the country's economic fluctuations, depending on the type of dominant shocks. The counterfactual case without FXIs indicates that Vietnam would experience significantly

[2] For empirical studies on the Balassa–Samuelson relationship, see Berka et al. (2018), Canzoneri et al. (1999), Chong et al. (2012), and Lee et al. (2008).

more volatile inflation and output growth without FXIs, implying that a systematic FXI policy significantly contributes to macroeconomic stability in the country mainly by mitigating the adverse effects of the external shock as well as the country's own monetary policy disturbances.

This study relates to studies on FXIs and their role in achieving macroeconomic stability.[3] Among the numerous empirical studies on the efficacy of FXIs, Domac and Mendoza (2004), Blanchard et al. (2015), and Fratzscher et al. (2019) are particularly relevant to this study, because they emphasize the role of FXIs in reducing FX-rate volatility. In terms of the model structure for the quantitative analysis, this study relates closely to Benes et al. (2015), Devereux and Yetman (2014), and Erceg et al. (2020). While they do not conduct empirical exercises, and merely perform some quantitative simulations based on calibration, these studies also use an open economy DSGE model, with some frictions to make FXIs potentially effective, as in this study.[4] Regarding the empirical methodology, this study follows Lubik and Schorfheide (2007) in adopting a Bayesian DSGE approach to identify the policy reaction functions in a small open economy DSGE model, while this paper's focus is not only an interest rate policy but also an FXI policy. The present study also relates to the quantitative analysis of the Balassa–Samuelson relationship that was pioneered by Asea and Mendoza (1994). Among others, Devereux (1999) models the real FX rate as a non-stationary variable on the balanced-growth path in a two-sector growth model. Meza and Urrutia (2011) show, by examining the transition dynamics rather than the balanced-growth path, that the developments in the real FX rate in Mexico have been consistent with the Balassa–Samuelson relationship. Berka et al. (2018) model the real FX rate as a stationary variable in their DSGE model, and show that the quantitative simulation is consistent with the real FX-rate dynamics in the euro area.

The remainder of the paper proceeds as follows. Section 2 presents an overview of the developments in FX rates and FXIs in Vietnam. Section 3 describes the model for analyzing the effects of FXIs, while Section 4 estimates the model parameters based on Vietnamese data, and provides a quantitative analysis. Concluding remarks are presented in Section 5.

[3]See BIS (2005), Disyatat and Galati (2007), and Hofman et al. (2020) for an extensive survey of FXIs in EMEs, including their motivations and efficacy.

[4]See also Buffie et al. (2018), Garcia et al. (2009), and Jeanne and Sandri (2020) for an analysis of FX policy using an open economy DSGE model.

2 Foreign Exchange Rate and Intervention in Vietnam

This section presents an overview of the FX rate and FXI policy in Vietnam. First, it describes the developments in the real and nominal FX rates in the last several decades, and shows that those developments have been consistent with the Balassa–Samuelson relationship. It then describes the FXI policy in Vietnam and shows that FXIs are well approximated by a feedback rule that responds to the nominal FX rate; the rule is derived from a simple optimization problem for the central bank.

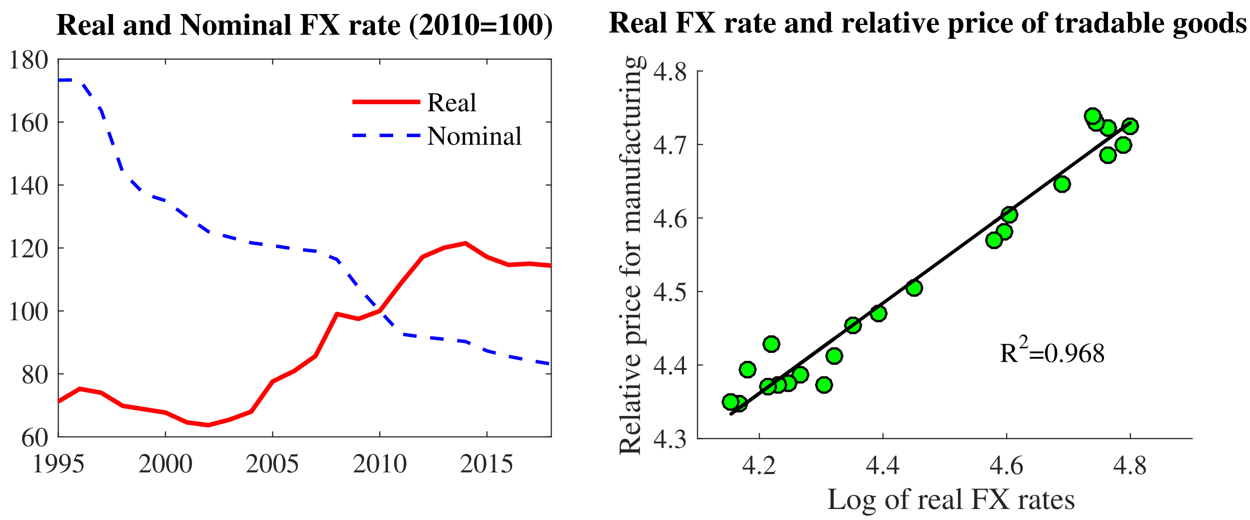
2.1 Developments in Foreign Exchange Rate

Over the last several decades, Vietnam has experienced secular appreciation and depreciation trends in the real and nominal FX rates, respectively. The first panel in Figure 1 shows the real and nominal FX rates vis-à-vis the US dollar, from 1995. The figure indicates that the real FX rate is on a secular trend of appreciation, and that it has appreciated by more than 60 percent in the last two decades. On the other hand, the nominal FX rate has moved in the opposite direction, and has continuously depreciated, for the last two decades, by more than 50 percent in total. Thus, by definition, the difference between the trends in the real and nominal FX rates is accounted for by high and volatile inflation, whose average has been approximately 8 percent for the last two decades.

The developments in the real FX rate in Vietnam have mostly been tracked by the manufacturing sector's relative price. Theoretically, if the law of one price for tradable goods is satisfied, the real FX rate can be approximated by the tradable-goods price relative to the price index of a consumption basket.[5] Following the literature, the relative price for the manufacturing sector (= the GDP deflator for the manufacturing sector divided by the GDP deflator for the whole economy) is used as a proxy for the relative price of tradable goods in Vietnam. The second panel in Figure 1 shows the scatter plots between the relative price for the manufacturing sector and the real FX rate in the last two decades. While the

[5] The law of one price for tradable goods is defined as, $P_{T,t} = F_t P^*_{T,t}$, where $P_{T,t}$ and $P^*_{T,t}$ are the tradable-goods prices in the home and foreign countries, respectively, while F_t is the nominal FX rate. By dividing both sides of the equation by the aggregate price levels in the home and foreign countries, P_t and P^*_t, respectively, we obtain $P_{T,t}/P_t = (F_t P^*_t/P_t) P^*_{T,t}/P^*_t$, suggesting that the real FX rate, $F_t P^*_t/P_t$, is proportional to the relative price of tradable goods, $P_{T,t}/P_t$, if the relative price in the foreign country is stable.

Figure 1: Foreign Exchange Rate in Vietnam



Note: In the left panel, the real FX rate is the nominal FX rate vis-à-vis the US dollar deflated by the CPI rates in Vietnam and the US

law of one price for tradable goods fits the data poorly in some countries, the figure indicates that the real FX rate vis-à-vis the US dollar can be surprisingly well tracked by the relative price for the manufacturing sector in Vietnam, as predicted by the theory (R-squared is more than 0.96); this probably reflects the fact that the manufacturing sector in Vietnam is an export-oriented sector, with many foreign direct investment (FDI) firms.

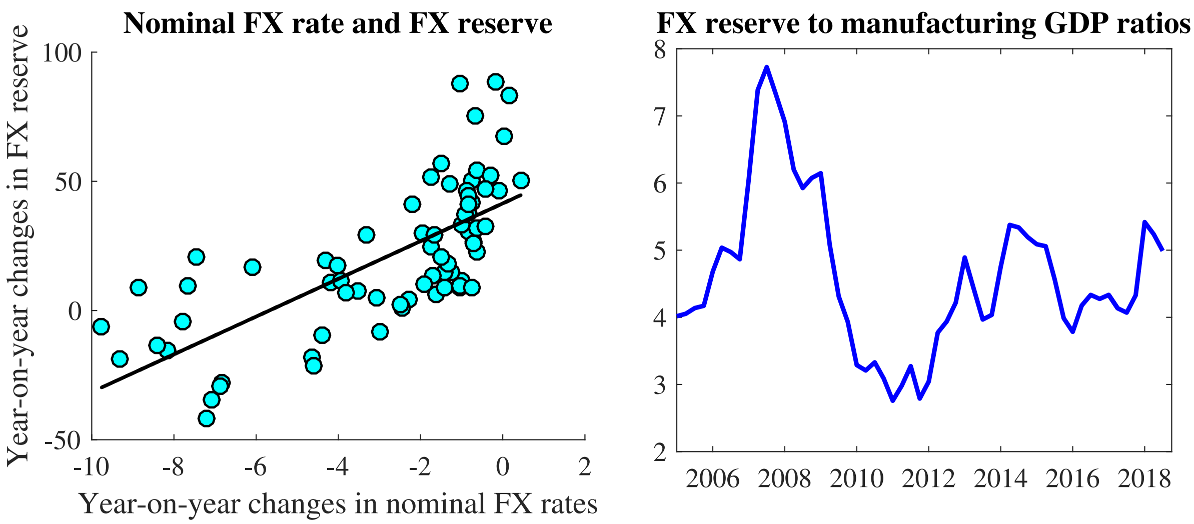
Such an almost one-to-one relationship between the relative price for tradable goods and the real FX rate implies that the secular trend of appreciation in the real FX rate can perhaps be explained by the Balassa–Samuelson relationship. The Balassa–Samuelson relationship, which is one of the conventional theories that explain developments in the real FX rate, predicts a cointegration relationship between the real FX rate and the relative productivity of the tradable-goods sector, given that the relative price of tradable goods should be inversely proportional to the sector's productivity relative to the whole economy. Since the share of output is cointegrated with relative productivity on the balanced-growth path in a standard growth model under some conditions, the theoretical prediction of the Balassa–Samuelson relationship can be reformulated by a cointegration relationship between the output share of tradable goods and the real FX rate. To examine this hypothesis in Vietnam, first, the output share of the manufacturing sector is chosen as a proxy for the output share of tradable goods. Then, the Engle-Granger cointegration test is applied to these two series in Vietnam to test the null hypothesis that they are not cointegrated. Even with the relatively small sample size ($n = 24$) for annual data, the null hypothesis is rejected at the 10 percent level (p-value is 0.081), suggesting that the real FX rate in Vietnam can be accounted for by the relative productivity of tradable goods, consistent with the Balassa–Samuelson relationship. In the next section, I use this cointegration relationship to characterize the balanced-growth path in our small open economy DSGE model, and more formally examine the underlying drivers of the real FX rate by a Bayesian method.

2.2 Policy Rule for Foreign Exchange Intervention

FXIs have been actively used in many EMEs to stabilize FX rate fluctuations. Specifically, Frankel (2019) has recently pointed out that most EMEs adopt neither a free-floating regime nor a hard-currency peg; instead, they follow a "systematic managed floating" system, which is an intermediate regime wherein a central bank systematically responds to market pressure by FXIs to avoid abrupt fluctuations in the FX market (i.e., lean against the wind) while allowing some of the market pressure to be reflected in the FX rate. Under the systematic managed floating regime, a central bank intervenes in the FX market to lean against the wind by carefully balancing the benefit from reducing the volatility of FX rates against the risk of running out of FX reserves. Since holding excessive FX reserves is also costly for them, a typical strategy of central banks is to accumulate FX reserves during normal times, up to a certain target level, and sell the FX reserves in the FX market to support their own currencies in the event of depreciation pressure.

Considering the Vietnamese FX regime and developments in the country's FX reserves, Vietnam is categorized as a typical country that adopts the systematic managed floating regime. First, in Vietnam, the central bank sets the target FX rate vis-à-vis the US dollar, and attempts to smooth the volatility of the FX rate by systematically intervening in the FX market to contain it within a $+/-$ 3 percent trading band of the target rate. Furthermore, the central bank does not adopt a fixed-target rate, but gradually adjusts it daily to allow some market pressure to be reflected in the FX rate, which is also consistent with the systematic managed floating system. Second, the developments in the FX reserves imply that Vietnam follows the systematic managed floating regime. The first panel in Figure 2 shows the scatter plots between changes in the nominal FX rate and Vietnam's FX reserves. The figure shows

Figure 2: Foreign Exchange Interventions in Vietnam



Note: The left panel uses the data from 2001Q1 to 2018Q3, while the right panel uses the data from 2005Q1 to 2018Q3.

a clear and positive relationship between them, implying that the central bank in Vietnam sells their FX reserves in response to depreciation in the nominal FX rate to lean against the wind in the FX market. The right panel in Figure 2 shows the FX reserves relative to the manufacturing GDP in Vietnam. The figure indicates that the ratio does not have a trend but has fluctuated around a certain level, implying that the central bank stabilizes the FX reserves around a specific level by accumulating them in normal times for sale in the face of depreciation pressure.

Given these motivations for the systematic managed floating regime, this study assumes that the central bank follows a feedback rule that responds to the FX rate and the lagged reserve-to-GDP ratios, as in Frankel (2019):

$$\Delta Res_t = \beta_0 + \beta_1 \Delta FX_t + \beta_2 \frac{Res_{t-j}}{GDP_{t-j}} + \varepsilon_t, \tag{1}$$

where ΔRes_t is the percentage change in the amount of FX reserves while ΔFX_t is the percentage change in the FX rate. Here, ε_t is the discretionary deviation from the policy rule (i.e., a FX-policy shock), which is estimated as an error term in the estimation of the FX-policy rule. In this FXI policy rule, it is expected that $\beta_1 > 0$ and $\beta_2 < 0$, implying that the central bank accumulates FX reserves when (i) the nominal FX rate appreciates and (ii) their reserve-to-GDP ratio declines, and vice versa. That is, under the systematic managed floating regime, the central bank is expected to conduct FXIs to lean against the wind in the FX market while taking care of the level of FX reserves. This FXI policy rule is a reduced-form policy rule for the central bank; however, in the appendix, it is shown that the rule can be derived from the optimization problem of the central bank to minimize the loss function based on (i) the volatility of the FX rate, (ii) the deviations from the optimal level of the FX reserves, and (iii) the volatility of the FX reserves.

To examine the empirical fit of the FXI policy rule, the parameter values, β_1 and β_2, are estimated using Vietnamese quarterly data from 2004Q4 to 2018Q3. In the estimation, ΔFX_{t-1} is used as an instrumental variable for ΔFX_t to avoid a potential endogeneity problem that stems from the effect of the FXI policy shock on the FX rate, following the literature on the estimation of a monetary policy rule.[6] Additionally, the lag for the reserve-to-GDP ratio is set at $j = 2$ to fit the Vietnamese data. The estimation result shows that both β_1 and β_2 are statistically significant in Vietnam, and that the quarter-on-quarter growth in FX reserves will (i) decline by 8.6 percent in response to a FX depreciation of one percentage point, and (ii) increase by 0.1 percent in response to a percentage point decline in reserve-to-GDP ratios, both of which imply that Vietnam follows the systematic managed floating regime.[7] While the FXI policy rule is more formally estimated in Section 4 using a Bayesian method, the estimation result here is used as a prior means for the Bayesian estimation to help identify the parameters of the FXI policy rule.

Given that the central bank in Vietnam systematically conducts FXIs by following a feedback rule (1), the next question is, to what extent does the systematic FXI policy contribute to macroeconomic stability? In the empirical literature, Fratzscher et al. (2019) show that many central banks attempt to smooth the volatility of FX rates through FXIs, and that they succeed in doing so in many cases. Furthermore, Domac and Mendoza (2004)

[6] Given that the selling of FX reserves by the central bank positively impacts FX rates, any discretionary FXI policy shocks, ε_t, in (1) are negatively correlated with ΔFX_t, and lead to a negative bias in the OLS estimator of β_1. In the estimation of a monetary policy rule, Clarida et al. (2000) estimate the feedback rule of the nominal interest rate that responds to inflation using historical inflation rates as an instrumental variable to avoid the endogeneity problem that stems from the effects of the monetary policy shock on inflation.

[7] Frankel (2019) estimates a similar FXI policy rule for Turkey and obtains a statistically significant result for $\beta_1 > 0$ and $\beta_2 < 0$, and concludes that Turkey follows the systematic managed floating regime.

and Blanchard et al. (2015) show that countries associated with frequent FXIs have experienced lower volatility or smaller responses of FX rates in the event of capital flow shocks. These empirical studies, which use reduced-form estimation, provide strong evidence for the efficacy of FXIs. However, these studies alone may not suffice to explain the role of a systematic FXI policy because a significant proportion of the effects of any systematic policy is a consequence of changing the endogenous behavior or expectation formation of economic agents (i.e., the Lucas critique). Therefore, quantitative studies based on a structural model are necessary to further investigate the effects of systematic FXI policy and its contribution to macroeconomic stability. Such effects of a systematic FXI policy are analogous to the effects of a systematic monetary policy that follows a feedback rule. For instance, Clarida et al. (2000), by comparing simulation exercises under different monetary policy regimes in a DSGE model, argue that the monetary policy rule of the nominal interest rate, which systematically responds to inflation more strongly, is key to understanding the decline in inflation in the Volcker and Greenspan era. In a similar vein, in Section 4, the efficacy of systematic FXIs is quantified by comparing simulation exercises with and without the systematic FXI policy in a small open economy DSGE model.

3 Small Open Economy DSGE Model

This section describes a small open economy DSGE model for a quantitative analysis of FXIs. While the model follows a standard small open economy DSGE model (e.g., Schmitt-Grohe and Uribe, 2017), there are two main features that distinguish it from conventional models. First, the real FX rate is modeled as a non-stationary variable, rather than a stationary variable, as in a standard model, to be consistent with Vietnamese data. As shown in the previous section, the real FX rate is well tracked by the relative price of the manufacturing sector and cointegrated with its output share. Thus, the real FX rate is modeled as a non-stationary variable, consistent with the Balassa–Samuelson relationship, and detrended using the cointegration relationship on the balanced-growth path. Second, FXIs are modeled as a policy rule, as in the previous section, and are assumed to have possible effects on the FX rate. In the next section, the parameters associated with the policy effect are estimated using a Bayesian method on Vietnamese data.

Except for the two features above, the model mostly follows a standard small open economy DSGE framework. The economy comprises households, consumption-goods firms, and intermediate-goods firms. There are two types of consumption goods, tradable and non-tradable, while the law of one price for tradable goods between the country and the outside world is assumed. In the spirit of small open economy models, the real interest rate in the world is assumed to be exogenous, while the FX rate is determined by the uncovered interest-rate parity (UIP), with risk premiums to induce short-term deviations from it. In what follows, each type of agent's behavior is described in turn.

3.1 Households

A representative household allocates its income to the consumption basket, C_t, and savings. The consumption basket consists of tradable and non-tradable consumption goods,

$$C_t = \left[\iota^{\frac{1}{\eta}} C_{T,t}^{\frac{\eta-1}{\eta}} + (1-\iota)^{\frac{1}{\eta}} C_{N,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

where $C_{T,t}$ and $C_{N,t}$ are the consumption of the tradable and non-tradable goods, respectively. ι and η are the parameters for the share of the tradable goods in the consumption basket and that for the elasticity between the tradable and non-tradable goods, respectively. The price level of the consumption basket (i.e., the consumer price index, CPI) is given by,

$$P_t C_t = P_{T,t} C_{T,t} + P_{N,t} C_{N,t}, \tag{3}$$

where $P_{T,t}$ and $P_{N,t}$ are the prices of the tradable and non-tradable consumption goods, respectively. Then, the demand functions for the tradable and non-tradable goods are derived from the household's optimal allocation between the tradable and non-tradable goods,

$$C_{T,t} = \iota \left(\frac{P_{T,t}}{P_t} \right)^{-\eta} C_t \quad \text{and} \quad C_{N,t} = (1-\iota) \left(\frac{P_{N,t}}{P_t} \right)^{-\eta} C_t, \tag{4}$$

Given these demand functions for the tradable and non-tradable goods, the monopolistic firms in each sector solve their optimization problems.

The household supplies a labor force to obtain the wage income, $W_t L_t$, where W_t denotes the nominal wage and L_t denotes the hours worked. In addition, since all firms in the economy are owned by the household, it obtains the dividend, D_t, from the firms as another source of income. The household then allocates the income to the consumption basket, C_t, and savings. The household can borrow and save in the form of nominal one-period domestic bonds, B_t, and one-period external debt, b_t^*. The household's budget constraint in period t

is formulated as

$$P_tC_t + \frac{B_t}{R_t} + P_t\frac{b_t^*}{Q_t(r_t^* + \zeta_t)} = B_{t-1} + P_t\frac{b_{t-1}^*}{Q_t} + \sum_{j=T,N} W_{j,t}L_{j,t} + D_t + T_t, \tag{5}$$

where Q_t is the real FX rate, R_t is the nominal domestic interest rate, r_t^* is the real foreign interest rate, ζ_t is a time-varying risk premium for external debt, and T_t is a lump sum transfer from the government. Following convention, an increase in Q_t means an appreciation of the domestic currency. In the spirit of a small open economy model, the foreign real interest rate is assumed to be exogenous, and to follow the process,

$$\log r_t^* = (1 - \rho_{rr})\bar{r^*} + \rho_{rr}\log r_{t-1}^* + \varepsilon_{rr,t},$$

where $\varepsilon_{rr,t}$ is an iid shock with standard deviation, σ_{rr}, while $\bar{r^*}$ is a steady state value for r_t^*. The time-varying risk premium for external debt, ζ_t, is specified later.

The household chooses their consumption, $C_{T,t}$ and $C_{N,t}$, labor supply, $L_{T,t}$ and $L_{N,t}$, and short-term domestic bonds and external debt, B_t and b_t^*, to maximize their lifetime utility,

$$E_0\sum_{t=0}^{\infty}\beta^t U\left(C_t - hC_{t-1}, L_{T,t}, L_{N,t}\right),$$

subject to Constraints (2) and (5). $\beta \in (0, 1)$ is the constant discount factor, while h is the parameter for external habit formation. A functional form for the utility function, $U(\cdot)$, will be specified shortly.

3.2 Consumption-Good Firms

The tradable and non-tradable consumption-good firms produce the final goods, $Y_{T,t}$ and $Y_{N,t}$, by aggregating the intermediate goods, $Y_{T,t}(i)$ and $Y_{N,t}(i)$, based on the following CES production function in a competitive market:

$$Y_{j,t} = \left(\int_0^1 Y_{j,t}(i)^{\frac{\nu-1}{\nu}}di\right)^{\frac{\nu}{\nu-1}},\ j = T, N,$$

where $\nu > 1$ is the elasticity of substitution. Let $P_{T,t}(i)$ and $P_{N,t}(i)$ be the prices of the tradable and non-tradable intermediate goods. The price index for the tradable and non-tradable intermediate goods, $P_{T,t}$ and $P_{N,t}$, is then defined as

$$P_{j,t} = \left(\int_0^1 P_{j,t}(i)^{\nu-1}di\right)^{-\frac{1}{\nu-1}},\ j = T, N,$$

while the demand for each intermediate good is derived from profit maximization by the consumption-good firms,

$$Y_{j,t}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t}}\right)^{-\nu} Y_{j,t}, \ j = T, N \tag{6}$$

3.3 Intermediate-Good Firms

A continuum of intermediate-good firms indexed by i produces differentiated intermediate tradable and non-tradable goods using labor, $L_{T,t}(i)$ and $L_{N,t}(i)$, based on the following technology:

$$Y_{j,t}(i) = Z_t A_{j,t} L_{j,t}(i)^{\alpha}, \ j = T, N, \tag{7}$$

where Z_t is a stationary component of aggregate productivity, which is common to all firms across the two sectors and follows the process,

$$\log Z_t = \rho_z \log Z_{t-1} + \varepsilon_{z,t},$$

where $\varepsilon_{z,t}$ is an iid shock with standard deviation, σ_z. Additionally, $A_{j,t}$ is a non-stationary and sector-specific component of productivity in period t. Let $a_{j,t} \equiv A_{j,t}/A_{j,t-1}$, and assume that $a_{j,t}$ follows the process,

$$\log a_{j,t} = (1 - \rho_{aj}) \log \bar{a}_j + \rho_{aj} \log a_{j,t-1} + \varepsilon_{aj,t}, \ j = T, N,$$

where $\varepsilon_{aj,t}$ is an iid shock with standard deviation, σ_{aj}, while $\bar{a}_j$ is a steady-state value for the sector-specific productivity growth.

Under monopolistic competition, the intermediate-good firm, i, in each sector, j ($j = T, N$), maximizes its discounted profits by setting the price of its differentiated product subject to the household's demand (4) and the consumption-good firms' demand (6). Furthermore, following the New Keynesian literature, the intermediate-good firm faces a quadratic cost for deviating from the target inflation rate, $\bar{\pi}$, as well as the previous period's inflation rate, π_{t-1}. The optimization problem for the intermediate-good firm in period t is formulated as

$$\max \sum_{k=1}^{\infty} \frac{\Lambda_{t+k}}{\Lambda_t P_{t+k}} \left[P_{j,t+k}(i) Y_{j,t+k}(i) - W_{t+k} L_{j,t+k}(i) - \frac{\gamma_j}{2} \left(\frac{P_{j,t+k}(i)}{P_{j,t+k-1}(i)} - \pi_{t+k-1}^{\xi} \pi^{*1-\xi} \right)^2 P_{t+k} Y_{t+k} \right]$$

subject to (4), (6), and (7). Here, γ_j is the parameter for sector-specific price stickiness, while ξ is that for inflation indexation common across the two sectors. Λ_{t+k}/Λ_t is a stochastic discount factor for the household from periods t to $t+k$, where $\Lambda_t \equiv \partial U(\cdot)/\partial C_t$. As in a conventional New Keynesian model, the New Keynesian Phillips curve with inflation indexation for the tradable and non-tradable sectors is derived from the intermediate-good firm's optimization.

3.4 Central Bank

Unlike a conventional DSGE model, the central bank has two policy tools for stabilizing the economy: the short-term nominal interest rate, R_t, and the FXI using the FX reserves, Res_t. For both policy tools, this study does not examine the optimal policy; instead, it assumes a simple feedback rule to empirically investigate the effects of these policies. The following section estimates the parameter values for the policy rules using a Bayesian method and performs some counterfactual simulations under different parameter values to examine the efficacy of FXIs.

Regarding the interest-rate policy, the central bank sets the short-term nominal interest rate following the Taylor-type policy rule with interest-rate smoothing. In addition to the response to inflation and output growth, as in a conventional monetary policy rule, the nominal interest rate possibly responds to changes in the nominal FX rate,

$$R_t = (R_{t-1})^{\rho_R} \left[R^* \left(\frac{\pi_t}{\bar{\pi}} \right)^{\phi_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\phi_y} \left(\frac{Q_t/P_t}{Q_{t-1}/P_{t-1}} \right)^{\phi_q} \right]^{1-\rho_R} \exp(v_{m,t}), \tag{8}$$

The central bank can deviate from the rule by adding the "monetary policy shock," $v_{m,t}$, which follows the process,

$$v_{m,t} = \rho_m v_{m,t-1} + \varepsilon_{m,t}.$$

where $\varepsilon_{m,t}$ is an iid shock with standard deviation, σ_m. This monetary policy shock captures all discretionary deviations from the monetary policy rule.

Regarding the FXI policy, the central bank buys and sells their FX reserves, Res_t, following a simple feedback rule based on the nominal FX rate and the amount of the FX reserves, as described in Subsection 2.2:

$$\Delta Res_t = \Delta \bar{Res}_t \left(\frac{Q_t/P_t}{Q_{t-1}/P_{t-1}} \right)^{\theta_q} \left(\frac{Res_{t-1}/Y_{T,t-1}}{\bar{Res}_t/\bar{Y}_T} \right)^{\theta_{res}} \exp(v_{f,t}), \tag{9}$$

where the variables with bars are the steady-state values on the balanced-growth path. As discussed in Subsection 2.2, the central bank is expected to lean against the wind (i.e., $\theta_q > 0$)

and accumulate the FX reserves when the amount is insufficient (i.e., $\theta_{res} < 0$). When these parameters are estimated by a Bayesian method, the estimated values in Subsection 2.2 are used for their prior means. Finally, the central bank can deviate from the FXI rule by adding the "FXI policy shock," $v_{f,t}$, which follows the process,

$$v_{f,t} = \rho_f v_{f,t-1} + \varepsilon_{f,t},$$

where $\varepsilon_{f,t}$ is an iid shock with standard deviation, σ_f. The FXI policy shock captures all discretionary and unsystematic deviations from the FXI rule.

The central bank's balance sheet comprises FX reserves on its asset side and one-period nominal bonds on its liability side. Thus, the central bank's balance-sheet identity is specified as

$$P_t \frac{Res_t}{Q_t(r_t^* + \zeta_t)} = \frac{B_t}{R_t}$$

Finally, the amount of lump-sum transfer from the government is specified as follows:

$$T_t = P_t \frac{Res_{t-1}}{Q_t(r_{t-1}^* + \zeta_{t-1})} \left((r_{t-1}^* + \zeta_{t-1}) - \frac{Q_t/P_t}{Q_{t-1}/P_{t-1}} R_{t-1} \right) \tag{10}$$

This transfer rule suggests that the central bank transfers all the profits and losses associated with the management of their FX reserves.

3.5 Market Clearing

To close the model, the market-clearing conditions for the tradable- and non-tradable-goods markets need to be satisfied. First, since the non-tradable goods should be consumed only in the domestic market, their market-clearing condition is

$$Y_{N,t} = C_{N,t}.$$

Second, the market-clearing condition for the tradable goods is derived by aggregating the household's budget constraints with (i) the central bank's balance sheet, (ii) the government's transfer rule (10), and (iii) the law of one price for the tradable goods in the domestic and foreign markets. The law of one price for the tradable goods between the country and the outside world is specified as

$$\frac{P_{T,t}}{P_t} = \frac{1}{Q_t}, \tag{11}$$

which suggests that the relative price of the tradable goods is equal to the reciprocal of the real FX rate.[8] As is well known, the law of one price for the tradable goods specified in (11) is empirically controversial for some countries. In Vietnam, however, as described by Figure 1 in Subsection 2.1, the manufacturing sector's deflator relative to the GDP deflator, which is a proxy for the relative price of the tradable goods, i.e., the left-hand side of Equation (11), has almost perfectly tracked the real FX rate for the last two decades, which implies that the assumption in Equation (11) is reasonable in the empirical analysis, at least for the last several decades in Vietnam. Under Assumptions (i), (ii), and (iii), the market-clearing condition for the tradable goods is formulated as

$$Y_{T,t} - C_{T,t} = \frac{Res_t + b_t^*}{r_t^* + \zeta_t} - (Res_{t-1} + b_{t-1}^*).$$

Note that the market-clearing condition for the tradable goods is equivalent to the balance-of-payment identity in the model. That is, since the excess supply for the tradable goods in the domestic market, $Y_{T,t} - C_{T,t}$, is consumed in foreign countries, the left-hand side of this equation can be interpreted as the trade surplus. The right-hand side is the income balance and the resultant increase in net foreign assets, which comprise those held by the household, b_t, and the FX reserves held by the central bank, Rev_t.

3.6 UIP Condition and Effects of FXIs

To derive the equilibrium conditions, first, the utility function is parameterized as follows:

$$U\left(C_t - hC_{t-1}, L_{T,t}, L_{N,t}\right) = \frac{\left(\frac{C_t - hC_{t-1}}{A_{T,t}^{\iota} A_{N,t}^{1-\iota}} - \chi \sum_{j=T,N} \frac{L_{j,t}^{1+\omega}}{1+\omega}\right)^{1-\sigma}}{1-\sigma}. \tag{12}$$

Following the literature (e.g. An and Schorfheide, 2007), the consumption basket in the utility function is deflated by $A_{T,t}^{\iota} A_{N,t}^{1-\iota}$ to ensure that the economy evolves along the balanced-growth path. As is well known, without this assumption, the above form of the utility function (i.e., the GHH utility function) is not consistent with balanced growth path. The first-order conditions for the household's optimization yield the equilibrium conditions, including the labor-supply function for each sector, $W_{j,t}/P_t = \chi L_{j,t}^{\omega},\ j = T, N$, and the Euler equation for consumption, $U_C(t) = \beta R_t \mathbb{E}_t[U_C(t+1)/(\pi_{t+1} a_{T,t+1}^{\iota} a_{N,t+1}^{1-\iota})]$, where U_C is a

[8] Here, as in the conventional small open economy models in Chapter 8 of Schmitt-Grohe and Uribe (2017), it is implicitly assumed that the relative prices of the tradable and non-tradable goods in foreign countries are stable.

marginal utility of consumption. In addition, by defining the stochastic discount factor, $\Lambda_{t+1} \equiv \beta U_C(t+1)/(U_C(t) a^{\iota}_{T,t+1} a^{1-\iota}_{N,t+1})$, the first-order condition for the external debt, b^*_t, yields the UIP condition,

$$\mathbb{E}_t \left[\Lambda_{t+1} \frac{R_t}{\pi_{t+1}} \right] = (r^*_t + \zeta_t) \mathbb{E}_t \left[\Lambda_{t+1} \frac{Q_t}{Q_{t+1}} \right], \tag{13}$$

indicating that the return from domestic bonds should be equal to that from external debt. This UIP condition implies that changes in the risk premium for external debt, ζ_t, potentially influence the real exchange rate.

With this UIP condition in mind, next, the risk premium for external debt, ζ_t, is assumed to consist of the following three components,

$$\zeta_t = \zeta \left[\exp(-b^*_t - \bar{b^*}) - 1 \right] + X_t + v_{q,t}. \tag{14}$$

The first component, $\zeta \left[\exp(-b^*_t - \bar{b^*}) - 1 \right]$, indicates that the risk premium is a decreasing function with respect to b^*_t. That is, the risk premium for external debt increases as the net foreign debt held by the household increases, thus pushing back the amount of the household's foreign assets to their steady-state value. As is well known in the small open economy model literature, without this risk premium, a steady state for foreign assets would not exist.[9] Nevertheless, this first component is not quantitatively important for the FX rate dynamics because the parameter ζ is calibrated to an arbitrarily small number just to secure the existence of a steady state in a quantitative analysis.

The second component of the risk premium in (14), X_t, represents the effects of FXIs on the risk premium. X_t is assumed to follow the process,

$$X_t = \rho_X X_{t-1} + \psi FXI_t,$$

where FXI_t is the size of FXIs in period t. This formulation implies that FXIs are assumed to directly influence the risk premium for external debt and consequently have effects on the FX rate through the UIP condition (13) in the model. The parameters ψ and ρ_X represent the magnitude of the FXI policy effects and their persistence, respectively. I take this parsimonious and reduced-form approach to modeling the effects of FXIs, rather than embedding a specific transmission mechanism of FXIs into the model, for the following two reasons.

[9] See Schmitt-Grohe and Uribe (2003) for more details on ways to close a small open economy model, including the assumption of the existence of a risk premium for external debt employed here.

First, while the empirical studies identify significant effects of FXIs, particularly in EMEs with shallow FX markets, it is still theoretically controversial why and how FXIs influence the FX rate in EMEs.[10] Second, the contribution of this paper is mostly empirical. That is, while this approach relies on a somewhat ad-hoc assumption without micro-foundations to make FXIs potentially effective, whether FXIs are *quantitatively* effective is an empirical question in the quantitative analysis, given that a Bayesian estimation in the empirical exercise may find this channel quantitatively negligible (i.e., $\psi \approx 0$). Note that when $\psi = 0$, any transfers between b_t^* and Rev_t do not influence the FX rate as in a standard DSGE model.

On the size of FXIs in period t, FXI_t, the literature emphasizes the importance of distinguishing FXIs from other changes in the FX reserves driven by, for instance, the FX reserve accumulation in normal time. Hence, given the FXI policy rule (9), the size of FXIs in this model is defined as,

$$\begin{aligned} FXI_t &\equiv \log\left(\frac{\Delta Res_t}{\Delta \bar{Res}_t}\right) - \log\left(\frac{Res_{t-1}/Y_{T,t-1}}{\bar{Res}_t/\bar{Y}_T}\right)^{\theta_{res}} \\ &= \log\left(\frac{Q_t/P_t}{Q_{t-1}/P_{t-1}}\right)^{\theta_q} + v_{f,t}, \end{aligned}$$

implying that FXI_t equals the changes in the FX reserves excluding the mean reverting FX reserve accumulation in normal time. Then, given the FXI policy rule (9), FXI_t consists of systematic and non-systematic FXIs, the first and second component of the second line of the equation.

The third and last component of the risk premium in (14), $v_{q,t}$, is an exogenous fluctuation, which follows the process,

$$v_{q,t} = \rho_q v_{q,t-1} + \varepsilon_{q,t},$$

where $\varepsilon_{q,t}$ is an iid shock with standard deviation, σ_q. This part helps the model account for deviations from UIP in the quantitative analysis, and the stochastic shock, $\varepsilon_{q,t}$, is called the "UIP shock" hereafter.

[10]While some theoretical studies, including Gabaix and Maggiori (2015) and Fanelli and Straub (2020), recently provide rigorous micro-foundations for FXIs primarily relying on financial frictions, the mechanisms they propose are too specific and stylized to be used for a quantitative analysis for estimation. Erceg et al. (2020) assume that the FX rate deviates from UIP and that FXIs influence the deviations as this paper does, while they focus more on non-linearity through the balance-sheet channel.

3.7 Balanced Growth Path

Since the model assumes the sector-specific non-stationary component of productivity, $A_{T,t}$ and $A_{N,t}$, the existence of a balanced-growth path is not trivial. Specifically, the following proposition specifies the conditions for having a balanced-growth path in the model:

Proposition 1. *A balanced-growth path exists if and only if either of the following two conditions is satisfied: (i) The functional form for the consumption basket in (2) is Cobb-Douglas (i.e., $\eta = 1$), or (ii) the non-stationary components of productivity in the tradable and non-tradable sectors, $A_{T,t}$ and $A_{N,t}$, respectively, are cointegrated.*

Proof. Let the rate of cumulative non-stationary growth (i.e., the non-stationary growth rate from Time 0 to Time t) of C_t, $C_{j,t}$, and $P_{j,t}/P_t$ be $\exp(g_{c,t}), \exp(g_{c,j,t})$, and $\exp(g_{p,j,t})$, respectively, where $j = T, N$. The demand function in (4) implies that $g_{c,j,t} = -\eta g_{p,j,t} + g_{c,t}$ for all j and t. Meanwhile, the budget constraint in (3) implies that $g_{c,t} = g_{p,j,t} + g_{c,j,t}$ for all j and t. Hence, if a balanced-growth path exists, we should have

$$(1 - \eta)g_{p,j,t} = 0 \quad \text{for all } j, t.$$

This implies that either (i) $\eta = 1$, or (ii) $g_{p,j,t} = 0$ for all j and t should be satisfied. In the case in (ii), we have $g_{c,t} = g_{c,T,t} = g_{c,N,t}$, indicating that $A_{T,t}$ and $A_{N,t}$ are cointegrated, because $g_{c,j,t}$ is equal to $\log(a_{j,t})$. □

While this proposition merely suggests that either Condition (i) or Condition (ii) needs to be satisfied for a balanced-growth path to exist, the following corollary provides a useful clue to which condition is more likely to be satisfied for a particular country.

Corollary 1. *On the balanced growth path, if Condition (i) in Proposition 1 is satisfied, the real FX rate is non-stationary and cointegrated with the relative productivity between the tradable and non-tradable sectors, $A_{T,t}/A_{N,t}$, as argued by the Balassa–Samuelson relationship. On the other hand, if Condition (ii) in Proposition 1 is satisfied, the real FX rate is stationary on the balanced-growth path.*

Proof. Let the non-stationary growth rate of the real FX rate be $g_{q,t}$. Then, we have $g_{q,t} = -g_{p,T,t}$, by the definition of the real FX rate. In the case in (i), given that $g_{c,t} = \iota g_{c,T,t} + (1 - \iota)g_{c,N,t}$, we have:

$$g_{q,t} = g_{c,T,t} - g_{c,t} = (1 - \iota)(g_{c,T,t} - g_{c,N,t}),$$

which implies that the real FX rate is cointegrated with the relative productivity, $A_{T,t}/A_{N,t}$, of order $1-\iota$. On the other hand, in the case in (ii), given that $p_{T,t}=0$, we have $g_q=0$, which means that the non-stationary growth of the real FX rate is zero, and the real FX rate is stationary. □

Intuitively, if the productivities across the sectors are cointegrated, as stated in Condition (ii), the relative productivity, $A_{T,t}/A_{N,t}$, is stationary, by definition, thus leading the real FX rate to be a stationary variable as well. On the other hand, if the productivities across the sectors are not cointegrated, either of the sectors (tradable or non-tradable) produces the goods increasingly more efficiently than the other. Therefore, the output share and the relative price for the growing sector continue to increase and decrease, respectively, and a balanced-growth path exists only if the consumption basket is specified as Cobb-Douglas. In this case, since the real FX rate is proportional to the relative price across the sectors under the law of one price for tradable goods, it is also cointegrated with the relative productivity growth for the tradable goods sector, which is exactly what is suggested by the Balassa–Samuelson relationship in the literature.

As discussed in Subsection 2.1, a salient feature of the Vietnamese data is that the real FX rate exhibits a non-stationary upward trend that is cointegrated with the share of tradable goods in output, consistent with the Balassa–Samuelson relationship. Hence, in the empirical analysis hereafter, the CES function for the consumption basket (2) is assumed to be Cobb-Douglas (i.e., Condition (i) is satisfied) to reconcile the stylized fact in Vietnam with the existence of a balanced-growth path, consistent with the Balassa–Samuelson relationship. While Condition (i) looks somewhat restrictive at first glance, the following back-of-envelop calculation implies that it is not a bad assumption for the Vietnamese economy: When Condition (i) is satisfied and $\eta=1$, we should have $g_{q,t}=g_{c,T,t}-g_{c,t}$, in the long-run. In Vietnam, the GDP and the manufacturing GDP growth rates, the proxies for $g_{c,t}$ and $g_{c,T,t}$, respectively, from 1995 to 2018 are 6.6 percent and 9.2 percent, respectively, and so the gap between them is 2.6 percent, i.e., $g_{c,T,t}-g_{c,t}=2.6$. Given that the rate of appreciation of the real FX rate during the same periods was 2.1 percent, i.e., $g_{q,t}=2.1$, the Vietnamese data have been broadly consistent with the balanced-growth path under Condition (i) in the last three decades, i.e., $g_{q,t}\approx g_{c,T,t}-g_{c,t}$.

While the balanced-growth path under Condition (i) is consistent with Vietnamese data for the last three decades, the relationship between the sectoral growth rate and the non-stationary real FX rate is an arguable issue, generally. First, the non-stationarity of the real

FX rate is arguable. In particular, it is statistically difficult to determine whether the real FX rate is stationary or non-stationary if time series data are available only for several decades. While some empirical studies that use very long time series data find the real FX rate to be non-stationary, quantitative studies that focus on advanced economies offer some evidence that the real FX rate is a very persistent but stationary variable (e.g., Rabanal et al., 2011; Rabanal and Rubio-Ramirez, 2015).[11] Second, whether the sectoral-growth pattern should be consistent with the balanced growth path is arguable, in the first place.[12] While this study assumes the existence of a balanced growth path, the relationship between the longer-term sectoral-growth pattern and the real FX rate across countries is a challenging but interesting topic for future research.

4 Quantitative Analysis

This section quantitatively assesses the effects of FXIs using the small open economy DSGE model described in the previous section. Specifically, the effects of FXIs in Vietnam are examined through a two-step approach: First, I estimate the structural parameters based on Vietnamese data and decompose the variances of the macroeconomic variables (e.g., the real and nominal FX rates, inflation, and output growth) into the structural shocks. Second, I quantify the efficacy of FXIs through the variance decomposition in a counterfactual exercise. In this exercise, the hypothetical economy without FXIs is constructed by changing the parameters of the FXI policy, while keeping the other structural parameters unchanged.

4.1 Baseline Analysis

4.1.1 Estimation

First, some parameters are calibrated to their conventional values. For the preference parameters, the discount factor, β, the CRRA coefficient, σ, and the inverse of Frisch elasticity, ω, are calibrated to $0.99^{1/4}$, 2.0, and 1/2, respectively. The elasticity of the risk premium, ζ, is assigned an arbitrarily small number, 0.001, to secure the steady state. For the produc-

[11] For empirical studies using long time series data, see Engel and Kim (1999) and Engel (2000).

[12] Herrendorf et al. (2014) argue that sectoral-growth patterns across countries are not consistent with balanced growth in the long run, and suggest some theories to account for them. Meza and Urrutia (2011) examine the real FX rate under the "unbalanced" growth path to analyze the real FX rate in Mexico.

tion parameters, the labor share, α, and the mark-up parameter, ν, are set to 0.64 and 6.0, respectively, both of which are conventional values. The target inflation rate, $\bar{\pi}$, is set to $1.04^{1/4}$, based on the targeted value for inflation in Vietnam. Finally, the steady-state level of external debt, $\bar{b}^*$, is chosen such that the ratio of the external debt to the manufacturing GDP equals 247 percent, which has been the average level in Vietnam for the last decade.

Second, the rest of the structural parameters, including the volatility of shocks, are estimated using a Bayesian method on Vietnamese data. Specifically, I estimate 31 parameters (γ_H, γ_F, ξ, h, ψ, ι, $\bar{Rev}$, $\bar{a}_N$, $\bar{a}_T$, $\bar{r^*}$, ρ_R, ϕ_π, ϕ_y, ϕ_q, θ_{res}, θ_q, $\rho_{a,N}$, $\rho_{a,T}$, ρ_z, ρ_m, ρ_q, ρ_f, ρ_{rr}, ρ_s, σ_{aN}, σ_{aT}, σ_z, σ_m, σ_q, σ_f, σ_{rr}) using the quarterly data from 2005Q1 to 2018Q3 for the following seven variables in Vietnam: (1) GDP growth, (2) GDP growth for the manufacturing sector, (3) the inflation rate, (4) the short-term nominal interest rate (the discount rate), (5) the FX reserves to the manufacturing GDP ratio, (6) the FX rate vis-á-vis the US dollar, and (7) the real interest rate in the US (the federal funds rate deflated by the US CPI). The prior distributions for the parameters of the FXI policy rule are based on the estimated values in Subsection 2.2, while those for the other parameters are based on their conventional values.

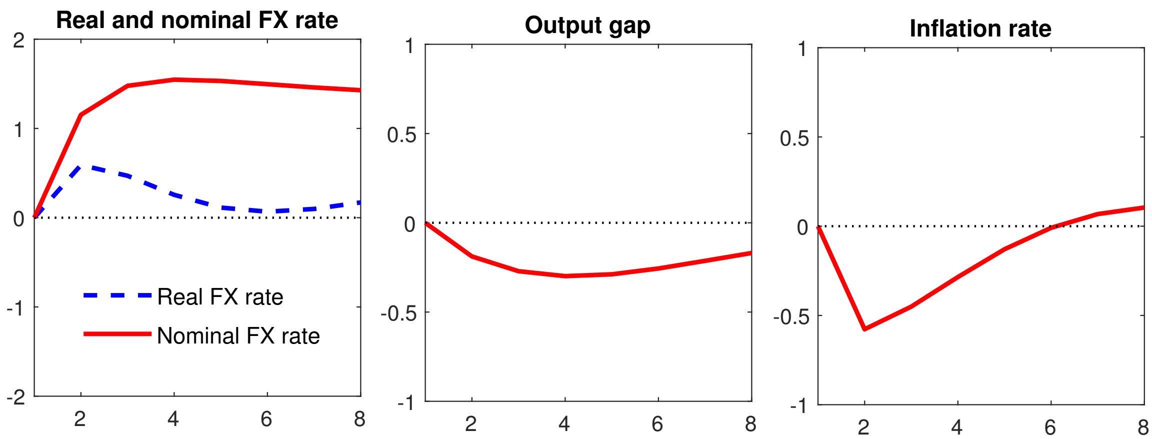
Table 1 summarizes the prior distributions and the estimation results. Some comments are in order: First, the estimated values of the parameters for the cost of price changes in both sectors and indexation, γ_H, γ_F, and ξ are very small, implying that the Phillips curve in Vietnam is steep and that the inflation inertia is small. The steep Phillips curve probably reflects the fact that the inflation rate in Vietnam has been high and volatile, while the real GDP growth has been relatively stable. Second, the posterior mean of the effects of FXIs on the risk premium, ψ, is positive and statistically significant, although the prior distribution is set to strongly favor zero.[13] The positive and statistically significant estimated value of ψ implies that FXIs in Vietnam have had significant effects on the FX rate. Furthermore, the persistence parameter, ρ_X, is around 0.3, implying that the effects of FXIs are moderately persistent. Third, the estimated monetary policy rule suggests that the central bank raises the nominal interest rate in response to depreciation in the nominal FX rate ($\phi_q < 0$) in addition to inflation and output growth. This suggests that the central bank in Vietnam leans against the wind in the FX market not only by FXIs but also by the nominal interest

[13]While the prior mean for ψ is set to 5.0, note that this prior distribution strongly favors zero because mode of the Gamma distribution with the same values for the mean and standard deviation is zero, while the density function is decreasing.

Table 1: Estimated Parameter Values

parameter	posterior mean	90% CI	prior dist.	Prior mean	prior stdev
γ_H	13.34	[6.68 19.68]	Gamm	60	30
γ_F	0.36	[0.11 0.59]	Gamm	60	30
ξ	0.25	[0.11 0.38]	Beta	0.5	0.15
h	0.55	[0.5 0.61]	Beta	0.4	0.05
ψ	37.49	[25.07 50.07]	Gamm	5.0	5.0
ι	0.14	[0.11 0.18]	Beta	0.5	0.15
$\bar{Rev}$	0.03	[0.02 0.03]	Gamm	0.04	0.01
$\bar{a}_N$	1.016	[1.014 1.019]	Gamm	1.016	0.002
$\bar{a}_T$	1.021	[1.018 1.025]	Gamm	1.024	0.004
$\bar{r^*}$	0.998	[0.997 1]	Gamm	0.998	0.002
ρ_R	0.91	[0.87 0.94]	Beta	0.5	0.15
ϕ_π	1.93	[1.12 2.72]	Gamm	1.5	0.5
ϕ_y	0.70	[0.2 1.18]	Gamm	1.0	0.5
ϕ_q	0.58	[0.19 0.94]	Gamm	1.0	0.5
θ_{res}	-0.11	[-0.14 -0.07]	Norm	-0.1	0.03
θ_q	9.33	[7.72 10.89]	Gamm	8.6	1.00
$\rho_{a,N}$	0.46	[0.28 0.63]	Beta	0.5	0.15
$\rho_{a,T}$	0.30	[0.14 0.47]	Beta	0.5	0.15
ρ_z	0.85	[0.76 0.95]	Beta	0.5	0.15
ρ_m	0.67	[0.55 0.8]	Beta	0.5	0.15
ρ_q	0.66	[0.52 0.79]	Beta	0.5	0.15
ρ_f	0.36	[0.19 0.51]	Beta	0.5	0.15
ρ_{rr}	0.38	[0.22 0.54]	Beta	0.5	0.15
ρ_X	0.31	[0.13 0.49]	Beta	0.5	0.15
σ_{aN}	0.009	[0.007 0.011]	Invg	0.01	Inf
σ_{aT}	0.014	[0.011 0.016]	Invg	0.01	Inf
σ_z	0.006	[0.004 0.008]	Invg	0.01	Inf
σ_m	0.002	[0.002 0.003]	Invg	0.01	Inf
σ_q	0.021	[0.014 0.029]	Invg	0.01	Inf
σ_f	0.104	[0.08 0.128]	Invg	0.01	Inf
σ_{rr}	0.006	[0.005 0.007]	Invg	0.01	Inf

Figure 3: Impulse Response to the FXI



Note: The figure shows the impulse response to the FXI shock, ε_f, to quantify the effects of the FXI of 1 percentage point of GDP.

rate.

4.1.2 Impulse Response to FXIs

To quantify the effects of FXIs, this subsection examines the impulse response to the FXI shock, ε_f, in the FXI policy rule (9). As a positive (negative) FXI shock means a decrease (an increase) in the supply of the US dollar by the central bank, it is expected to make it difficult (easy) for private investors to borrow in the external debt market. To capture this transmission mechanism of FXIs inside the model, a positive (negative) FXI shock is assumed to raise (reduce) the risk premium for external debt, ζ_t, by influencing X_t in (14). Then, the change in the risk premium influences the FX rate through the UIP condition (13).

Figure 3 shows the impulse response of the nominal and real FX rate, the output gap, and the inflation rate to a negative FXI shock (i.e., selling of the US dollar) of 1 percentage point of GDP. The figure indicates that FXIs have intuitive and sizable policy effects in Vietnam. Regarding the effects on the real and nominal FX rate (the left panel in Figure 3), the figure indicates that (i) the real FX rate appreciates by approximate 0.3 percentage point on impact and returns to the previous level within a few quarters, and (ii) the nominal FX rate appreciates by an approximate 1.2 percentage point on impact and keep the appreciated level

Table 2: Variance Decomposition

	Productivity	External	FXI	Monetary
Real FX rate	69.7	2.6	8.8	18.9
Nominal FX rate	2.2	23.4	72.1	2.3
Inflation rate	62.3	3.8	13.5	20.4
Output growth	78.7	2.8	10.9	7.7
FX reserve	12.4	47.1	8.3	32.2

Note: The table shows the results of the variance decomposition for the real and nominal FX rate, inflation rate, output growth, and FX reserves. The fluctuations of these five variables are decomposed into the contributions of four groups of structural shocks: (i) the productivity shocks (the non-stationary productivity shock for the tradable and non-tradable sectors, ε_{aT} and ε_{aN}, and the stationary productivity shock, ε_z), (ii) the external shocks (the UIP shock, ε_q, and the US monetary policy shock, ε_{rr}), (iii) the FXI shock (ε_f), and (iv) the monetary policy shock (ε_m).

in the long run. The moderate and short-lived effects on the real FX rate and the significant and persistent effects on the nominal FX rate are consistent with the past empirical literature. Furthermore, as a result of the FX rate appreciation, FXIs have sizable effects on output and inflation as well (the middle and right panel in Figure 3). Specifically, the output gap declines by around 0.25 percentage-point at the peak, while the inflation rate declines by 0.5 percentage-point on impact and gradually returns to the previous level. Hence, selling the US dollar through FIXs helps dampen the inflationary pressure by supporting the domestic currency value, while it induces moderate but adverse effects on real economic activity.

4.1.3 Variance Decomposition

Table 2 presents the results of the variance decomposition for the real and nominal FX rates, the inflation rate, output growth, and the FX reserves. Using Kalman smoothing, the fluctuations of these five variables are decomposed into the contributions of four groups of structural shocks: (i) the productivity shock (the non-stationary productivity shock for the tradable and non-tradable sectors, ε_{aT} and ε_{aN}, and the stationary productivity shock, ε_z), (ii) the external shock (the UIP shock, ε_q, and the US monetary policy shock, ε_{rr}), (iii) the FXI shock (ε_f), and (iv) the monetary policy shock (ε_m).

The table shows the following three notable features. First, around 70 percent of the fluctuations in the real FX rate can be explained by the productivity shocks. This result implies that the real FX rate is basically determined in a way that is consistent with the Balassa–Samuelson relationship in the model. Accordingly, the policy shocks that include the FXI and monetary policy shock account for only less than 30 percent of the real FX-rate fluctuations, while the external shock that includes the deviations from the UIP condition (i.e., the UIP shock) and the US monetary policy shock is almost negligible in explaining the real FX rate in Vietnam. Second, in contrast, the productivity shock can explain only a negligible amount of fluctuations in the nominal FX rate. Instead, the FXI policy shock is a dominant driver for it. This result is intuitive, given that the nominal FX rate in Vietnam has been relatively stable and moving in the completely opposite direction to the real FX rate due to the active FXIs under the systematic managed floating system, as described in Section 2. Third, the inflation rate and output growth are driven mainly by the productivity shock, and the external shock plays an almost negligible role in explaining their fluctuations, as is similar to the real FX rate. Fourth and finally, the FXI shock accounts for only less than 10 percent of FX-reserve fluctuations. Thus, more than 90 percent of changes in the FX reserves in Vietnam are accounted for by systematic responses to the nominal FX rate, pointing to the importance of the analysis of the systematic FXIs that respond to the nominal FX-rate fluctuations. Regarding the root drivers of the systematic responses of the FX reserves, the external shock and the monetary shock have larger shares than the productivity shock, implying that the systematic FXIs absorb and mitigate the propagation of those shocks. In the following subsection, we will explore the effects of the systematic FXI policy by a counterfactual analysis.

4.2 Counterfactual Analysis for the Efficacy of FXIs

The estimation result in the previous subsection indicates that Vietnam's central bank has actively used FXIs as a tool for leaning against the wind in the FX market, and that the FXI policy shock has significant effects on the real and nominal FX rate. Given these significant effects of FXIs, an essential question for policymakers is, to what extent does the FXI policy contribute to macroeconomic stability in Vietnam? To answer this question, a counterfactual policy exercise is conducted in this subsection for the case without FXIs. Specifically, a hypothetical economy without FXIs is constructed by assuming that (i) the FX reserves do not respond to the nominal FX rate (i.e., $\theta_q = 0$) and (ii) the FXI shock is always zero (i.e., the variance of $\varepsilon_{f,t}$ is set to zero). Assumption (i) aims to stop systematic FXIs from leaning against the nominal FX-rate fluctuations, while Assumption (ii) aims to stop non-systematic and discretionary FXIs through the FXI policy shock. Since the central bank is assumed to stop conducting both the systematic and the non-systematic FXIs in this scenario, this counterfactual policy framework can be interpreted as a floating FX regime without any FXIs. Since all the structural parameters, except these two, remain unchanged in the counterfactual simulation, we can examine the extent to which FXIs contribute to macroeconomic stability by comparing the counterfactual simulation results to the baseline results.

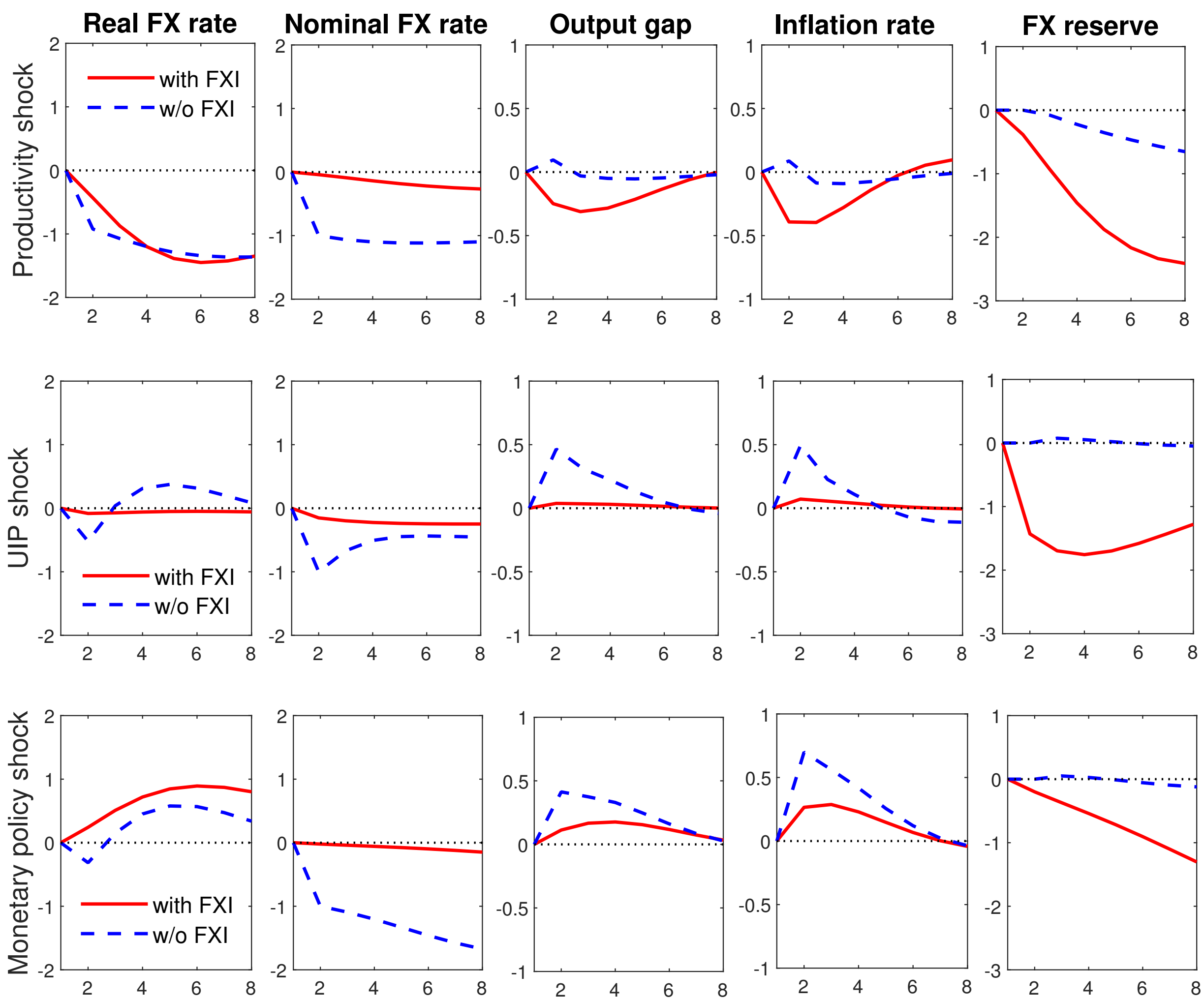
In what follows, first, the impulse responses to the productivity, UIP, and monetary policy shocks under the counterfactual FX-policy regime are computed and compared with the baseline results to understand how the systematic FXI policy dampens or amplifies those responses. Then, by examining the results of the variance decomposition in the counterfactual exercise, we investigate how much and why FXIs contribute to macroeconomic stability in Vietnam. Finally, we briefly consider the case of a more stringent inflation-targeting regime.

4.2.1 Impulse Responses under the Counterfactual FX Policy

Figure 4 presents the impulse-response functions under the baseline and the counterfactual FX policies. The figure shows the responses of the real and nominal FX rates, output gap, inflation rate, and FX reserves to the productivity shock for the tradable goods (ε_{aT}), the UIP shock (ε_q), and the monetary policy shock (ε_m). In the figure, the red, bold lines represent the responses in the baseline case (i.e., with FXIs), while the dashed, blue lines represent the ones under the counterfactual FX policy (i.e., without FXIs). The signs and sizes of these shocks are adjusted and standardized, such that the nominal FX rate without FXIs depreciates by one percentage point on impact. Since the impulse response function is an endogenous reaction to exogenous shocks, the differences between the red, bold lines and blue, dashed lines are interpreted as the effects of the systematic FXIs formulated in Equation (9).

There are several notable features in the figure: First, while the systematic FXIs have minor effects on the real FX rate (the first column), they effectively mitigate the depreciation pressure on the nominal FX rate (the second column). More specifically, when the central bank conducts systematic FXIs that respond to the nominal FX rate based on the FXI policy rule (9), the size of the response of the nominal FX rate vis-à-vis the US dollar to the

Figure 4: Impulse Responses with and without FXIs



Note: The figure presents the impulse response functions under the baseline and the counterfactual FX policies. In the figure, the red, bold lines represent the responses in the baseline case (i.e., with FXIs), while the dashed, blue lines represent the ones under the counterfactual FX policy (i.e., without any FXIs). The responses in the figure include those of the real and nominal FX rates, output gap, inflation rate, and FX reserves to the negative productivity shock for tradable goods (ε_{aT}), the depreciation UIP shock (ε_q), and the easing monetary policy shock (ε_m). The size of the shocks is standardized, such that the absolute size of the response of the nominal FX rate is equal to 1 percentage point on impact.

productivity, UIP, and monetary policy shocks become less than 10 percent of those for the case without the systematic FXI policy. These mitigating effects of systematic FXIs emanate from the endogenous response of the FX reserves. That is, with the systematic FXIs, the central bank sells and decumulates the FX reserves in response to the depreciation pressure in the FX market, as shown in the last column in Figure 4, suggesting that the systematic FXI policy uses the FX reserves as an effective shock absorber to stabilize the nominal FX rate as a nominal anchor.[14]

Second, considering the response of the output gap or inflation rate to the productivity shock (the first row), the volatility is larger for the case with than for the case without FIXs. This result implies that the systematic FXI policy amplifies their responses, thus possibly destabilizing the economy. With a negative productivity shock in the tradable goods sector, the real and nominal FX rates depreciate due to the changes in the relative price between the tradable and non-tradable goods (i.e., the Balassa–Samuelson effect). With FXIs, however, such depreciation pressure in the FX market would be mitigated and become smaller. The smaller depreciation of the nominal FX rate reduces inflationary pressure in the domestic economy, thus decreasing the inflation rate and output gap further, and amplifying their responses. This transmission mechanism to amplify the responses to the negative productivity shock is the same as in previous studies on the currency peg, such as Gali and Monacelli (2005) and Chapter 9 in Schmitt-Grohe and Uribe (2017). In these studies, given a negative shock to tradable goods endowment or the terms of trade, a country adopting a currency peg faces a severer economic downturn because it cannot benefit from the mitigating effects through currency devaluation. That is, as several empirical studies including Forbes and Klein (2015) advocate, FX flexibility, rather than FXIs, can work as a shock absorber to dampen economic fluctuations when the productivity shock drives them.

Third, considering the responses of the output gap and inflation rate to the UIP and monetary policy shocks (the second and third row), the sizes of the responses are smaller in the case with FXIs. Therefore, in contrast to the case of the productivity shock, the systematic FXI policy dampens these responses rather than amplifies them. While the UIP shock induces the FX-rate depreciation and thus positively affects both the output and the

[14]In response to the productivity shock, the figure shows that the FX reserves decline even in the case without FXIs. In the event of an unexpected negative shock of tradable goods productivity, the neutral level of the FX reserves on the balanced-growth path becomes lower than before the shock, thus leading the FX reserves to decline and converge to the new steady-state level gradually.

Table 3: Standard Deviation of Macroeconomic Variables

	With FXI (Baseline)	Without FXI	Flexible IT
Real FX rate	1.00	1.87	1.77
Nominal FX rate	1.00	3.65	3.34
Output growth	1.00	2.31	2.16
Inflation rate	1.00	1.52	1.20
FX reserve	1.00	0.24	0.23

Note: The table shows the standard deviation (SD) of the real and nominal FX rates, output growth, inflation rate, and FX reserves in the model. The table shows the counterfactual SD relative to the baseline (the case with FXIs) by normalizing its SD to 1.

inflation rate by making the tradable goods more competitive, the systematic FXIs mitigate the depreciation pressure and dampen the responses of the output and the inflation rate. Similarly, while the easing monetary policy shock raises the inflation rate and the output gap, as in a canonical DSGE model, the systematic FXIs dampen these policy effects by counteracting the depreciation pressure in the FX market. Hence, in contrast to the case of the productivity shock, this result implies that the systematic FXIs can possibly contribute to macroeconomic stability by suppressing the nominal FX-rate fluctuations caused by the UIP or the monetary policy shocks.

4.2.2 Variance Decomposition under the Counterfactual FX Policy

Given that the systematic FXIs can either dampen or amplify impulse responses, depending on the type of the exogenous shocks, whether the systematic FXI policy contributes to macroeconomic stability is an empirical question. More specifically, FXIs contribute to macroeconomic stability if the external shocks and the monetary policy shock are the more dominant drivers in the economy than the productivity shocks, and vice versa.

Table 3 shows the standard deviation (SD) of the real and nominal FX rates, output growth, inflation rate, and FX reserves in the model. In the table, the SD in the baseline (i.e., the case with FXIs, the first column) is normalized to 1. Considering the case without FXIs (the second column), the table indicates that FXIs substantially dampen the fluctuations of the nominal FX rate in Vietnam. Specifically, without FXIs, the SD of the nominal FX rate would be more than triple, which is consistent with the impulse-response analysis in the

Table 4: Variance Decomposition without FXIs

	Productivity	External	FXI	Monetary
Real FX rate	22.0	67.2	0.0	10.8
Nominal FX rate	9.4	74.2	0.0	16.3
Inflation rate	10.3	52.3	0.0	37.5
Output growth	13.8	73.7	0.0	12.6
FX reserve	61.7	30.5	0.0	7.8

Note: The table shows the results of the variance decomposition for the real and nominal FX rates, inflation rate, output growth, and FX reserves in the case without FXIs. The fluctuations of these five variables are decomposed into the contributions of four groups of structural shocks: (i) the productivity shocks (the non-stationary productivity shock for the tradable and non-tradable sectors, ε_{aT} and ε_{aN}, and the stationary productivity shock, ε_z), (ii) the external shocks (the UIP shock, ε_q, and the US monetary policy shock, ε_{rr}), (iii) the FXI shock (ε_f), and (iv) the monetary policy shock (ε_m). The contribution of the FXI policy shock is, however, equal to zero, by construction, because the FXI policy shock is set to zero in the counterfactual simulation.

previous subsection. Second and more importantly, the table indicates that the SD for the output growth and inflation rate would increase by 131 percent and 52 percent, respectively, in the counterfactual simulation without FXIs. Thus, while FXIs can either stabilize or destabilize the economy, as shown by the impulse-response analysis, Table 3 implies that FXIs contribute to macroeconomic stability in Vietnam.

In the model, the FXIs contribute to macroeconomic stability solely through the systematic FXIs that respond to the nominal FX rate. The non-systematic FXIs, on the other hand, are modeled as an iid exogenous policy shock to the FXI policy rule in Equation (9); thus, they do not contribute to macroeconomic stability by construction. As discussed in Section 2, how the systematic FXIs stabilize the economy is analogous to how systematic monetary policy contributes to macroeconomic stability. That is, similarly to how a systematic monetary policy that strongly responds to the inflation rate contributes to stabilizing inflation by calming down inflation expectations (Clarida et al., 2000), the systematic FXI policy contributes to macroeconomic stability by influencing the household's conditional expectations about future developments in the nominal FX rate. Such a policy implication about the systematic FXI policy is basically consistent with the previous literature on the efficacy of rule-based FXIs under a scarcity of FX reserves (Basu et al., 2018).

To further investigate how FXIs contribute to macroeconomic stability, Table 4 shows the results of the variance decomposition for the counterfactual case without FXIs. The structural shocks are grouped as in Table 2; however, the contribution of the FXI policy shock is equal to zero by construction because the FXI policy shock (i.e., non-systematic FXIs) is set to zero in the counterfactual simulation. The table indicates that in comparison with the baseline case in Table 2, the share of the external and the monetary policy shocks rises, while the share of the productivity shocks declines. This result is consistent with the impulse-response analysis, wherein FXIs amplify the response to the productivity shock while they dampen the responses to the UIP and monetary policy shocks. Particularly, the rise in the share of the external shock is remarkable. For the case with FXIs in Table 2, the share of the external shock is only around 20 percent for the nominal FX rate and less than 5 percent for the real FX rate, inflation rate, and output growth, respectively; however, in the case without FXIs, those shares rise to 50 to 70 percent for those variables. Thus, this result implies that FXIs in Vietnam contribute to macroeconomic stability by dampening the effects of the external shocks, as well as the effects of their own monetary policy shock.

While the argument that FXIs stabilize the economy by offsetting the effects of the external shock is relatively straightforward, the same argument for the effects of their own monetary policy disturbances seems somewhat strange at first glance. However, it is actually consistent with the experience during the global financial crisis (GFC) in Vietnam. During the GFC, Vietnam's central bank adopted massive monetary easing to support economic activity; however, the easy monetary policy eventually led to rapid credit growth, particularly among unproductive state-owned enterprises, and consequently induced double-digit inflation. Then, as the inflationary pressure in the domestic economy led to depreciation pressure in the FX market, the central bank attempted to mitigate the latter pressure by selling their FX reserves. That is, Vietnam's central bank essentially used FXIs to mop up the mess in the FX market caused by their own aggressive but somewhat reckless monetary easing.[15] Given that many other EMEs also adopt an inflexible FX system such as a currency peg for the purpose of not only mitigating the adverse effects of external shocks but also reducing domestic inflation caused by their own excessive monetary easing (e.g., Argentina in the 1990s), Vietnam's result, here, can be interpreted as one of the relatively common experiences among EMEs.

[15] See, for example, IMF (2009, 2010) for more details about their easing policy during the GFC, and its consequences.

Given the result that the monetary policy shock, in addition to the external shock, would substantially destabilize the economy without systematic FXIs, the next question relevant to policymakers is, what if the monetary policy shock does not exist? Since the monetary policy shock is a discretionary deviation from the monetary policy rule based on the 4 percent inflation target, this question is equivalent to asking, what if Vietnam's central bank adopts a more stringent inflation-targeting (IT) regime? This question is important for many EMEs because some, including Vietnam, discuss a shift from the monetary policy regime relying on FXIs to the one with flexible FX rates and more stringent IT. To answer this question, we examine the SD of the macroeconomic variables in the case without the monetary policy shock (i.e., the variance of $\varepsilon_{m,t}$ is set to zero), in addition to the FXIs. The third column of Table 3 indicates that the SD of the inflation rate is higher than in the baseline but substantially smaller than in the case without FXIs, and that the SD of the real and nominal FX rate and the output growth is almost at the same level as in the case with the monetary policy shock. Therefore, the central bank can stabilize the inflation rate to some extent, even without FXIs, by following a stricter IT regime as a nominal anchor for monetary policy, but a stricter IT regime is hard to substitute for FXIs in terms of macroeconomic stability as a whole.

In summary, the counterfactual simulation exercise suggests that while FXIs can either stabilize or destabilize the economy, they contribute to macroeconomic stability by stabilizing the nominal FX rate as a nominal anchor in Vietnam by mitigating the adverse effects of the external shock and excessive monetary easing. While the central bank can possibly stabilize the inflation rate without FXIs by strictly following the monetary policy rule, the interest rate policy is generally hard to achieve macroeconomic stability as a replacement for FXIs. Note, however, that these policy implications come with the caveat that the role of FXIs highly depends on which shocks are dominant for business cycles. For instance, for a country where the nominal FX rate is mainly driven by productivity shocks rather than external shocks, including the non-fundamental deviations from UIP, more FX flexibility rather than FXIs is desirable for macroeconomic stability. Thus, FXIs should have a relatively important role in small EMEs with underdeveloped FX markets because such countries tend to be more susceptible to external shocks. In other words, with more developed and deeper FX markets, a conventional nominal interest-rate policy with a stringent IT regime can perhaps replace FXIs as a policy tool to achieve macroeconomic stability, which is in line with IMF (2020).

5 Concluding Remarks

This study quantitatively assesses the role of foreign exchange interventions by introducing a systematic FXI policy that follows a feedback rule responding to the nominal FX rate into a small open economy DSGE model. While the systematic FXI policy can either dampen or amplify economic fluctuations depending on the type of shock, namely productivity, external, or monetary, a quantitative analysis of Vietnamese data using a Bayesian method reveals that FXIs significantly contribute to macroeconomic stability. Moreover, with reasonable FXIs that insulate an economy from the external shock, the real FX rate is mostly accounted for by productivity shocks, pointing to the importance of the Balassa–Samuelson relationship in Vietnam.

There are several avenues for future works. First, while this paper empirically assesses the effects of FXIs and their role in achieving macroeconomic stability, the next question relevant for policymakers is, what is the optimal policy mix for the central bank? Indeed, some empirical studies argue that FXIs under an IT regime stabilize the economy more successfully.[16] To answer this question, it is necessary to introduce more microfoundations for FXIs and to conduct a welfare analysis to solve the central bank's optimal policy. Second, while this study focuses on the Vietnamese economy in the last two decades, the framework can be applied to the empirical assessment of other EMEs' FX policies in other periods. Since some features, including the non-stationary real FX rate, are observed in other EMEs, applying the analytical framework in this study to other EMEs may provide more general policy implications for EMEs' policymakers.

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[16]See, for instance, Berganza and Broto (2012) and Pourroy (2012).

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Appendix: FXI policy and Central Bank's Optimization

In the estimation, the following feedback rule responding to the nominal FX rate and the historical reserve-to-GDP ratio is used for the FXI policy:

$$\Delta Res_t = \beta_0 + \beta_1 \Delta FX_t + \beta_2 \frac{Res_{t-1}}{GDP_{t-1}} + \varepsilon_t. \tag{15}$$

This appendix aims to derive this feedback-policy rule from a central bank's optimization problem.

First, given that the central bank attempts to (i) smooth out the volatility of the nominal FX rate, (ii) keep the FX reserves close to the optimal level, and (iii) avoid large changes in the FX reserves, the loss function for the central bank is formulated as follows:

$$\frac{1}{2}\left(\Delta FX_t\right)^2 + \frac{\lambda_1}{2}\left(Res_t - \bar{Res}\right)^2 + \frac{\lambda_2}{2}\left(\Delta Res_t\right)^2$$

In the loss function, the first term represents the loss incurred by the volatility of FX rates, $(\Delta FX_t)^2$, while the second term represents the loss incurred by the deviations of FX reserves, Res_t, from their optimal level, $\bar{Res}$. The last term implies that the central bank would gradually change the amount of their FX reserves. $\lambda_1 \geq 0$ and $\lambda_2 \geq 0$ are the parameters for the weight of each term in the loss function.

Second, changes in FX rates are assumed to follow a simple process:

$$\Delta FX_t = x_t - \chi \Delta Res_t, \tag{16}$$

where x_t is an exogenous component for FX rate growth, and the second part implies that the central bank can support their own currency's value by selling their FX reserves in the FX market (i.e., $\chi \geq 0$). In other words, if FXIs are not effective at all, then $\chi = 0$ and the FX rate is exogenously determined only by x_t.

Finally, the optimization problem for the central bank is formulated as a minimization problem of the loss function (5) subject to (16). The first-order condition with respect to ΔRes_t yields the following policy rule for FXIs:

$$\Delta Res_t = \frac{\chi}{\lambda_1 + \lambda_2} \Delta FX_t - \frac{\lambda_1}{\lambda_1 + \lambda_2} \left(Res_{t-1} - \bar{Res}, \right) \tag{17}$$

which is exactly the same as the feedback rule used in the main text. Some comments are in order. First, the policy rule suggests that the central bank's FX reserves positively respond to FX rates. Particularly, the central bank sells their FX reserves ($\Delta Res_t < 0$) in the event of depreciation pressure ($\Delta FX_t < 0$) to lean against the wind. Second, the second term suggests that when the FX reserves are less than optimal, the central bank attempts to raise the reserves to converge them to their optimal level, and vice versa. The convergence speed depends on the relative sizes of the weights in the loss function, λ_1 and λ_2. Third, if the central bank follows this policy rule for FXIs, it is challenging to identify and estimate the effects of FXI from data. That is, even if Equation (16) specifies the *negative* correlation between FXIs and the FX rates (i.e., selling the FX reserves positively impacts FX rates), the observed relationship between them in empirical data should be *positive*, as described in Equation (17), due to the endogenous policy response by the central bank. Thus, while we usually observe a clear and positive relationship between them in many EMEs, it should not be interpreted to mean that selling FX reserves causes depreciation of the nominal FX rate. Rather, it should be interpreted to mean that the central bank systematically sells their FX reserves in response to the depreciation of the nominal FX rates. Paradoxically, Equation (17) implies that the more negative the relationship between FXIs and the FX rates in Equation (16) is, the more positive the relationship between them is observed in data. The economic intuition is that when the central bank knows that FXIs are more effective in supporting their own currency in the face of depreciation pressure, it reacts to the depreciation pressure more aggressively, thus leading to the more positive correlation between FXIs and FX rates.