Terms-of-trade Shocks and Exchange Rate Regimes in a Small Open Economy*

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Abstract

We examine the impact of terms-of-trade shocks on important macroeconomic variables by numerically solving a dynamic stochastic general equilibrium model of a small open economy. The model considers nominal price rigidity under different exchange rate regimes. The numerical solutions obtained are consistent with the empirical regularities documented by Broda (2004), in which output responses to shocks are smoother in floats than in pegs; in moving from pegs to floats, the rise in nominal exchange rate volatility is coupled by the rise in real exchange rate volatility; and in both exchange rate regimes, net foreign assets is the most volatile variable.

JEL Classification: F32, F41

Keywords: Terms-of-trade; imperfect competition; nominal price rigidities; exchange rate regimes

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1. Introduction

The merit which is often attributed to flexible exchange rate regimes over fixed exchange rate regimes is their ability to insulate the economy more effectively against real shocks. This hypothesis was first proposed by Friedman (1953) in the early 1950s. Since then the choice of the exchange rate regime has been an area of great controversy and debate. In theory, the presence of price stickiness explains why the exchange rate regime may matter. When an economy is hit by real shocks, the economy that can change relative prices more quickly will have smaller and smoother adjustment in output. This is particularly true in an economy with price stickiness where the speed at which relative prices can adjust depends crucially on the exchange rate regime. Under flexible exchange rate regimes, relative prices can adjust instantly through changes in nominal exchange rate; while under fixed exchange rate regimes, relative prices can adjust only at the speed that is permitted by price stickiness, which is usually much slower. Therefore, flexible exchange rate regimes allow smoother adjustment in output and quicker adjustment in relative prices than fixed exchange rate regimes.

The theoretical proposition by Friedman has subsequently prompted international economists to examine the effects of shocks on economic variables of different types of exchange rate regimes. While some focused on building theoretical models (Poole, 1970 and Dornbusch, 1980), others focused on documenting empirical regularities (Baxter and Stockman, 1989; Taylor, 1993; Devereux, 1999; Collard and Dellas, 2002; Bleaney and Fielding, 2002 and Broda, 2004).

From the theoretical perspective, many economists still believe that the relative merits of the exchange rate regimes crucially depend on the type and the nature of shocks hitting the economy. When the shocks are nominal in nature, fixed exchange rate regimes automatically prevent them from affecting real output. For instance, when money demand increases, under fixed exchange
rate regimes, money supply increases as the monetary authority buys foreign currency to prevent the appreciation of the local currency. This leaves real output unchanged. In contrast, under flexible exchange rate regimes, money supply is left unchanged and the local currency is allowed to appreciate so real output falls and money demand returns to its initial level.

When the shocks are real in nature, flexible exchange rate regimes are more effective as they allow a smoother adjustment to real shocks. For instance, when terms-of-trade deteriorates in an economy where prices are sticky, under flexible exchange rate regimes, the nominal exchange rate depreciates. The depreciation of nominal exchange rate, in turn, reduces the price of tradable goods which partially offsets the effect of the negative terms-of-trade shock. However, under fixed exchange rate regimes, money supply decreases as the monetary authority contracts money supply to prevent a nominal depreciation of local currency. This response is inherently contractionary and induces an additional fall in real output. Therefore, fixed exchange rate regimes have to rely on the adjustment in domestic prices to pull the economy out of recession.

From the empirical perspective, the empirical evidence is far from conclusive on the effects of shocks on real output, real exchange rate and nominal exchange rate. Baxter and Stockman (1989) show empirical insensitivity of output volatility to the type of exchange rate regime. They also find that a broad range of real macroeconomic variables are independent of the underlying exchange rate regimes. Devereux (1999) analyzes the effects of supply, fiscal and money shocks using a model with nominal goods priced in the sellers’ currency and with prices which are sticky over one period. He finds that the exchange rate does not respond to either supply shocks or fiscal shocks so macroeconomic volatility is the same across fixed and flexible systems. In contrast, Collard and Dellas (2002) suggest larger differences in volatility across regimes. They find that output volatility is significantly higher under fixed exchange rate regimes relative to flexible

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1 Poole (1970) predicted that the standard deviations of output across exchange rate regimes crucially depend on the nature of the shocks. When the shocks are nominal (real) in nature, then the standard
exchange rate regimes. Using data from 80 developing countries, Bleaney and Fielding (2002) also show that countries with fixed exchange rate regime have significantly greater output variance than a typical floating-rate country.

While the theoretical literature emphasizes that the relative merits of fixed and flexible exchange rate regimes depend on the nature of the shocks, the empirical literature does not clearly distinguish between nominal and real shocks. Hence, it would be meaningful for an empirical study to clearly identify real shocks from nominal shocks. This is particularly true if one can study the effects of terms-of-trade shocks on macroeconomic variables under alternative exchange rate systems. There are two reasons for choosing terms-of-trade shocks. Firstly, terms-of-trade disturbances are regarded as a major source of output fluctuations in a small open economy (Mendoza, 1995 and Kose, 2002). Secondly, since most developing countries’ export earnings are dominated by a narrow range of primary commodities (Kose, 2002) and the prices of these primary commodities are subjected to large price fluctuations in the world market, terms-of-trade fluctuations in developing countries are observed to be more volatile.

Because of the prominent role played by exchange rate regimes in developing countries, Broda (2004) examines the effect of a single real shock given by terms-of-trade changes of a country under different exchange rate regimes. Using data from 75 developing countries from 1973 to 1996, he identifies the responses of real GDP, real exchange rate and consumer prices to exogenous terms-of-trade changes across different regimes. His findings generally support Friedman’s proposition. First, the short run real GDP response to terms-of-trade shocks is significantly smaller in countries with flexible exchange rate regimes than those with fixed exchange rate regimes. Second, the depreciation of real exchange rate is immediate after a negative terms-of-trade shock under flexible exchange rate while the depreciation is slower under deviations in fixed (flexible) is relatively smaller.
fixed exchange rate. Third, countries with flexible exchange rate regimes can absorb real shocks better than those with fixed exchange rate regimes.

Given the significance of terms-of-trade fluctuations on domestic macroeconomic variables, understanding the transmission and propagation of terms-of-trade fluctuations is crucial in the design and conduct of macroeconomic policies in both industrialized and developing countries. In this paper, we use an intertemporal equilibrium framework with nominal price rigidities and imperfect competitive markets to analyze the dynamics of some macroeconomic variables arising from term-of-trade fluctuations under alternative exchange rate systems. We adapt the model of Lane and Milesi-Ferretti (2004) and construct an intertemporal framework with tradable and nontradable sectors. The existence of traded and nontraded goods provides a richer framework for analyzing the dynamics of important macroeconomic variables resulting from terms-of-trade shocks. Furthermore, by incorporating nontraded goods, the model is extended to involve both intertemporal and intratemporal substitution effects.

In our model, the nontraded sector is assumed to be a monopolistic competitive market where prices are sticky. The traded sector, on the other hand, is assumed to be a perfectly competitive market where prices are fully flexible and the law of one price holds. The asymmetric treatment of the two sectors allows us to show the link between the sectors when there is a terms-of-trade disturbance. We clearly show the propagation mechanism of terms-of-trade shocks on the dynamics of some macroeconomic variables.

Monacelli (2004) uses a dynamic general equilibrium model of a small open economy combining nominal price rigidity with a systematic behavior of monetary policy. He considers shocks due to productivity, domestic preferences, world interest rate and world demand but not terms-of-trade shocks.

This model was originally used to show that countries with net external liabilities have larger real exchange rate depreciation, in which the main channel of transmission works through the relative price of nontraded goods rather than through the relative price of traded goods across countries.

We follow the assumption in Lane and Milesi-Ferretti (2004) that the domestic aggregate demand conditions matter more for the nontraded sector than the traded sector.
We use numerical solution methods to demonstrate the impulse responses of macroeconomic aggregates induced by a negative terms-of-trade shock. We examine the link between terms-of-trade shock and some macroeconomic aggregates by numerically solving a dynamic stochastic general equilibrium model of a small open economy. The numerical solutions of the model are compared with the empirical regularities documented by Broda (2004). Our results are broadly consistent with the following empirical regularities. First, the responses of short-run output to shocks are significantly smoother in floats than in pegs; second, in moving from pegs to floats, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate; and third, in all types of exchange rate regimes, the most volatile variable is the holding of net foreign assets.

The paper is organized as follows: section 2 lays out a dynamic general equilibrium model of a small economy that combines nominal price rigidity with a terms-of-trade shock; the model parameterization is provided in section 3; the fluctuations of the output, the real exchange rate and the price level as a result of terms-of-trade shocks are analyzed in section 4; and the conclusions are in section 5.

2. The Model

We derive an intertemporal model of a small open economy to analyze the way in which terms-of-trade shock affects some real variables in an economy with different exchange rate regimes. To address the intratemporal aspects of the problem, we make three main assumptions. First, the importable is consumed but not produced, and the exportable is produced but not consumed. In other words, the importable and the nontradable are consumed domestically but the exportable and the nontradable are produced domestically. Second, investment is held constant and the capital stock is an endowment which is not affected by the terms-of-trade shocks. Third,
the economy is small in the sense that it cannot influence the terms-of-trade of the economy. We also assume that the output of the traded goods sector is an endowment of the tradable good $y_T$, which is sold in the world markets at the export price of $P^x_T$, where $P^x_T$ is measured in units of the imported consumption good and the imported consumption good is used as the numeraire. Since consumption of the export goods is assumed to be zero, $P^x_T$, by definition is the terms-of-trade and is exogenous to the country.

2.1 The households

Consider an economy populated by a continuum of yeoman-farmers along the unit interval $[0,1]$. The representative agent aims to maximize the intertemporal utility function which is given by:

\[ V^j = \sum_{t=0}^{\infty} \beta^t \left[ \frac{\sigma}{\sigma - 1} C^\sigma_{t\sigma} \left( \frac{1}{\gamma^\theta} (\sigma - 1) \frac{1}{\gamma^\theta} + (1 - \gamma) \right) \right], \]

where $\beta \in (0,1)$, $\sigma$, $k > 0$. $\beta$ is a preference parameter which is known as the subjective discount or time preference factor, $\sigma$ is the intertemporal elasticity of substitution, and $k$ is the marginal disutility of work. $y_{Nt}(j)$ is the production of $j$-th variety of the nontraded goods. The subscripts $N$ and $t$ represent nontradable goods and time, respectively. The second term in the objective function captures the disutility of work effort. The consumption index $C$, aggregates the consumption of traded goods ($C_T$) and nontraded goods ($C_N$):

\[ C_t = \left[ \frac{1}{\gamma^\theta} C^\theta_{Nt} + (1 - \gamma) \frac{1}{\gamma^\theta} C^\theta_{Nt} \right], \]

\[ \frac{\sigma}{\sigma - 1} C^\sigma_{t\sigma} \left( \frac{1}{\gamma^\theta} (\sigma - 1) \frac{1}{\gamma^\theta} + (1 - \gamma) \right) \]

\[ \text{Many (Senhadji, 1998 and Backus et al., 1994) have modeled terms-of-trade as an endogenous variables. However, by studying Granger-Sims statistical causality, Mendoza (1995) found that except for the United States and a few major fuel exporters, the null hypothesis of exogeneity of terms-of-trade for small open economies cannot be rejected.} \]
where \( \theta > 1 \) which is the intratemporal elasticity of substitution between the traded and nontraded goods, and \( \gamma \in [0,1] \) is the share of consumption of traded good in total consumption.

The consumption-based price index is given by:

\[
P_t = \left[ \gamma P_{Nt}^{1-\theta} + (1-\gamma) P_{Nt}^{1-\theta} \right]^{\frac{1}{1-\theta}}
\]

where \( P_{Nt} \) is the price of the traded good expressed in units of domestic currency. \( P_{Nt} \) is the price of the nontraded good. Agent \( j \) is the monopoly producer of variety \( j \) of the nontraded good and faces the demand function:

\[
y_{Nt}(j) = \left( \frac{P_{Nt}(j)}{P_{Nt}} \right)^{1-\mu} C_{Nt}^\mu \quad \mu > 1
\]

where \( \mu \) is the price elasticity of demand faced by each monopolist and \( C_{Nt}^\mu \) is the aggregate consumption of nontraded goods. The nontraded consumption and price can be written as:

\[
C_{Nt} = \int_0^1 c_N(z)^{\mu-1} dz^{\mu-1}, \text{ and}
\]

\[
P_{Nt} = \left[ \int_0^1 p_N(z)^{1-\mu} dz \right]^{\frac{1}{1-\mu}}.
\]

Each domestic agent holds only one type of asset, namely an internationally traded bond, \( B \).

The agent produces a single nontraded good, \( y_{Nt}(j) \), in a monopolistic competitive way and he receives a constant endowment of \( y_T \) units of traded good. The flow of budget constraint faced by agent \( j \) is given by:

\[
P_{Nt} B_{t+1} = (1 + r_t)B_t + P_{Nt} \gamma_{Nt}(j) + P_T y_T - P_C,
\]

where \( B_t \) (in units of the traded good) is the number of real bonds and \( r_t \) is the return of the international bond. Maximization of (1) subject to (4) and (7) generates the relationships:

\[
E_t \left( \frac{C_{Nt+1}}{C_{Nt}} \right) = \beta^{-\sigma} E_t \left( 1 + r_{t+1} \right)^{-\sigma} \left( \frac{P_{Tt}}{P_{Nt+1} / P_{Nt+1}} \right)^{\sigma-\theta},
\]
where $E_t$ is the expectation operator. Equation (8) is the Euler equation governing the dynamic evolution of consumption. Given the interest rate, if the aggregate price level relative to the price of traded goods is currently low relative to its future value, the present consumption is encouraged over the future consumption. However, it also encourages substitution from traded to nontraded goods. The former effect dominates if intertemporal elasticity of substitution is greater than the intratemporal elasticity of substitution ($\sigma > \theta$), and vice versa.

Equation (9) relates consumption of nontraded and traded goods. The elasticity of substitution between the two goods is parameterized by $\theta$. When the relative price is unity, the relative consumption of nontraded good is larger the smaller the parameter $\gamma$. Finally, equation (10) shows the equilibrium supply of nontraded goods. The higher is the consumption index, $C$, the lower is the production level. Additionally, the larger is the relative price of nontraded good to the aggregate price level, the larger is the production level.

2.2 Domestic firms

The production sector is characterized by households that act as a monopoly in the production of a single traded good. Each household maximizes profits by choosing the price of the good $j$ that it produces subject to the demand for this good. However, as in Calvo (1983), the firms set prices on a staggered basis where $\phi$ is the probability that the firm keeps its price fixed in a given period and $1 - \phi$ is the probability that the firm changes its price. The probability draws are assumed to be independent and identically distributed (iid) over time. This implies that, when allowed to reset its price, domestic firm $j$ will choose $P_{Nt+k}^{new}(j)$ to maximize:
subject to the demand schedule:

\[(12) \quad y_{N_t+k}(j) \leq \left[ \frac{p_{N_t+k}^{new}(j)}{p_{N_t+k}} \right]^\mu C_{N_t}^A, \]

where \( \Lambda_{t,z+k} \) is the time-varying portion of the firm’s discount factor and \( MC \) is the marginal cost.

The necessary first-order condition of this problem gives:

\[(13) \quad p_{N_t}^{new}(j) = \left( \frac{\mu}{\mu - 1} \right) \frac{E_t \left\{ \sum_{k=0}^{\infty} (\beta \phi)^k \Lambda_{t,z+k} MC_{t+k} Y_{N_t+k}(j) \right\}}{E_t \left\{ \sum_{k=0}^{\infty} (\beta \phi)^k \Lambda_{t,z+k} Y_{N_t+k}(j) \right\}}. \]

Note that if a firm was able to freely adjust its price each period, it will choose a constant mark-up over marginal cost, i.e. \( \phi = 0 \) implies:

\[(14) \quad p_{N_t}^{new}(j) = \left( \frac{\mu}{\mu - 1} \right) MC_t. \]

Given the pricing rule, in a symmetric equilibrium where the law of large numbers holds, the nontradable aggregate price index evolves according to:

\[(15) \quad P_{N_t} = \left[ \beta \phi P_{N_t-1}^{1-\mu} + (1 - \beta \phi) \left( p_{N_t}^{new} \right)^{1(1-\mu)} \right]. \]

### 2.3 International capital market

As in Soto (2003), we assume imperfect international capital markets where the interest rate depends on the stock of net foreign debt of the economy. In particular, the interest rate is given by:

\[(16) \quad (1 + r_s) = \left[ 1 + r_s^* \left( \frac{B_t}{\tilde{B}} \right)^\psi \right], \]

where \( (1 + r_s^*) \) is the risk-free international interest rate and \( \psi \geq 0 \) is a parameter that measures the premium the domestic economy must pay. This expression implies that a country with large stock of debt over a stock of minimum debt, \( \tilde{B} \), starts paying a premium over the interest rate that
prevails in the international capital market. However, for stock of debt below this threshold, the country receives a discount.

### 2.4 Prices and real exchange rate

The nominal exchange rate \( e_t \) is the price of one unit of foreign currency expressed in units of domestic currency. The real exchange rate is defined as:

\[
q_t = \frac{e_t P_t^*}{P_t}.
\]

The foreign price level is assumed to be given and the foreign currency denominated price of tradable is normalized to be one. When the law of one price holds for traded goods, it implies that \( q_t = P_{t}/P_t \).

### 2.5 Monetary policy and exchange rate regimes

The formulation of monetary policy by the domestic authority follows a generalized rule, in which deviations of inflation, nontraded output and nominal exchange rate from their long-run target have a feedback on short-run movements of the nominal interest rate. As in many others (Taylor, 1993; Clarida, Gali, and Gertler, 1999; Rotemberg and Woodford, 1998 and Monacelli, 2004), the following equation describes the target for the nominal interest rate:

\[
(1 + i_t) = \left( \frac{P_t}{P_{t+1}} \right)^{\alpha_p} y^{\alpha_y} N_t e^{\alpha_e}.
\]

From equation (18) the monetary authority reacts to the contemporaneous level of inflation, nontraded output and nominal exchange rate. The determination of the actual short-run interest rate that accounts for the desire of the monetary authority to smooth changes in the interest rate is:

\[
(1 + i_t) = (1 + \tilde{i}_t)^{\gamma} (1 + i_{t-1})^{\gamma}.
\]

### 2.6 Steady state equilibrium

We first consider the situation in which all prices are fully flexible. All variables are assumed to be constant at the steady state. We normalize the endowment of the traded good so that the
relative price of nontraded goods in terms of traded goods is unity in the steady state, \( \left( \frac{P_{N0}}{P_{T0}} \right) = 1 \). In this symmetric equilibrium, \( \bar{y}_{N0} = \bar{C}_{N0} = (1-\gamma)\bar{C}_0 \) and \( \bar{C}_{N0} = (1-\gamma)\bar{C}_{T0}/\gamma \).

The aggregate price level, the price of traded good and consumption of traded goods are constant at the steady state. At the initial steady state, we also assume that the terms-of-trade is one, \( \bar{P}_{T0}^s = 1 \). Then, from equation (8), the steady state value for the real domestic interest rate is:

\[
(20) \quad \bar{r}_0 = \beta^{-1} - 1.
\]

Given the stock of minimum foreign debt \( \bar{B} \), at steady state the following relationship is observed:

\[
(21) \quad \bar{B}_0 = \left( \frac{1+r}{1+r^*} \right)^{1/\psi} \bar{B}
\]

If we assume \( r = r^* \), then \( B = \bar{B} \). From equation (7), the consumption of traded goods in steady state satisfies:

\[
(22) \quad \bar{C}_{T0} = r\bar{B}_0 + \bar{y}_{T0}.
\]

The steady state consumption and production of nontraded goods is given by:

\[
(23) \quad \bar{y}_{N0} = \bar{C}_{N0} = \left( \frac{\mu - 1}{\mu k} \right)^{1/\sigma} (1-\gamma)^{1/\sigma}.
\]

The term \( (\mu - 1)/\mu \) is the inverse of the markup for the fully flexible prices case. From this expression, output of the nontraded goods will be larger, the more competitive is the nontraded goods sector (the larger is \( \mu \)), the less taxing is work effort (the smaller is \( k \)) and the larger is the weight placed on the consumption of nontraded goods in the utility function (the larger is \( (1 - \mu) \)).

2.7 The log-linearized version of FOC and other conditions

The model is solved by taking a log-linear approximation around the steady state. We let a variable with hat, \( \hat{X} \) to denote the log-deviation of a variable from the steady state and a variable
with bar, $\bar{X}$ to denote a variable at steady state. Then, the model can be described by a system of linear equations as discussed in the following subsections.

2.7.1 Aggregate supply and inflation

Let $\hat{x}_{Ni}$ be the output gap in the nontraded sector which is measured as the deviation between the stochastic component of current output and the potential output. The following equation shows the inflation of nontraded goods:

$$\hat{\pi}_t = \lambda \hat{x}_{Ni} + E_t \hat{\pi}_{Ni+1},$$

where $\lambda = \frac{(1-\phi)(1-\beta\phi)}{\phi}$ and $E_t$ is the expectation operator. This equation suggests that inflation is positively related to output gap.

2.7.2 Aggregate demand

By taking a log-linear approximation of (8) and (17), the following equation can be obtained:

$$E_t \left( \hat{C}_t - \hat{C}_{t+1} \right) = E_t \left[ -\sigma \hat{r}_t + (\theta - \sigma)(\hat{q}_{t+1} - \hat{q}_t) \right].$$

This equation shows that the consumption of traded goods adjusts according to the evolution of real interest rate and real exchange rates. From the log-linear approximation of (3), (9) and (17), an expression that relates the output gap in the nontraded sector with the real exchange rate and the consumption of traded goods is derived as:

$$\hat{x}_{Ni} = \frac{\theta}{1-\gamma} \hat{q}_t + \hat{C}_t - \hat{z}_t,$$

where the last term denotes the potential output which is assumed to follow a stationary stochastic process.

2.7.3 Real interest rate and current account

The log-deviation of the real interest rate faced by domestic agents corresponds to:

$$\hat{r}_t = \hat{r}_t^* + \psi \hat{B}_t.$$
(28)  
\[ \hat{\delta}_{t+1} = (1 + \bar{r}_e) \left( \hat{r}_t + \hat{B}_t \right) - \frac{C_T}{B_0} \hat{C}_t + \frac{\bar{y}_T}{B_0} \left( \hat{P}^*_t - \hat{P}^*_T \right) \]

2.7.4  
**Uncovered interest parity condition with nominal and real interest rates**

The uncovered interest parity defines a linear expression for the exchange rate which can be expressed as:

(29)  
\[ \hat{i}_t = \hat{i}_t^* + E_t \left( \hat{\delta}_{t+1} - \hat{r}_t \right) \]

where \( \hat{i}_t \) and \( \hat{i}_t^* \) are domestic and foreign nominal interest rate respectively and \( \hat{i}_t = \log(1 + i_t / 1 + \bar{r}) \) The relationship between the nominal interest rate and real exchange rate can be shown as

(30)  
\[ \hat{r}_t = \hat{r}_t + E_t \left( \hat{P}^*_t - \hat{P}^*_t \right) \]

2.7.5  
**Monetary policy rule**

Equation (19) is obtained by taking a log-linear approximation of (17) and (18)

(31)  
\[ \hat{i}_t = \bar{\omega}_x \hat{x}_t + \bar{\omega}_y \hat{y}_t \hat{y}_t + \bar{\omega}_e \hat{e}_t + \bar{\chi} \hat{i}_{t-1} \]

where \( \bar{\omega}_x = (1 - \chi) \omega_x \), \( \bar{\omega}_y = (1 - \chi) \omega_y \), and \( \bar{\omega}_e = (1 - \chi) \left( \omega_e / (1 - \omega_e) \right) \). Following Monacelli (2004), this specification allows us to approximate the systematic behavior of monetary policy under the floating and the fixed exchange rate regimes. In particular, \( \omega_e = 0 \) describes the behavior of the monetary authority practicing the floating exchange rate regime; whereas \( \omega_e \in (0,1] \) approximates the behavior of the monetary authority practicing policies ranging from managed to the fixed exchange rate regimes.

2.7.6  
**Exogenous stochastic process**

The stochastic processes for the world (foreign) interest rate, terms-of-trade and potential output can be summarized as

(32)  
\[ (1 + i_t^*) = (1 + i_{t-1}^*) \exp(\varepsilon_t^\omega) \]
\begin{align}
\text{(33)} & \quad P_{t+1}^x = P_{t+1}^{x^*} \rho^{\sigma} \exp(\varepsilon_t^{x^*}) \\
\text{(34)} & \quad z_t = z_{t-1} \rho^{\sigma} \exp(\varepsilon_t^{z}) \notag
\end{align}

with \( E_t \varepsilon_{t+1}^u = 0 \), \( E_t \varepsilon_{t+1}^u \varepsilon_{t+1}^{u^*} = \Sigma \) where \( \mu = i^* \), \( P_T^x \), \( z \) where \( \varepsilon_t^u \) are iid with zero means.

3. **Model parameterization**

The model is solved numerically\(^6\) and the parameter choices for the model are summarized in Table 1. By following the business cycle literature, the discount rate \( \beta \) is set at 0.99 and the marginal disutility of work effort \( k \) is set at 3. The price elasticity between nontraded goods or the steady-state markup \( \mu \) is set at 1.2. As it is now common in the literature using Calvo pricing, the probability of price non-adjustment \( \phi \) is set at 0.75. In other words, this implies that the average frequency of price adjustment is four quarters. The elasticity of intertemporal substitution \( \sigma \) is set at 1/4, whereas the elasticity of intratemporal substitution \( \theta \) is set at 1/6. This assumes that the intertemporal elasticity dominates intratemporal elasticity of substitution. Following Soto (2003), these values are not set based on any estimation but are arbitrary\(^7\). Degree of openness is allowed to vary from completely closed to completely open. This implies that \( \gamma \in (0, 1) \).

As to the monetary policy rule parameters, we follow the benchmark values in Monacelli (2004), where \( \omega_\pi \) is set to 1.5, \( \omega_y \) is set to 0 and \( \omega_\varepsilon \in (0, 1) \). To calibrate the sources of stochastic volatility, we assume US interest rate is the driving force describing the world (nominal and real) interest rate and the world price is constant. As a result, by following from Monacelli (2004), \( \rho^{i^*} \) is 0.8 and \( \sigma_{\varepsilon'} \) is 0.01379. Following Mendoza's (1995) study on developing countries, the mean

\(^6\) For the numerical solution of the model, we modify Uhlig’s MATLAB program. The program is implemented using the methods of undetermined coefficients. For details of the program and the methodology, please refer to Uhlig (1997).
serial correlation of the terms-of-trade $\rho_{TP}$ equals to 0.414 and the standard deviation $\sigma_{TP}$ equals to 0.1177. Since the potential output is nonobservable, the serial correlation of the potential output $\rho_z$ and the standard deviation $\sigma_z$ is arbitrarily fixed at 0.5 and 1 respectively.

**Table 1** Calibration of model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition and Description</th>
<th>Value</th>
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<tbody>
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<td>$\theta$</td>
<td>Intratemporal elasticity of substitution</td>
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<tr>
<td>$\sigma$</td>
<td>Intertemporal elasticity of substitution</td>
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<tr>
<td>$\phi$</td>
<td>Probability of price non-adjustment</td>
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<td>$\gamma$</td>
<td>Degree of openness</td>
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<td>$\beta$</td>
<td>Discount rate</td>
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<td>$\kappa$</td>
<td>Intertemporal elasticity of labour supply</td>
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<td>Elasticity of net foreign asset to interest differentials</td>
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</tr>
<tr>
<td>$\sigma_e$</td>
<td>Standard deviation of foreign nominal interest rate</td>
<td>1.379</td>
</tr>
<tr>
<td>$\rho_{TP}$</td>
<td>Autocorrelation of terms-of-trade</td>
<td>0.414</td>
</tr>
<tr>
<td>$\sigma_{TP}$</td>
<td>Standard deviation of terms-of-trade</td>
<td>11.77</td>
</tr>
<tr>
<td>$\rho_z$</td>
<td>Autocorrelation of potential output</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>Standard deviation of potential output</td>
<td>1</td>
</tr>
<tr>
<td>$\omega_e$</td>
<td>Responsiveness of monetary policy to exchange rate</td>
<td>0.25 and 0.99</td>
</tr>
<tr>
<td>$\omega_z$</td>
<td>Responsiveness of monetary policy to inflation</td>
<td>1.5</td>
</tr>
<tr>
<td>$\omega_y$</td>
<td>Responsiveness of monetary policy to output</td>
<td>0</td>
</tr>
</tbody>
</table>

4. The volatility of the output, the real exchange rate and the price level

We conduct an experiment to investigate whether the baseline model illustrated above can replicate the quantitative evidence reported in Broda (2004). To characterize a fixed (flexible) exchange rate regime, we let $\omega_e$ approach one (zero). The benchmark calibration described above permits us to choose $\omega_e = 0.99$ for fixed exchange rate regime and $\omega_e = 0.25$ for a more flexible exchange rate regime, arbitrarily select the elasticities of intertemporal and intratemporal substitution will not be

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7 Since the goal is not to address the quantitative results about the response of the trade balance and the current account, arbitrarily select the elasticities of intertemporal and intratemporal substitution will not
exchange rate regime. We then investigate whether the model described is able to generate similar volatility in output, real exchange rate and price level as documented by Broda.

Figures 1a and 1b illustrate the effect of a negative shock to the terms-of-trade. In this model, a deteriorating terms-of-trade generates a decline in overall price level. Nontraded output falls with Keynesian price rigidities. Additionally, nominal exchange rate depreciation is also associated with real exchange rate depreciation.

4.1 Sensitivity analysis: Different degree of rigidities in nominal exchange rate

Table 2 and Figure 2 summarize the standard deviations of key macroeconomic variables with different degrees of rigidities in nominal exchange rate when the model is driven by the terms-of-trade shock.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Standard Deviation HP-Filtered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\omega = 0.25$</td>
</tr>
<tr>
<td>price of nontradables</td>
<td>0.311</td>
</tr>
<tr>
<td>price</td>
<td>1.020</td>
</tr>
<tr>
<td>nominal exchange rate</td>
<td>1.055</td>
</tr>
<tr>
<td>real exchange rate</td>
<td>0.627</td>
</tr>
<tr>
<td>nontradable output</td>
<td>2.824</td>
</tr>
<tr>
<td>consumption</td>
<td>0.642</td>
</tr>
</tbody>
</table>

Notes: Standard deviations are obtained from Hodrick-Prescott filtered data. $\omega$ shows the responsiveness of monetary policy to exchange rate. The higher the value of $\omega$, the more responsive is the monetary policy to exchange rate implying the more rigid the exchange rate regime.

Several interesting results emerge. First, under a flexible exchange rate regime, the real nontradable output has a smaller fluctuation when countries are hit by terms-of-trade shock whereas the price level, the nominal and the real exchange rates have larger fluctuations. On the

have significant influence on the results of the analysis.
other hand, under a fixed exchange rate regime, the real nontradable output tends to fluctuate more whereas the price level, the nominal and the real exchange rates have smaller fluctuations. These observations are consistent with Broda (2004) and Mussa (1986). Second, in moving from fixed to flexible, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. This observation implies that nominal and real exchange rates are strongly correlated. Countries, moving from fixed to floating exchange rate regime, will experience a dramatic rise in the volatility of the real exchange rate. The correlation between nominal and real exchange rates is consistent with the Mussa's (1986) facts. Monacelli (2004) also shows that this result is robust to other types of shocks such productivity, preference, world interest rate and world demand shocks. Third, small open economies that peg their exchange rates achieve lower fluctuation in price than those whose exchange rates float. Fourth, the volatility of the holding of net foreign assets is always the largest in all types of exchange rate regimes but this fluctuation tends to be smaller under a more flexible exchange rate regime.

Figure 2  Variability of some macroeconomic variables in moving from flexible to fixed
4.2 Sensitivity analysis: Different degrees of price rigidities

We address the role of price rigidities under two exchange rate regimes: the flexible vs. the fixed exchange rate. We set the probability of price non-adjustment $\phi$, at 0.25, 0.50 and 0.75. When $\phi = 0.25$, $\phi = 0.50$ and $\phi = 0.75$, prices completely adjust after approximately 1.3 quarters, 2 quarters and 4 quarters respectively. The simulation results are summarized in Table 3. Despite the type of regime adopted by a small open economy, the volatility of the nontradable output increases when the probability of non-price adjustment increases from 0.25 (flexible prices) to 0.75 (rigid prices). This is particularly true under the fixed exchange rate regime. This result supports the conventional wisdom that real output, after experiencing a specific type of real shock, should have smoother responses if the price adjustments to shocks are quicker.

Table 3 Statistics for the calibrated economy with different degrees of price rigidities

<table>
<thead>
<tr>
<th>Variables</th>
<th>$\phi = 0.25$</th>
<th>$\phi = 0.50$</th>
<th>$\phi = 0.75$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed</td>
<td>Float</td>
<td>Fixed</td>
</tr>
<tr>
<td>Price of nontradables</td>
<td>3.007</td>
<td>2.269</td>
<td>1.592</td>
</tr>
<tr>
<td>Price</td>
<td>0.638</td>
<td>1.131</td>
<td>0.639</td>
</tr>
<tr>
<td>Nominal exchange rate</td>
<td>0.008</td>
<td>1.174</td>
<td>0.008</td>
</tr>
<tr>
<td>Real exchange rate</td>
<td>1.506</td>
<td>1.542</td>
<td>0.798</td>
</tr>
<tr>
<td>Consumption</td>
<td>0.908</td>
<td>0.684</td>
<td>0.866</td>
</tr>
</tbody>
</table>

Note: $\phi$ shows the probability of non-price adjustment. When $\phi$ is 0.5, prices completely adjust after 2 quarter and when $\phi$ is 0.75, prices completely adjust after 4 quarters. In other words, the larger the value of $\phi$, the higher the degree of rigidity in prices.

4.3 Sensitivity analysis: Different degrees of openness

In this section we test the sensitivity of the predictions of the model to alternative values of a critical parameter – degree of openness. The results are shown in Table 4. A few interesting results stand out. First, when the degree of openness reaches its highest possible value, the real exchange rate is almost twice more volatile under flexible than it is under fixed. Second, both
exchange rates - nominal and real - are always more volatile under flexible. Third, nontradable output is always more volatile under fixed than floating exchange rates.

Table 4 Statistics for the calibrated economy with different degrees of openness

<table>
<thead>
<tr>
<th>Variables</th>
<th>Fixed</th>
<th>Float</th>
<th>Fixed</th>
<th>Float</th>
<th>Fixed</th>
<th>Float</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ = 0.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price of nontradables</td>
<td>0.516</td>
<td>0.404</td>
<td>0.531</td>
<td>0.311</td>
<td>0.505</td>
<td>0.307</td>
</tr>
<tr>
<td>Price</td>
<td>0.302</td>
<td>1.246</td>
<td>0.647</td>
<td>1.020</td>
<td>0.472</td>
<td>1.114</td>
</tr>
<tr>
<td>Nominal exchange rate</td>
<td>0.009</td>
<td>0.760</td>
<td>0.007</td>
<td>1.055</td>
<td>0.007</td>
<td>0.987</td>
</tr>
<tr>
<td>Real exchange rate</td>
<td>0.388</td>
<td>0.818</td>
<td>0.266</td>
<td>0.627</td>
<td>0.127</td>
<td>0.298</td>
</tr>
<tr>
<td>Nontradable output</td>
<td>3.833</td>
<td>3.880</td>
<td>4.225</td>
<td>2.824</td>
<td>4.029</td>
<td>3.001</td>
</tr>
<tr>
<td>Consumption</td>
<td>0.718</td>
<td>0.865</td>
<td>0.840</td>
<td>0.642</td>
<td>0.781</td>
<td>0.684</td>
</tr>
</tbody>
</table>

Note: γ measures the degree of openness where the larger the value of γ, the more open is an economy.

5. Conclusions

We examine the link between terms-of-trade shocks and some macroeconomic variables by numerically solving a dynamic stochastic general equilibrium model of a small open economy. The model combines nominal price rigidity under different exchange rate regimes. The numerical solutions are compared with the actual empirical regularities. In the model, households consume tradable and nontradable goods. The traded sector is viewed as a perfectly competitive market where prices are fully flexible and covered by the law of one price. The nontraded sector, on the other hand, is assumed to be a monopolistic competitive market where prices in this sector are sticky. The economy is small in the sense that it cannot influence the terms-of-trade of the economy. Generally, the simulations show that the model duplicates many of the stylized facts documented by Broda (2004). First, under a more flexible exchange rate regime, the real nontraded output has smaller fluctuations but the price and real exchange rate have larger fluctuations when countries are hit by terms-of-trade shocks. This result is in favor of Friedman’s prediction that short run output responses to shocks are significantly smoother in floats than in
pegs. Second, in moving from fixed to flexible, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. This implies that countries, moving from fixed to floating exchange rate regime, will experience a dramatic rise in the volatility of the real exchange rate. Third, the volatility of the holding of net foreign assets is always the largest in all types of exchange rate regimes but this fluctuation tends to be smaller under a more flexible exchange rate regime.

Sensitivity analysis shows that despite the type of regime adopted by a small open economy, the volatility of the nontradable output increases when the probability of non-price adjustment increases. Additionally, despite the degree of openness, volatility of the nontradable output is always higher under fixed than floating exchange rates.

The appealing results obtained from the model suggest other topics for further investigation. The artificial economy and the numerical methods employed here can be used to explore quantitatively the effects of other economic policies implemented in small open economies.
Figure 1a  Effect of negative terms-of-trade shock under fixed exchange rate regime
Figure 1b  Effect of negative terms-of-trade shock under flexible exchange rate regime
References


