Intermediate Goods Trade and Exchange Rate Pass-through

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Abstract

For a small open economy characterized by intermediate goods trade, exchange rate changes affect not only the relative price of domestic consumption goods to foreign consumption goods, but also the relative price of local input to imported intermediate goods in the trade sector. Therefore, the adjustment role of a flexible exchange rate as an efficient mechanism in face of external shocks will be subject to the degree of exchange rate pass-through to both imported consumption goods and intermediate goods. In this paper, we develop a small open economy model with intermediate goods trade to investigate the implication of exchange rate pass-through to input prices for economic dynamics and the desirability of flexible exchange rates. Our model shows that in the presence of either terms of trade shocks or non-traded productivity shocks, the degree of exchange rate pass-through to input prices affects the economy more than does the degree of pass-through to goods prices. Furthermore, we find that, compared with the full exchange rate pass-through case, a delayed pass-through to input prices leads to more welfare loss than does a delayed pass-through to goods prices.

JEL classification: F3, F4

Key words: Intermediate goods trade, Exchange rate pass-through to input prices, Welfare.

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1 Introduction

Recently, the issue of exchange rate pass-through has been extensively studied in the New Open Economy Macroeconomics literature. The degree of exchange rate pass-through has important implications for the international transmission of shocks and the desirability of flexible exchange rates. For example, Devereux and Engel (2003) show that, in a two country model, if the prices are set in the currency of buyers (LCP) and the pass-through from the exchange rate to consumer prices is zero, then the optimal monetary policy should keep the exchange rate fixed.\(^1\) For a small open economy, Devereux, Lane, and Xu (2006) find that the degree of exchange rate pass-through is critical for the assessment of monetary rules. With full pass-through, stabilizing the exchange rate involves a trade-off between real stability and inflation stability and the best monetary policy rule is to stabilize non-traded goods prices. With delayed pass-through, the trade off disappears and the best monetary policy rule is CPI price stability. Meanwhile, there are also a large number of empirical studies that measure the degree of exchange rate pass-through or explore the determinants of exchange rate pass-through. For example, see Campa and Goldberg (2002), Choudhri and Hakura (2006), Devereux and Yetman (2005), and Bouakez and Rebei (2005).

These theoretical and empirical studies, however, focus only on the exchange rate pass-through to the price of imported consumption goods and then to domestic consumption prices. An important change of the trade pattern during the last thirty years is the increase in the share of intermediate goods trade in total trade. As well documented by Feenstra (1998), Hummels et al. (1998), and Yi (2003), the vertical structure whereby intermediate goods are imported to produce finished products that are re-exported has been a more and more important feature of today’s global production and trade. Moreover, the EMU data confirm that intermediate goods trade is a major component of total trade, since the degree of intra-zone openness is 4.39% for capital goods, 16.46% for intermediate goods and 9.22% for consumption goods. In an economy with intermediate goods trade, exchange rate changes will affect not only the relative price of domestic consumption goods to foreign

\(^1\)Also see Corsetti and Pesenti (2002) and Engel (2002).
consumption goods, but also the relative price of local inputs to imported intermediate goods in the trade sector. Hence, under a flexible exchange rate regime, the adjustment of these relative prices in face of external shocks will depend on the extent of exchange rate pass-through to both goods prices and input prices. This implies that, in a small open economy with intermediate goods trade, the desirability of a flexible exchange rate will be subject to the degree of exchange rate pass-through to both imported consumption goods prices and imported input prices. Therefore, it is important to explore the implication of exchange rate pass-through to input prices for economic dynamics and the desirability of flexible exchange rates.

To address this issue, we develop a small open economy two-sector model with sticky prices, where the trade sector is characterized by intermediate goods trade. In this model, we allow for limited/incomplete exchange rate pass-through to both consumption goods prices and input prices. We find that, in the presence of either terms of trade (TOT) shocks or non-traded productivity shocks, the degree of exchange rate pass-through to input prices affects the economy more than does the exchange rate pass-through to good prices. This is because the delayed exchange rate pass-through to consumption prices only affects the composition of consumption, but not the production side. The limited exchange rate pass-through to input prices, however, will hinder the adjustment of the relative price of local inputs to imported intermediate goods in the trade sector, and thus dampen the response of trade sector, consumption, and output to shocks. Hence, compared with the full pass-through case, delayed exchange rate pass-through to input prices will have a larger impact on the economic dynamics than will the delayed exchange rate pass-through to consumption prices.

We also find that in face of uncertainties, endogenous exchange rate volatility depends critically on the degree of exchange rate pass-through to imported input prices, but not on the degree of pass-through to consumption prices. Exchange rate volatility decreases when the degree of exchange rate pass-through to input prices is lower. This is because, to respond to a shock, an efficient adjustment of the relative prices of local inputs to imported inputs in
traded sector is essential for the economy. Nevertheless, delayed exchange rate pass-through to input prices hinders the role of exchange rate changes in adjusting the relative price of inputs in traded goods production. Therefore, less exchange rate movement is needed with incomplete exchange rate pass-through to input prices.

To explore the implication of delayed exchange rate pass-through to input prices for the desirability of a flexible exchange rate, we calculate the welfare using a perturbation method. Our result shows that for the same degree of limited exchange rate pass-through, a delayed pass-through to input prices leads to more welfare loss than a delayed pass-through to consumption goods prices under a flexible exchange rate regime. Intuitively, as the incomplete pass-through to input prices affects the production of traded goods, it has a bigger impact on the real variables of the economy. Therefore, if input prices in the traded goods sector can be adjusted efficiently, the economy can gain more or lose less when disturbed by TOT shocks or non-traded sector productivity shock. This implies that an efficient relative input price adjustment is more important to economies with intermediate goods trade.

Our results are related to some findings in Devereux and Engel (2007). They build a two-country model with intermediate goods trade and develop a view of exchange rate policy as a trade-off between the desire to smooth fluctuations in real exchange rates to reduce distortions in consumption allocations, and the need to allow flexibility in the nominal exchange rate to facilitate terms of trade adjustment in intermediate input levels. Meanwhile, they also find that the optimal exchange rate volatility depends on the stickiness of intermediate goods price. In this paper, however, we emphasize the role of delayed pass-through to input prices and focus on the relative importance of two types of exchange rate pass-through for the economy and the desirability of flexible exchange rates. Our model framework closely follows Devereux, Lane, and Xu (2006). We incorporate intermediate goods trade in their two-sector small open economy model to analyze two types of exchange rate pass-through. In a similar two-sector small open economy model, Bouakez, Rebei, and Vencatachellum (2007) investigate the optimal degree of pass-through of oil prices and show its relationship
with monetary policy rules. But in their model, oil is a consumption good instead of an intermediate good.

Regarding the implication of intermediate goods trade and multiple stages of production structure for monetary policy, Shi and Xu (2007a) and Huang and Liu (2006) both investigate the effects of vertical production and trade on monetary policy and the international transmission of shocks in a two-country model setting. Devereux and Poon (2004) and Shi and Xu (2007b) explore monetary policies for a small open economy with intermediate goods trade. The former studies how the occasionally binding financial constraint for import intermediates affects the monetary policy in emerging market economies, while the latter shows how intermediate goods trade affects the welfare ranking of different monetary rules. Huang and Liu (2007) assess the role of intermediate inputs trade and multiple stages of production in accounting for some stylized facts about international business cycles. These papers, however, focus on the impact of intermediate goods trade on monetary policy, whereas our paper concentrates on the implication of delayed exchange rate pass-through to input prices for a small open economy with intermediate goods trade.

This paper is organized as follows. Section 2 presents the basic small open economy model with intermediate goods trade. Section 3 discusses the dynamic responses of the economy in a baseline model. Section 4 examines the welfare implications. Section 5 reports the sensitivity analysis of results. Section 6 concludes.

2 Basic model

2.1 Households

The representative household’s preference is given by

\[ U = E_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{C^1_1 - \sigma}{1 - \sigma} - \eta \frac{L^{1+\psi}_t}{1 + \psi} \right), \tag{2.1} \]

where \( C_t \) is the aggregate consumption index and \( L_t \) is the labor supply. The household consumes both domestically produced non-traded goods and imported foreign goods. We
assume that aggregate consumption is a CES function of consumption of non-traded goods and import goods. That is, \( C_t = [\alpha \frac{1}{\rho} C_{Nt}^{\frac{1}{1-\rho}} + (1-\alpha) \frac{1}{\rho} C_{Ft}^{\frac{1}{1-\rho}}]^{\frac{1}{\frac{1}{\rho}-1}} \), where \( \rho > 0 \) is the elasticity of substitution between domestic non-traded goods, \( C_N \), and foreign goods, \( C_F \). Therefore, the consumer price index is given by:

\[
P_t = [\alpha P_{Nt}^{1-\rho} + (1-\alpha) P_{Ft}^{1-\rho}]^{\frac{1}{1-\rho}}
\]  

(2.2)

where \( P_{Nt} \) (\( P_{Ft} \)) is the time \( t \) price of the non-traded (imported) consumption good. The consumption of both non-traded and imported goods is differentiated, with elasticity of substitution across varieties equal to \( \lambda \). Hence, we have \( C_{Nt} = \int_0^1 C_{Nt}(i) \frac{\lambda-1}{\lambda+1} \frac{di}{i^\lambda} \), and \( C_{Ft} = \int_0^1 C_{Ft}(i) \frac{\lambda-1}{\lambda+1} \frac{di}{i^\lambda} \), with \( \lambda > 1 \).

The household’s budget constraint is as follows

\[ P_t C_t + P_t \frac{\psi}{2} (D_{t+1} - \bar{D})^2 + (1 + i_t^*) S_t D_t + (1 + i_t) B_t = W_t L_t + \Pi_t + S_t D_{t+1} + B_{t+1} \]  

(2.3)

where \( S_t \) is the nominal exchange rate and \( D_t(B_t) \) is the amount of foreign-currency (domestic currency) debt held by consumers. Households can borrow in foreign currency bonds at a given world interest rate \( i_t^* \), or in domestic currency bonds at a domestic interest rate \( i_t \). Trade in foreign currency bonds, however, is subject to small portfolio adjustment costs. As discussed by Schmitt-Grohé and Uribe (2003), these portfolio adjustment costs eliminate the unit root in the economy’s net foreign assets. If the household borrows an amount, \( D_{t+1} \), then these portfolio adjustment costs are \( \frac{\psi}{2} (D_{t+1} - \bar{D})^2 \) (denominated in the aggregate consumption goods), where \( \bar{D} \) is an exogenous steady state level of net foreign debt. Households own all domestic production firms and therefore receive the profits on these firms. As export goods firms are perfectly competitive, profits from the traded goods sector are zero. But monopoly firms in the non-traded sector will earn profits. The household’s revenue in any period then comes from wage income, \( W_t L_t \), profits from the non-traded goods sector, \( \Pi_t \), and new loans from the domestic and international capital markets. The household then uses these to consume and pays the debt repayment from the last period, \( (1 + i_t^*) S_t D_t + (1 + i_t) B_t \), as well as portfolio adjustment costs.
The household’s optimum can be characterized by the following conditions:

\[
\frac{1}{1 + i_{t+1}^*} \left[ 1 - \psi_D P_t (D_{t+1} - D) \right] = \beta E_t \left[ \frac{C^*_t P_t}{C^*_{t+1} P_{t+1}} \frac{S_{t+1}}{S_t} \right] \tag{2.4}
\]

\[
\frac{1}{1 + i_{t+1}^*} = \beta E_t \left( \frac{C^*_t P_t}{C^*_{t+1} P_{t+1}} \right) \tag{2.5}
\]

\[W_t = \eta L^\psi_t P_t C^\sigma_t.\] \tag{2.6}

Equations (2.4) and (2.5) represent the Euler equation for the purchase of foreign and domestic currency bonds respectively. Combining them gives the interest rate parity for this model. Equation (2.6) is the labor supply equation.

Given the demand for aggregate consumption, the household will choose non-traded goods and imported goods to minimize expenditures. We can thus derive demand for non-traded and imported goods as follows:

\[C_{Nt} = \alpha \left( \frac{P_{Nt}}{P_t} \right)^{-\rho} C_t \tag{2.7}\]

\[C_{Ft} = (1 - \alpha) \left( \frac{P_{Ft}}{P_t} \right)^{-\rho} C_t. \tag{2.8}\]

### 2.2 Production Firms

In this economy, there are two final goods sectors, the non-traded goods sector and the traded goods (export goods) sector, which differ in their production technologies and pricing behaviors.

#### 2.2.1 Non-traded Goods Sector

The non-traded goods sector is monopolistically competitive and contains a unit interval [0,1] of firms indexed by \(j\). The production technology in this sector is linear:

\[Y_{Nt}(j) = A_t L_{Nt}(j).\] \tag{2.9}

where \(A_t\) is the productivity of non-traded goods sector. Each firm produces a differentiated non-traded good, which is an imperfect substitute in the production of composite goods, \(Y_N\),
produced by a representative competitive firm. Thus, aggregate non-traded goods output, $Y_N$, is defined as

$$Y_N = \left( \int_0^1 Y_{Nt}(j)^{\frac{\lambda-1}{\lambda}} dj \right)^{\frac{1}{\lambda-1}} \tag{2.10}$$

where $\lambda$ is the elasticity of substitution between differentiated non-traded goods. Therefore, the demand faced by each individual non-traded goods firm $j$ is

$$Y_{Nt}(j) = \left( \frac{P_{Nt}(j)}{P_{Nt}} \right)^{-\lambda} Y_{Nt} \tag{2.11}$$

where $\frac{P_{Nt}(j)}{P_{Nt}}$ is the relative price of each variety with respect to the aggregate non-traded goods price index, $P_{Nt}$, which is given by

$$P_{Nt} = \left( \int_0^1 P_{Nt}(j)^{1-\lambda} \right)^{1/(1-\lambda)}. \tag{2.12}$$

Following Rotemberg (1982), we assume that each firm bears a small direct cost of price adjustment. As a result, firms will only adjust prices gradually in response to a shock to demand or marginal cost. Thus, a firm will maximize its expected profit stream, using the household’s marginal utility as the discount factor. We may define the objective function of the non-traded firm $j$ as:

$$E_t \sum_{l=0}^{\infty} \beta^{\Gamma_{l+1}} \left[ P_{Nt+l}(j) Y_{Nt+l}(j) - MC_{Nt+l}(j) Y_{Nt+l}(j) - \frac{\psi_{PN}}{2} P_{l+1} \left( \frac{P_{Nt+l}(j) - P_{Nt+l-1}(j)}{P_{Nt+l-1}(j)} \right)^2 \right], \tag{2.13}$$

where $\Gamma_{l+1} = \frac{1}{\psi_{PN} \Gamma_t}$ is the marginal utility of wealth for a representative household, and $MC_{Nt}(j)$ represents the marginal cost for non-traded firm $j$, and the third term inside parentheses describes the cost of price adjustment incurred by firm, $j$.

Given assumptions of linear production technology and perfectly competitive labor market, $MC_{Nt}(j) = \frac{W_t}{N_t}$, which is identical across firms. Since all non-traded goods firms also face the same downward-sloping demand function and price adjustment cost, we may write the optimal price setting equation in a symmetric manner as:

$$P_{Nt} = \frac{\lambda}{\lambda-1} MC_{Nt} - \frac{\psi_{PN}}{\lambda-1} Y_N \frac{P_N}{P_{Nt-1}} \left( \frac{P_{Nt}}{P_{Nt-1}} \right)^{\frac{\lambda}{\lambda-1}} \left( \frac{P_{Nt+1}}{P_{Nt}} \right)$$

$$+ \frac{\psi_{PN}}{\lambda-1} E_t \left[ \beta^{\Gamma_{t+1}} P_{t+1} \frac{P_{Nt+1}}{P_{Nt}} \left( \frac{P_{Nt+1}}{P_{Nt}} \right)^{\frac{\lambda}{\lambda-1}} \right]. \tag{2.14}$$
Hence, the non-traded goods price follows a dynamic adjustment process when $\psi P_N > 0$. This Rotemberg pricing is equivalent to the standard Calvo pricing, as we can choose the value of $\psi P_N$ to match the price dynamics under Calvo pricing.

### 2.2.2 Traded Goods Sector

Following Devereux, Lane, and Xu (2006), we assume that the traded sector is competitive and take the world price of export goods, $P^*_T$, as given. In particular, the law of one price holds for export goods. Therefore, the domestic currency price of export goods is

$$P_T = S_t P^*_T.$$  \hspace{1cm} (2.15)

In this economy, each firm, $i$, imports intermediate goods to produce homogenous traded goods and re-exports the output to the world market. Export good firms’ production function is given as follows

$$Y_T = [\alpha_T^{\frac{1}{1-\theta}} L_T^{\frac{\theta - 1}{\theta}} + (1 - \alpha_T)^{\frac{1}{1-\theta}} IM_T^{\frac{\theta - 1}{\theta}}]^{\frac{1}{\theta - 1}},$$  \hspace{1cm} (2.16)

where $\alpha_T$ is the share of labor in the traded good firms’ production, $\theta > 0$ is the elasticity of substitution between local labor and import intermediates.\(^2\) The marginal cost, $MC_T$, is given by

$$MC_T = [\alpha_T W_t^{1-\theta} + (1 - \alpha_T)(P_M)^{1-\theta}]^{1/(1-\theta)},$$  \hspace{1cm} (2.17)

where $P_M$ is the domestic currency price of the intermediate goods. We discuss how this price is determined in the following subsection. Since the traded sector is perfectly competitive, in equilibrium, we have

$$P_T = MC_T.$$  \hspace{1cm} (2.18)

### 2.3 Prices of Imported Consumption Goods and Intermediates

To determine the domestic prices of imported consumption and inputs, we will allow for the possibility that there is some delay between movements in the exchange rate and the

\(^2\)For simplicity, we assume that the productivity of traded goods sector is constant over time and is normalized to 1.
adjustment of imported consumption and intermediate goods prices. Without loss of generality, we assume that the domestic prices are adjusted in the same manner as prices in the non-traded goods sector. That is, in the face of exchange rates changes, foreign export firms which adjust the local currency price of their goods, are subject to a price adjustment cost of a similar form to that of the domestic non-traded goods firms. Therefore, these price adjustment costs will determine the degree of exchange rate pass-through to imported consumption prices and intermediate inputs prices. Finally, it is assumed that the intermediate goods are also differentiated with elasticity of substitution, \( \lambda \), across varieties.

Thus, the problem of a foreign firm that sets intermediate goods prices may be described as follows

\[
E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \left( \frac{P_{Mt}(i)}{S_t} - W_t^s \right) I_{Mt}(i) - \frac{\psi_{Pr}}{2} \left[ \frac{P_{Mt}(i) - P_{Mt-1}(i)}{P_{Mt-1}(i)} \right]^2 \right\},
\]

where \( W_t^s \) can be considered as the marginal cost of imported inputs in terms of foreign currency, \( I_{Mt}(i) = \left( \frac{P_{Mt}(i)}{P_{Mt-1}} \right)^{-\lambda} I_{Mt} \) is the demand for import intermediate goods, \( i \), and \( I_{Mt} \) is the total demand for import intermediates of the domestic country. For simplicity, we assume that the foreign currency price of inputs is \( P_{Mt}^* = \frac{\lambda}{\lambda-1} W_t^s \). Thus, the imported input price faced by domestic traded firms is given by

\[
P_{Mt} = S_t P_{Mt}^* - \frac{\psi_{Pr}}{\lambda - 1} I_{Mt} \left( \frac{P_{Mt}}{P_{Mt-1}} - 1 \right) + \frac{\psi_{Pr}}{\lambda - 1} E_t \left[ \frac{P_{t+1}}{I_{Mt}} \left( \frac{P_{Mt+1}}{P_{Mt}} - 1 \right) \right].
\]

The interpretation of (2.19) is that the foreign firm wishes to achieve an identical price in the domestic market as in the world market. But it incurs quadratic price adjustment costs, and unless \( \psi_{Pr} = 0 \), it will move its price only gradually towards the desired price. The higher these adjustment costs, the lower the degree of exchange rate pass-through into domestic imported intermediate goods prices.

Given the assumption that the consumption of import goods is also differentiated with elasticity of substitution, \( \lambda \), across varieties, we can derive the domestic price of imported
consumption goods similarly:

\[
P_{Ft} = SP_{Ft} - \frac{\psi_{PF}}{\lambda - 1} \left( \frac{P_{Ft}}{P_{Ft-1}} - 1 \right) + \frac{\psi_{PF}}{\lambda - 1} E_t \left[ \beta \frac{P_{Ft+1}}{P_{Mt}} \left( \frac{P_{Ft+1}}{P_{Ft}} - 1 \right) \right],
\]

where \( P_{Ft} \) is the world price of foreign consumption goods, and \( T_{Mt} \) is the demand for the foreign consumption goods. Similarly, the parameter \( \psi_{PF} \) determines the degree of exchange rate pass-through to imported consumption goods prices.

In our model, for simplicity, we assume that \( P_{Mt} \) and \( P_{Ft} \) are constant over time and we normalize them as unity. Therefore, the terms of trade, \( \frac{P_{Mt}}{P_{Ft}} \), or \( \frac{P_{Mt}}{P_{Ft}} \) can be simply represented by \( P_{Tt} \).

### 2.4 Monetary Policy Rules

The monetary authority uses a short-term domestic interest rate as the monetary instrument, so the monetary policy can be described by the following equation:

\[
1 + i_{t+1} = \left( \frac{P_{Nt}}{P_{Nt-1}} \frac{1}{\bar{\pi}_n} \right)^{\mu_{\pi_n}} (1 + \bar{i}).
\]

The parameter \( \mu_{\pi_n} \) allows the monetary authority to control the inflation rate in the non-traded goods sector around a target rate of \( \bar{\pi}_n \). In this paper, we assume that the monetary authority targets the inflation rate of non-traded goods (NPT rule), so that \( \mu_{\pi_N} \to \infty \). This rule is analogous to a domestic inflation targeting rule. As shown by Devereux, Lane and Xu (2006), with full pass-through, stabilizing the non-traded goods price is the best monetary policy rule. Since the exchange rate is flexible under such a rule, this rule also represents a flexible exchange rate regime. This is also equivalent to the case where monetary authority simply set the non-traded price inflation to the steady state value.
2.5 Equilibrium

From the market clearing conditions of non-traded goods and import consumption goods, we have

\[ Y_{Nt} = \alpha \left( \frac{P_{Nt}}{P_t} \right)^\rho Z_t \]  \hspace{1cm} (2.22)

\[ TM_t = (1 - \alpha) \left( \frac{P_{Fl}}{P_t} \right)^\rho Z_t, \]  \hspace{1cm} (2.23)

where \( Z_t \) is the total demand for aggregate goods and is given by

\[ Z_t = C_t + \frac{\psi_D}{2} (D_{t+1} - \bar{D})^2 + \frac{\psi_{PN}}{2} \left( \frac{P_{Nt}}{P_{Nt-1}} - 1 \right)^2 + \frac{\psi_{PM}}{2} \left( \frac{P_{Mt}}{P_{Mt-1}} - 1 \right)^2 + \frac{\psi_P}{2} \left( \frac{P_{Pt}}{P_{Pt-1}} - 1 \right)^2. \]  \hspace{1cm} (2.24)

In our model, the demand for aggregate goods comes from household consumption, portfolio adjustment costs, and price adjustment costs. These adjustment cost are included as they are paid in terms of aggregate consumption goods. Meanwhile, the labor market clearing conditions must be satisfied:

\[ L_{Tt} + L_{Nt} = L_t. \]  \hspace{1cm} (2.25)

In a symmetric equilibrium, the domestic bond market clearing implies that \( B_t = 0 \). Therefore, the aggregate budget constraint for the economy can be rewritten as

\[ P_t C_t + P_t \frac{\psi_D}{2} (D_{t+1} - \bar{D})^2 + S_t (1 + i^*_t) D_t + P_t \frac{\psi_{PN}}{2} \left( \frac{P_{Nt}}{P_{Nt-1}} - 1 \right)^2 
+ P_{Mt} IM_t = P_{Nt} Y_{Nt} + P_{Tt} Y_{Tt} + S_t D_{t+1}. \]  \hspace{1cm} (2.26)

This implies that total expenditures, which comprise household consumption, the purchase of import intermediates, bond adjustment costs, price adjustment costs,\(^3\) and total foreign debt repayment, should be equal to total receipts, which are composed of output of each sector, plus new net foreign borrowing.

Finally, the equilibrium of our model is defined as follows.\(^4\) Given the stochastic process of the terms of trade, \( P_{Tt}^n \), or the productivity shock of non-traded goods sector, \( A_t \), and the

\(^3\)The adjustment costs of import prices are in terms of domestic consumption goods, but they are paid by foreign firms. Therefore, they are not included in the total expenditure.

\(^4\)The details of the equilibrium conditions are given in the Technical Appendix.
monetary policy rule, $\mu_n$, an equilibrium is characterized by a collection of 19 sequences: $\{C_t, L_t, L_Nt, L_Tt, IMt, TMt, Y_Nt, Y_Tt, Z_t, D_t\}$ and $\{P_t, P_Nt, P_Ft, PMt, MCT_t, P_Tt, S_t, It, W_t\}$, such that: (a) households optimally choose consumption, bond holding, and labor supply; (b) both non-traded goods firms and traded goods firms maximize profits; (c) non-traded goods market, traded goods market, labor market, domestic bond market, and foreign bond market all clear.

3 Model Dynamics

3.1 Calibration

Our model is solved numerically using a second-order approximation to the true dynamic stochastic system, where the approximation is done around the non-stochastic steady state given in the Technical Appendix.\(^5\) Values of structural parameters for the model are described in Table 1.

We set the coefficient of risk aversion, $\sigma$, to 2, as is commonly assumed in the literature.\(^6\) The discount factor, $\beta$, is calibrated at 0.99, which implies a steady state annual real interest rate of 4%. For simplicity, we also assume that the world interest rate is constant over time and equals to the steady state interest rate. We set the elasticity of labor supply, $\frac{1}{\phi}$, to 1, as in Christiano et. al (1997). Following Basu and Fernald (1998), the elasticity of substitution across individual export goods, $\lambda$, equals 11, implying a steady state markup of 10%. We set $\alpha_T=0.3$, so that the share of labor in the production of trade goods is equal to that

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\(^5\)Our model is solved by Dynare.

\(^6\)It should be noted that the utility function in this paper (separable between consumption and leisure) is inconsistent with balanced growth under the calibrated value of $\sigma = 2$. However, in this paper we focus on the short run dynamics around the steady state instead of balance growth path, so non-separability should not be a critical issue. Also, this utility function is used extensively in the new open economy macroeconomic literature. See, for example, Obstfeld and Rogoff (2002), Chari, Kehoe and McGrattan (2002), Devereux and Engel (2003), and Devereux, Lane and Xu (2006). If the log utility (consistent with balance growth) is used instead, the quantitative result of the model does not change much.
Table 1: Calibration Parameters

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</table>

estimated in Cook and Devereux (2006). The share of non-traded goods in the consumption basket, $\alpha$ is set to 0.6. This is close to the evidence cited in Schmitt-Grohe and Uribe (2001) for Mexico, and by Cook and Devereux (2006) for Malaysia and Thailand. We set $\eta = 1$ as it is only a scale parameter in our model.

Regarding the degree of nominal rigidity, the standard estimates in the literature are that prices usually adjust on average after four quarters. We set the parameters governing the cost of adjustment in the non-traded sector, $\psi_{PN}$, to 120, which implies a Calvo-type price adjustment probability of approximately 0.75. In our benchmark model, we set $\psi_{PM} = \psi_{PF} = 0$, so that exchange rate changes fully pass through to prices of both import consumption goods and imported inputs. When we consider incomplete exchange rate pass-through to imported consumption goods and intermediate goods, we will set $\psi_{PM} = \psi_{PF} = 120$ as well. Following Schmitt-Grohe and Uribe (2003), we set the coefficient of bond adjustment cost, $\phi_D = 0.0007$.

We set the elasticity of substitution between local labor and import intermediates in the traded sector, $\theta = 0.99$, and the elasticity of substitution between domestic goods and foreign goods in the consumption basket, $\rho = 0.99$. The value of both parameters approximately represents the standard Cobb-Douglas case with unitary elasticity of substitution.

In numerical exercises, we set $\mu_{\pi_N} = 900$ for the NPT rule. In a benchmark case, we
set $A_t = 1$, so the shock considered only is the TOT shock, $\frac{P_r}{P_F}$. Following Devereux, Lane, and Xu (2006), we assume that the TOT shock follows an AR(1) stochastic process with $\rho_{tot} = 0.77$ and $\sigma_{tot} = 0.01$.

3.2 Impulse Response Functions

In this subsection, we analyze the response of the economy to TOT shocks under flexible exchange rates. The discussion focuses on consumption, employment, sectoral output, and some nominal variables such as prices of both imported consumption goods and imported inputs, and nominal exchange rates.

Figures 1 show the response of the economy to a positive TOT shock under different degrees of exchange rate pass-through to imported consumption goods prices and input prices. In the case of full pass-through ($\psi_{P_m} = \psi_{P_r} = 0$), in face of a positive TOT shock, the trade sector expands, such that traded output, employment, and imported intermediate goods all increase. Meanwhile, the nominal exchange rate appreciates and the domestic price of imported goods decreases, which implies that aggregate demand will shift from non-traded goods to import foreign consumption goods. As a result, the non-traded goods sector shrinks. At the aggregate level, consumption will fall first and then rise gradually. In contrast, total employment will rise sharply first and then decline later.

When incomplete pass-through to consumption prices ($\psi_{P_r} = 120$ and $\psi_{P_m} = 0$) is considered, compared to the full pass-through case, the local currency price of imported consumption goods decreases less, which implies that the expenditure switching effects between non-traded goods and imported goods will also be smaller. Therefore, the non-traded output decreases less. Meanwhile, the consumption price also adjusts more slowly, which leads to a larger change of consumption. But, the response of the traded goods sector is not affected by the incomplete exchange rate pass-through to imported consumption price as such a pass-through has no impact on the relative price of inputs in that sector. This implies that the degree of exchange rate pass-through to imported consumption goods mainly affects the composition of the consumption basket.
However, when we consider the incomplete pass-through to input prices instead of that to consumption prices ($\psi_{Pl} = 120$ and $\psi_{Pc} = 0$), for the same degree of limited pass-through, the response of the economy is quite different. In this case, the relative price of local labor to imported inputs cannot be adjusted efficiently, so the substitution between these two inputs in the traded goods sector is weakened, which hinders the expansion of the traded goods sector. Therefore, we can see that employment, imported intermediate goods, and output in this sector increase much less than in the full exchange rate pass-through case. This also mitigates the shrinkage of non-traded goods sector and the increase in imported consumption goods. As a result, the response of consumption and employment will both be dampened in the beginning. With incomplete exchange rate pass-through to input prices, exchange rate appreciation is limited, so exchange rate changes are also small.

Finally, when we consider limited pass-through to both imported consumption and inputs, the response of the traded goods sector is almost the same as in the case with only limited pass-through to input prices. Since, in this case, the relative price between imported consumption goods and non-traded goods cannot be adjusted efficiently, the shrinkage of the non-traded goods sector is even less than that in the previous case. Hence, the responses of economic variables are similar to those in the case with only incomplete pass-through to input prices.

In summary, the model dynamics show that, if we simply consider limited exchange rate pass-through to import consumption goods ($\psi_{Pc} > 0$), then consumption, employment, the non-traded goods sector and imported goods consumption will be affected. However, when we consider delayed pass-through to input prices ($\psi_{Pl} > 0$), almost all variables, especially the traded goods sector will be strongly affected. This is because the delayed exchange rate pass-through to consumption prices only affects the composition of consumption, but not the traded goods sector. The limited exchange rate pass-through to input prices, however, hinders the adjustment of the relative price of local inputs to imported intermediate goods in the trade goods sector, and thus dampen the response of traded sector, consumption, and output to TOT shocks. Hence, the incomplete exchange rate pass-through to imported input
Table 2: Means and Standard Deviations of Major Variables under TOT Shocks

<table>
<thead>
<tr>
<th></th>
<th>(ψ_{PM} = 0, ψ_{PF} = 0)</th>
<th>(ψ_{PM} = 0, ψ_{PF} = 120)</th>
<th>(ψ_{PM} = 120, ψ_{PF} = 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC</td>
<td>0.9820</td>
<td>0.9820</td>
<td>0.9813</td>
</tr>
<tr>
<td>σ_C</td>
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<td>0.0054</td>
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<td>0.9804</td>
<td>0.9814</td>
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</tr>
<tr>
<td>σ_P</td>
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<td>0.0102</td>
<td>0.0102</td>
</tr>
<tr>
<td>ES</td>
<td>0.9603</td>
<td>0.9593</td>
<td>0.9969</td>
</tr>
<tr>
<td>σ_S</td>
<td>0.0526</td>
<td>0.0526</td>
<td>0.0235</td>
</tr>
</tbody>
</table>

prices has a larger impact on the economic dynamics than does the incomplete exchange rate pass-through to import consumption prices.

### 3.3 Moments of Major Variables

To further illustrate the impact of incomplete exchange rate pass-through to imported input prices on the response of the economy to TOT shocks, in Table 2, we compare the mean and standard deviation of consumption, labor and prices under two types of exchange rate pass-through. Table 2 shows that a change in ψ_{PF} affects the consumption volatility only, while a change in ψ_{PM} affects both the mean and the volatility of consumption and employment. Therefore, Table 2 supports what we show in impulse response functions. Incomplete pass-through to imported input prices (ψ_{PM}) has a larger impact on the economic dynamics than does incomplete pass-through to imported consumption prices (ψ_{PF}).

Table 2 also shows that, in both cases, with delayed exchange rate pass-through, the mean of the price level increases and its volatility decreases.\footnote{Incomplete exchange rate pass-through to imported consumption implies that the exchange rate appreciation has a smaller impact on domestic prices, so that domestic price changes will be small. With limited...}
is that in face of TOT shocks, the endogenous exchange rate volatility depends crucially on
the degree of exchange rate pass-through to imported input prices, but not on the degree of
exchange rate pass-through to consumption prices. When we change $\psi_{P_F}$, the exchange rate
volatility does not change. However, when we increase $\psi_{P_M}$ from 0 to 120, the exchange
rate volatility decreases significantly. It is only about 25% of that in the case with full
exchange rate pass-through. Figure 2 shows that even a small value of $\psi_{P_M}$ will lead to a
sharp decrease in exchange rate volatility. Intuitively, in face of a TOT shock, an efficient
adjustment of relative prices of local inputs to imported inputs in the traded goods sector
is essential for the economy. Nevertheless, a delayed exchange rate pass-through to input
prices hinders the role of exchange rate changes in adjusting the relative prices of inputs in
traded goods production. Therefore, less exchange rate movement is needed with incomplete
exchange rate pass-through to input prices.

4 Welfare Evaluation

We now analyze the welfare consequences of different types of exchange rate pass-through
under flexible exchange rates. The welfare measurement we use here is the conditional
expected lifetime utility of the representative household at time zero. Following Schmitt-
Grohe and Uribe (2004) and Kim and Kim (2003), the expected lifetime utility is computed
conditional on the initial state being the deterministic steady state, which is the same for all
cases. To measure the magnitude of welfare differences across different regimes, we define
$\zeta_k$ as the percentage change of deterministic steady state consumption that will give the
exchange rate pass-through to input prices, the exchange rate appreciation is limited, so that domestic price
changes are also small.

In our model, the exchange rate can be simply pinned down by the equation $MC_T = SP_T^T$ in the traded
goods sector, as the traded goods sector is perfectly competitive. With a NPT targeting rule, nominal wage
is almost fixed (recall that $MC_N t = W_t$). Therefore, the exchange rate is mainly determined by $P_M$, which
does not depend on $\psi_{P_F}$.
same conditional expected utility, $EU$, under regime $k$. That is, $\zeta_k$ is given implicitly by:

$$
\frac{1}{1-\rho}[(1 + \zeta_k)\bar{C}]^{1-\rho} - \frac{\bar{L}^{1+\psi}}{1-\beta} = EU_k,
$$

where a bar over a variable denotes the deterministic steady state of that variable. If $\zeta_k > 0(< 0)$, the welfare under regime $k$ is implied to be higher (lower) than that of the steady state case. Higher values of $\zeta_k$ correspond to higher welfare. The welfare $EU_k$ is computed by taking second-order Taylor approximations of the structural equations around the deterministic steady state.

Our welfare results are reported in Table 3. In the presence of a TOT shock, under flexible exchange rates, incomplete exchange rate pass-through to both imported input prices and imported consumption prices reduces welfare. Compared to the benchmark model ($\psi_{PM} = \psi_{PF} = 0$), when the exchange rate pass-through to import consumption prices is delayed and incomplete, welfare decreases by approximately 20%. However, when the exchange rate pass-through to input prices is incomplete, the welfare is reduced by about 50%. This implies that under a flexible exchange rate regime, for same degree of limited exchange rate pass-through, a delayed pass-through to input prices leads to more welfare loss than that to imported consumption prices.

To understand where the welfare loss of changing $\psi_{PF}(\psi_{PM})$ comes from, we can go back to Table 2. Table 2 shows that the welfare loss caused by an increase in $\psi_{PF}$ from 0 to 120 is mainly due to an increase of consumption volatility, while the welfare loss of
increasing $\psi_{PM}$ from 0 to 120 comes from a decrease in the mean of consumption and an increase in mean of employment. Intuitively, this is because with a TOT shock, incomplete pass-through to input prices affects the production of traded goods and then affects the size of the consumption basket, while delayed pass-through to imported consumption prices only affects the composition of consumption, as shown by the dynamics of the economy. In other words, this welfare comparison shows that when a small open economy with intermediate goods trade is disturbed by a TOT shock, an efficient relative input price adjustment is more important. This implies that when we investigate the issues of exchange rate pass-through, we should also consider the exchange rate pass-through to imported input prices, especially for small open economies characterized by intermediate goods trade.

5 Sensitivity Analysis

In the above analysis, we have shown that, in the presence of terms of trade shocks, the degree of exchange rate pass-through to input prices affects the economy more than does the degree of exchange rate pass-through to goods prices. We also find that exchange rate volatility depends critically on the degree of exchange rate pass-through to input prices. Furthermore, we find that, for the same degree of limited exchange rate pass-through, a delayed pass-through to input prices leads to more welfare loss than that to goods prices.

Does these results depend on the nature of shocks? In this section, we will check the robustness of our results by reexamining these issues when the economy is disturbed by the non-traded sector productivity shock. Now $P^*_T$, $P^*_F$ is assumed to be constant and normalized to 1. We also assume that $\log(A_t)$ follows an AR(1) stochastic process with $\rho_A = 0.80$ and $\sigma_A = 0.01$.9

9Stockman and Tesar (1995) estimate the stochastic process of $A_t$ (instead of $\log(A_t)$ using US and OECD country data and find the persistence of non-traded sector productivity shock and its standard error is 0.632 and 0.0199, respectively. Ortega and Rebei (2006) estimate the productivity shock process in non-traded sector in a small open economy using the Bayesian estimation techniques and Canadian data. They find the persistence of $\log(A_t)$ lies in the range of [0.7419, 0.8404] using a prior of 0.85. Liu and Pappa (2008) use
From Figure 3, we can see that the impulse response functions to the productivity shock are different from those to the TOT shock. But we can still find that the impact of productivity shocks on the economy is quite different when the source of incomplete exchange rate pass-through lies in different goods. For the same degree of delayed exchange rate pass-through, the limited pass-through to intermediate goods has larger effect on the dynamics of major economic variables than that to imported final consumption goods.

Since the monetary policy targets the non-traded goods inflation, $P_{Nt}$ does not respond to the non-traded sector productivity shock. This implies a positive productivity shock will cause an increase in wage, which in turn leads to an increase in traded firm’s marginal cost. As a result, the exchange rate depreciates since traded sector is competitive. The positive shock also leads to an increase in consumption. In the case of full pass-through, an increase of $S_t$ implies increases in imported consumption goods prices (and price level) and input prices. The expenditure switching effect then implies that the consumption of non-traded goods will increase and the non-traded sector will expand. Note that the non-traded labor still decreases because of the positive technology shock. Traded sector, however, does not expand much in face of the exchange rate depreciation. This is because both wage and imported input price increase, which offset the effect of exchange rate depreciation.

When incomplete pass-through to consumption price is present, the imported consumption price will not increase with the exchange rate depreciation. Hence, the price level will not increase as much as in the first case and the consumption can increase more. Meanwhile, the expenditure switching effect is smaller and the non-traded sector expand less, which in turn implies the non-traded labor will decrease more. The response of traded sector is almost the same as that in the full pass-through case. With delayed pass-through to input prices, the imported input price in terms of local currency will be sticky. Hence, the exchange rate depreciation needed to equalize the marginal cost and price in traded sector is smaller, which in turn leads to a smaller increase in $P_f$. Therefore, the non-traded

$\rho_A = 1$ and $\sigma_A = 0.01$. Hence, our calibration of the stochastic process of non-traded sector productivity shock is consistent with those in the literature.
labor will decrease even more. More importantly, the response of the traded sector is much larger in face of exchange rate depreciation. The traded sector will expand a lot, so the traded output, traded labor, and total labor will increase, compared to the first two cases. The response of major variables for the last case ($\psi_{PM} = 120$ and $\psi_{PF} = 120$) is almost the same as the case with limited pass-through to input prices.

From Table 4, we can also find the pattern of changes in mean and standard deviation of major variables is very similar to those under TOT shocks, as listed in Table 3. For example, when $\psi_{PF}$ increases from 0 to 120, the volatility of exchange rate is unchanged, but when $\psi_{PM}$ increases from 0 to 120, $\sigma_S$ is reduced by about 50 percent, almost the same as the percentage change under TOT shocks. So the exchange volatility depends on the degree of pass-through to input prices. For the welfare results, Table 5 shows that the size of the welfare loss caused by productivity shocks in non-traded sector is also affected by the source of incomplete exchange rate pass-through. Compared to the case for delayed pass-through to consumption goods price, the productivity shock leads to more welfare loss when the degree of exchange rate pass-through to input price prices is limited. This result is qualitatively similar to that under the TOT shock, although the magnitude of welfare loss and the channels through which limited pass-through affected welfare are somewhat different. Table 4 shows that the welfare loss caused by an increase in $\psi_{PF}$ from 0 to 120 is mainly due to increases in consumption and employment volatility, while the welfare loss of increasing $\psi_{PM}$ from 0 to 120 comes from a decrease in the mean of consumption and a further increase in employment volatility.

6 Conclusion

The issues of exchange rate pass-through to import consumption good prices have been extensively discussed recently, but relatively less attention has been paid to exchange rate pass-through to imported input prices in the literature. To explore this issue, we incorporate intermediate goods trade structure into a two-sector small open economy model with sticky prices. In this paper, incomplete exchange rate pass-through to both consumption goods
Table 4: Means and Standard Deviations of Major Variables under Productivity Shocks

<table>
<thead>
<tr>
<th></th>
<th>$\psi_{PM} = 0, \psi_{PF} = 0$</th>
<th>$\psi_{PM} = 0, \psi_{PF} = 120$</th>
<th>$\psi_{PM} = 120, \psi_{PF} = 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$EC$</td>
<td>0.9808</td>
<td>0.9808</td>
<td>0.9807</td>
</tr>
<tr>
<td>$\sigma_C$</td>
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<td>0.0090</td>
<td>0.0055</td>
</tr>
<tr>
<td>$EL$</td>
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<td>0.9818</td>
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</tr>
<tr>
<td>$\sigma_L$</td>
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<tr>
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<tr>
<td>$\sigma_P$</td>
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<td>0.0044</td>
</tr>
<tr>
<td>$ES$</td>
<td>0.9947</td>
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</tr>
<tr>
<td>$\sigma_S$</td>
<td>0.0191</td>
<td>0.0191</td>
<td>0.0101</td>
</tr>
</tbody>
</table>

Table 5: Welfare Comparison under Productivity Shocks (%)

<table>
<thead>
<tr>
<th></th>
<th>$\xi_{NTP}$</th>
<th>$\psi_{PF} = 0$</th>
<th>$\psi_{PF} = 120$</th>
<th>Change</th>
</tr>
</thead>
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<tr>
<td>$\psi_{PM} = 0$</td>
<td>-0.003</td>
<td>-0.006</td>
<td>-0.003</td>
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<tr>
<td>$\psi_{PM} = 120$</td>
<td>-0.009</td>
<td>-0.0010</td>
<td>-0.001</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>-0.006</td>
<td>-0.004</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
prices and input prices are both considered to study if the source of incomplete pass-through matters for the economic dynamics and the welfare implications.

We find that, in the presence of TOT shocks or productivity shocks, the degree of exchange rate pass-through to input prices affects the economy more than does the exchange rate pass-through to good prices. Another finding is that in this small open economy, exchange rate volatility depends critically on the degree of exchange rate pass-through to input prices. Regarding the welfare implications, we find that the desirability of exchange rate flexibility will be affected by both the exchange rate pass-through to imported consumption goods prices and to imported intermediate goods prices. However, compared to the full pass-through case, a delayed exchange rate pass-through to input prices leads to more welfare loss than does that to goods prices. Our result implies that an efficient input price adjustment is more important to the economies characterized by intermediate goods trade.
References


Figure 1: The IRF to TOT shock

- **Consumption to +TOT**
  - Case 1: Full pass-through. \( \psi_{PM} = 0, \psi_{PF} = 0 \)
  - Case 2: Delayed pass-through to imported consumption goods prices. \( \psi_{PM} = 0, \psi_{PF} = 120 \)
  - Case 3: Delayed pass-through to imported input prices. \( \psi_{PM} = 120, \psi_{PF} = 0 \)
  - Case 4: Delayed pass-through to both goods and input. \( \psi_{PM} = 120, \psi_{PF} = 120 \)

- **Labor to +TOT**
- **Non-traded Labor to +TOT**
- **Traded Labor to +TOT**
- **Traded Output to +TOT**
- **Price to +TOT**
- **Exchange Rate to +TOT**
Figure 2:
Ex Volatility and Ex Pass−through to Input Price
Figure 3: The IRF to Non-traded Sector Productivity shock

- **Case 1**: Full pass-through, $\psi_{PM} = 0$, $\psi_{PF} = 0$.
- **Case 2**: Delayed pass-through to imported consumption goods prices, $\psi_{PM} = 0$, $\psi_{PF} = 120$.
- **Case 3**: Delayed pass-through to imported input prices, $\psi_{PM} = 120$, $\psi_{PF} = 0$.
- **Case 4**: Delayed pass-through to both goods and inputs, $\psi_{PM} = 120$, $\psi_{PF} = 120$. 

\[ \text{Deviation from ss} \]

- **Consumption to } +A_t**
- **Labor to } +A_t**
- **Traded Labor to } +A_t**
- **Traded Output to } +A_t**
- **Price to } +A_t**
- **Exchange Rate to } +A_t**