Exchange Rate Pass-Through and Unemployment Dynamics

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ABSTRACT

This paper develops a small open economy model with nominal rigidities and search-matching frictions to study the implications of incomplete exchange rate pass-through for unemployment dynamics. The model shows that incomplete exchange rate pass-through to the prices of imported goods has a larger impact on unemployment movements than does incomplete pass-through to the prices of imported inputs. Also, the effect of delayed exchange rate pass-through on unemployment dynamics depends critically on the nature of the shock that disturbs the economy.

1. Introduction

In recent years, the implications of incomplete exchange rate pass-through for the transmission of shocks and monetary policy have been widely studied. For instance, Devereux and Engel (2003) stress that fixed exchange rate regime is the optimal monetary policy for an open economy in the presence of local currency pricing. Devereux et al. (2006) show that when exchange rate pass-through to the prices of consumption goods is high, central banks should target the inflation rate of non-traded goods. On the other hand, with low exchange rate pass-through, strict CPI inflation targeting is the optimal monetary policy. Shi and Xu (2010) investigate how different types of exchange rate pass-through can affect the dynamics of a small open economy. Taylor (2000) argues that low exchange rate pass through to domestic prices is related to low inflation policy regime. Devereux and Yetman (2010) stress that low exchange rate pass-through is caused by nominal price rigidities.[1] However, the aforementioned studies have given little attention to the effect of incomplete pass-through on the dynamics of unemployment. Meanwhile, unemployment is often considered as undesirable and it has been the central topic of recent policy debates. Thus, it is important for us to understand how the degree of exchange rate pass-through affects the behavior of unemployment and the desirability of flexible exchange rate policy.

In this paper, I develop a small open economy model with Mortensen-Pissarides type search-matching frictions to study the dynamics of different labor market variables under different exchange rate pass-through environments. To ensure that monetary policy is non-neutral, I incorporate price rigidities into the model. Hence, the model economy features both nominal and real frictions. Moreover, in this model, I allow for delayed exchange rate pass-through to both imported consumption goods prices and imported inputs prices. Given the increase of vertical trade around the globe in the past few decades, changes in exchange rate not only affect the relative price of imported goods to domestic goods, but also the relative price of imported inputs to domestic inputs.[2] Thus, the effect of external shocks on domestic variables depends on the degree of pass-through to imported goods prices as well as that to imported inputs prices.

The model shows that the effect of incomplete exchange rate pass-through on unemployment dynamics varies and depends critically on the nature of the shock that is affecting the economy. In particular, the model predicts that incomplete exchange rate pass-through will amplify the effect of a foreign interest rate shock on unemployment, but it will mitigate the effect of a foreign demand shock. The intuition for these results works as follows. In a standard frictionless business cycle model, the marginal product of labor is equal to the marginal rate of substitution between consumption and leisure, and both are equal to the wage rate. However, with search frictions, there are positive gains from forming a match in the labor market and the marginal product of labor differs from the marginal rate of substitution. Moreover, the surplus associated with each employment relationship and firms' hiring decision depends critically on the gap between the marginal product of labor and the marginal rate of substitution.

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The mode predicts that delayed exchange rate pass-through to imported goods prices amplifies the response of the gap between the marginal product of labor and the marginal rate of substitution to a foreign interest rate shock. It enlarges the surplus a firm receives from a match, causing larger movements in hiring and unemployment. However, it is a different story in the presence of a foreign demand shock. Incomplete pass-through to imported goods prices reduces the response of the gap between the marginal product of labor and the marginal rate of substitution to a foreign demand shock.

The model also shows that incomplete exchange rate pass-through to imported goods prices has a larger effect on the real variables than does incomplete exchange rate pass-through to imported inputs prices. In the current model, domestic goods are produced with labor and imported inputs. Without price rigidities, the degree of exchange rate pass-through to imported inputs will affect the marginal cost of domestic goods and, in turn, the price and demand for domestic consumption goods. However, with price rigidities, the effect of the degree of exchange rate pass-through to imported inputs prices on domestic prices and demand becomes insignificant.

I also find that, with the same degree of delay in exchange rate pass-through, incomplete exchange rate pass-through to imported inputs prices generates more welfare losses than incomplete pass-through to imported goods prices. This result is consistent with Shi and Xu (2010). The reason is that incomplete pass-through to imported goods prices tends to stabilize the response of overall consumption to shocks and it generates less volatility in consumption than incomplete pass-through to imported inputs prices.

The rest of the paper is organized as follows. Section 2 characterizes the general equilibrium model. Section 3 looks at the impulse responses of selected variables to external shocks and describes the welfare measure. Section 4 conducts sensitivity analysis and section 5 concludes.

2. The Model

The theoretical model is similar to the one in Cheng (2012). It consists of both nominal and real frictions. Nominal rigidities are introduced to the model through price adjustment costs faced by domestic firms. Moreover, as in the search-matching literature, I assume that job search is time-consuming and costly. At the beginning of each period, a constant fraction of existing workforce separates from each firm exogenously. Firms can then post vacancies to attract new workers. The number of new hires is determined by a matching function and the wage rate is determined by each firm-worker pair through Nash bargaining.

2.1 Households

The model economy consists of a large number of identical and infinitely-lived households. Each household has a continuum of members on the unit interval. The preference of the representative household is given by

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \chi N_t\right) \qquad (1)$$

where C_t is the aggregate consumption index, N_t is the number of employed household members and χ represents the disutility of work. The unemployed and employed members within each household consume the same amount of goods due to income pooling. The consumption index is given by a CES function

$$C_t = \left[\alpha^{\frac{1}{\nu}} C_{D,t}^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C_{F,t}^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}} \qquad (2)$$

Where $C_{D,t}$ and $C_{F,t}$ denote domestic goods and imported goods respectively, ν represents the elasticity of substitution between domestic and foreign goods. The consumer price index (CPI) takes the form

$$P_t = \left[\alpha P_{D,t}^{1-\nu} + (1-\alpha) P_{F,t}^{1-\nu}\right]^{\frac{1}{1-\nu}} \qquad (3)$$

Each household consumes a variety of domestic and foreign goods. Thus, $C_{D,t} = \left[\int_0^1 C_{D,t}(i)^{\frac{\lambda-1}{\lambda}} di\right]^{\frac{\lambda}{\lambda-1}}$ and $C_{F,t} = \left[\int_0^1 C_{F,t}(i)^{\frac{\lambda-1}{\lambda}} di\right]^{\frac{\lambda}{\lambda-1}}$, where λ is the elasticity of substitution across different varieties. The household budget constraint is given by

$$P_tC_t+P_t\frac{\psi_D}{2}(D_t-D)^2+S_tR^*_{t-1}D_{t-1}+R_{t-1}B_{t-1}=W_tN_t+\Pi_t+S_tD_t+B_t \quad (4)$$

where S_t is the nominal exchange rate, B_t (D_t) is the household's holdings of domestic (foreign) currency debt. The interest rate on nominal domestic debt is denoted by R_t and that on foreign debt is denoted by R_t^*. W_t is the nominal wage rate. Firms are owned by the household. Π_t is the nominal profits. The household faces debt adjustment costs. The adjustment cost function takes the form

$$P_t\frac{\psi_D}{2}(D_t-D)^2$$

where D is the steady-state value of the foreign debt holdings.[3] R_t^* is assumed to be exogenous and constant over time.

At the beginning of period t, a fraction, 1-ρ, of employed workers separates from each firm exogenously. These workers are not allowed to search until the next period. This implies that the law of motion of employment follows

$$N_t=\rho N_{t-1}+p_tU_t$$

Where $U_t = 1 - N_{t-1}$ is the number of unemployed workers who are currently searching for jobs and p_t is the probability of finding a job.

Given B_{t-1}, D_{t-1}, N_t, all market prices and firms' profits, the representative household chooses C_t, B_t and D_t to maximize (1) subject to its budget constraint (4). The first order conditions are given by

$$\frac{1}{R_t^*}\left[1-\frac{\psi_DP_t}{S_t}(D_t-D)\right]=\beta E_t\left[\frac{C_tP_t}{C_{t+1}P_{t+1}}\frac{S_{t+1}}{S_t}\right] \quad (5)$$

and

$$\frac{1}{R_t}=\beta E_t\left[\frac{C_tP_t}{C_{t+1}P_{t+1}}\right] \quad (6)$$

Equation (5) and equation (6) are the respective Euler equations for domestic and foreign borrowings. The household chooses domestic consumption goods and foreign goods to minimize its expenditures, given the aggregate consumption index. Thus, the demand for domestic goods is

$$C_{D,t}=\alpha\left(\frac{P_{D,t}}{P_t}\right)^{-\nu}C_t$$

and the demand for imported goods is

$$C_{F,t}=(1-\alpha)\left(\frac{P_{F,t}}{P_t}\right)^{-\nu}C_t$$

2.2 Firms

There are four types of firms in this economy: wholesale firms, retail firms, importers and exporters. The competitive wholesale firms combine labor, N_t, and imported inputs, M_t, to produce intermediate goods. The production function of a wholesale firm is given by

$$Y_{I,t}=\left[\omega^{\frac{1}{\phi}}(N_t)^{\frac{\phi-1}{\phi}}+(1-\omega)^{\frac{1}{\phi}}M_t^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}$$

where φ is the elasticity of substitution between labor and imported inputs and ω is the weight of domestic labor in the production function.

The number of new hires or matches, H_t, is a function of the number of vacancies V_t and the number of unemployed workers U_t. As in the search-matching literature, the matching function takes a standard Cobb-Douglas form

$$H_t = \gamma_H U_t^{\gamma} V_t^{1-\gamma}$$

Where γ_H represents the efficiency of the matching process. The employment of each wholesale firm follows the law of motion

$$N_t = \rho N_{t-1} + q_t V_t$$

The ratio of vacancies to unemployed workers, $\theta_t = V_t/U_t$, represents the tightness of the labor market. $q_t = H_t/V_t = \gamma_H \theta_t^{-\gamma}$ is the probability of filling a vacancy and $p_t = H_t/U_t = \gamma_H \theta_t^{1-\gamma}$ is the probability of finding a job. The value of each wholesale firm can be written as

$$J_t = \frac{P_{I,t}}{P_t} Y_{I,t} - \frac{W_t}{P_t} N_t - \frac{P_{M,t}}{P_t} M_t - \Gamma V_t + E_t \beta \Lambda_{t,t+1} J_{t+1}$$

where $\Lambda_{t,t+1} \equiv C_t/C_{t+1}$ and $\beta \Lambda_{t,t+1}$ is the stochastic discount factor. $P_{I,t}$ is the price of the intermediate goods and $P_{M,t}$ is the price of the imported inputs. Γ is the vacancy posting cost. Taking all market prices, the wage rate, the probability of filling a vacancy, q_t, and its existing labor stock, N_{t-1} as given, each wholesale firm chooses imported inputs, M_t, and vacancies, V_t, to maximize its value. The maximization problem results in the following optimality conditions:

$$M_t = (1-\omega) \left(\frac{P_{M,t}}{P_{I,t}} \right)^{-\phi} Y_{I,t}$$

and

$$MRPN_t + \rho E_t \beta \Lambda_{t,t+1} G_{t+1} = \frac{W_t}{P_t} + G_t \qquad (7)$$

Where $G_t \equiv \Gamma/q_t$ denotes the costs per new hire and $MRPN_t = (P_{I,t}/P_t)\omega^{1/\varphi} N_t^{-(1/\varphi)} Y_{I,t}^{(1/\varphi)}$ represents the marginal revenue product of labor. The equation above indicates that the marginal benefit of hiring a new worker is equal to the marginal revenue product of labor and the present value of the future hiring costs. On the other hand, the marginal cost of hiring comprises the real wage rate and the current hiring costs.

Nash Bargaining

Unlike in a standard business cycle model, the nominal wage in this model is determined by a Nash bargaining process between each employee and the firm. Due to search frictions, there are gains from trade in the labor market. Each matched firm-worker pair negotiates a wage rate that maximizes the surplus it receives. Let V_t^N denote the value to a household member of being employed in terms of aggregate consumption goods. V_t^N can be expressed as

$$V_t^N = \frac{W_t}{P_t} - MRS_t + E_t \left\{ \beta \Lambda_{t,t+1} \left[\rho V_{t+1}^N + (1-\rho) V_{t+1}^U \right] \right\}$$

Where W_t is the nominal wage rate in period t and $MRS_t = -U_{n,t}/U_{c,t} = \chi C_t$ is the marginal rate of substitution between leisure and consumption. MRS_t can also be interpreted as the marginal disutility of work in terms of aggregate consumption goods. If the negotiation breaks down, I assume that the worker leaves the labor market and cannot search for jobs until the next period. Thus, the value of being unemployed is given by

$$V_t^U = E_t \beta \Lambda_{t,t+1} \left[p_{t+1} V_{t+1}^N + (1-p_{t+1}) V_{t+1}^U \right]$$

The surplus a worker receives from having a job in period t is denoted by $S_t^H = V_t^N - V_t^U$, which can be expressed as

$$S_t^H = \frac{W_t}{P_t} - MRS_t + E_t\left[\beta\Lambda_{t,t+1}(\rho - p_{t+1})S_{t+1}^H\right] \qquad (8)$$

The surplus that a firm obtains from establishing an employment relationship with a worker is given by

$$S_t^F = MRPN_t - \frac{W_t}{P_t} + E_t[\rho\beta\Lambda_{t,t+1}S_{t+1}^F] \qquad (9)$$

Combining the equation above with equation (7) yields $S_t^F = G_t$. Thus, in equilibrium, the surplus that a firm receives from finding a match is equivalent to the recruiting costs. Moreover, I assume the nominal wage is determined through Nash bargaining, so each firm-worker pair solves the following problem:

$$\max_{W_t} \left(S_t^H\right)^{\eta} \left(S_t^F\right)^{1-\eta}$$

where η represents the worker's bargaining power. The first order necessary condition is then given by

$$\eta S_t^F = (1-\eta)S_t^H \qquad (10)$$

The total surplus from a match is given by $S_t^T \equiv S_t^F + S_t^H$. Combining equations (8) and (9) with the Nash condition (10), we have

$$S_t^T = MRPN_t - MRS_t + E_t[\beta\Lambda_{t,t+1}(\rho - \eta p_{t+1})S_{t+1}^T] \qquad (11)$$

Equation (11) shows that the total surplus from a match depends on the current gap between the marginal revenue product of labor and the marginal rate of substitution and the discounted continuation value.

The reservation wage of the worker can be obtained by setting $S_t^H = 0$. It can be expressed as

$$\Omega_t^H = MRS_t - E_t\beta\Lambda_{t,t+1}(\rho - p_{t+1})S_{t+1}^H \qquad (12)$$

The reservation wage of the worker depends on the marginal disutility of work and the discounted continuation value. Similarly, one can obtain the reservation wage of the firm by setting $S_t^F = 0$. It is given by

$$\Omega_t^F = MRPN_t + E_t\rho\beta\Lambda_{t,t+1}S_{t+1}^F \qquad (13)$$

It can be shown that the optimal wage rate is equal to the geometric average of the worker's and the firm's reservation wages. More specifically, it is given by

$$\frac{W_t}{P_t} = \eta\Omega_t^F + (1-\eta)\Omega_t^H$$

Combining $S_t^F = (\Gamma\theta_t^{\gamma}/\gamma_H)$ and the fact that $S_t^F = (1-\eta)S_t^T$, we can rewrite equation (11) as:

$$\frac{\Gamma\theta_t^{\gamma}}{\gamma_H} = (1-\eta)(MRPN_t - MRS_t) + \beta E_t\left\{(\rho - \eta p_{t+1})\Lambda_{t,t+1}\frac{\Gamma\theta_{t+1}^{\gamma}}{\gamma_H}\right\} \qquad (14)$$

As the above equation shows, hiring in the current model depends critically on the gap between the marginal revenue product of labor and the marginal rate of substitution. The total surplus from a match will rise when the marginal revenue product of labor surges. As a result, firms will post more vacancies to attract new workers. On the other hand, as the marginal disutility of work rises, workers will demand higher wages, which will cause hiring to fall.

Retailers

In this economy, there is a continuum of monopolistically competitive retail firms indexed by i on the unit interval. Retailers purchase intermediate goods from the wholesale firms and differentiate the intermediate goods at no cost. The differentiated goods are then sold to domestic households and export firms. The demand function for the retail good i is given by

$$Y_{D,t}(i) = \left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\lambda} Y_{D,t}$$

where λ is the elasticity of substitution across differentiated goods and $Y_{D,t}$ is the total demand for retail goods. As in Rotemberg (1982), I assume that retail firms face price adjustment costs when they change their prices. Each retailer chooses a price to maximize its expected profit stream:

$$\max_{P_{D,t}(i)} E_t \sum_{k=0}^{\infty} \beta^k \Xi_{t,t+k} \left[\begin{array}{c} P_{D,t+k}(i) Y_{D,t+k}(i) - P_{I,t+k} Y_{D,t+k}(i) \\ -\frac{\psi_{PD}}{2} P_{t+k} \left(\frac{P_{D,t+k}(i)}{P_{D,t+k-1}(i)} - 1 \right)^2 \end{array} \right]$$

Where $\Xi_{t,t+k} = (P_t C_t / (P_{t+k} C_{t+k}))$. The optimal price setting equation is then given by[4]

$$\begin{aligned} P_{D,t} &= \frac{\lambda}{\lambda - 1} P_{I,t} - \frac{\psi_{PD}}{\lambda - 1} \frac{P_t}{Y_{D,t}} \frac{P_{D,t}}{P_{D,t-1}} \left(\frac{P_{D,t}}{P_{D,t-1}} - 1 \right) \\ &\quad + \frac{\psi_{PD}}{\lambda - 1} E_t \left[\beta \Xi_{t,t+1} \frac{P_{t+1}}{Y_{D,t}} \frac{P_{D,t+1}}{P_{D,t}} \left(\frac{P_{D,t+1}}{P_{D,t}} - 1 \right) \right] \end{aligned}$$

Importers

To allow for the possibility that exchange rate changes only pass through slowly to the prices of imported consumption goods, I assume that there is a continuum of price-setting consumption goods importers. These importers purchase foreign goods at a foreign currency price P_t^*, and differentiate the foreign goods at no cost. The differentiated goods are then sold to domestic households. Similar to the retail firms, importers in this economy face price adjustment costs. The adjustment costs will delay the response of import prices to any changes in the nominal exchange rate. In other words, the higher the adjustment costs, the lower the degree of exchange rate pass-through to imported goods prices. In particular, each importer chooses $P_{F,t}(j)$ to solve the following maximization problem:

$$\max_{P_{F,t}(j)} E_t \sum_{k=0}^{\infty} \beta^k \Xi_{t,t+k} \left[\left(P_{F,t+k}(j) - S_{t+k} P^*_{t+k} \right) Y_{F,t+k}(j) - \frac{\psi_{PF}}{2} P_{t+k} \left(\frac{P_{F,t+k}(j)}{P_{F,t+k-1}(j)} - 1 \right)^2 \right]$$

subject to the demand function

$$Y_{F,t}(i) = \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\lambda} Y_{F,t}$$

Since all importers face the same price adjustment cost and the same demand function, they will choose the same price. The optimal price $P_{F,t}$ of imported goods is given by

$$\begin{aligned} P_{F,t} &= \frac{\lambda}{\lambda - 1} S_t P^*_{F,t} - \frac{\psi_{PF}}{\lambda - 1} \frac{P_t}{Y_{F,t}} \frac{P_{F,t}}{P_{F,t-1}} \left(\frac{P_{F,t}}{P_{F,t-1}} - 1 \right) \\ &\quad + \frac{\psi_{PF}}{\lambda - 1} E_t \left[\beta \Xi_{t,t+1} \frac{P_{t+1}}{Y_{F,t}} \frac{P_{F,t+1}}{P_{F,t}} \left(\frac{P_{F,t+1}}{P_{F,t}} - 1 \right) \right] \end{aligned}$$

In a similar manner, I assume that there is a continuum of price-setting intermediate goods importers. These importers purchase foreign inputs at a foreign currency price of $P_{M,t}^*$, and sell the imported inputs to domestic wholesale firms. We can obtain the optimal price of imported inputs as:

$$P_{M,t} = \frac{\lambda}{\lambda-1}S_t P_t^* - \frac{\psi_{PM}}{\lambda-1}\frac{P_t}{Y_{M,t}}\frac{P_{M,t}}{P_{M,t-1}}\left(\frac{P_{M,t}}{P_{M,t-1}}-1\right) + \frac{\psi_{PM}}{\lambda-1}E_t\left[\beta\Xi_{t,t+1}\frac{P_{t+1}}{Y_{M,t}}\frac{P_{M,t+1}}{P_{M,t}}\left(\frac{P_{M,t+1}}{P_{M,t}}-1\right)\right]$$

Exporters

Next, I assume that export firms face a standard demand schedule for their exports

$$Y_{X,t} = (P_{X,t})^{-\xi}Y_t^*$$

Where $P_{X,t}=P_{D,t}/(S_tP_t^*)$ is the relative price of exports, ξ is the elasticity of export demand with respect to the relative price. P_t^* is the foreign price level and Y_t^* is the exogenous foreign income. I assume that $\log(Y_t^*)$ follows a AR(1) process with autoregressive coefficient ρ_y and variance σ_y^2.

An increase in $P_{X,t}$ implies that goods from the home country are relatively more expensive than those from the foreign country. Thus, when $P_{X,t}$ surges, exports of home country will fall.

2.3 Monetary Policy

I assume that the central bank sets short-term interest rate according to a simple interest rate rule:

$$R_t = \overline{R}(\pi_t/\overline{\pi})^{\phi_\pi} \qquad (15)$$

where $\pi_t=P_t/P_{t-1}$. This is a Taylor-type rule that responds only to movements in CPI inflation.

2.4 Equilibrium Conditions

In this subsection, I describe the equilibrium conditions. Since final output can be either consumed by domestic households or exported to the rest of the world. In equilibrium, we have

$$Y_{D,t} = C_{D,t} + Y_{X,t}$$

The market clearing conditions for domestic consumption goods and foreign consumption goods are given by

$$Y_{D,t} - Y_{X,t} = \alpha\left(\frac{P_{D,t}}{P_t}\right)^{-\nu}Z_t$$

and

$$Y_{F,t} = (1-\alpha)\left(\frac{P_{F,t}}{P_t}\right)^{-\nu}Z_t$$

respectively. Z_t is the total demand for aggregate goods, which is given by

$$Z_t = C_t + \frac{\psi_D}{2}(D_{t+1}-D)^2 + \frac{\psi_{PD}}{2}\left(\frac{P_{D,t}}{P_{D,t-1}}-1\right)^2 + \frac{\psi_{PM}}{2}\left(\frac{P_{M,t}}{P_{M,t-1}}-1\right)^2 + \frac{\psi_{PF}}{2}\left(\frac{P_{F,t}}{P_{F,t-1}}-1\right)^2 + G_tH_t$$

Finally, the representative household owns all firms and receives total profits:

$$\begin{aligned}\Pi_t &= (P_{D,t} - P_{I,t})Y_{d,t} - \frac{\psi_{PD}}{2}P_t\left(\frac{P_{D,t}}{P_{D,t-1}} - 1\right)^2 \\ &+(P_{M,t} - S_t P^*_{M,t})Y_{M,t} - \frac{\psi_{PM}}{2}P_t\left(\frac{P_{M,t}}{P_{M,t-1}} - 1\right)^2 \\ &+(P_{F,t} - S_t P^*_{F,t})Y_{F,t} - \frac{\psi_{PF}}{2}P_t\left(\frac{P_{F,t}}{P_{F,t-1}} - 1\right)^2\end{aligned}$$

2.5 Calibration

I set the discount factor, β, to a standard value of 0.99. The separation rate, 1-ρ, is calibrated to 0.06. This implies that ρ is equal to 0.94, which is the same as the estimate obtained by Boz et al. (2009). The elasticity of substitution among domestic goods, λ, is set to 11, following Shi and Wu (2010). This implies that the steady-state price markup is 10 percent. The elasticity of substitution between domestic and imported consumption goods, ν, is set to 2/3, as in Cook and Devereux (2006b). ξ is also set to 2/3, implying that foreign households have the same elasticity of demand as domestic households. The relative bargaining power of a worker, η, and the matching function parameter, γ, are both calibrated to 0.5, which are standard in the search-matching literature.[5]

Following Devereux.et al. (2006), the share of imported consumption goods in the aggregate consumption index, 1-α, is calibrated to 0.45. The share of domestic inputs in the production function, ω, is set to 0.5 and the elasticity of substitution between labor and imported inputs, φ, is set to 2/3, which are close to the values used in Cook and Devereux (2006a).

The values for the efficiency parameter in the matching function, γ_H, the cost of posting a vacancy, Γ and the parameter that governs the disutility of work, χ, are set to target i) the probability of filling a vacancy, q, ii) the steady state unemployment, U, and iii) the ratio of the marginal rate of substitution to the marginal revenue product of labor, MRS/MRPN. Following Boz et al. (2009), the steady-state unemployment rate, U, is set to to 0.0821 and the probability of filling a vacancy, q, is calibrated to 0.7. The ratio of the marginal rate of substitution to the marginal revenue product of labor is set to 0.9. This implies the fraction of hiring costs to output is approximately equal to 0.3 percent, which is similar to the value in Monacelli et al. (2010). The price adjustment cost parameter, ψ_{PD}, is set to 170, which corresponds to a Calvo price adjustment probability of 0.75. In the benchmark model, I set $\psi_{PF}=\psi_{PM}=0$, implying full exchange rate pass-through. Following Schmitt-Grohe and Uribe (2003), the debt adjustment cost parameter, ψ_D, is set to 0.0007. Moreover, I set $\rho_y= 0.98$ and $\sigma_y = 0.036$. These values are similar to those estimates for export demand shocks in Christensen et al. (2009).

3. Impulse Responses

To understand how the degree of exchange rate pass-through affects the model's dynamics, I simulate the responses of some key macroeconomic variables to a foreign demand shock. I focus on three cases. First, I allow for complete exchange rate pass-through to both imported goods prices and imported inputs prices by setting the price adjustment cost parameters, ψ_{PF} and ψ_{PM}, to zero. In the second case, I set $\psi_{PF}= 170$ and $\psi_{PM}=0$, which implies that the prices of imported consumption goods will adjust slowly to changes in the nominal exchange rate.[6] Then, I consider limited exchange rate pass-through to the prices of imported inputs and set the price adjustment cost parameters, ψ_{PM} and ψ_{PF} to 170 and 0 respectively.

Figure 1 displays the impulse responses of the selected variables to a one percent positive foreign demand shock. In the case of complete exchange rate pass-through ($\psi_{PF} = 0$, $\psi_{PM}=0$), an unexpected increase in foreign demand raises exports and output. Moreover, it triggers an appreciation in the nominal exchange rate. This causes the relative price of foreign goods to domestic goods to fall. Firms increase the use of imports and households substitute imported goods for domestic consumption goods. Hence, both imported inputs and imported goods surge after the shock. Consumption increases and inflation occurs.

How would unemployment be affected by the shock? To understand the dynamics of unemployment, it is useful to log-linearize equation (14) to get

$$\widehat{\theta}_t = \left(\frac{1-\psi}{\gamma}\right)\left[\frac{1}{1-\varpi}\widehat{MRPN}_t - \frac{\varpi}{1-\varpi}\widehat{MRS}_t\right] - \frac{\psi}{\gamma}\widehat{r}_t + \beta\left(\rho - \frac{\eta p}{\gamma}\right)E_t\widehat{\theta}_{t+1} \quad (16)$$

where $\psi \equiv \beta(\rho-\eta p)$ and $\varpi \equiv((MRS)/(MRPN))$. $r_t = -\Lambda_{t,t+1}$ is the log-deviation of real interest rate from its steady-state value. Note that ϖ denotes the steady-state ratio of the marginal rate of substitution to the marginal revenue product of labor.

The above equation indicates that hiring in this model is mainly affected by shocks through three different channels: (i) a marginal revenue product of labor channel, (ii) a marginal value of work channel and (iii) a real interest rate channel.

The rise in consumption after the shock leads to an increase in the marginal rate of substitution, which tends to lower employment. Also, the real interest rate surges after the shock as the monetary authority attempts to control inflation. However, as the use of imported inputs surges, the marginal product of labor increases, which tends to raise hiring. Based on our baseline calibration, the effect of the marginal revenue product of labor channel dominates the effect of the marginal rate of substitution channel and the real interest rate channel, unemployment falls as a result.

When the prices of imported consumption goods cannot respond instantly to changes in the nominal exchange rate ($\psi_{PF}=170, \psi_{PM}=0$), the consumption price index rises more. This causes a large increase in domestic interest rates as the monetary authority tries to stabilize inflation. The rise in domestic rates attracts foreign capital inflow and triggers a stronger exchange rate appreciation, which dampens the response of output. Moreover, as Figure 2 shows, delayed pass-through to imported goods prices mitigates the response of the gap between the marginal revenue product of labor and the marginal rate of substitution. As a result, the impact of a foreign demand shock on unemployment is reduced.

With limited exchange rate pass-through to the imported inputs prices ($\psi_{PF}=0, \psi_{PM}=170$), the impact of a foreign demand shock on imported inputs becomes milder. However, the effects on other selected macroeconomic variables remain almost the same. This is due to the fact that, in the current model, domestic goods are produced with labor and imported inputs. The degree of exchange rate pass-through to imported inputs prices will affect the marginal cost of domestic goods and, in turn, the price and the demand for domestic consumption goods. However, given that the price of domestic goods is sticky, the effect of incomplete pass through to imported inputs prices becomes insignificant.

Welfare Evaluation

To understand the implication of incomplete exchange rate pass-through for the desirability for flexible exchange rate regime, I now examine the welfare performance of different types of exchange rate pass-through. The welfare is measured by the conditional expected lifetime utility of the representative household. Following Schmitt-Grohe and Uribe (2004), the conditional expected utility is obtained by a second-order approximation to the model.[7] To measure the degree of welfare differences across different exchange rate pass-through specifications, I follow Shi and Xu (2010) and compute the fraction of steady-state consumption, denoted by Θ, that the household needs to have in order to obtain the same expected conditional utility under regime k. More specifically, Θ is defined implicitly as

$$\frac{\log(1+\Theta)C - \chi N}{1-\beta} = EU_k$$

where C and N represent the steady-state values of aggregate consumption and employment respectively. EU_k is the conditional expected utility under specification k.

Table 2 displays the result. The table shows that, compared with the case of full exchange rate pass-through, delayed pass-through to consumption goods prices reduces welfare by about 0.07% in terms of steady state consumption. On the other hand, incomplete pass-through to imported inputs prices lowers the steady-state

consumption by 0.16%. This implies that delayed pass-through to imported inputs prices generates more welfare losses than incomplete pass through to imported goods prices. In fact, this result is consistent with Shi and Xu (2010).

Moments of Selected Variables

Table 3 displays the means and the standard deviations of the selected variables under different exchange rate pass-through environments. As the table shows, when exchange rate pass through to imported goods prices is delayed, the volatility of unemployment drops, but the volatility of consumption becomes higher. Compared with the case of full pass-through, delayed pass through to imported inputs prices lowers the mean of unemployment and consumption. The result shows that the welfare loss under incomplete pass-through to imported goods prices is mainly due to an increase in consumption volatility. And the welfare loss under incomplete pass-through to import inputs prices mainly comes from an increase in the mean of employment and a decrease in the mean of consumption.

4. Sensitivity Analysis

Thus far, we learn from the previous analysis that incomplete exchange rate pass-through to imported goods prices has a larger impact on the model's dynamics than incomplete pass-through to imported inputs prices. And incomplete exchange rate pass-through dampens the response of unemployment. It is natural to ask whether these results are sensitive to the nature of the shock that is disturbing the economy. In this subsection, I check the robustness of our findings by assuming that the model economy is disturbed by foreign interest rate shocks instead of foreign demand shocks. Unlike foreign demand shocks, which affect the real demand for exports, foreign interest rate shocks change the relative price of current consumption to future consumption. I now assume that $\log(R_t^*)$ follows an AR(1) process with autoregressive coefficient ρ_r and variance σ_r^2. As in Uribe and Yue (2006), the first-order autocorrelation, ρ_r, and the standard deviation, σ_r, are calibrated to 0.83 and 0.007 respectively.

Figure 3 displays the impulse responses of selected variables to a positive foreign interest rate shock. The size of the shock is set to 25 basis points. In the case of complete exchange rate pass-through ($\psi_{PF}=0, \psi_{PM}=0$), an unexpected increase in the foreign interest rate lowers the aggregate consumption and output. Also, higher foreign rates initiate a nominal exchange rate depreciation. This causes exports to rise and imports to fall as the relative price of foreign goods to domestic goods surges.

As the price of imported goods increases, CPI inflation spikes after the shock due to high exchange rate pass-through. The inflation targeting rule implies that the monetary authority will raise domestic interest rates to fight inflation. This action will put more downward pressure on consumption. Thus, overall consumption precipitates sharply after the shock.

The marginal product of labor and the domestic price level both fall after the shock, as the demand for domestic goods falls. This will discourage firms from hiring. Moreover, the real interest rate surges after the shock as the monetary authority attempts to control inflation. However, these two effects are competing with a counteracting channel. As overall consumption plummets, the marginal rate of substitution between leisure and consumption drops significantly. The fall in the marginal rate of substitution results in a lower real wage rate and generates higher surplus from a match, which will encourage firms to hire. Under our baseline calibration, the latter effect dominates the former ones and unemployment falls after a positive foreign interest rate shock.

I now turn attention to the case of limited exchange pass-through to imported goods prices ($\psi_{PF}=170$, $\psi_{PM}=0$). The impacts of a foreign interest rate shock on output and consumption become milder when pass-through to imported goods prices is delayed. As Devereux et al. (2006) point out, with full exchange rate pass-through, stabilizing CPI inflation in the face of sticky domestic prices will restrain the movements in the nominal exchange rate, which will undermine the role of exchange rate in insulating the domestic economy from foreign shocks. On the other hand, with incomplete exchange rate pass-through to consumption goods prices, the nominal exchange rate can fully react to the shock, which mitigates the damage to domestic economy.

As the impacts of the shock on output and inflation become more subdued, the marginal revenue product of labor drops less and the real interest rate rises by a smaller amount. As Figure 4 shows, the gap between the

marginal revenue product of labor and the marginal rate of substitution becomes wider in this case. The incentives of hiring are higher and the unemployment rate falls by a larger amount. The result shows that, unlike in the case of foreign demand shocks, incomplete pass-through to imported goods prices amplifies the response of unemployment when the economy is disturbed by foreign interest rate shocks.

In the case of delayed pass-through to imported inputs prices ($\psi_{PF}=0$, $\psi_{PM}=170$), the figure shows that the responses of our selected variables remain mostly the same. The result indicates that incomplete pass-through to imported inputs prices has little effect on the model's dynamics, which is consistent with our previous analysis.

Table 4 displays the welfare result when the economy is driven by foreign interest rate shocks. Again, compared with the full pass-through case, incomplete pass through to imported inputs prices cause more welfare loss than incomplete pass through to imported goods prices.

Table 5 displays the mean and standard deviations of the selected variables. As the table shows, in the case of incomplete exchange rate pass through to imported goods prices, the volatility of unemployment rises. Moreover, the welfare loss under incomplete pass-through to imported inputs prices comes from an increase in employment mean. These results jibe with our previous findings.

5. Conclusion

In this paper, I investigate how the degree of exchange rate pass-through affects the impact of external shocks on unemployment and other labor market variables. This is of particular interest due to the important role of unemployment in monetary policy debates. I find that incomplete exchange rate pass-through to imported consumption goods prices has a larger effect on the response of unemployment than does incomplete pass-through to imported inputs prices. This is due to the fact that domestic goods are produced with labor and imported inputs in the current model. With sticky domestic prices, the degree of exchange rate pass-through to imported inputs only has marginal effect on the price and the demand for domestic consumption goods.

I also examine the welfare performance of different exchange rate pass-through specifications. I find that incomplete exchange rate pass-through to imported inputs prices generates higher welfare losses, which are measured in steady-state consumption, than incomplete pass-through to imported goods prices. The welfare loss is mainly due to an increase in the mean of employment and a decrease in the mean of consumption. Finally, the model shows that the effect of incomplete exchange rate pass-through on unemployment dynamics depends critically on the nature of the shock that is affecting the economy. In the face of a foreign demand shock, incomplete exchange rate pass-through mitigates the response of unemployment. On the other hand, delayed pass-through to import prices amplifies the impact of a foreign interest rate shock on unemployment.

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Table 1:
Calibrated Parameter Values

Description	Parameter	Value
Discount Factor	β	0.99
Worker's Bargaining Power	η	0.5
Matching Function Parameter	γ	0.5
Job Survival Rate	ρ	0.94
Elasticity of substitution	ν, ϕ	2/3
Elasticity of substitution between varities	λ	11
Export demand parameter	ξ	2/3
Weight on domestic goods	α	0.55
Weight on domestic inputs	ω	0.5
Probability of Filling a Vacancy	q	0.7
Price Adjustment Cost Parameter	ψ_{PD}	170

Table 2:
Welfare Comparison under Foreign Demand Shocks

	Conditional Welfare	Θ (%)	Change relative to Full Pass-Through
$\psi_{PF}= 0, \psi_{PM}= 0$	-91.9171	0.6996	0
$\psi_{PF}= 170, \psi_{PM}= 0$	-91.9943	0.6219	-0.0777
$\psi_{PF}= 0, \psi_{PM}= 170$	-92.0814	0.5343	-0.1653

Θ is the welfare gain in terms of steady state consumption.

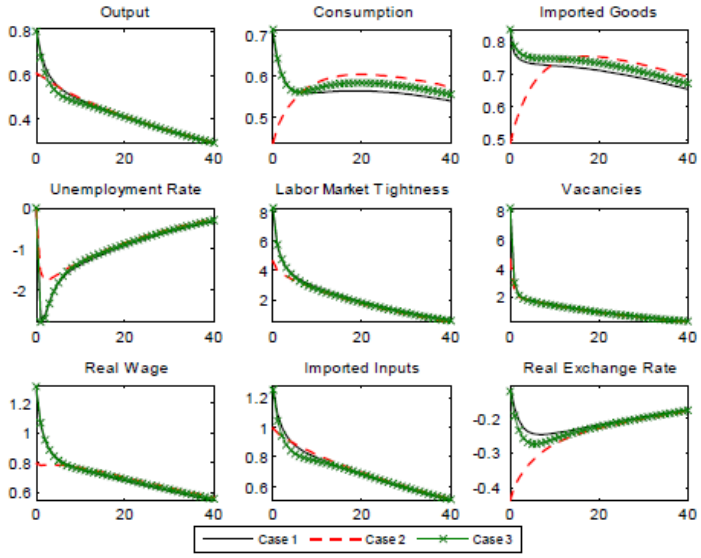

Figure 1: Impulse Response Functions to a Foreign Demand Shock. (Case 1: Full pass-through; Case 2: Delayed pass-through to imported goods prices, Case 3: Delayed pass-through to imported inputs prices)

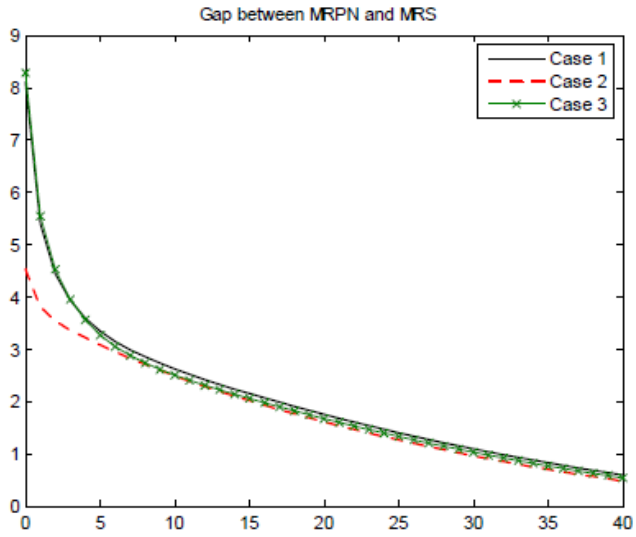

Figure 2: Response of the Gap between the Marginal Revenue Product of Labor and the Marginal Rate of Substitution to a Foreign Demand Shock. (Case 1: Full pass-through; Case 2: Delayed pass-through to imported goods prices, Case 3: Delayed pass-through to imported inputs prices)

Table 3:
Means and Standard Deviations under Foreign Demand Shocks

Description	$\psi_{PF}=0,$ $\psi_{PM}=0$	$\psi_{PF}=170,$ $\psi_{PM}=0$	$\psi_{PF}=0,$ $\psi_{PM}=170$
$E(Y_d)$	0.998	0.9988	0.9983
σ_{Y_d}	0.1178	0.1162	0.1163
$E(C)$	1.0073	1.0078	1.0061
σ_C	0.2048	0.2128	0.2097
$E(U)$	1.0343	1.032	1.0302
σ_U	0.2981	0.2609	0.2954
$E(s)$	0.9925	0.9927	0.9926
σ_s	0.0640	0.0726	0.0663

Table 4:
Welfare Comparison under Foreign Rate Shocks

	Conditional Welfare	Θ (%)	Change relative to Full Pass-Through
$\psi_{PF}=0, \psi_{PM}=0$	-92.6679	-0.0536	0
$\psi_{PF}=170, \psi_{PM}=0$	-92.6717	-0.0573	-0.0037
$\psi_{PF}=0, \psi_{PM}=170$	-92.7242	-0.1098	-0.0562

Θ is the welfare gain in terms of steady state consumption.

Table 5:
Means and Standard Deviations under Foreign Rate Shocks

Description	$\psi_{PF}=0,$ $\psi_{PM}=0$	$\psi_{PF}=170,$ $\psi_{PM}=0$	$\psi_{PF}=0,$ $\psi_{PM}=170$
$E(Y_d)$	1.0029	1.0027	1.0029
σ_{Y_d}	0.0123	0.0072	0.0113
$E(C)$	1.0239	1.0253	1.0240
σ_C	0.0626	0.0558	0.0625
$E(U)$	1.0431	1.0493	1.0430
σ_U	0.0684	0.0968	0.0676
$E(s)$	0.9956	0.9949	0.9954
σ_s	0.0071	0.0165	0.0085

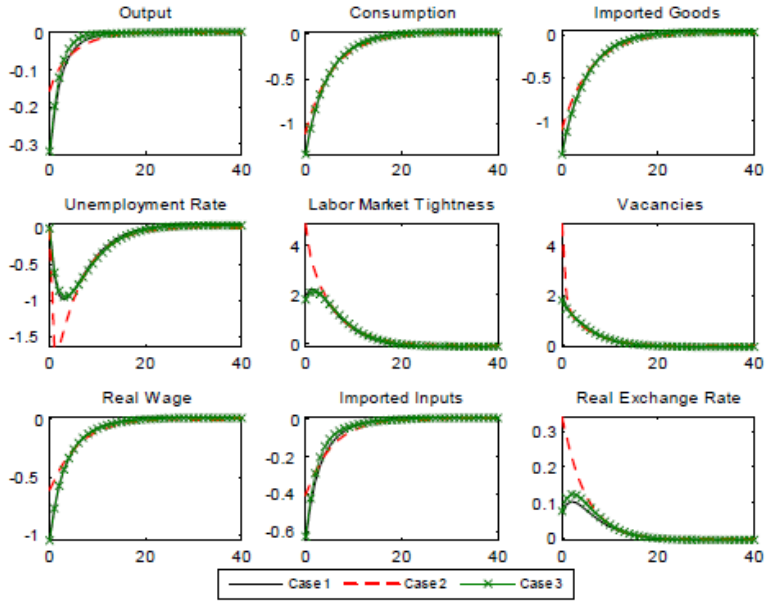

Figure 3: Impulse Response Functions to a Foreign Interest Rate Shock. (Case 1: Full pass-through; Case 2: Delayed pass-through to imported goods prices, Case 3: Delayed pass-through to imported inputs prices)

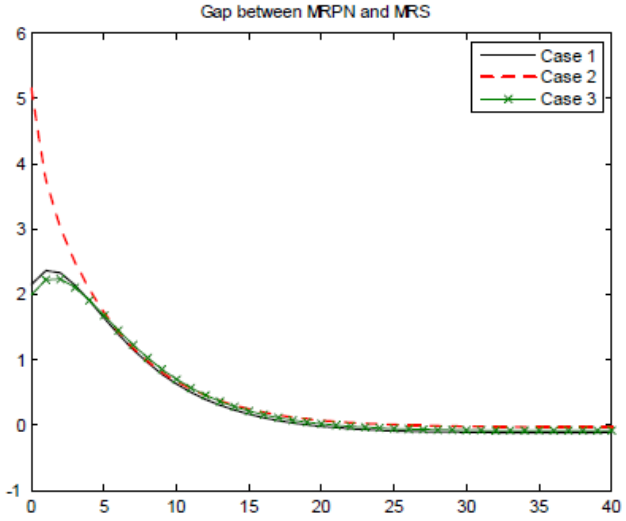

Figure 4: Response of the Gap between the Marginal Revenue Product of Labor and the Marginal Rate of Substitution to a Foreign Rate Shock. (Case 1: Full pass-through; Case 2: Delayed pass-through to imported goods prices, Case 3: Delayed pass-through to imported inputs prices)

Endnotes:
1. Also see Engel (2002), Corsetti and Pesenti (2005), Bacchetta and van Wincoop (2003) and Campa and Goldberg (2005).
2. See Shi and Xu (2010).
3. Introducing debt adjustment costs to the model can ensure that the model has a stationary distribution. See Schmitt-Grohe and Uribe (2003) for details.
4. Note that this Rotemberg pricing generates the same price dynamics as the standard Calvo pricing up to first order.
5. See Shimer (2004) and Monacelli et al. (2010).
6. Setting ψ_{PF} to 170 implies that the speed of price adjustment for foreign imports is equal to that of domestic goods.
7. The solution is obtained with Schmitt-Grohe and Uribe's MATLAB codes, which is available at http://www.columbia.edu/~mu2166/2nd_order.htm