Raw materials world price changes and exchange rates in a small open economy

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Abstract
This paper studies the impact of a rise in the world price of imported raw materials (oil) on the small open economy exchange rate. We obtain a depreciation which magnitude depends on the share and substitutability in the productive structure.
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1. Introduction

The recent rise in the world price of oil and its impact on exchange rates in importing countries points to the need for an explicit introduction of imported raw materials into the so-called “New Open Economy Macroeconomics” (NOEM) models. As is well-known, this new approach, pioneered by the Obstfeld and Rogoff’s (1995) Redux model (OR), is characterized by a certain nominal rigidity, explicitly defined micro-foundations and imperfect competition in an intertemporal framework.

The introduction of raw materials into the NOEM models is not completely new. For instance, Bergin and Feenstra (2000a,b) consider intermediate goods along with translog preferences in order to explain
endogenous persistence. On the other hand, in the models by McCallum and Nelson (1999, 2000), and Obstfeld (2001) only trade in raw materials is assumed. Finally, in Garcia-Cebro and Varela-Santamaria (2004), a vertical specialization structure is introduced in the two-country model.

In this paper, we introduce raw materials into the NOEM models in a different way. Our objective is to study the impact of an increase in the world price of raw materials on the exchange rate in a small open economy that imports those raw materials. To do this, we consider two-sector economy similar to that used in Obstfeld and Rogoff (1995) and Lane (1997): a monopolistically competitive nontraded-goods sector that uses labor as the only production input. On the other hand, the tradables sector is perfectly competitive. But, unlike these works, which assume an endowment of a constant quantity of the traded good, our model supposes endogenous traded output. This means that the implications of current account unbalances are taken into account. Also, and perhaps the most important difference, we assume that traded-goods firms use labor and imported raw materials as production inputs. This is a key aspect of our model as it allows us to analyze external supply shocks such as world raw materials price changes. In this framework, we find that the greater the share and/or the lower the substitutability, the bigger the impact of the rise in the world price of raw materials on exchange rate depreciation.

2. The model

We consider a small open economy populated by a continuum of households \( i \in [0,1] \). They provide labor inputs to firms allocated to two sectors: a monopolistically competitive nontraded-goods sector and a perfectly competitive tradables sector.\(^2\) The economy is integrated in the capital world market in which it can borrow and lend. The only traded assets are bonds denominated in terms of tradable goods.

2.1. Preferences and optimization of households

The utility function of the representative household is

\[
U = \sum_{s>t} v^{s-t} \left[ \log C_s + \chi \log \left( \frac{M_s}{P_s} \right) - kL_s \right]
\]

where \( C, \) defined below, is the consumption index, \( (M/P) \) are real balances, and \( kL \) is the disutility of work. Also, in (1), \( 0 < v < 1, \chi > 0, k > 0. \)

The representative household faces the following intertemporal budget constraint, expressed in nominal terms:

\[
P_tC_t + M_t + P_{T,t} B_t + T_t = W_{T,t} L_{T,t} + W_{N,t} L_{N,t} + \pi_{T,t} + \pi_{N,t} + M_{t-1} + P_{T,t-1} (1 + r_{t-1}) B_{t-1}
\]

where \( B \) are bonds, \( T \) taxes, \( L_T \) and \( L_N \) is labor employed, paying a nominal wage \( W_T \) and \( W_N \). Household also is recipient of residual profits in the two sectors, \( \pi_T \) and \( \pi_N. \) Since we assume free mobility of labor between sectors, \( W_{T,t} = W_{N,t} = W_t. \)

\(^1\) We assume that the reader is familiar with the “redux” model by Obstfeld and Rogoff (1995), and do not present the detailed steps leading to our results for brevity.

\(^2\) Throughout the paper, we shall denote the nontradables and tradables sectors’ variables with subscripts “\(N\)” and “\(T\),” respectively. Also, the whole economy variables will bear neither subscript “\(N\)” nor “\(T\).”
The first-order conditions for the maximization of (1) subject to (2) are given by (3)–(5):

\[
\frac{P_{t+1}}{C_t} = \frac{v(1+r_t)}{C_{t+1}} \frac{P_{t+1}}{P_t} \quad (3)
\]

\[
\frac{M_t}{P_t} = \gamma C_t \frac{(1+r_t)P_{t+1}}{(1+r_t)P_{t+1} - P_t} \quad (4)
\]

\[
\frac{W_t}{P_tC_t} = k \quad (5)
\]

In Eqs. (3)–(5) the composite consumption and price indexes are, in a Cobb–Douglas structure, given by

\[
C = C_T^\gamma C_N^{1-\gamma} \quad (6)
\]

\[
P = \frac{P_T^\gamma P_N^{1-\gamma}}{\gamma^\theta (1-\gamma)^{1-\gamma}} \quad (7)
\]

In (6) and (7), \(\gamma\) and \(1-\gamma\) are the share of traded goods and nontraded goods in the composite indexes, respectively. Also, \(C_N\), \(P_N\) and \(P_T\) are given by

\[
C_N = \left[ \int_0^1 C_N(i,z)^{\frac{\theta+1}{\theta}} \, dz \right]^{\frac{\theta}{\theta+1}} \quad (8)
\]

\[
P_N = \left[ \int_0^1 P_N(z)^{1-\theta} \, dz \right]^{\frac{1}{1-\theta}} \quad (9)
\]

\[
P_T = EP_T^* \quad (10)
\]

where \(\theta > 1\). In (8), \(C_N(i,z)\) is denoting household \(i\)'s consumption of nontraded good \(z\), which price is \(P_N(z)\). Eq. (10) shows the domestic nominal price of the traded good which is determined by the exogenous and constant international price \(P_T^*\), and the nominal exchange rate \(E\), defined as the home-currency price of foreign currency.

On the other hand, the allocation of consumption across nontraded and traded goods is derived in the usual way and the results are:

\[
C_T = \gamma \frac{PC}{P_T} \quad (11)
\]
\[ C_N = (1 - \gamma) \frac{PC}{P_N} \]  

(12)

2.2. Firms

In the tradables sector, we assume that firms, with a CES production technology with decreasing returns to scale, use home labor and imported raw materials to produce final traded goods:

\[ Y_T(z) = \left[ \delta L_T(z) + (1 - \delta) I(z) \right]^{\frac{1}{1-\sigma}} \]  

(13)

where \( \delta \) and \( 1 - \delta \) are, respectively, the share of home labor, \( L_T \), and imported raw materials, \( I \), with elasticity of substitution between them given by \( 0 < \sigma < 1 \), and \( 0 < \beta < 1 \) is the corresponding parameter of returns to scale.\(^3\) In (13), \( L_T \) is given by

\[ L_T(z) = \int_0^1 L_T(i, z) \, di = L_T(i, z) = L_T(i) \]  

(14)

Hence, the cost function for the competitive firm is given by

\[ C_S = W L_T(z) + P_T I(z) \]  

(15)

where \( P_T \) is the home price of imported raw materials.

The first-order condition for the optimization problem, which is derived by minimization of (15) subject to (13), yields:

\[ Y_T = (\beta P_T)^{\beta/(1-\beta)} \left[ \delta^{1-\sigma} W^{1-\sigma} + (1 - \delta)^{1-\sigma} P_T^{1-\sigma} \right]^{-\beta/(1-\beta)(1-\sigma)} \]  

(16)

In the nontradables sector, monopolistically competitive, firms use home labor as the only production factor to produce nontraded goods:

\[ Y_N(z) = \alpha L_N(z) \]  

(17)

where \( \alpha \) is a parameter and \( L_N(z) = \int_0^1 L_N(i, z) \, di = L_N(i, z) = \int_0^1 L_N(i, z) \, dz = L_N(i) \).

The representative firm faces the demand function of product \( z \) given by

\[ y^d_N(z) = \left[ \frac{P_N(z)}{P_N} \right]^{-\theta} C_N \]  

(18)

\(^3\) We require \( \beta < 1 \) (decreasing returns to scale) to ensure an equilibrium in the tradables sector. Also, because we think about “materials” as energy (oil), throughout the paper, we shall assume that \( \sigma < 1 \). This probably is the empirically relevant case. In fact, in the calibration of their model, McCallum and Nelson (1999, 2000), assume \( \sigma = 0.33 \).
Hence, the profit function is
\[ \pi_N(z) = P_N(z)Y_N(z) - WL_N(z) \]  
(19)

By maximizing (19) subject to (17) and (18), we obtain the prices set by firms in the nontradables sector:
\[ P_N(z) = \left( \frac{\theta}{\theta - 1} \right) \frac{W}{x} \]  
(20)

2.3. Government budget and foreign constraints

By assuming that there is no government spending, we have that
\[ M_t - M_{t-1} + T_t = 0 \]  
(21)

On the other hand, introducing (21) in (2), taking into account that \( P_{T,t}Y_{T,t} = \pi_{T,t} + W_{T,t}L_{T,t} + P_{I,t}I_{T,t} \) and \( P_{N,t}Y_{N,t} = \pi_{N,t} + W_{N,t}L_{N,t} \), we derive the foreign constraint for this small open economy:
\[ B_t - B_{t-1} = r_{t-1}B_{t-1} + Y_{T,t} - R_tI_t + g_tY_{N,t} - (P_t/P_{T,t})C_t \]  
(22)

where
\[ R_t = (P_{I,t}/P_{T,t}) \] and \( g_t = (P_{N,t}/P_{T,t}) \)

3. Steady state

Denoting the steady-state variables by an upper bar, the intertemporal budget constraint requires that
\[ \bar{C}_T = \bar{Y}_T - \bar{R}\bar{I} + \bar{r}\bar{B} \]  
(23)

Furthermore, it must be verified that
\[ \bar{C}_N = \bar{Y}_N \]  
(24)

In the initial steady state we assume that \( \bar{B}_0 = 0 \). Also, in order to obtain a closed-form solution for this particular steady state, we shall assume that \( \bar{L}_{T0} = \bar{Y}^{1/\beta}_{T0} \). So, from (11), (12), (16) and (20), we obtain
\[ g = \frac{\bar{P}_{N0}}{\bar{P}_{T0}} = \frac{\theta}{\theta - 1} \frac{\delta\beta}{\alpha} \frac{1}{\bar{Y}^{(1-\beta)/\beta}_{T0}} \]  
(25)

\[ \bar{R}_0 = \beta(1 - \delta) \bar{Y}^{(1-\beta)/\beta}_{T0} \]  
(26)

\[ \bar{Y}_{N0}^{1/\beta} = \frac{1 - \beta + \delta\beta \alpha(1 - \gamma)(\theta - 1)}{\delta\beta \gamma \theta} \]  
(27)
4. Results: short run and long run

As is standard in literature, we consider the short run as a period in which there is some type of nominal rigidity. Specifically, following Hau (2000) and others, we assume wage rigidity such that wages are set for period \( t \) (the short run), and can be adjusted only at period \( t+1 \). From period \( t+1 \) on, the economy reaches a new steady state that we refer to as the long run. We linearize the equations around the initial steady state, denoting by hats percentage deviations from that steady state; thus, for any variable \( X \), \( \hat{X} = \frac{dX}{X_0} \) and \( \hat{X} = \frac{dX}{X_0} \) will denote the short-run and long-run deviations, respectively. The only exception is bond holdings, which is given by \( \hat{B} = \frac{dB}{YT_0} \). This means that, in the short run, we have that

\[
\hat{W} = 0
\] (28)

Also, while in the long-run current account is balanced, in the short run the change in net foreign assets is given by

\[
B_t = Y_{Tt} - R_{It} - C_{Tt}
\] (29)

By linearizing Eqs. (3) and (4), we obtain that the money-market equilibrium requires that the exchange rate jumps immediately from the short run to the long run in a such a way that

\[
\hat{E} = \hat{E}
\] (30)

Moreover, introducing the linearized Eqs. of (7) and (10) into the linearized equation of (4), taking into account (20), (28) and (30), we obtain:

\[
\gamma \hat{E} = - \hat{C}
\] (31)

Eq. (31) shows the so-called MM framework in the Redux model; that is, the combinations of exchange rate changes and consumption changes in the short run which clear the money market.

On the other hand, from the linearization of Eqs. (6), (7), (10)–(12), (16), (20) and (22), taking into account (25)–(28), (30) and the first-order condition in the minimization of (15), we may write:

\[
\hat{p} = (1 - \delta)\beta(\delta \sigma^{-1} - 1) \hat{R} + \left[\delta^2 \beta(1 - \beta)^{-1} + (1 - \delta) \beta \delta \sigma\right]
\]

\[
+ (1 - \beta + \delta \beta)(1 - \gamma) \hat{E} - (1 - \beta + \delta \beta) \hat{C}
\] (32)

Finally, combining the linearization of Eqs. (5)–(7), (10), (12), (13), (16), (17), (20), (23) and (24) along with (32), we have:

\[
\hat{E} = \frac{\hat{p}(1 - \delta)(\bar{r} + 1)}{\bar{r} \psi_1 + \psi_2} \hat{R} + \frac{\bar{r} \psi_3 + \psi_4}{\bar{r} \psi_1 + \psi_2} \hat{C}
\] (33)

where \( \hat{R} (>0) \) is representing a shock derived from a change (rise) in the world price of imported raw materials and \( \psi_1, \psi_2, \psi_3, \) and \( \psi_4 \) are positive coefficients to structural parameters of the model such as \( \delta \).
and $\sigma$, among others. Eq. (33) shows the so-called GG schedule in the Redux model; that is, the combinations of exchange rate and short-run consumption changes which clear factor and product markets, fulfilling the intertemporal budget constraint.

The solving of the model for the effect of a rise in the world price of imported raw materials ($\hat{R}$) on exchange rate is obtained from (31) and (33):

$$
\hat{E} = \beta(1 - \delta) \frac{\delta + (1 - \beta)(1 - \delta\sigma)}{(1 - \beta)(1 - \beta + \delta\beta(1 + \sigma)) + \delta^2\beta(1 - \sigma + \sigma\beta)} \hat{R}
$$

(34)

The graphical solution is given at point A in Fig. 1.

As we can see, in both Eq. (34) and Fig. 1, the rise in the world price of imported raw materials (oil) depreciates the currency of the small open economy ($\hat{E} > 0$). Moreover, we find that the greater the share of imported raw materials and/or the lower its substitutability, the larger the depreciation. The intuition of this outcome is as follows: when $\hat{R} > 0$, as one can derive from the linearization of (16), it reduces short-run output in the tradables sector, which leads to a decrease in income. Lower income translates into smaller consumption. In the money market, this in turn brings about a decrease in the money demand which, in order to clear the market, requires an increase in the exchange rate. The depreciation is greater (smaller) provided the share of imported raw materials is high (low) because the fall in traded output, income and consumption would be greater (smaller). This would require a greater (lower) rise in the exchange rate in the money market. Substitutability of imported raw materials by home labor works in a similar way. This is corroborated in (34) where one can obtain that $\partial(\hat{E}/\hat{R})/\partial\delta < 0$ and $\partial(\hat{E}/\hat{R})/\partial\sigma < 0$.

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References