

PRODUCTION INTERDEPENDENCE AND WELFARE

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Abstract

The international welfare effects of a country's monetary policy shocks have been controversial in the literature. While a unilateral monetary expansion increases the production efficiency in each country, it affects terms of trade in favor of one country against another depending on the currencies of price setting. We show that the increased world production interdependence magnifies the efficiency-improvement effect while dampening the terms-of-trade effect. As a consequence, a unilateral monetary expansion can be mutually beneficial and thus Pareto improving regardless of in which currency unit prices are set. In this sense, international monetary policy transmission may not be a source of potential conflict in a world with production interdependence.

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1 Introduction

The welfare consequence of international monetary policy transmission has long concerned economists and policymakers. In a world with international trade linkages for goods and assets, how a country's monetary policy surprises affect its own and trading partners' wellbeing is crucial to the stability of the international monetary system. For instance, since the breakdown of the Bretton Woods system, concerns over competitive devaluations have been an important topic in academic writings and popular presses, and have motivated designs of international monetary institutions and rules to prevent countries from adopting "beggar-thy-neighbor" policies or engaging in a devaluation spiral. It is often argued that currency devaluation following a unilateral monetary expansion may benefit the source country at the cost of trading partners.

Do countries' monetary policy expansions necessarily have negative international welfare spillover effects? In the earlier literature, discussions on such issues have usually been based upon the classical Mundell-Fleming-Dornbusch model, which, however, is not built on explicit micro-foundations and thus fails to provide a consistent welfare metric for policy analysis. Welfare analysis in this literature typically rests upon ad-hoc objective functions.¹

The new open-economy macroeconomic models pioneered by Obstfeld and Rogoff (1995) emphasize the roles of monopolistic distortions and nominal rigidities with explicit micro-foundations. These models provide a sound theoretical apparatus that is apt at carrying out welfare analysis — the utility function of a country's representative household serves as a natural measure for the country's welfare. However, controversial welfare results have been obtained in this class of models, depending on whether price contracts are set in sellers' or buyers' currency unit. While a unilateral monetary expansion helps alleviate monopolistic distortions so as to raise output to a more efficient level in each country, it affects terms of trade in favor of one country and against another depending on the currencies of price setting.

If prices are set in sellers' currency unit, then a unilateral monetary expansion weakens the source (home) country's terms of trade, causing international expenditure switching to its goods. The worsened terms of trade reduce the home country's purchasing power, and the expenditure switching forces its households to work harder. Depending on parameter values, the efficiency-improvement effect may or may not outweigh the terms-of-trade effect, so that the home country's welfare may rise [e.g., Obstfeld and Rogoff (1995)] or fall [e.g., Corsetti and Pesenti (2000)]. The foreign country's welfare necessarily improves since both effects work to its favor. In contrast, if prices are set in buyers' currency unit, then the home monetary expansion, while generating two effects both in favor of the home country, worsens the foreign country's terms of trade, causing

international expenditure switching to foreign goods, so that foreign real purchasing power declines and its households have to work harder to meet the higher demand for its goods. Under plausible parameter values, the terms-of-trade effect tends to dominate the efficiency-improvement effect, so the foreign's welfare falls [e.g., Betts and Devereux (2000)]. In other words, under buyers' local currency pricing, monetary policy can be a beggar-thy-neighbor instrument.²

These controversial welfare results present an issue of concern for monetary policy making in an increasingly globalized world economy. If sellers' local currency pricing behavior better captures reality, then a country's attempt to close its domestic output gap through creating monetary surprises may end up hurting itself since the improvement in production efficiency can be more than offset by the deterioration of its terms of trade. The terms-of-trade consideration may thus provide a useful commitment device to discourage a benevolent central bank from trying to create surprise inflation. By contrast, if buyers' local currency pricing is an empirically more relevant phenomenon, then a country would be tempted to engineer surprise devaluations to close its own output gap while "free-riding" on trading partners. This raises the possibility of "competitive devaluation," a concern shared by the traditional Mundell-Fleming-Dornbusch model. Since in reality both sellers' and buyers' local currency pricing behaviors are present [e.g., Obstfeld and Rogoff (2000) and Goldberg and Knetter (1997)], any policy recommendations emanating from this literature must be highly qualified.

In this paper, we propose to resolve this controversy by incorporating an empirically relevant feature into an otherwise standard new open-economy macroeconomic model. Specifically, we maintain that countries can trade not only finished goods but also intermediate goods produced at various stages of processing. Such a chain structure of production and trade has been of rising importance in modern world trade [e.g., Feenstra (1998), Hummels, et al. (2001), and Yi (2003)], and yet remarkably overlooked in the new open-economy macroeconomic literature. We show that this increased world production interdependence magnifies the efficiency-improvement effect while dampening the terms-of-trade effect. As a consequence, a unilateral monetary expansion can be mutually beneficial and thus Pareto improving regardless of the currencies of price setting.

Production interdependence in the form of multiple stages of processing and trade magnifies the efficiency-improvement effect for two reasons. First, with monopolistic distortions at each stage of processing, there is a greater degree of production inefficiency to be improved upon along a longer processing chain. Second, given staggered price-setting, material costs and firms' marginal costs rise less in the home currency unit and (due to home currency devaluation) fall more in the foreign currency unit at a more advanced processing stage. Thus firms at a later processing stage would raise their prices set in the home currency unit by less and lower their

prices set in the foreign currency unit by more. With a greater number of processing stages, the rise in the home price level becomes more sluggish and the fall in the foreign price level becomes more pronounced, so that real aggregate demand and consumption rise by more in each country.

That said, to produce more consumption goods requires more labor along with more material inputs, which seems to render the welfare effects potentially ambiguous. Such a concern is, however, not substantiated. As production and trade move from less to more advanced processing stages, the patterns in the price adjustments across different stages make material inputs increasingly cheaper than labor, and firms would have stronger incentives to substitute away from labor toward material inputs. As a result, aggregate employment would not rise monotonically with the number of processing stages. With a larger number of processing stages, households can enjoy more consumption without necessarily working harder, while the terms-of-trade effect becomes relatively less important. In consequence, the unilateral monetary expansion tends to benefit both countries, regardless of whether prices are set in sellers' or buyers' local currency unit. In this sense, international monetary policy transmission may not be a source of potential conflict in a world with production interdependence.

The rest of the paper is organized as follows. Section 2 sets up the model. Section 3 illustrates the controversy of the welfare results in the literature, based on a degenerate version of the model with a single stage of processing. Section 4 presents the main results in the model with multiple stages of production and trade and shows that it may help resolve the controversy. Section 5 concludes. We focus on explaining intuitions in the main text and relegate analytical results and proofs to the Appendix.

2 A Model with Multiple Stages of Production and Trade

Consider a discrete-time, two-country world economy, with a home country and a foreign country. Each country is populated by an infinitely-lived representative household. Each household derives utility from consumption of finished goods, real money balances, and leisure. Production of consumption goods in each country needs to go through $N \geq 1$ stages of processing. In particular, production of finished goods requires labor supplied by domestic households and intermediate inputs supplied by domestic and foreign producers. Production of intermediate goods requires labor and less processed intermediate inputs supplied by domestic and foreign firms, and so on. Production of raw materials requires only domestic labor input. At each processing stage, there is a continuum of firms indexed in the interval $[0, 1]$, each producing a differentiated good. Labor market is perfectly competitive and goods markets are monopolistically competitive. Firms at each

processing stage set prices in a staggered fashion in the spirit of Taylor (1980). While all goods are tradable, labor is immobile across countries. The households have access to a complete set of state-contingent nominal bonds denominated in the home currency unit.³ Figure 1 illustrates the production and trading structure of this world economy.

2.1 Preferences and Technologies

Given the symmetry between the two countries, we focus on presenting the economic environment in the home country. The representative household in the home country has a utility function

$$\mathbb{E} \sum_{t=0}^{\infty} \beta^t \left[\ln C_t + \Psi \ln \left(\frac{M_t}{\bar{P}_{Nt}} \right) - \kappa L_t \right], \quad (1)$$

where C_t denotes consumption, M_t/\bar{P}_{Nt} denotes real money balances, L_t denotes labor supply, $\beta \in (0, 1)$ is a subjective discount factor, and \mathbb{E} is an expectation operator. Note that the linearity of the period utility function in labor hours is a consequence of aggregation when labor is assumed to be indivisible and such a utility function is consistent with any labor supply elasticity at the *individual* level.

The household faces a sequence of budget constraints

$$\bar{P}_{Nt} C_t + E_t D_{t,t+1} B_{t+1} + M_t \leq W_t L_t + \Pi_t + B_t + M_{t-1} + T_t, \quad (2)$$

where B_{t+1} is a state-contingent bond, $D_{t,t+1}$ is the price of the bond, W_t is the nominal wage rate, and T_t is a lump-sum transfer from the domestic government.

The consumption good is a composite of final goods produced at stage N by domestic as well as foreign producers. The consumption basket is given by

$$C_t = \left[\gamma^{\frac{1}{\eta}} \bar{Y}_{NHt}^{\frac{\eta-1}{\eta}} + (1-\gamma)^{\frac{1}{\eta}} \bar{Y}_{NFt}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \quad (3)$$

where $\bar{Y}_{NH} = \left(\int_0^1 Y_{NH}(i)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}$ denotes a composite of domestically produced final goods and $\bar{Y}_{NF} = \left(\int_0^1 Y_F(i)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}$ is a composite of imported final goods. The parameter θ measures the elasticity of substitution between differentiated goods produced within a country; while η is the elasticity of substitution between goods produced in different countries. Given θ and η , the parameter $1 - \gamma$ determines the steady-state ratio of imports to domestic output. To ensure existence of equilibrium under monopolistic competition, we assume that $\theta > 1$.

The household maximizes utility subject to (2)-(3) and a borrowing constraint $B_t \geq -\bar{B}$ for some large positive number \bar{B} , for each $t \geq 0$, with initial conditions M_{-1} and B_0 given. From the first order conditions, we obtain demand functions for a type i finished good produced in the

two countries:

$$Y_{NHt}^d(i) = \gamma \left[\frac{P_{NHt}(i)}{\bar{P}_{NHt}} \right]^{-\theta} \left[\frac{\bar{P}_{NHt}}{\bar{P}_{Nt}} \right]^{-\eta} C_t, \quad (4)$$

$$Y_{NFt}^d(i) = (1 - \gamma) \left[\frac{P_{NFt}(i)}{\bar{P}_{NFt}} \right]^{-\theta} \left[\frac{\bar{P}_{NFt}}{\bar{P}_{Nt}} \right]^{-\eta} C_t, \quad (5)$$

where $\bar{P}_{NH} = \left(\int_0^1 P_{NH}(i)^{1-\theta} di \right)^{\frac{1}{1-\theta}}$ is a price index of stage- N goods produced and used in the home country, and $\bar{P}_{NF} = \left(\int_0^1 P_{NF}(i)^{1-\theta} di \right)^{\frac{1}{1-\theta}}$ a price index of stage- N goods made in the foreign country and sold to the home country. The overall price level in the home country is an average of the two, that is,

$$\bar{P}_{Nt} = \left[\gamma \bar{P}_{NHt}^{1-\eta} + (1 - \gamma) \bar{P}_{NFt}^{1-\eta} \right]^{\frac{1}{1-\eta}}. \quad (6)$$

To produce a final good requires primary factors (i.e., labor in this model) and intermediate goods produced at stage $N - 1$ (by domestic as well as foreign producers); to produce a stage- $(N-1)$ intermediate good requires primary factors and less-processed intermediate goods produced at stage $N - 2$; and so on. In general, the production function for a firm $i \in [0, 1]$ at stage $n \in \{2, \dots, N\}$ is given by

$$Y_{nt}(i) = \bar{Y}_{n-1,t}(i)^\phi L_{nt}(i)^{1-\phi}, \quad (7)$$

where $L_n(i)$ is the labor input and $\bar{Y}_{n-1}(i) = \left[\gamma^{\frac{1}{\eta}} \bar{Y}_{n-1,H}^{\frac{\eta-1}{\eta}} + (1 - \gamma)^{\frac{1}{\eta}} \bar{Y}_{n-1,F}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$ is the intermediate input supplied by firms at stage $n - 1$, consisting of home produced goods $\bar{Y}_{n-1,H} = \left[\int_0^1 Y_{n-1,H}(i)^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}$ and imported goods $\bar{Y}_{n-1,F} = \left[\int_0^1 Y_{n-1,F}(i)^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}$. The output is either sold in the home market or exported to the foreign market so that $Y_n(i) = Y_{nH}(i) + Y_{nH}^*(i)$. The production of raw materials at stage $n = 1$ requires only labor input, with a linear production function given by $Y_1(i) = L_1(i)$, where the output is either sold to the home market or exported so that $Y_1(i) = Y_{1H}(i) + Y_{1H}^*(i)$.

2.2 Optimal Price-Setting Rules

Firms are as monopolistic competitors in output markets and price-takers in input markets. To generate real effects of monetary policy shocks, we assume that, in each country, pricing decisions at each processing stage are staggered. In particular, in each period, a fraction $1/2$ of home producers at a given stage $n \in \{1, \dots, N\}$ can adjust prices. Once a new price is set, it remains in effect for 2 periods. We sort the indices of firms at each stage so that those indexed by $i \in [0, 1/2]$ set prices in even periods of time and those indexed by $i \in (1/2, 1]$ set prices in odd periods.

We consider the welfare implications of our model under two alternative pricing policies. In one scenario, prices are rigid in sellers' local currency, so that changes in nominal exchange rate would

be completely passed through; in the other scenario, prices are rigid in buyers' local currency, and exchange rate pass-through might be incomplete.

2.2.1 Sellers' Local Currency Pricing

We now derive the optimal pricing decisions when prices are set in sellers' local currency. In this case, the law of one price (LOOP) holds not only for each individual type of goods, but also for the composite goods produced at each stage. Denote by \mathcal{E}_t the nominal exchange rate (measured by home currency units per unit of foreign currency). Then the LOOP implies that

$$\bar{P}_{nHt} = \mathcal{E}_t \bar{P}_{nHt}^*, \quad \bar{P}_{nFt} = \mathcal{E}_t \bar{P}_{nFt}^*, \quad (8)$$

for all $n \in \{1, \dots, N\}$, where \bar{P}_{nHt} and \bar{P}_{nFt} denote the home price indices of goods produced by home firms and by foreign firms, respectively, and \bar{P}_{nHt}^* and \bar{P}_{nFt}^* are the corresponding foreign price indices. It is worth noting that, since home goods and foreign goods are imperfect substitutes, the purchasing power parity in general fails to hold, that is, $\bar{P}_{nt} \neq \mathcal{E}_t \bar{P}_{nt}^*$ unless $\gamma = 1/2$, in which case, there is no steady-state home-bias.

If a home firm $i \in [0, 1]$ at stage $n \in \{1, \dots, N\}$ can set a new price, it chooses a price $P_{nHt}(i)$ to maximize the profit

$$\mathbf{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau} [P_{nHt}(i) - V_{n\tau}(i)] Y_{n\tau}^d(i), \quad (9)$$

taking the unit cost function $V_{n\tau}(i)$ and the demand function $Y_{n\tau}^d(i) = Y_{nH\tau}^d(i) + Y_{nF\tau}^{*d}(i)$ as given.

The unit cost for a firm at stage 1 is simply the nominal wage rate since labor is the only input at that stage. That is,

$$V_1(t) \equiv V_1(i, t) = W(t). \quad (10)$$

The unit cost for a firm at stage $n \geq 2$ is derived from minimizing the cost $\bar{P}_{n-1} \bar{Y}_{n-1} + W L_n$ subject to the production function (7), and is given by

$$V_n(t) \equiv V_n(i, t) = \tilde{\phi} \bar{P}_{n-1}(t)^\phi W(t)^{1-\phi}, \quad (11)$$

where $\tilde{\phi} = \phi^{-\phi} (1 - \phi)^{-(1-\phi)}$ is a constant and $\bar{P}_{n-1}(s^t)$ is the price index of all goods produced at stage $n - 1$. In particular, the price index of stage- n goods is given by

$$\bar{P}_{nt} = \left[\gamma \bar{P}_{nHt}^{1-\eta} + (1 - \gamma) \bar{P}_{nFt}^{1-\eta} \right]^{\frac{1}{1-\eta}}, \quad (12)$$

where $\bar{P}_{nH} = \left[\int_0^1 P_{nH}(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}}$ and $\bar{P}_{nF} = \left[\int_0^1 P_{nF}(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}}$ are the price indices of home goods and of imported goods, respectively.

The demand schedules resulting from cost-minimization are given by

$$Y_{nHt}^d(i) = \gamma \left(\frac{P_{nHt}(i)}{\bar{P}_{nHt}} \right)^{-\theta} \left(\frac{\bar{P}_{nHt}}{\bar{P}_{nt}} \right)^{-\eta} \left(\frac{\phi}{1-\phi} \right)^{1-\phi} \left(\frac{W_t}{\bar{P}_{nt}} \right)^{1-\phi} \int_0^1 Y_{n+1,t}(j) dj, \quad (13)$$

$$Y_{nFt}^d(i) = (1-\gamma) \left(\frac{P_{nFt}(i)}{\bar{P}_{nFt}} \right)^{-\theta} \left(\frac{\bar{P}_{nFt}}{\bar{P}_{nt}} \right)^{-\eta} \left(\frac{\phi}{1-\phi} \right)^{1-\phi} \left(\frac{W_t}{\bar{P}_{nt}} \right)^{1-\phi} \int_0^1 Y_{n+1,t}(j) dj, \quad (14)$$

where $n \in \{1, \dots, N-1\}$. Equation (13) says that the demand for a type i good produced at stage n will be higher if its price relative to the price index of all such goods is lower, if the price index of these goods relative to the overall price index of stage- n goods is lower, or if the cost of materials relative to the cost of labor is lower. The demand function in (14) can similarly be interpreted.

The solution to firm i 's profit maximization problem gives the optimal price setting rules

$$P_{nHt}(i) = \frac{\theta}{\theta-1} \frac{\text{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau} V_{n\tau} Y_{n\tau}^d(i)}{\text{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau} Y_{n\tau}^d(i)}, \quad (15)$$

where $n \in \{1, \dots, N\}$. The pricing rule in (15) says that the optimal price set by a home firm is a constant markup over a weighted average of the firm's two-period expected marginal costs. The weights are normalized quantities of demand for its products in the corresponding periods. Similarly, a foreign firm who can set a new price will set its price, $P_{nFt}^*(i)$, as a markup over a weighted average of its current and expected future marginal costs.

2.2.2 Buyers' Local Currency Pricing

We now consider the case where firms can price-discriminate markets in different countries and set prices in buyers' local currency. In this case, the law of one price in general does not hold. When a home firm i can set new prices, it chooses prices $P_{nHt}(i)$ for its products to be sold in the home market, and $P_{nHt}^*(i)$ for those to be exported, to maximize its two-period profit, taking the demand functions in each market as given. The firm's objective function is given by

$$\text{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau} \{ [P_{nHt}(i) - V_{n\tau}(i)] Y_{nH\tau}^d(i) + [\mathcal{E}_t P_{nHt}^*(i) - V_{n\tau}(i)] Y_{nH\tau}^{*d}(i) \}, \quad (16)$$

where $Y_{nH}^d(i)$ is the domestic demand for the firm's product given by (13), and $Y_{nH}^{*d}(i)$ is the foreign's demand for the firm's product, given by the foreign counterpart of (14).

The resulting optimal pricing decision rules are given by

$$P_{nHt}(i) = \frac{\theta}{\theta-1} \frac{\text{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau} V_{n\tau} Y_{nH\tau}^d(i)}{\text{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau} Y_{nH\tau}^d(i)}, \quad (17)$$

$$P_{nHt}^*(i) = \frac{\theta}{\theta-1} \frac{\text{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau} V_{n\tau} Y_{nH\tau}^{*d}(i)}{\text{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau} \mathcal{E}_\tau Y_{nH\tau}^{*d}(i)}, \quad (18)$$

where $n \in \{1, \dots, N\}$. The optimal pricing decisions by firms in the foreign country (i.e., the choices of $P_{nFt}^*(i)$ and $P_{nFt}(i)$) can similarly be derived.

2.3 Monetary Policy, Market Clearing, and Equilibrium

The monetary authority in each country injects newly created money through lump-sum transfers to the representative domestic household, so that

$$T_t = M_t - M_{t-1}, \quad T_t^* = M_t^* - M_{t-1}^*. \quad (19)$$

The stocks of money supply grow according to $M_t = \mu_t M_{t-1}$ and $M_t^* = \mu_t^* M_{t-1}^*$, where the money growth rates μ_t and μ_t^* follow stationary stochastic processes.

Labor market clearing requires that $\sum_{n=1}^N \int_0^1 L_{nt}^d(i) di = L_t$ and $\sum_{n=1}^N \int_0^1 L_{nt}^{*d}(i) di = L_t^*$. Bond market clearing implies that $B_t + B_t^* = 0$.

An *equilibrium* for this economy is a collection of allocations and prices such that (i) taking wages and prices as given, each household's allocations solve its utility maximization problem; (ii) taking wages and all prices but its own as given, each firm's allocations and prices solve its profit-maximization problem; (iii) markets for labor, money, and bonds clear; (iv) monetary policies are as specified.

In what follows, we focus on a symmetric equilibrium in which all firms in a given price-setting cohort make identical pricing decisions. In such an equilibrium, firms are identified by the country in which they operate, the stage on which they produce, and the time at which they can change prices. Thus, from now on, we drop the individual firm index i , and denote by, for example, $P_{nH}(t)$ the price set for the home market by a firm that operates in the home country, produces on stage n , and gets the chance to change its price at time t . We log-linearize the equilibrium conditions around a balanced-trade steady state and use lowercase letters to denote log-linearized variables. The log-linearized equilibrium conditions under sellers' local currency pricing (SLCP) and under buyers' local currency pricing (BLCP) are summarized in Tables 1 and 2, respectively. Since we are interested in the welfare consequence of international monetary policy interdependence, we shall focus on a perfect foresight equilibrium following a unilateral monetary expansion.

3 Single Stage of Processing: Ambiguous Welfare Results

In this section, we explain why the welfare consequence of a unilateral monetary expansion can be ambiguous when all production and trade occur at a single stage. This case corresponds to $N = 1$ in our model.

Consider a unilateral monetary policy expansion in the home country so that $m_t = 1$ and $m_t^* = 0$ for all t . We show in the Appendix that, following such a shock, home currency depreciates fully (i.e., $e_t = 1$ for all t), the nominal wage rate rises immediately in the home country but is

unaffected in the foreign country (i.e., $w_t = 1$ and $w_t^* = 0$ for all t), and nominal aggregate demand rises fully in the home country but remains unchanged in the foreign country (i.e., $\bar{p}_{Nt} + c_t = 1$ and $\bar{p}_{Nt}^* + c_t^* = 0$). These results obtain regardless of how many processing stages there are or in which currency prices are rigid, since they are derived from the households' optimizing behaviors. Yet, the real effects of money and therefore the welfare implications of the monetary expansion do depend on the number of processing stages and the currencies of price-setting.

3.1 Welfare Implications of Sellers' Local Currency Pricing (SLCP)

We first examine the case with sellers' local currency pricing. In this case, the optimal pricing equations in Table 1 imply that the adjustment of the prices set by home firms, p_{1Ht} , and by foreign firms, p_{1Ft}^* , are determined by the firms' marginal costs, which coincide with the domestic nominal wage rates. Given the patterns of nominal wage adjustments, home firms that can adjust prices will raise their prices fully, while foreign firms would choose to keep their prices unchanged (i.e., $p_{1Ht} = 1$ and $p_{1Ft}^* = 0$ for all t). Since half of the firms in each country cannot adjust prices, the price index of home produced goods does not rise fully until the end of the contract duration, and the price index of foreign made goods remains at the steady-state level. In particular, we have $\bar{p}_{1H0} = 1/2$, $\bar{p}_{1Ht} = 1$ for $t \geq 1$, and $\bar{p}_{1Ft}^* = 0$ for all $t \geq 0$.

Despite the unchanged price of foreign goods in the foreign currency unit, the price of imported goods facing the home household increases due to the home currency depreciation. The home price level thus rises, but does not rise fully until the end of the contract duration because of staggered pricing-setting. The foreign household faces a lowered price index of imported goods in the impact period since the prices of these goods are only partially adjusted in the home currency unit and the adjustment does not catch up with the home currency depreciation until the end of the contract duration. Given that the price index of foreign produced goods remains unchanged, the fall in the import price index in the foreign currency unit implies that the foreign price level has to fall.

Since nominal aggregate demand in the home country rises fully, while the price level rises only partially in the impact period, home consumption rises in that period, so do home real money balances. In particular, the price adjustment patterns imply that $c_0 = \gamma/2$ and $c_t = 0$ for all $t \geq 1$. In the foreign country, nominal aggregate demand remains unchanged while the price level falls in the impact period, so that consumption and real money balances rise on impact. It is easy to show that $c_0^* = (1 - \gamma)/2$ and $c_t^* = 0$ for all $t \geq 1$. Thus, the home monetary expansion tends to raise the welfare of both countries through raising each country's consumption and real money balances.

That said, in each country, the representative household's welfare depends not only on consumption and real balances, but also on labor effort. To obtain the responses of labor effort, we first integrate the demand for labor [i.e., $L_1(i) = Y_1(i)$ and $L_1^*(i) = Y_1^*(i)$] across firms within a country, and then use the goods demand functions (4)-(5) and their foreign counterparts (for $N = 1$) to relate each country's employment to world consumption and its own terms of trade. Specifically, the log-linearized employment under SLCP are given by

$$l_t = -2\eta\gamma(1-\gamma)\tau_{1t} + \gamma c_t + (1-\gamma)c_t^*, \quad (20)$$

$$l_t^* = -2\eta\gamma(1-\gamma)\tau_{1t}^* + \gamma c_t^* + (1-\gamma)c_t, \quad (21)$$

where $\tau_{1t} = \bar{p}_{1Ht} - \bar{p}_{1Ft} - e_t$ denotes the home country's terms of trade, and $\tau_{1t}^* = -\tau_{1t}$ is the foreign counterpart. It follows that a country's employment decreases with its terms of trade. As its terms of trade improve, a country's real purchasing power increases and the world demand for its products falls (through an expenditure-switching effect) so that its household could work less hard to support the same consumption allocation. For this reason, an improvement in a country's terms of trade tends to improve its welfare.

Following the home country's monetary expansion, the home currency depreciates, and under SLCP, its terms of trade are worsened. Specifically, the adjustments of nominal exchange rate and prices in the two countries imply that $\tau_{10} = -1/2$ and $\tau_{1t} = 0$ for all $t \geq 1$, which is to say that the home country's terms of trade are worsened until the end of the contract duration. This contributes to increasing the labor effort of the home household and reducing the effort of the foreign household. Thus, the terms-of-trade variation can potentially generate a "beggar-thy-self" effect, as emphasized by Corsetti and Pesenti (2000).

To make the welfare analysis more explicit, we define the welfare in a country as the present value of the life-time utility of its representative household. In the spirit of Lucas (1987), Cooley and Hansen (1989), and Betts and Devereux (2000), we use a consumption-equivalence measure as a welfare metric and we gauge the welfare gain in each country from the home monetary expansion by the percentage increase in its representative household's steady-state consumption that would make the household indifferent between the cases with and without the expansion. Specifically, the welfare gain in the home country is given by the percentage change in the home household's steady-state consumption, Δ , that solves the following equation

$$\sum_{t=0}^{\infty} \beta^t \left[\ln(C_t) + \Psi \ln\left(\frac{M_t}{P_{Nt}}\right) - \kappa L_t \right] = \sum_{t=0}^{\infty} \beta^t \left[\ln(C(1+\Delta)) + \Psi \ln\left(\frac{M}{P_N}\right) - \kappa L \right], \quad (22)$$

where the variables with time-subscripts denote the equilibrium values in the presence of the monetary expansion, and those without the subscripts denote the corresponding steady-state

values. In terms of log-linearized variables, the solution of Δ is given by⁴

$$\ln(1 + \Delta) = (1 - \beta) \sum_{t=0}^{\infty} \beta^t [(1 + \Psi) c_t - \kappa L l(t)], \quad (23)$$

The welfare gain in the foreign country is similarly computed.

In the special case with $N = 1$, we have $\kappa L = 1/\mu$, where $\mu = \theta/(\theta - 1)$ denotes the steady-state markup of price over marginal cost. Using the solutions of consumption, real balances, and labor efforts, we obtain closed-form expressions for the two countries' welfare gains as

$$\ln(1 + \Delta) = \frac{1 - \beta}{2} \left[\gamma(1 + \Psi) - \frac{1}{\mu}(1 + 2(\eta - 1)\gamma(1 - \gamma)) \right], \quad (24)$$

$$\ln(1 + \Delta^*) = \frac{1 - \beta}{2} [(1 - \gamma)(1 + \Psi) + 2(\eta - 1)\gamma(1 - \gamma)/\mu], \quad (25)$$

Thus, given that $0 < \beta < 1$, whether a country is better off or worse off depends on the parameters η , the elasticity of substitution between home goods and foreign goods; γ , the steady-state share of domestically produced goods in total output (so that $1 - \gamma$ measures the degree of openness); and μ , the steady-state markup by monopolistically competitive firms within each country.⁵

In light of (25), it is theoretically possible for the home monetary expansion to reduce the foreign country's welfare (for example, when γ is close to one and η close to zero). Yet, under empirically plausible parameter values, in particular, with $\eta \geq 1$ [e.g., Backus, et al. (1995)], the foreign country tends to gain from the home monetary expansion. In contrast, as in light of (24), the monetary expansion can reduce the home country's welfare for reasonable parameter values. For example, given $\eta \geq 1$, home welfare falls if $\gamma \leq 1/\mu$. Thus, the monetary expansion may have a "beggar-thy-self" effect for small values of γ and μ . Further, a larger value of η also tends to reduce the welfare. These results conform to the finding by Corsetti and Pesenti (2000), who assume a value of η equal to 1.⁶

The reason why the home monetary expansion may have a "beggar-thy-self" effect under SLCP is that, although the expansion raises home consumption and real money balances, it also leads to home currency depreciation and terms-of-trade deterioration, the latter of which tends to reduce its real purchasing power and to force its household to work harder to meet the increased world demand for its products. While the increased consumption and real money balances tend to raise the country's welfare, the increased labor efforts tend to reduce it. The fall in welfare becomes more likely, the larger the steady-state degree of openness (measured by $1 - \gamma$), the smaller the home firms' monopoly power (measured by μ), or the greater the elasticity of substitution between home goods and foreign goods (measured by η). The foreign country gains as long as $\eta \geq 1$ since the home monetary expansion not only raises foreign consumption and real money balances, it

also improves the foreign's terms of trade, and thus reduces the world demand for foreign goods, resulting in lowered demand for foreign labor effort.

3.2 Welfare Implications of Buyers' Local Currency Pricing (BLCP)

Under buyers' local currency pricing, a firm can charge different prices for its products sold in different countries. For the products to be sold in the domestic markets, firms' pricing decisions under BLCP are similar to those under SLCP. In particular, since the nominal wage rate in the home country rises fully following its monetary expansion, while foreign's nominal wage rate remains unchanged, home firms will accordingly raise the prices of their products to be sold in the home market while foreign firms will keep unchanged the prices of their products to be sold in the foreign market. For the products to be exported, however, the pricing decisions will depend on the exchange-rate adjusted marginal costs. With the home currency depreciation, firms in the two countries face an increased marginal cost in the home currency unit but unchanged marginal cost in the foreign currency unit. Thus, home firms would choose to keep unchanged the prices of their products to be exported, while foreign firms would choose to raise the prices of their products to be sold in the home market.

These price adjustment patterns, when coupled with staggered pricing decisions, imply that the home price level does not rise fully until the end of the contract duration, while the foreign price level remains unchanged all the time. Thus, home consumption and real money balances rise on impact and fall back to the steady state afterwards, while foreign consumption and real balances remain unchanged. Specifically, it is easy to show that, under BLCP, the responses of consumption during the impact period are $c_0 = 1/2$ and $c_0^* = 0$; and the responses of employment are $l_0 = \gamma/2$ and $l_0^* = (1 - \gamma)/2$. All real variables return to the steady state from period 1 onward. It follows that the two countries's welfare gains under BLCP are given by

$$\ln(1 + \Delta) = \frac{1}{2}(1 - \beta) \left[1 + \Psi - \frac{\gamma}{\mu} \right], \quad (26)$$

$$\ln(1 + \Delta^*) = -\frac{1}{2}(1 - \beta) \frac{1 - \gamma}{\mu}. \quad (27)$$

Clearly, with reasonable parameter values, the unilateral monetary expansion in the home country unambiguously raises its own welfare at the expense of the foreign country's and it is therefore a "beggar-thy-neighbor" instrument.

To understand this result, we note that, following the home country's monetary expansion, the foreign household faces worsened terms of trade. In particular, the foreign's terms of trade are given by $\tau_t^* = \bar{p}_{1Ft} - \bar{p}_{1Ht}^* - e_t$. Since the foreign's import price index \bar{p}_{1Ht}^* remains unchanged and the rise in the export price index \bar{p}_{1Ft} does not fully catch up with the home currency

depreciation due to staggered price-setting, the foreign's terms of trade tend to be deteriorated. The loss in the foreign country's real purchasing power offsets the gain in its labor income, so that its consumption remains unchanged. With unchanged consumption and increased labor effort, the foreign country's welfare falls. In contrast, the home country's welfare improves since the terms of trade work to its favor so that its household can afford to consume more without having to work too much harder.

3.3 Currencies of Price-Setting: Ambiguous Welfare Implications

The previous two subsections have illustrated that, if all production and trade occur at a single stage, then the welfare implications of a country's unilateral monetary expansion under sellers' local currency pricing are generally different from those under buyers' local currency pricing. Such difference is often an important source of the debate on issues such as "competitive devaluation." If sellers' local currency pricing better captures reality, then the model suggests that a country's attempt to close its domestic output gap through creating a unilateral monetary surprise may end up hurting its own welfare since the improvement in its production efficiency can be more than offset by the deterioration in its terms of trade. The terms-of-trade consideration may thus provide a useful commitment device to discourage a benevolent central bank from trying to create surprise inflation. By contrast, if buyers' local currency pricing is empirically more relevant, then a country would be tempted to engineer surprise devaluation to close its own output gap while "free-riding" on trading partners. This raises the possibility of "competitive devaluation," a concern shared by the traditional Mundell-Fleming-Dornbusch model.

Thus, were we to view the model with a single stage of processing and trade as an appropriate theoretical framework for welfare analysis in an open economy, the issue would boil down to an empirical question: Are price contracts set primarily in sellers' local currency or in buyers' local currency? As we have mentioned in the Introduction, the existing studies reveal that both types of local currency pricing are empirically significant phenomena. This suggests that whether a country's attempt to devalue its currency will have a "beggar-thy-self" or "beggar-thy-neighbor" effect may be rather ambiguous. However, as we will demonstrate below, when production and trade need to go through multiple stages, such ambiguity disappears.

4 Multiple Stages of Processing: Resolving the Ambiguity

As we have alluded to in the Introduction, one characteristic of modern globalization is the growing importance of international trade along a vertical chain with multiple stages of production. Such

interconnectedness between countries and industries has implications for the international welfare effects of monetary shocks, and as such, it may help resolve the ambiguity in the welfare results under different assumptions on the currencies of price-setting. We turn now to showing that this is indeed the case.

4.1 Some Intuitions

We start by providing some intuitions behind the transmission mechanism embodied in the production and trading chain. Our central idea is that, as production and trade are stretched over a larger number of processing stages, the home price level will rise by less while the foreign price level will *fall* by more, and over a longer period of time, resulting in a greater increase in real aggregate demand in both countries following the home monetary expansion. These patterns emerge in the adjustment of the price level and the response of real aggregate demand regardless of in which currency price contracts are set. With a reasonable number of processing stages, the increase in real aggregate demand and thus in production efficiency can overwhelm the terms-of-trade effect, leading to a welfare improvement in both countries.

The key to understanding the pattern in the adjustment of the price level is to understand how marginal costs at different stages of processing would respond to the home monetary expansion. We now discuss the intuitions for the marginal cost movements.

4.1.1 Sellers' local currency pricing

Consider first the case with sellers' local currency pricing and with multiple stages of production and trade. When there are two stages of processing, the marginal costs facing firms at the second stage are partially determined by the price index of all goods produced and traded at the first stage. In the impact period, as explained in Section 3.1, the price index of stage-one goods partially rises in the home country and falls in the foreign country, so do the marginal costs facing firms at the second stage. Thus, those stage-two firms that can set new prices would choose to partially raise their prices in the home country and lower their prices in the foreign country. With staggered price-setting, the price index of stage-two goods (including both domestically produced and imported) must rise by less in the home country and fall by more in the foreign country than does the price index of stage-one goods. Further, the incomplete adjustment in the price indexes of stage-two goods will persist for one more period than the price indexes of stage-one goods.

When there are three or more stages of processing, the same logic implies that the price index of goods at a more advanced processing stage has to rise by less in the home country and fall by more in the foreign country, and the incomplete adjustment of the price indexes would persist for

a longer period of time than the price indexes of goods produced and traded at a less advanced processing stage. Thus, the price level rises by less in the home country and falls by more in the foreign country and becomes more persistent in both countries as the number of processing stages grows larger.

4.1.2 Buyers' local currency pricing

Under buyers' local currency pricing, firms can set different prices for the products to be sold in different countries, so that when firms set prices for their goods to be exported, the relevant marginal costs need to be adjusted for currency units. At the first processing stage, the marginal cost is given by the domestic nominal wage rate, which rises fully in the home country. Thus, the marginal cost faced by home firms rises in the home currency unit, but remains unchanged in the foreign currency unit because of the home currency depreciation. Home firms would thus keep the prices of exported goods unchanged. Meanwhile, foreign firms face an unchanged nominal wage rate in the foreign currency unit so that they choose not to adjust the prices of goods to be sold in the domestic market. It follows that there will be no change in the price index of stage-one goods sold in the foreign market.

The unchanged stage-one foreign price index implies that foreign firms at the second stage face unchanged marginal costs and thus would choose to stay put even if they can set new prices. Yet, the price index of stage-two goods imported from the home country falls in the foreign currency unit since home firms at the second stage faces a partially adjusted marginal cost in the home currency unit and, given the home currency depreciation, a lowered marginal cost in the foreign currency unit. The unchanged prices of foreign's domestically produced goods and the lowered prices of its imported goods imply that the foreign price index of stage-two goods has to fall. As a consequence, foreign firms at the third processing stage face a lowered marginal cost and therefore would choose to lower their prices as well. This, when coupled with the lowered prices of goods imported from the home country, implies that the foreign price index of stage-three goods must fall by even more and for a longer period of time than the stage-two price index, and so on.

4.2 Some Analytical Results

The patterns of price adjustments described above are formally established in the Appendix. Specifically, we show that, following the home monetary expansion, the rise in the home price level becomes more gradual, the fall in the foreign price level becomes more pronounced, and both become more persistent as the production and trading chain grows longer, and these price

adjustment patterns do not depend on the currencies of price-setting [see Lemma 2 in the Appendix]. It follows that, with more stages of processing and trade, the real effect of the monetary expansion becomes larger and more persistent in both countries. Denote by y_{Nt} the response to the home monetary expansion of real aggregate demand (i.e., consumption in the current model) in the home country and by y_{Nt}^* the foreign counterpart when there are N stages of processing. The following proposition formally establish the monotonic relation between N and the responses of the real aggregate demand.

Proposition 1: *In a perfect foresight equilibrium, the following inequalities hold for all $N \geq 1$, regardless of the currency unit at which prices are set:*

$$y_{N+1,t} > y_{Nt}, \quad y_{N+1,t}^* > y_{Nt}^*, \quad 0 \leq t \leq N. \quad (28)$$

Proof: (see the Appendix)

4.3 Some Calibrated Results

The increase in real aggregate demand and hence in consumption as N rises tends to improve welfare in both countries. But if the rise in N were also associated with large increases in labor demand, as labor is an input of production at all stages, the overall welfare effect would seem to remain ambiguous. However, as it turns out, this concern needs not be substantiated. As we have explained earlier, the prices of goods at a more advanced processing stage rise less in the home country and fall more in the foreign country, while the nominal wage rate rises fully in the home country and remains unchanged in the foreign country. Thus, at a more advanced stage, labor becomes more expensive relative to intermediate inputs, so that firms would have a greater incentive to substitute intermediate inputs for labor inputs. For this reason, changes in aggregate employment in each country need not be monotone in N . In other words, a greater number of processing stages would allow for more consumption goods to be produced in both countries with a given amount of labor input, since firms would rely on using more goods to produce goods. This, when coupled with the monotonic relationship between changes in consumption and in N , makes it more likely for the monetary expansion to benefit both countries.

Now, what about the terms-of-trade effect? This effect tends to benefit one country at the expense of the other, and which country would indeed benefit from it depends on in which currency price contracts are set. In the special case with $N = 1$, as we have shown in Section 3, the terms-of-trade effect tends to dominate the efficiency improvement effect so that the international welfare implications of the home monetary expansion depend on assumptions about the currencies of price-setting. With a reasonable number of processing stages, however, the efficiency improvement

effect is magnified and the terms-of-trade consideration is made relatively less important. Under plausible parameter values, the home monetary expansion improves the welfare of both countries, regardless of whether price contracts are set in sellers' or buyers' local currency.

The remaining question is: How large is the number of processing stages required to generate welfare improvements in both countries following the home monetary expansion? To answer this question, we first calibrate the model's parameters, except for N , which we would treat as a free parameter. We then compute the impulse responses of consumption and labor efforts following the expansion. Finally, we compute the welfare gain, as given by (23), and we plot it against N . Details of the computation methods are available upon request from the authors.

We calibrate the parameters following the standard international business cycle literature. We consider one period in the model as corresponding to one half of a year, so that there is a minimum amount of exogenous nominal price staggering. Accordingly, the duration of each price contract is equal to one year, as is consistent with the empirical evidence surveyed by Taylor (1999). We set β , the subjective discount factor, to 0.98, so that the annual real interest rate in the steady state is about 4 percent. We assume a zero steady-state inflation rate, so the money demand equation implies that $\Psi = (1 - \beta)/v$, where $v = \bar{P}_N C/M$ is the steady-state velocity of money. Given the value of β , we set $\Psi = 0.0084$, corresponding to a steady-state annual velocity of 4.8.⁷ The parameter κ by itself is unimportant since what affects the equilibrium dynamics and the welfare is the term κL , which is given by

$$\kappa L = \frac{1}{\mu} \left[(\phi/\mu)^{N-1} + (1 - \phi) \frac{1 - (\phi/\mu)^{N-1}}{1 - \phi/\mu} \right],$$

where L is the steady-state employment. We set θ , the elasticity of substitution between goods produced within a country, to 7, so that the steady-state markup [$\mu \equiv \theta/(\theta - 1)$] at each processing stage is about 17 percent, which lies in an empirically reasonable range [e.g., Rotemberg and Woodford (1997)]. It is easy to show that the steady-state employment κL is a decreasing function of N . The larger N is, the greater is the cumulative markup across stages, and the further lies output below the efficiency frontier, and thus the greater is the room for efficiency improvement.

We next set η , the elasticity of substitution between goods made in different countries, to 1.5; and γ , the steady-state share of domestically produced goods in GDP, to 0.85. These values are standard in the literature [e.g., Backus, et al. (1995)]. Finally, we set $\phi = 0.9$, so that as N varies from 2 to 6, the share of total intermediate goods in gross sales across all stages of processing lies in the range between 0.43 and 0.71.⁸

Figures 2 and 3 plot the impulse responses of consumption and aggregate employment in the two countries under the calibrated parameters and for various N , when prices are set in sellers'

local currency and in buyers' local currency, respectively. These figures confirm our basic intuitions and the implications of our analytical results that the responses of real aggregate demand increase with N , while the responses of aggregate employment need not be monotonic in N due to the factor substitution effect. It is especially worth noting that, under sellers' local currency pricing, foreign aggregate employment falls because of its improved terms of trade. The fall in foreign employment is more pronounced, the larger is the number of processing stages, because, as production moves to a more advanced stage, firms would have a stronger incentive to substitute intermediate inputs for labor.

Figure 4 plots the responses of the home country's terms of trade under the two alternative currencies of price-setting. As N increases, the deterioration in the terms of trade under sellers' local currency pricing tends to be dampened, while the improvement in the terms of trade under buyers' local currency pricing tends to be reduced on impact and even reversed in the subsequent periods.

Since changes in consumption in the two countries increase with N while changes in employment need not, the welfare in both countries is an increasing function of N . Since the terms-of-trade movement tends to be dampened as the number of stages increases, the welfare gains in the two countries tend to become less dependent on the currencies of price-setting. The welfare gains in the calibrated model are plotted in Figures 5 and 6. If prices are rigid in sellers' currency [Figure 5], the home monetary expansion has a "beggar-thy-self" effect when there is a single stage of processing; yet, when N rises above 3, both countries experience a welfare gain. If prices are rigid in buyers' currency [Figure 6], the monetary expansion is a "beggar-thy-neighbor" instrument for small values of N ; but when N rises above 5, both countries gain from the expansion.

5 Conclusion

In their seminal work, Obstfeld and Rogoff (1995) envisioned that a monetary expansion, regardless of its source, could lead to a "general increase in world demand . . . , and both countries share the benefits equally" [p. 647]. Based on this result, they dismissed the fear of competitive devaluation, a caution often cast by the conventional Mundell-Fleming-Dornbusch models, as misleading. They wrote that "the earlier models may overstate the importance of the 'beggar-thy-neighbor' effects that a country inflicts on trading partners when it depreciates its currency" [p. 648]. Such optimism has stimulated a voluminous strand of literature [see Lane (2001) for a survey], with mixed and often ambiguous predictions on the international welfare effects of a country's currency

devaluation. A popular hypothesis in this strand of literature maintains that the welfare effects depend largely on the currencies at which prices are rigid.

We have re-examined this hypothesis by incorporating a production and trading chain, a feature of rising empirical importance, into an otherwise standard new open-economy macroeconomic model in the spirit of Obstfeld and Rogoff (1995). We have shown that the ambiguity in the welfare effects documented in the literature may disappear with plausibly sophisticated input and output connections between countries: with a reasonable number of stages along the production and trading chain, a country's currency devaluation can lead to a welfare improvement for both itself and its trading partner, regardless of the currencies of price-setting. In this sense, our theory provides support for Obstfeld and Rogoff's original optimism in a world with production interdependence.

Appendix: Proofs

We first establish several preliminary results, which will serve as intermediate steps to the proof of Proposition 1. We first have

Lemma 1: *There is a unique perfect foresight equilibrium in which*

$$w_t = 1, \quad w_t^* = 0, \quad \forall t \geq 0, \quad (29)$$

$$e_t = 1, \quad \forall t \geq 0, \quad (30)$$

$$\bar{p}_{nt} = 1, \quad \bar{p}_{nt}^* = 0, \quad \forall t \geq n, \quad 1 \leq n \leq N, \quad (31)$$

$$y_{Nt} = 0, \quad y_{Nt}^* = 0, \quad \forall t \geq N. \quad (32)$$

for all $N \geq 1$. These results hold independent of the currency in which prices are rigid. Further, if prices are set in sellers' local currency, then

$$p_{nHt} = 1, \quad p_{nFt}^* = 0, \quad \forall t \geq n - 1, \quad 1 \leq n \leq N; \quad (33)$$

while if prices are set in buyers' local currency, then

$$p_{nHt} = 1, \quad p_{nFt} = 1, \quad p_{nFt}^* = 0, \quad p_{nHt}^* = 0, \quad (34)$$

$$\forall t \geq n - 1, \quad 1 \leq n \leq N.$$

Proof: According to the home money demand equations (S6) or (B6) (in Tables 1 and 2), existence of a non-explosive solution to the equilibrium system requires that

$$\bar{p}_{Nt} + y_{Nt} = m_t = 1, \quad \bar{p}_{Nt}^* + y_{Nt}^* = m_t^* = 0, \quad (35)$$

which, along with the labor supply equations (S5) or (B5), leads to (29). Solving (S7) or (B7) forward, we obtain (30). Given (29) and (30), the equations in (33), (34), and (31) can then be proved by induction, using (S1)-(S4) and (B1)-(B4). Finally, given that (31) holds also for N , (32) follows immediately from (35). *Q.E.D.*

This Lemma shows that the home monetary expansion immediately raises its nominal wage rate, but has no effect on the foreign nominal wage rate. It also leads to a complete home nominal exchange rate depreciation. After n periods following the shock, the price index of stage- n goods in the home country will rise fully and the price index of stage- n goods in the foreign country will return to the steady state. After N periods, the real effects of the shock vanishes and aggregate demands in both countries return to the steady state.

The next Lemma establishes the patterns of price adjustments across different stages of processing under the two alternative assumptions about the currencies in which prices are rigid.

Lemma 2: *Suppose $N \geq 2$. If prices are set in sellers' local currency, then the following inequalities about pricing decisions hold for $n \in \{1, \dots, N - 1\}$:*

$$0 < p_{n+1,Ht} < p_{nHt}, \quad p_{n+1,Ft}^* < p_{nFt}^* \leq 0, \quad 0 \leq t \leq n - 1, \quad (36)$$

On the other hand, if prices are set in buyers' local currency, then the following inequalities about pricing decisions hold for $n \in \{1, \dots, N - 1\}$:

$$0 < p_{n+1,Ht} < p_{nHt}, \quad p_{n+1,Ft}^* \leq p_{nFt}^* \leq 0, \quad 0 \leq t \leq n - 1, \quad (37)$$

$$p_{n+1,Ht}^* < p_{nHt}^* \leq 0, \quad 0 < p_{n+1,Ft} \leq p_{nFt}, \quad 0 \leq t \leq n - 1, \quad (38)$$

Under either sellers' or buyers' local currency pricing, the following inequalities about price indices hold for $n \in \{1, \dots, N - 1\}$:

$$0 < \bar{p}_{n+1,t} < \bar{p}_{nt}, \quad \bar{p}_{n+1,t}^* < \bar{p}_{nt}^* \leq 0, \quad 0 \leq t \leq n. \quad (39)$$

Proof: To prove (36), we first use (S1)-(S4), along with the solutions $w_t = 1$ and $w_t^* = 0$ for nominal wages and $e_t = 1$ for the nominal exchange rate in (29) and (30), to get a recursive expression for each of the two pricing decision variables under SLCP:

$$\begin{aligned} p_{n+2,Ht} &= \frac{\phi\gamma}{2} [p_{n+1,Ht} + ap_{n+1,H,t-1} + (1-a)p_{n+1,H,t+1}] \\ &\quad + \frac{\phi(1-\gamma)}{2} [p_{n+1,Ft}^* + ap_{n+1,F,t-1}^* + (1-a)p_{n+1,F,t+1}^*] + 1 - \phi\gamma, \end{aligned} \quad (40)$$

$$\begin{aligned} p_{n+2,Ft}^* &= \frac{\phi\gamma}{2} [p_{n+1,Ft}^* + ap_{n+1,F,t-1}^* + (1-a)p_{n+1,F,t+1}^*] \\ &\quad + \frac{\phi(1-\gamma)}{2} [p_{n+1,Ht} + ap_{n+1,H,t-1} + (1-a)p_{n+1,H,t+1}] - \phi(1-\gamma), \end{aligned} \quad (41)$$

where $a \equiv 1/(1 + \beta)$. We then prove (36) by induction. It is easy to verify that the inequalities in (36) hold for $n = 1$. This establishes the result for $N = 2$. Now suppose that $N > 2$ and the inequalities hold for an arbitrary $n \in \{1, \dots, N - 2\}$. Fix an arbitrary t with $0 \leq t \leq n$. By the induction hypothesis and (33), we have

$$p_{n+1,Ht} \leq p_{nHt}, \quad p_{n+1,H,t-1} \leq p_{nH,t-1}, \quad p_{n+1,H,t+1} \leq p_{nH,t+1},$$

with at least one strict inequality, and

$$p_{n+1,Ft}^* \leq p_{nFt}^*, \quad p_{n+1,F,t-1}^* \leq p_{nF,t-1}^*, \quad p_{n+1,F,t+1}^* \leq p_{nF,t+1}^*,$$

with at least one strict inequality if and only if $n > 1$. Thus, from the recursive relations in (40) and (41), we have $p_{n+2,Ht} < p_{n+1,Ht}$ and $p_{n+2,Ft}^* < p_{n+1,Ft}^*$. This completes the proof of (36).

The proof of (37) and (38) is similar. In particular, note that (B1), (B2), and the solutions for nominal wage rate and the nominal exchange rate together imply that

$$p_{nHt}^* = p_{nHt} - 1, \quad p_{nFt} = p_{nFt}^* + 1. \quad (42)$$

Thus, (38) will be an immediate corollary if we can establish (37). To prove (37), we follow a similar procedure as in the case with SLCP. We begin by establishing a recursive expression for p_{nHt} and p_{nFt}^* using (B1)-(B4):

$$\begin{aligned} p_{n+2,Ht} &= \frac{\phi\gamma}{2} [p_{n+1,Ht} + ap_{n+1,H,t-1} + (1-a)p_{n+1,H,t+1}] \\ &\quad + \frac{\phi(1-\gamma)}{2} [p_{n+1,Ft}^* + ap_{n+1,F,t-1}^* + (1-a)p_{n+1,F,t+1}^*] + 1 - \phi, \end{aligned} \quad (43)$$

$$\begin{aligned} p_{n+2,Ft}^* &= \frac{\phi\gamma}{2} [p_{n+1,Ft}^* + ap_{n+1,F,t-1}^* + (1-a)p_{n+1,F,t+1}^*] \\ &\quad + \frac{\phi(1-\gamma)}{2} [p_{n+1,Ht} + ap_{n+1,H,t-1} + (1-a)p_{n+1,H,t+1}], \end{aligned} \quad (44)$$

Then, the inequalities in (37) can be proved by induction.

Finally, the inequalities in (39) follow from the definitions of the price indices in (S4) or (B4), and the inequalities in (36) or (37)-(38). *Q.E.D.*

Lemma 2 shows that the home monetary expansion leads to a rise in the home prices at each processing stage but a fall in the foreign prices. Further, at a more advanced processing stage, the rise in the home prices becomes more gradual and the fall in the foreign prices becomes more pronounced, and the movements in the prices become more persistent.

It follows that, as the number of stages increases, the home price level will rise more gradually and the foreign price level will fall by a greater magnitude. Given the money supply process in the two countries, the price adjustment patterns imply that real aggregate demands in both countries

will rise by a larger magnitude when the length of the production and trading chain grows. This is essentially the result in Proposition 1 in the text.

Proof of Proposition 1: It follows immediately from (35) and (39). *Q.E.D.*

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Notes

1. Obstfeld (2001) provides a useful survey of the postwar analytical thinking on international macroeconomics, and assesses the influence of Mundell and Fleming's work and the recent progress in the field.

2. In addition to the work cited above, there is a growing body of literature examining the international welfare effects of monetary policy shocks in a new open-economy macroeconomic model, some assuming sellers' local currency pricing, while some others assuming buyers' local currency pricing. For example, Bacchetta and van Wincoop (2000) study the effect of exchange-rate systems on trade and welfare in a model with buyers' currency pricing; Devereux and Engel (1998) analyze the welfare properties of fixed and floating exchange rate regimes and find that the optimal exchange rate regime depend on whether prices are set in the currency of producers or the currency of consumers.

3. This assumption implies that monetary shocks have no permanent effect on current account balances. This helps simplify the welfare analysis. See, also, Devereux and Engel (1998, 1999) and Chari, et al. (2002).

4. As in Obstfeld and Rogoff (1995), our model features monopolistic competition that creates a first-order distortion, the effect of which on welfare would dominate that of any higher-order distortions for small shocks. Thus, as in Obstfeld and Rogoff, it is sufficient for our welfare analysis to examine the first-order approximation of the perfect-foresight equilibrium system following a small, one-time shock. We are grateful to Chris Sims for pointing this out to us and for very useful discussions on related subjects.

5. The parameter Ψ measures the importance of real money balances in the utility function, and its value is typically small in light of most money demand regressions [e.g., Chari, et al. (2000)].

6. Corsetti and Pesenti (2000) also assume that the two countries may have different degrees of steady-state home-bias (i.e., the γ 's may differ across countries).

7. Here we use M1 as a measure of money supply to compute the velocity. The welfare results are not sensitive to the use of M2 or monetary base instead.

8. Let Φ denote the share of total intermediate goods in gross sales across all stages. Since the steady-state aggregate value added is given by $\bar{P}_N Y_N$, we have $1 - \Phi = \bar{P}_N Y_N / \sum_{n=1}^N \bar{P}_n Y_n = \frac{1 - \phi/\mu}{1 - (\phi/\mu)^N}$. From the BEA's 1997 Benchmark Input-Output Tables, the value of Φ is about 0.7 in the U.S. manufacturing sector.

Table 1. Equilibrium Conditions under Sellers' Local Currency Pricing

	Home	Foreign
(S1) Pricing decisions:	$p_{nHt} = \frac{1}{1+\beta}v_{nt} + \frac{\beta}{1+\beta}\mathbf{E}_t v_{n,t+1},$	$p_{nFt}^* = \frac{1}{1+\beta}v_{nt}^* + \frac{\beta}{1+\beta}\mathbf{E}_t v_{n,t+1}^*$
(S2) Unit costs:	$v_{nt} = \phi\bar{p}_{n-1,t} + (1-\phi)w_t,$	$v_{nt}^* = \phi\bar{p}_{n-1,t}^* + (1-\phi)w_t^*$
(S3) Price indices:	$\bar{p}_{nHt} = \frac{1}{2}[p_{nHt} + p_{nH,t-1}],$	$\bar{p}_{nFt}^* = \frac{1}{2}[p_{nFt}^* + p_{nF,t-1}^*]$
(S4) Price levels:	$\bar{p}_{nt} = \gamma\bar{p}_{nHt} + (1-\gamma)[\bar{p}_{nFt}^* + e_t],$	$\bar{p}_{nt}^* = \gamma\bar{p}_{nFt}^* + (1-\gamma)[\bar{p}_{nHt} - e_t]$
(S5) Labor supply:	$w_t = \bar{p}_{Nt} + c_t,$	$w_t^* = \bar{p}_{Nt}^* + c_t^*$
(S6) Money demand:	$x_t = (1-\beta)m_t + \beta\mathbf{E}_t x_{t+1},$ $(x_t \equiv \bar{p}_{Nt} + c_t),$	$x_t^* = (1-\beta)m_t^* + \beta\mathbf{E}_t x_{t+1}^*$ $(x_t^* \equiv \bar{p}_{Nt}^* + c_t^*)$
(S7) Nominal exchange rate:	$e_t = (1-\beta)(m_t - m_t^*) + \beta\mathbf{E}_t e_{t+1}$	
(S8) Real exchange rate:	$q_t = c_t - c_t^*$	

Table 2. Equilibrium Conditions under Buyers' Local Currency Pricing

	Home	Foreign
(B1) Pricing decisions:	$p_{nHt} = \frac{1}{1+\beta}v_{nt} + \frac{\beta}{1+\beta}\mathbf{E}_t v_{n,t+1},$ $p_{nHt}^* = \frac{1}{1+\beta}[v_{nt} - e_t] +$ $\frac{\beta}{1+\beta}\mathbf{E}_t [v_{n,t+1} - e_{t+1}],$	$p_{nFt}^* = \frac{1}{1+\beta}v_{nt}^* + \frac{\beta}{1+\beta}\mathbf{E}_t v_{n,t+1}^*$ $p_{nFt} = \frac{1}{1+\beta}[v_{nt}^* + e_t] +$ $\frac{\beta}{1+\beta}\mathbf{E}_t [v_{n,t+1}^* + e_{t+1}]$
(B2) Unit costs:	$v_{nt} = \phi\bar{p}_{n-1,t} + (1-\phi)w_t,$	$v_{nt}^* = \phi\bar{p}_{n-1,t}^* + (1-\phi)w_t^*$
(B3) Price indices:	$\bar{p}_{nHt} = \frac{1}{2}[p_{nHt} + p_{nH,t-1}],$ $\bar{p}_{nFt} = \frac{1}{2}[p_{nFt} + p_{nF,t-1}],$	$\bar{p}_{nFt}^* = \frac{1}{2}[p_{nFt}^* + p_{nF,t-1}^*]$ $\bar{p}_{nHt}^* = \frac{1}{2}[p_{nHt}^* + p_{nH,t-1}^*]$
(B4) Price levels:	$\bar{p}_{nt} = \gamma\bar{p}_{nHt} + (1-\gamma)\bar{p}_{nFt},$	$\bar{p}_{nt}^* = \gamma\bar{p}_{nFt}^* + (1-\gamma)\bar{p}_{nHt}^*$
(B5) Labor supply:	$w_t = \bar{p}_{Nt} + c_t,$	$w_t^* = \bar{p}_{Nt}^* + c_t^*$
(B6) Money demand:	$x_t = (1-\beta)m_t + \beta\mathbf{E}_t x_{t+1},$ $(x_t \equiv \bar{p}_{Nt} + c_t)$	$x_t^* = (1-\beta)m_t^* + \beta\mathbf{E}_t x_{t+1}^*$ $(x_t^* \equiv \bar{p}_{Nt}^* + c_t^*)$
(B7) Nominal exchange rate:	$e_t = (1-\beta)(m_t - m_t^*) + \beta\mathbf{E}_t e_{t+1}$	
(B8) Real exchange rate:	$q_t = c_t - c_t^*$	

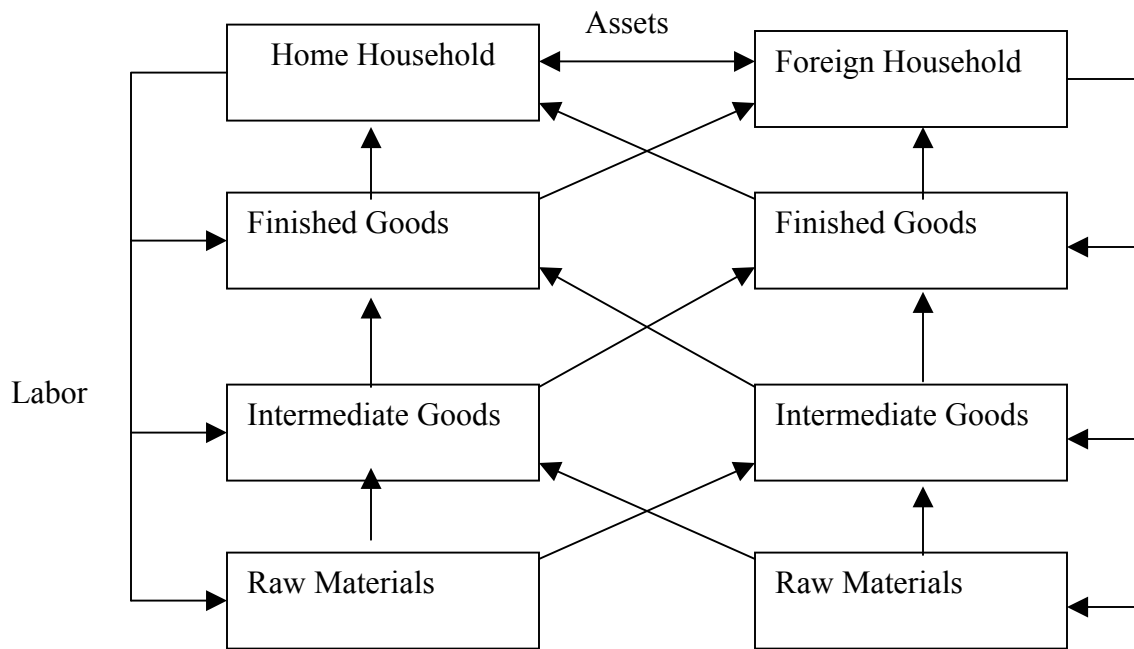


Figure 1: ---The international production and trading structure

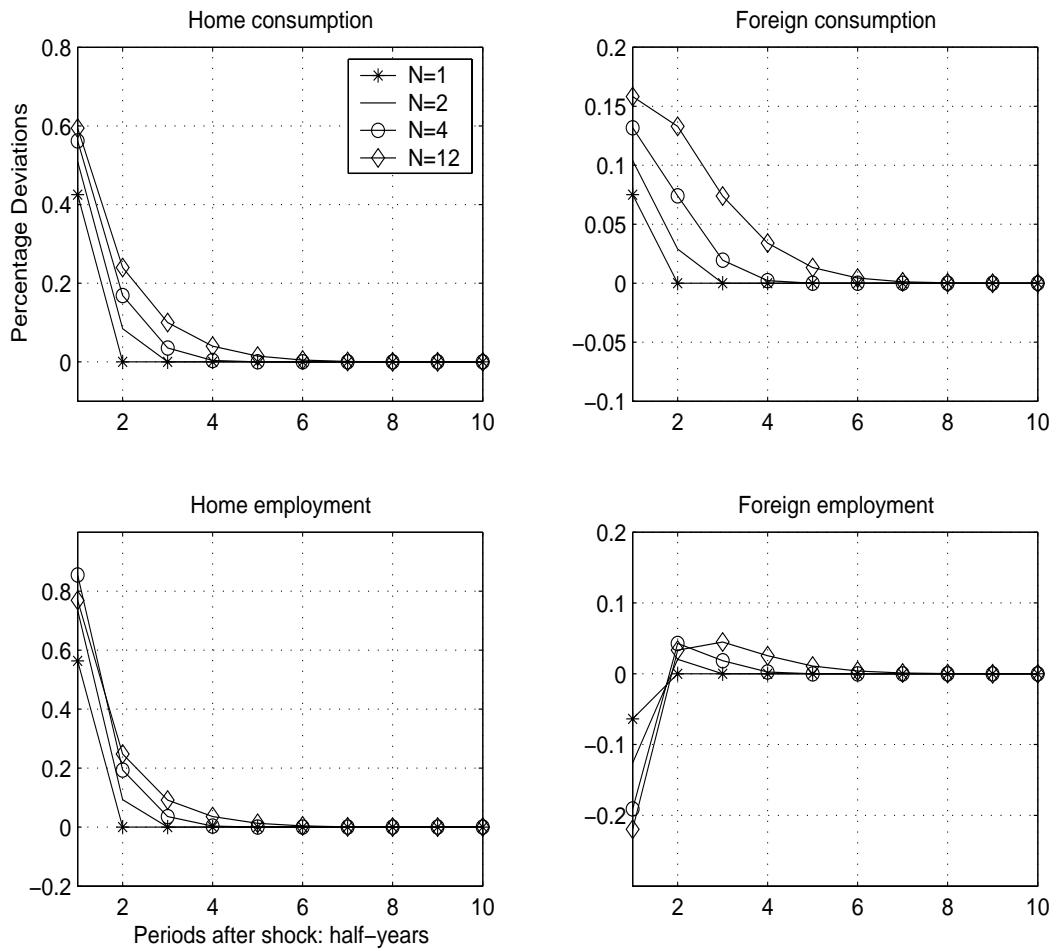


Figure 2:—The impulse responses of consumption and employment under sellers' local currency pricing.

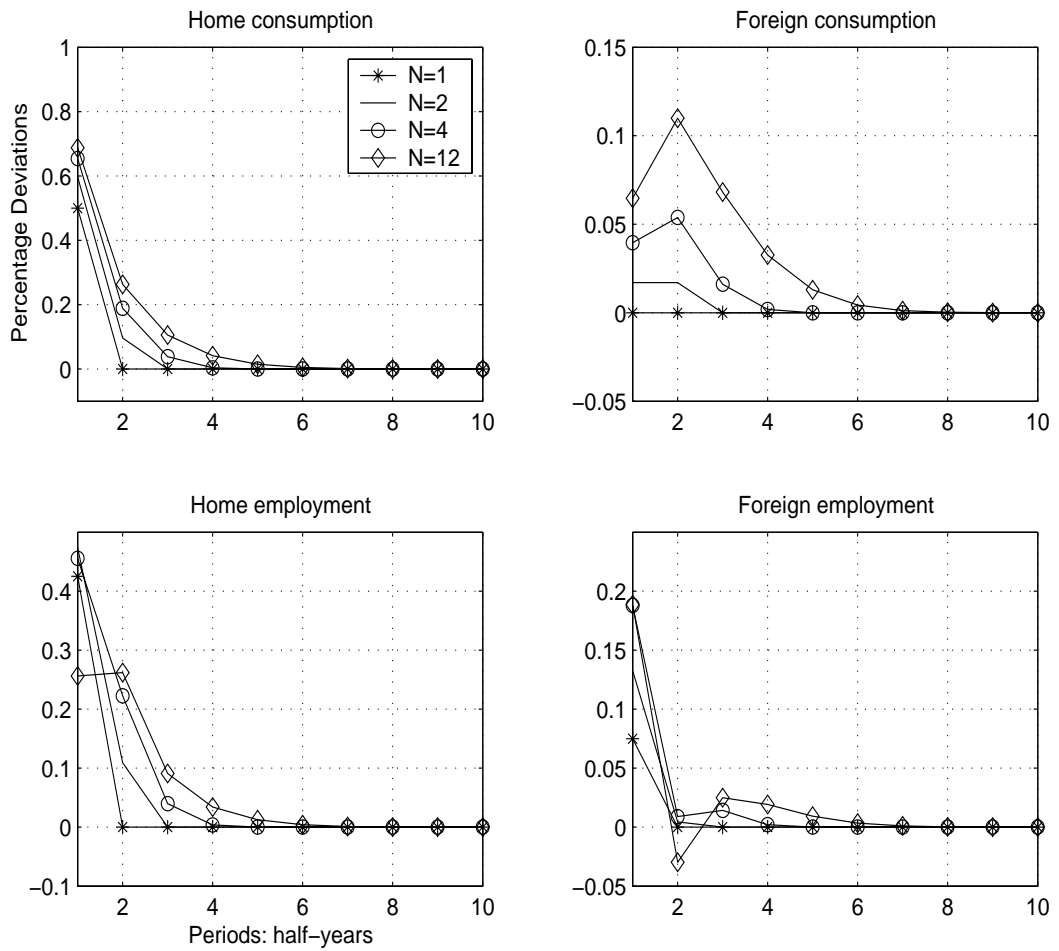


Figure 3:—The impulse responses of consumption and employment under buyers' local currency pricing.

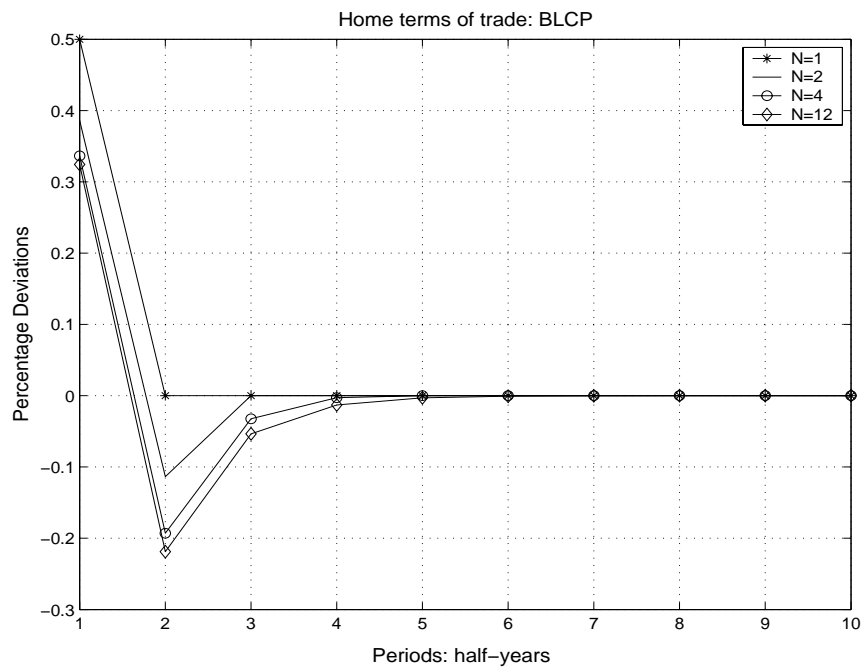
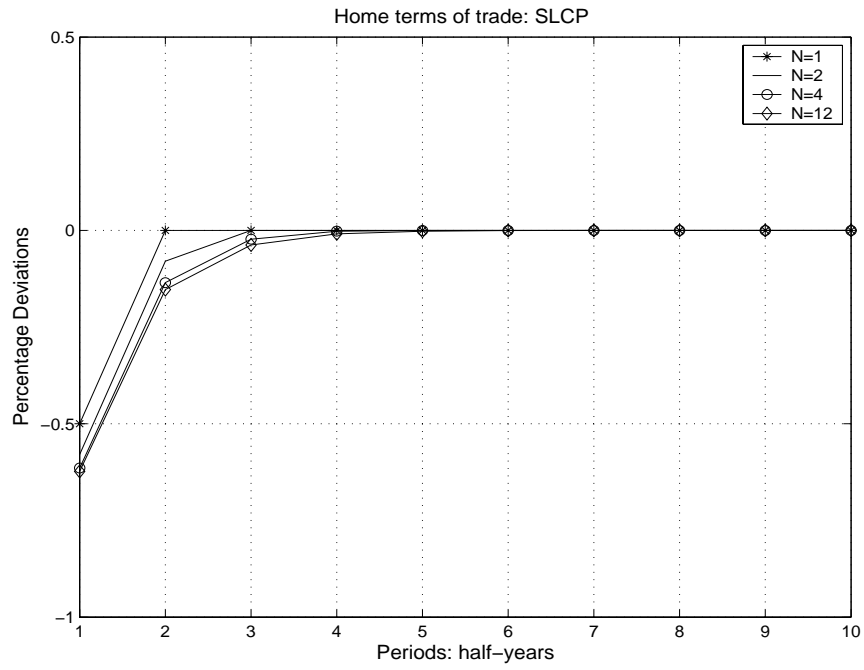


Figure 4:—The impulse responses of the home country's terms of trade.

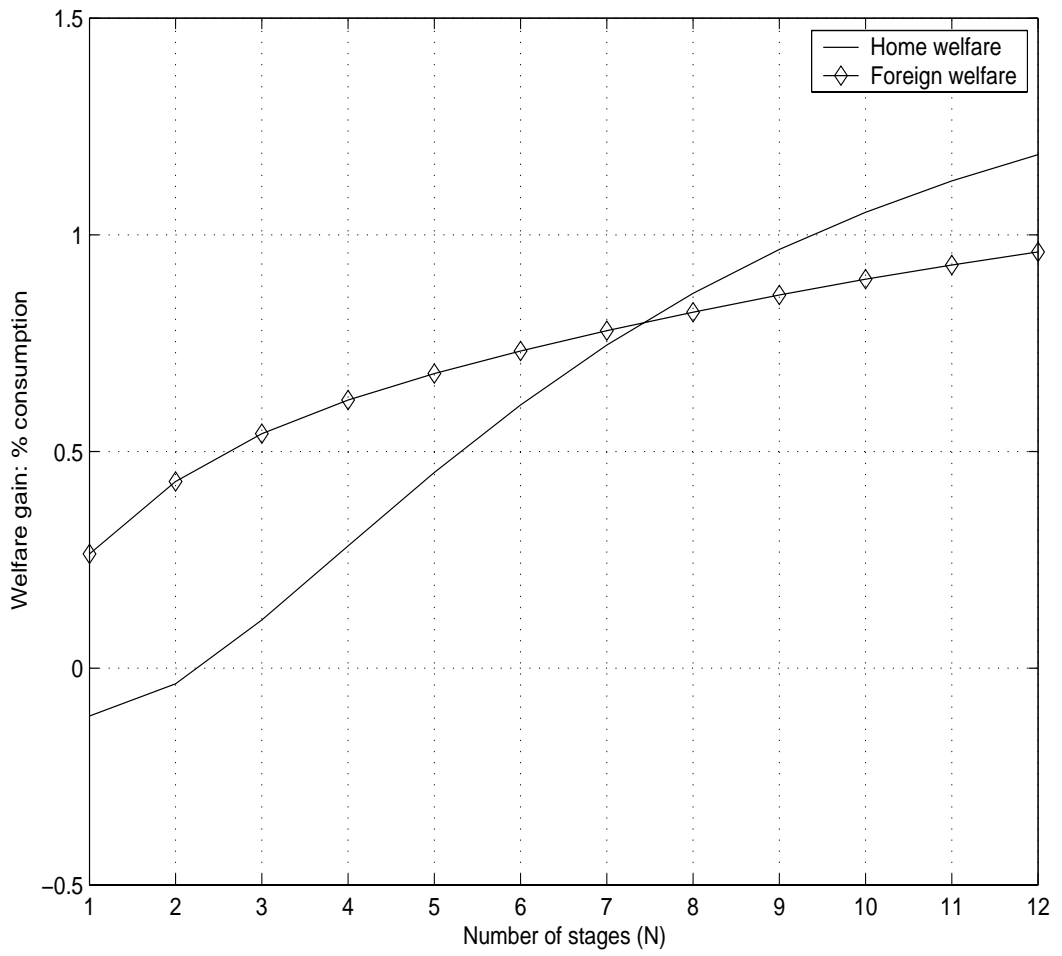


Figure 5:—Welfare gains under sellers' local currency pricing.

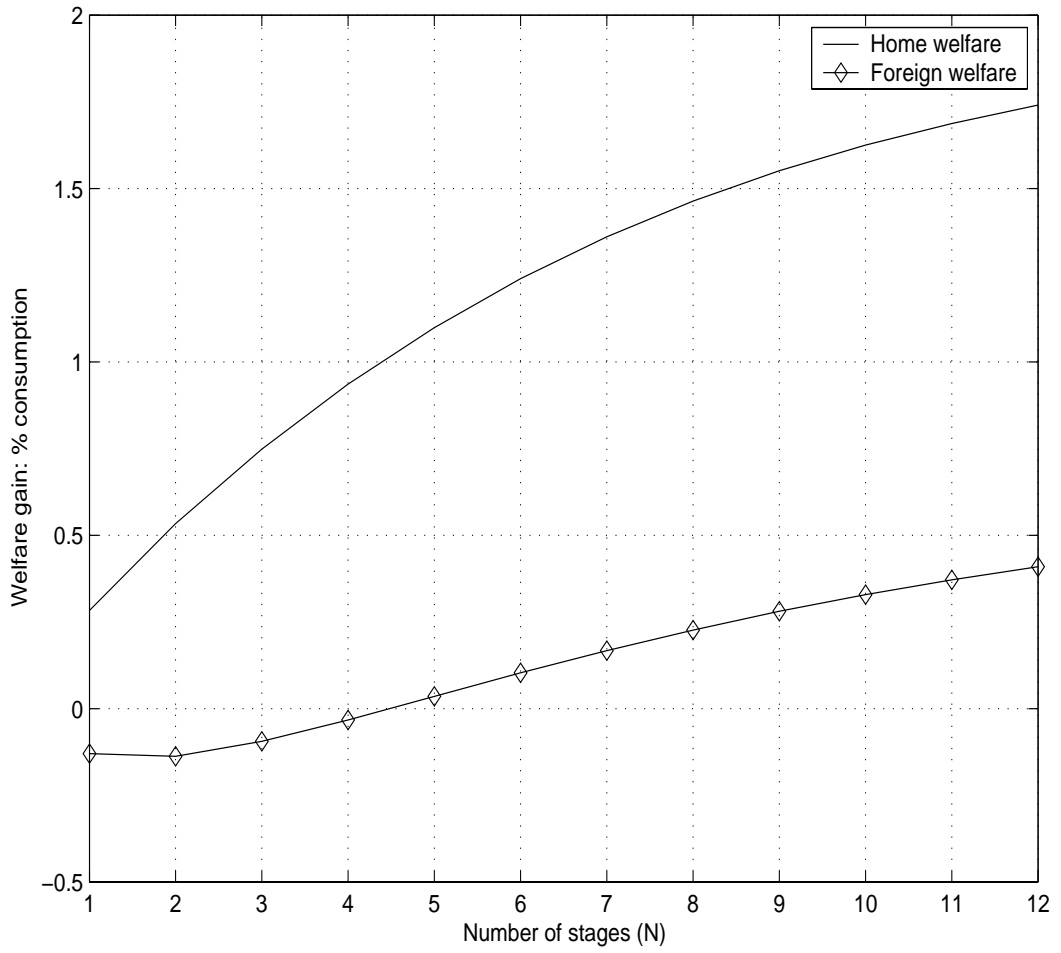


Figure 6:—Welfare gains under buyers' local currency pricing.