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Abstract

We study international transmissions and welfare implications of monetary shocks in a two-country world with multiple stages of production and multiple boarder-crossings of intermediate goods. This empirically relevant feature is important, as it has opposite implications for two external spillover effects of a unilateral monetary expansion. If all production and trade are assumed to occur in a single stage, the conflict-of-interest terms-of-trade effect tends to dominate the common-interest efficiency-improvement effect for reasonable parameter values, so that the international welfare effects would depend in general on the underlying assumptions about the currencies of price setting. The stretch of production and trade across multiple stages of processing magnifies the efficiency-improvement effect and dampens the terms-of-trade effect. Thus, a monetary expansion can be mutually beneficial regardless of its source or the pricing assumptions.

JEL classification: E32, F31, F41

Key Words: Vertical production and trade; Monopolistic competition; Terms of trade; Welfare

1. Introduction

Over the past several decades, nations have become substantially more interdependent through an increased global interconnectedness along a vertical production and trading chain stretching across many stages of processing, involving goods that cross borders multiple times. Feenstra (1998), Hummels, Rapoport, and Yi (1998), Hummels, Ishii, and Yi (2001), and Yi (2003) analyze this evolving nature of global production and trade, and argue that it may help understand many of the phenomena observed in the past fifty years. For instance, Yi (2003) demonstrates that the multiple border-crossings of goods embodied in a global production and trading chain is a key to unlocking the mysteries of the large rise in world trade over the past half century and, in particular, the non-linear pattern in this rise. Huang and Liu (2000, 2004b) show that incorporating a vertical production and trading chain featuring multiple border crossings of intermediate goods into a full-fledged DSGE model introduces a powerful transmission mechanism of shocks that may help explain the quantity anomaly documented in the international business cycle literature through reproducing some of the key stylized facts concerning cross-country business cycle correlations.[1]

The present paper seeks to explore the implications of this risen global production and trade interdependence for the welfare consequence of international monetary policy transmission, an issue that has long concerned economists and policymakers. Traditionally, the issue was analyzed in the classical Mundell-Fleming-Dornbusch framework. The new open economy macroeconomics (NOEM) literature recently developed by Obstfeld and Rogoff (1995) and others emphasizes the relevance of monopolistic distortions and nominal rigidities with local currency pricing, which provides a micro-founded theoretical apparatus that is apt at carrying out the welfare analysis in international macroeconomics.[2] A domestic monetary expansion in these models typically has two external spillover effects arising from international trade linkages for goods and assets: an "aggregate-demand externality" and a "terms-of-trade externality." On the one hand, it alleviates monopolistic distortions and thus raises output and employment to more efficient levels for both the source (home) country and its trade partner (foreign). On the other hand, it affects terms of trade in favor of one country against the other depending on currencies of price setting: the foreign's terms of trade improve if prices are set in sellers' local currency unit (SLCP), but worsen

[1]The relevance of focusing on production and trade in intermediate goods has also been suggested by Obstfeld (2001, 2002), McCallum and Nelson (2000), Burstein, Eichenbaum, and Rebelo (2003), and Corsetti and Dedola (2003). Yet, in these models, the imported intermediate goods cross border only once. In particular, the latter two feature a non-traded distribution services sector which helps generate incomplete exchange-rate pass-through. As we will show below, our model that features multiple border crossings of intermediate goods can generate incomplete exchange rate pass-through and dampened fluctuations in the terms of trade even if all produced goods are traded.

[2]See, for example, Obstfeld (2001) for a survey of the postwar analytical thinking on the welfare analysis in international macroeconomics and an assessment of the influence of Mundell and Fleming's work on the recent progress in NOEM. See also Lane (2001).

if prices are set in buyers' local currency unit (BLCP). Thus, while the efficiency-improvement effect tends to make both countries better off, the terms-of-trade effect tends to make one country better off but the other country worse off.

An important lesson from the NOEM literature, where all production of and trade in goods occur in one stage, is that the conflict-of-interest terms-of-trade effect tends to dominate the common-interest efficiency-improvement effect for many reasonable parameter values, under either SLCP or BLCP.[3] This gives rise to varying welfare results dependent of the underlying assumption on the currencies of price setting.[4]

The main finding of the current paper is that the multiple border-crossings of goods embedded in a vertical production and trading chain, as is modeled in a full-fledged DSGE framework here, magnifies the common-interest efficiency-improvement effect and dampens the conflict-of-interest terms-of-trade effect. As a consequence, a monetary expansion can be mutually beneficial regardless of its source, parameter values, or the pricing assumption.

The basic intuition for the above result is that the increased global production and trade interdependence in the form of a vertical production and trading chain makes the world economy substantially behave as a closed one, whereas the only first-order welfare effects of international monetary policy transmission are the ones associated with efficiency losses due to monopoly power, and whereas the terms-of-trade effects become only of secondary importance. To understand this intuition, note that, on the one hand, with monopolistic distortions at each stage of processing, there is a larger degree of production inefficiency to be improved upon along a longer processing chain, where this greater potential in efficiency gain is materialized as upstream goods cross borders downstream many times, multiplying the efficiency gain at each stage.[5] On the other hand, the multiple border-crossings of goods also reduce the effective degree of market segmentation and increase the degree of effective competition between home and foreign producers, making the terms-of-trade effects muted. This happens since, given staggered price contracts at each stage of processing, material costs and thus 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, inducing producers at a later processing stage to raise their prices set in the home currency unit by less and to 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, regardless of whether prices are set in sellers' or

[3]See Corsetti and Pesenti (2001) and Betts and Devereux (2000), respectively, among others.

[4]The real world features both SLCP and BLCP behaviors. See, for example, Obstfeld and Rogoff (2000) and Goldberg and Knetter (1997).

[5]As we will show below, the total markup distortion substantiated in the vertical production and trading chain is not a simple sum but a compounded multiplicative of the markup distortions at different stages of processing.

buyers' local currency unit. In consequence, real aggregate demand and consumption rise along with production by more in each country.

The pattern in price adjustments across different stages of production and trade described above also introduces a factor substitution effect, which is relevant for welfare since to produce more consumption goods requires more labor along with more material inputs. As production and trade move from less to more advanced processing stages, the pattern in the price adjustments across stages makes material inputs increasingly cheaper than labor services, creating stronger incentives for producers to substitute materials for labor. As a consequence, aggregate employment would not rise monotonically with the number of processing stages. With a larger number of processing stages, relatively more goods would be used in producing goods while the terms-of-trade effect becomes relatively less important, and households can enjoy more consumption without necessarily working harder, which is welfare improving for both countries.

The rest of the paper is organized as follows. Section 2 sets up the model. Section 3 describes the welfare measure and experiment. Section 4 illustrates varying welfare results in a degenerate version of our model with a single stage of production and trade. Section 5 presents the main results in the model with multiple stages of production and trade. Section 6 concludes. We focus on explaining intuitions in the main text and relegate analytical results and derivations or 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).[6] While all goods are tradable, labor is immobile across countries. The households have access to a complete set of

[6]We assume staggered price contracts rather than the standard (and simpler) predetermined prices since, as we show below, the propagation mechanism of the model with multiple stages of production and trade relies on unsynchronized price setting at least among firms at some processing stages.

state-contingent nominal bonds denominated in the home currency unit.[7] Figure 1 illustrates the production and trading structure of this world economy.

2.1. Preferences and technologies

We focus on presenting the economic environment in the home country. The representative household in the home country has a utility function

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

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 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

$$\bar{P}_{Nt}C_t+\mathrm{E}_tD_{t,t+1}B_{t+1}+M_t\leq W_tL_t+\Pi_t+B_t+M_{t-1}+T_t, \tag{2}$$

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

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

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 $t\geq0$, 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:

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

[7] This implies that monetary shocks have no permanent effect on current account balances, which helps simplify the welfare analysis. See, also, Devereux and Engel (1998, 1999) and Chari, Kehoe, and McGrattan (2002).

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

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,

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

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 $n \in \{2,\ldots,N\}$ is given by

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

where $L_n(i)$ is the labor input and $\bar{Y}_{n-1}(i) = \left[\gamma^{\frac{1}{\eta}}\bar{Y}^{\frac{\eta-1}{\eta}}_{n-1,H} + (1-\gamma)^{\frac{1}{\eta}}\bar{Y}^{\frac{\eta-1}{\eta}}_{n-1,F}\right]^{\frac{\eta}{\eta-1}}$ 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 monopolistic competitors in output markets and price-takers in input markets. In each period, a fraction $1/2$ of home producers at a given stage $n \in \{1,\cdots,N\}$ 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.[8]

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.

[8]We restrict our attention to two periods of price-setting contracts to keep analytical tractability in our analysis below. Allowing for price contracts to last for more than two periods does not alter the qualitative transmission mechanism embodied in the vertical production and trading chain.

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

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

for all $n \in \{1, \ldots, N\}$, 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 $n \in \{1, \ldots, N\}$ can set a new price, it chooses a price $P_{nHt}(i)$ to maximize the profit

$$\mathrm{E}_t \sum_{\tau=t}^{t+1} D_{t,\tau}[P_{nHt}(i) - V_{n\tau}(i)] Y^d_{n\tau}(i), \tag{9}$$

taking the unit cost function $V_{n\tau}(i)$ and the demand function $Y^d_{n\tau}(i) = Y^d_{nH\tau}(i) + Y^{*d}_{nH\tau}(i)$ 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,

$$V_1(t) \equiv V_1(i,t) = W(t). \tag{10}$$

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

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

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

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

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

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

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

where $n \in \{1, \cdots, N-1\}$. 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 be similarly interpreted.

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

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

where $n \in \{1, \ldots, N\}$. 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 the present value of its expected profit in the current and the next periods, taking the demand functions in each market as given. The firm's objective function is given by

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

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

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

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

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

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

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.[9]

Labor market clearing requires that $\sum_{n=1}^{N} \int_0^1 L_{nt}^d(i)di = L_t$ and $\sum_{n=1}^{N} \int_0^1 L^{*d}_{nt}(i)di = L_t^*$. 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 at 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 at 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.

3. The Nature of the Welfare Experiment

To put our welfare analysis into context, we consider a unilateral monetary expansion in the home country, under which $m_t = 1$ and $m_t^* = 0$ for all t. 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

[9] To keep in line with the literature [e.g., Obstfeld and Rogoff (1995)], we choose to focus on exogenous changes in money supply growth as a source of monetary shocks. This is not our literal interpretation of how monetary policy has actually been conducted in the United States or its trading partners. Some have argued that simple interest rate rules such as a Taylor rule can better describe the US monetary policy. In our model with perfect foresight, there is a one-to-one mapping between money growth and nominal interest rate. But it is not clear how to draw a similar mapping between exogenous money growth rule and endogenous interest rate rules. In our view, this issue in itself is important enough to deserve an investigation in another paper.

measure as a welfare metric. 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

$$\sum_{t=0}^{\infty}\beta^t\left[\ln(C_t)+\Psi\ln\left(\frac{M_t}{\bar{P}_{Nt}}\right)-\kappa L_t\right]=\sum_{t=0}^{\infty}\beta^t\left[\ln(C(1+\Delta))+\Psi\ln\left(\frac{M}{\bar{P}_N}\right)-\kappa L\right], \qquad (20)$$

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 by[10]

$$\ln(1+\Delta)=(1-\beta)\sum_{t=0}^{\infty}\beta^t\left[(1+\Psi)\,c_t-\kappa L\,l_t\right], \qquad (21)$$

The welfare gain in the foreign country can be similarly computed.

As we show in the Appendix (Lemma A.1), following the home monetary expansion specified above, 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 representative 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. So we examine these different cases in sequel.

4. Single-Stage Production and Trade: A Benchmark Case

This section illustrates the international monetary policy transmission mechanism in a benchmark case of our model with a single stage of production and trade. We show that the international welfare effects of the unilateral monetary expansion depend in general on the choice of the currency at which price contracts are set. Since this benchmark case model with a single stage of processing is familiar in the literature, we focus here on the main results, and relegate the details of derivations to the Appendix (see Section A.3).

[10] 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 those of higher-order distortions for small shocks. Thus, it is sufficient for our welfare analysis to examine the first-order approximation of the equilibrium system following a small shock. Woodford (2003) describe scenarios in which second-order approximations are appropriate. See, also, Pappa (2004) for second-order approximations for welfare analysis in an open-economy setup. We are grateful to Chris Sims for useful discussions on related subjects.

4.1. Welfare implication of sellers' local currency pricing

We first examine the case with sellers' local currency pricing. In the Appendix, we show that the welfare gains in the two countries following the home country's unilateral monetary expansion are given by

$$\ln(1+\Delta) = \frac{1-\beta}{2}\left\{\gamma(1+\Psi) - \frac{1}{\mu}\left[1+2(\eta-1)\gamma(1-\gamma)\right]\right\}, \tag{22}$$

$$\ln(1+\Delta^*) = \frac{1-\beta}{2}\left[(1-\gamma)(1+\Psi) + 2(\eta-1)\gamma(1-\gamma)/\mu\right]. \tag{23}$$

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.[11]

In light of (23), 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 (22), 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 (2001), who assume a value of η equal to 1.[12]

While the home monetary expansion raises consumption and real money balances in the home country, the country's terms-of-trade deteriorates under SLCP. The worsened terms of trade tend to reduce the home country's 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 its goods, resulting in lowered labor efforts. In the Appendix, we provide closed-form expressions for consumption and employment that make these effects transparent.

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

[12] They also assume that the two countries may have different degrees of steady-state home-bias (i.e., the γ's may differ across countries).

4.2. Welfare implication of buyers' local currency pricing

Under BLCP, as we show in the Appendix, the international welfare effects of the monetary expansion are given by

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

$$\ln(1+\Delta^*) = -\frac{1}{2}(1-\beta)\frac{1-\gamma}{\mu}. \tag{25}$$

Clearly, with reasonable parameter values, the monetary expansion in the home country raises its own welfare at the expense of the foreign's. In this sense, it is a "beggar-thy-neighbor" policy.

The foreign welfare falls mainly because the home monetary expansion tends to worsen the foreign terms of trade under BLCP. This is so because, under BLCP, the foreign's import price index $\bar{p}^*_{1Ht}$ remains unchanged, while 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 loss in real purchasing power resulting from the worsened terms of trade offsets the gain in its labor income, so that foreign consumption remains unchanged. With unchanged consumption and increased labor effort, its welfare falls. In contrast, the home country's welfare improves because the monetary expansion raises home consumption and also improves its terms of trade, so that its household can afford to consume more without having to work too much harder.

4.3. Currencies of price-setting: ambiguous welfare results

To summarize, if all production and trade occur at a single stage, then the international transmission and welfare effects of a country's monetary expansion depends in general on the choice of currency at which price contracts are set. Sellers' local currency pricing has generally different implications from buyers' local currency pricing. Were we to view the model with a single stage of production 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 unit or in buyers' local currency unit? Existing studies reveal that both types of local currency pricing are empirically significant (e.g., Obstfeld and Rogoff (2000) and Goldberg and Knetter (1997)). Thus, any welfare results obtained from a benchmark model like this would have to be qualified.

5. Multi-Stage Production and Trade: Resolving the Ambiguity

The main finding of this paper is that, as is to be demonstrated now, when production and trade need to go through multiple stages, the varying welfare results under different assumptions on the currencies of price-setting obtained from the degenerate case of the model may disappear.

5.1. Some intuitions

We start by providing some intuitions behind the transmission mechanism embodied in the vertical 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. The reason why the upward movements of marginal costs in terms of home currency unit, and thus the home price level, can be attenuated through multiple stages of processing is similar to that in a closed-economy [e.g., Huang and Liu (2001)]. Briefly, following a monetary expansion, the cost of primary factors in the competitive factor markets increase immediately, so that the marginal cost for firms at the first stage rises immediately, forcing these firms to change their prices fully whenever they have the chance to renew price contracts. But firms at the second stage do not face a full change in their marginal cost, because the marginal cost of these firms is partly determined by the price index of the first-stage goods, and the price index records both the prices newly adjusted and the prices fixed by previous contracts. Thus, these firms at the second stage do not have an incentive to adjust their prices fully even if they have the chance to renew contracts. Likewise, firms at the third stage face an even smaller change in their marginal cost and thus have an even smaller incentive to adjust their prices, and so on.

In an open economy, a unilateral monetary shock affects marginal costs of production at various stages of processing in each country not only through affecting the costs of primary factors and the costs of domestically produced intermediate goods, it also affects marginal costs through movements in the exchange rate.[13] With multiple stages of production and multiple boarder crossings of intermediate goods, marginal costs in the foreign currency unit and thus the foreign price level would fall in response to a home monetary expansion, and the magnitude of the fall would increase with the number of processing stages, regardless of at which currency prices of traded goods are set. This feature allows the home monetary expansion to raise the foreign

[13]A special case of our model with two stages of processing extends the small open model in McCallum and Nelson (1999) to a two-country environment, with intermediate goods crossing boarder once. As we show below, to have a unilateral monetary expansion to benefit all countries involved, regardless of currencies of pricing, requires *multiple* boarder crossings of intermediate goods.

consumption and output, despite that the foreign money supply remains unchanged. Indeed, this is a unique feature and the novelty of the our open-economy model. It is therefore worth spending some effort to understand the intuition behind this new feature.

5.1.1. Sellers' local currency pricing

Consider first the case with sellers' local currency pricing. At the first stage of production and trade, 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 demonstrated in Section 3, 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 $t \geq 0$. On the other hand, 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 first-stage home price index 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 first-stage foreign price index has to fall.

At the second stage 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, since 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.

5.1.2. Buyers' local currency pricing

Under buyers' local currency pricing, firms can set prices in different currencies for the products to be 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. When firms set prices for their goods to be exported, however, the pricing decisions will depend on the relevant marginal costs that are need to be adjusted for currency units.

At the first processing stage, the marginal cost is given by the domestic nominal wage rate, which we recall from Section 3 rises fully in the home country following its monetary expansion, but remains unchanged in the foreign country. This implies that, 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. Accordingly, all firms will raise the prices of their products to be sold in the home market while keep unchanged the prices of their products to be sold in the foreign market. It follows that there will be no change at any time in the price index of stage-one goods sold in the foreign market, while the price index of stage-one goods sold in the home market does not rise fully until the end of the contract duration owing to staggered pricing decisions.

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.

5.2. Some analytical results

The patterns of price adjustments described above are formally established in the Appendix. Specifically, we show there 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 A.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 establishes 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 in which prices are set:*

$$y_{N+1,\,t} > y_{Nt}, \quad y^*_{N+1,\,t} > y^*_{Nt}, \quad 0 \leq t \leq N. \tag{26}$$

Proof. (See the Appendix)

5.3. 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 (21), and we plot it against N.[14]

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.[15] The parameter κ by itself is unimportant since what affects the equilibrium dynamics and the welfare is the term κL, which is given by

$$\kappa L = \frac{1}{\mu}\left[(\phi/\mu)^{N-1} + (1-\phi)\frac{1-(\phi/\mu)^{N-1}}{1-\phi/\mu}\right], \tag{27}$$

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

[14]Details of the computation methods are available upon request from the authors.

[15]Here we use M1 as a measure of money supply to compute the velocity. The welfare results are not sensitive to alternative measures such as M2 or monetary base.

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.[16]

Figures 2 and 3 plot the impulse responses of consumption, aggregate employment, and the period utility flows in the two countries under the calibrated parameters and for various N, when prices are set in sellers' local currency unit and in buyers' local currency unit, 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. Given the patterns of responses in consumption and employment and consistent with our intuition, under SLCP, there's a short-run fall in home household's utility for small values of N, and a rise for a large enough N; and the foreign household's utility rises for all values of N. It is particularly interesting that, under BLCP, while the home utility rises in the short-run for all N; the foreign utility falls on impact and, when N becomes larger, the initial fall is dampened and even reversed in subsequent periods.

Figure 4 plots the responses of the home country's terms of trade at various stages of processing under the two alternative currencies of price-setting, where we fix $N = 12$. As we move from a less advanced stage to a more advanced stage (i.e., as n rises), 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. To understand what drives the reversal in the terms of trade under BLCP, we plot in Figure 5 the home country's export price indices and import price indices at various stages of processing, where all prices are in home currency unit. The figure reveals that export prices fall (in foreign currency unit) and the fall becomes more pronounced at a more advanced stage, whereas import prices rise and rise by less at a more advanced stage. The adjustments in export prices are more sluggish than those in import prices. In particular, at the end of the price contract period when all firms have had a chance to set new prices, import prices adjust quickly to the new steady state, while export prices adjust more gradually and it takes longer periods for export prices to adjust to the new steady state. Therefore, the reversal in the terms of trade adjustments is mainly driven by the relatively more sluggish adjustments in export prices. The

[16]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.

reversal in the terms of trade in turn drives the reversal in foreign's utility flows under BLCP, as reported in Figure 3.

Since it is only the changes in consumption but not necessarily changes in employment in each country that increase with N, each country's welfare 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 of the currencies of price-setting. The welfare gains in the calibrated model are plotted in Figures 6 and 7. If prices are rigid in sellers' local currency unit (Figure 6), the home monetary expansion has a "beggar-thy-self" effect when there is a single stage of production and trade; yet, when N rises above 3, both countries experience a welfare gain. If prices are rigid in buyers' local currency unit (Figure 7), 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. Under either currency of pricing, the home welfare is more sensitive than the foreign welfare to changes in the number of processing stages.[17]

6. Conclusion

The welfare consequence of international monetary policy transmission has been a frequent topic in academic writing and popular press since the breakdown of the Bretton Woods system, and it continues to be such nowadays, as is manifested by the ongoing debate concerning the recent and potential future movements in the exchange rates of the Dollar against other major currencies such as the RMB (Yuan) and the Euro. An important finding from the welfare analysis in the new open economy macroeconomics (NOEM) literature is that an independent monetary expansion typically generates two types of externality associated with international trade in goods and assets, an "aggregate-demand externality" that tends to make all countries better off through improving the production efficiency in each country and a "terms-of-trade externality" that tends to make one country better off but its trade partner worse off. Since the conflict-of-interest terms-of-trade effect tends to dominate the common-interest efficiency-improvement effect for many reasonable parameter values in the standard NOEM models where all production of and trade in goods occur in a single stage, which country is the one that is better off and which is the one that is worse off generally depend on the currencies of price setting.

Given that it is the conflict-of-interest terms-of-trade externality that generally determines the welfare consequence of independent monetary policy in the standard NOEM models, recent research has paid much attention to the issue of international monetary policy cooperation and

[17]In the presence of transportation costs, the world economy would behave less like a closed economy, and it would require more processing stages for the monetary expansion to be welfare improving for all countries involved. It would then be an empirical issue to find out how large N can be in the data, which is an important subject for future research.

the design of international monetary institutions and rules that aims at preventing inward-looking policy actions from generating large terms-of-trade externality. For this purpose, this strand of literature typically abstracts from the common-interest efficiency-improvement effect associated with policy-induced reductions in monopolistic distortions.[18] It instead focuses exclusively on the potential gains from coordinating countries' policy actions to internalize the terms-of-trade externality. Some of the studies find that, under various specifications of the models' environments and parameter values, the gains of cooperation can be quantitatively small, and thus the lack of coordination may not be a big problem.[19]

The results presented in the current paper are somewhat complementary to the above finding. We have shown that once an empirically important vertical production and trading chain is incorporated into an otherwise standard NOEM model, the conflict-of-interest terms-of-trade consideration also becomes of secondary relevance, while the only first-order welfare effect is the one associated with the policy-induced reduction in monopolistic distortions. This suggests that, with a sophisticated production and trading chain in modern global economy, the terms-of-trade externality may not be an important source of concerns for pursuing independent monetary policy and the gains from cooperation or other efforts in internalizing the terms-of-trade externality are likely to be small under general conditions. The conclusion that an independent monetary expansion can be mutually beneficial regardless of its source is consistent with Obstfeld and Rogoff's (1995) original optimism, but holds for general parameter values and under arbitrary pricing assumptions in our model with a vertical production and trading chain.

Ample empirical evidence indicates that the vertical structure of production and trade has already become a defining characteristic of modern world economy. Existing studies also find that the multiple border-crossings of goods embodied in such a production and trading structure may provide a powerful mechanism to account for many empirical facts documented in the literature in international economics and finance. The present paper explores only a particular aspect of the international monetary policy transmission in a model that captures this real-world feature. The model that we have presented in this paper has a rich enough structure that allows one to study other important issues. For instance, one may consider a version of the model with other types of shocks, such as productivity shocks, to evaluate the potential benefits of international policy coordination. One may also study optimal monetary policy rules under alternative monetary policy regimes such as independent central banks versus monetary union in an open economy with multiple boarder-crossings of intermediate goods. In light of the empirical evidence and our theoretical findings, future research along these lines should be both important and promising.

[18] For example, Clarida, et al. (2002) introduce production subsidies to offset the steady-state markup distortions, while Obstfeld and Rogoff (2002) restrict their attention to policy rules, the commitment to which precludes the use of unilateral monetary expansion to raise employment and output systematically toward their competitive levels.

[19] See, for example, Obstfeld and Rogoff (2002), Benigno and Benigno (2003), and Jansen, et al. (2004).

Appendix A.

A.1. Proofs of some lemmas and Proposition 1

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

Lemma A.1. *Given that $m_t = 1$ and $m_t^* = 0$ for all t, there is a unique perfect foresight equilibrium in which*

$$w_t = 1, \quad w_t^* = 0, \qquad \forall\, t \geq 0, \tag{28}$$

$$e_t = 1, \qquad \forall\, t \geq 0, \tag{29}$$

$$\bar{p}_{nt} = 1, \quad \bar{p}_{nt}^* = 0, \quad \forall\, t \geq n, \quad 1 \leq n \leq N, \tag{30}$$

$$y_{Nt} = 0, \quad y_{Nt}^* = 0, \qquad \forall\, t \geq N. \tag{31}$$

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

$$p_{nHt} = 1, \quad p_{nFt}^* = 0, \quad \forall\, t \geq n-1, \quad 1 \leq n \leq N; \tag{32}$$

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

$$p_{nHt} = 1, \quad p_{nFt} = 1, \quad p_{nFt}^* = 0, \quad p_{nHt}^* = 0, \qquad \forall\, t \geq n-1, \quad 1 \leq n \leq N. \tag{33}$$

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

$$\bar{p}_{Nt} + y_{Nt} = m_t = 1, \quad \bar{p}_{Nt}^* + y_{Nt}^* = m_t^* = 0, \tag{34}$$

which, along with the labor supply equations (S5) or (B5), leads to (28). Solving (S7) or (B7) forward, we obtain (29) . Given (28) and (29), the equations in (32), (33), and (30) can then be proved by induction, using (S1)-(S4) and (B1)-(B4). Finally, given that (30) holds also for N, (31) follows immediately from (34). *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 A.2. *Suppose $N \geq 2$. If prices are set in sellers' local currency, then the following inequalities about pricing decisions hold for $n \in \{1, \ldots, N-1\}$:*

$$0 < p_{n+1,Ht} < p_{nHt}, \quad p^*_{n+1,Ft} < p^*_{nFt} \leq 0, \quad 0 \leq t \leq n-1, \tag{35}$$

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

$$0 < p_{n+1,Ht} < p_{nHt}, \qquad p^*_{n+1,Ft} \leq p^*_{nFt} \leq 0, \qquad 0 \leq t \leq n-1, \tag{36}$$

$$p^*_{n+1,Ht} < p^*_{nHt} \leq 0, \qquad 0 < p_{n+1,Ft} \leq p_{nFt}, \qquad 0 \leq t \leq n-1, \tag{37}$$

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

$$0 < \bar{p}_{n+1,t} < \bar{p}_{nt}, \quad \bar{p}^*_{n+1,t} < \bar{p}^*_{nt} \leq 0, \quad 0 \leq t \leq n. \tag{38}$$

Proof. To prove (35), 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 (28) and (29), to get a recursive expression for each of the two pricing decision variables under SLCP:

$$\begin{aligned} p_{n+2,Ht} = {} & \frac{\phi\gamma}{2}[p_{n+1,Ht} + a p_{n+1,H,t-1} + (1-a) p_{n+1,H,t+1}] \\ & + \frac{\phi(1-\gamma)}{2}[p^*_{n+1,Ft} + a p^*_{n+1,F,t-1} + (1-a) p^*_{n+1,F,t+1}] + 1 - \phi\gamma, \end{aligned} \tag{39}$$

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

where $a \equiv 1/(1+\beta)$. We then prove (35) by induction. It is easy to verify that the inequalities in (35) hold for $n = 1$. This establishes the result for $N = 2$. Now suppose that $N > 2$ and the inequalities hold for an arbitrary $n \in \{1, \ldots, N-2\}$. Fix an arbitrary t with $0 \leq t \leq n$. By the induction hypothesis and (32), 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 (39) and (40), we have $p_{n+2,Ht} < p_{n+1,Ht}$ and $p^*_{n+2,Ft} < p^*_{n+1,Ft}$. This completes the proof of (35).

The proof of (36) and (37) is similar. In particular, note that (B1), (B2), and the solutions for nominal wage rate and the nominal exchange rate together imply that

$$p^*_{nHt} = p_{nHt} - 1, \quad p_{nFt} = p^*_{nFt} + 1. \tag{41}$$

Thus, (37) will be an immediate corollary if we can establish (36). To prove (36), 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):

$$\begin{aligned} p_{n+2,Ht} &= \frac{\phi\gamma}{2}[p_{n+1,Ht} + ap_{n+1,H,t-1} + (1-a)p_{n+1,H,t+1}] \\ &\quad + \frac{\phi(1-\gamma)}{2}[p^*_{n+1,Ft} + ap^*_{n+1,F,t-1} + (1-a)p^*_{n+1,F,t+1}] + 1 - \phi, \end{aligned} \tag{42}$$

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

Then, the inequalities in (36) can be proved by induction.

Finally, the inequalities in (38) follow from the definitions of the price indices in (S4) or (B4), and the inequalities in (35) or (36)-(37). *Q.E.D.*

Lemma A.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 (34) and (38). *Q.E.D.*

A.2. Employment dynamics with multi-stage production and trade

To obtain the welfare effects of monetary shocks, we need to obtain a solution to aggregate employments, which, in our model with multiple stages of production and trade, requires a few intermediate steps. We now describe the solution procedure. Labor market clearing implies that the aggregate employments in the two countries are given by

$$L_t = \sum_{n=1}^{N} \int_0^1 L_{nt}(j)dj, \quad L^*_t = \sum_{n=1}^{N} \int_0^1 L^*_{nt}(j)dj, \tag{44}$$

The sectoral employments are given by

$$\int_0^1 L_{nt}(j)dj = (1-\phi)\frac{V_{nt}}{W_{nt}} \int_0^1 Y_{nt}(j)dj, \quad \int_0^1 L^*_{nt}(j)dj = (1-\phi)\frac{V^*_{nt}}{W^*_{nt}} \int_0^1 Y^*_{nt}(j)dj,$$

where $Y_n(j) = Y_{nH}(j) + Y^*_{nH}$ and $Y^*_n(j) = Y^*_{nF}(j) + Y_{nF}(j)$ for all $j \in [0,1]$ and all $n \in \{1,\ldots,N\}$. The demand functions for individual varieties (i.e., $Y_{nH}(j)$, $Y_{nF}(j)$, etc.) are given by (13) and (14) and their foreign counterparts.

To solve for aggregate employment dynamics, we first solve for sectoral employments and sectoral outputs. Since we can obtain solutions to the price indices, consumptions, nominal wages, and exchange rates using the results established in Lemmas 1 and 2, we shall now relate sectoral employments and outputs to these variables.

We begin with outputs and focus on log-linearized equilibrium conditions. Denote by $\bar{Y}_{nt} = \int_0^1 Y_{nt}(j)$ and $\bar{Y}^*_{nt} = \int_0^1 Y^*_{nt}(j)$ the linear aggregates of sectoral outputs in the two countries. Then, using (13) and (14) and the relevant steady-state conditions, we obtain a recursive relation in $\bar{y}_{nt}$ and $\bar{y}^*_{nt}$ given (in log-linearized form) by

$$\begin{aligned}
\bar{y}_{nt} &= \gamma[\eta(\bar{p}_{nt} - \bar{p}_{nHt}) + (1-\phi)(w_t - \bar{p}_{nt}) + \bar{y}_{n+1,t}] + \\
&\quad (1-\gamma)[\eta(\bar{p}^*_{nt} - \bar{p}^*_{nHt}) + (1-\phi)(w^*_t - \bar{p}^*_{nt}) + \bar{y}^*_{n+1,t}], \qquad (45)\\
\bar{y}^*_{nt} &= \gamma[\eta(\bar{p}^*_{nt} - \bar{p}^*_{nFt}) + (1-\phi)(w^*_t - \bar{p}^*_{nt}) + \bar{y}^*_{n+1,t}] + \\
&\quad (1-\gamma)[\eta(\bar{p}_{nt} - \bar{p}_{nFt}) + (1-\phi)(w_t - \bar{p}_{nt}) + \bar{y}_{n+1,t}], \qquad (46)
\end{aligned}$$

for all $n \in \{1,\ldots,N-1\}$. For stage N, we use (4)-(5) and their foreign counterparts to get

$$\begin{aligned}
\bar{y}_{Nt} &= \eta\gamma(1-\gamma)[\bar{p}_{NF} - \bar{p}_{NH} + \bar{p}^*_{NF} - \bar{p}^*_{NH}] + \gamma c_t + (1-\gamma)c^*_t, \qquad (47)\\
\bar{y}^*_{Nt} &= \eta\gamma(1-\gamma)[\bar{p}^*_{NH} - \bar{p}^*_{NF} + \bar{p}_{NH} - \bar{p}_{NF}] + \gamma c^*_t + (1-\gamma)c_t, \qquad (48)
\end{aligned}$$

Sum up $\bar{y}_{nt}$ and $\bar{y}^*_{nt}$ to get

$$x_{nt} = (1-\phi)[w_t - \bar{p}_{nt} + w^*_t - \bar{p}^*_{nt}] + x_{n+1,t}, \quad n \in \{1,\ldots,N-1\} \qquad (49)$$

where $x_n = y_n + y^*_n$. For stage N, the corresponding conditions are given by $x_{Nt} = c_t + c^*_t$. Since we can solve for the consumption and thus x_{Nt} once we obtain solutions of the price indices using the results in Lemmas 1 and 2, we can then solve for x_{nt} by iterating on n using (49).

To solve for y_{nt}, we rewrite (45) as

$$\begin{aligned}
\bar{y}_{nt} &= \eta\gamma(1-\gamma)[\bar{p}_{nFt} - \bar{p}_{nHt} + \bar{p}^*_{nFt} - \bar{p}^*_{nHt}] + (1-\phi)[\gamma(w_t - \bar{p}_{nt}) + (1-\gamma)(w^*_t - \bar{p}^*_{nt})] \\
&\quad + (2\gamma - 1)\bar{y}_{n+1,t} + (1-\gamma)x_{n+1,t}, \quad n \in \{1,\ldots,N-1\}, \qquad (50)
\end{aligned}$$

from which, we can solve for $\bar{y}_{nt}$ by iterating on n, given the solutions of x_{nt} and $\bar{y}_{Nt}$.[20]

[20] Under SLCP, we have $\bar{p}_{nFt} = e_t + \bar{p}^*_{nFt}$ and $\bar{p}^*_{nHt} = \bar{p}_{nHt} - e_t$, so that the terms in the first square bracket in (50) can be reduced to $-2\tau_{nt}$, where $\tau_{nt} = \bar{p}_{nHt} - e_t - \bar{p}^*_{nFt}$ denotes the home country's terms of trade. This is not true under BLCP.

Upon obtaining $\bar{y}_{nt}$, it is straightforward to obtain the sectoral employment l_{nt}, since cost-minimizing implies that

$$l_{nt} = \phi(\bar{p}_{n-1,t} - w_t) + \bar{y}_{nt}, \quad n \in \{2, \ldots, N\}; \quad l_{1t} = \bar{y}_{1t}. \tag{51}$$

Aggregate employment is then a weighted average of sectoral employments given by $l_t = \sum_{n=1}^{N} a_n l_{nt}$, where $a_n = L_n/L$ is the steady-state ratio of employment in sector n to aggregate employment.

A.3. Equilibrium dynamics and welfare with a single stage of processing

We now derive the equilibrium dynamics of consumption and employment that are used to compute the welfare measures in the special case with $N = 1$.

We begin with the case where prices are set in sellers' local currency. As we have established in Lemma A.1, home aggregate demand rises fully while foreign aggregate demand stays unchanged in response to the unilateral home monetary expansion (see (34)). It then follows from the optimal price-adjustment patterns described in (32) that consumptions are given by $c_0 = \gamma/2$, $c_0^* = (1-\gamma)/2$, and $c_t = c_t^* = 0$ for all $t \geq 1$.

To obtain the employment dynamics, we note that, in the case with $N = 1$, employment in the home country is given by $l_t = \bar{y}_{1t}$, as described in (51). Then, it follows immediately from (47) and (48) that

$$l_t = -2\eta\gamma(1-\gamma)\tau_t + \gamma c_t + (1-\gamma)c_t^*, \tag{52}$$

$$l_t^* = -2\eta\gamma(1-\gamma)\tau_t^* + \gamma c_t^* + (1-\gamma)c_t, \tag{53}$$

where $\tau_t = \bar{p}_{1Ht} - \bar{p}_{1Ft}^* - e_t$ denotes the home country's terms of trade, and $\tau_t^* = -\tau_t$ is the foreign counterpart.

Under buyers' local currency pricing, the pricing decisions described in (33) imply that the consumption dynamics are given by $c_0 = 1/2$, $c_t = 0$ for all $t \geq 1$; and $c_t^* = 0$ for all $t \geq 0$. Given the consumption dynamics, we can obtain employment dynamics under BLCP from equations (47), (48), and (51). Specifically, we have $l_0 = \gamma/2$, $l_0^* = (1-\gamma)/2$, and $l_t = l_t^* = 0$ for all $t \geq 1$.

Once we obtain the dynamics of consumption and employment, it is straightforward to solve for the welfare measures defined in (21), where we use (27) to obtain the steady-state value of $\kappa L = 1/\mu$ when $N = 1$. These calculations lead to the expressions of welfare measures in (22)-(23) under SLCP and in (24)-(25) under BLCP in the text.

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Table 1. Equilibrium Conditions under Sellers' Local Currency Pricing

	Home	Foreign
(S1) Pricing decisions:	$p_{nHt} = \frac{1}{1+\beta} v_{nt} + \frac{\beta}{1+\beta} \mathrm{E}_t v_{n,t+1}$,	$p^*_{nFt} = \frac{1}{1+\beta} v^*_{nt} + \frac{\beta}{1+\beta} \mathrm{E}_t v^*_{n,t+1}$
(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:	$x_t = (1-\beta) m_t + \beta \mathrm{E}_t x_{t+1}$, $(x_t \equiv \bar{p}_{Nt} + c_t)$,	$x^*_t = (1-\beta) m^*_t + \beta \mathrm{E}_t x^*_{t+1}$ $(x^*_t \equiv \bar{p}^*_{Nt} + c^*_t)$
(S7) Nominal exchange rate:	$e_t = (1-\beta)(m_t - m^*_t) + \beta \mathrm{E}_t e_{t+1}$	
(S8) Real exchange rate:	$q_t = c_t - c^*_t$	

Table 2. Equilibrium Conditions under Buyers' Local Currency Pricing

	Home	Foreign
(B1) Pricing decisions:	$p_{nHt} = \frac{1}{1+\beta} v_{nt} + \frac{\beta}{1+\beta} \mathrm{E}_t v_{n,t+1}$,	$p^*_{nFt} = \frac{1}{1+\beta} v^*_{nt} + \frac{\beta}{1+\beta} \mathrm{E}_t v^*_{n,t+1}$
	$p^*_{nHt} = \frac{1}{1+\beta}[v_{nt} - e_t] +$	$p_{nFt} = \frac{1}{1+\beta}[v^*_{nt} + e_t] +$
	$\frac{\beta}{1+\beta} \mathrm{E}_t[v_{n,t+1} - e_{t+1}]$,	$\frac{\beta}{1+\beta} \mathrm{E}_t[v^*_{n,t+1} + e_{t+1}]$
(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:	$x_t = (1-\beta) m_t + \beta \mathrm{E}_t x_{t+1}$,	$x^*_t = (1-\beta) m^*_t + \beta \mathrm{E}_t x^*_{t+1}$
	$(x_t \equiv \bar{p}_{Nt} + c_t)$	$(x^*_t \equiv \bar{p}^*_{Nt} + c^*_t)$
(B7) Nominal exchange rate:	$e_t = (1-\beta)(m_t - m^*_t) + \beta \mathrm{E}_t e_{t+1}$	
(B8) Real exchange rate:	$q_t = c_t - c^*_t$	

Figure Legends

Figure 1: The international production and trading structure

Figure 2: The impulse responses of consumption, employment, and utility flows under sellers' local currency pricing

Figure 3: The impulse responses of consumption, employment, and utility flows under buyers' local currency pricing

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

Figure 5: The impulse responses of the home country's export price index and import price index under buyers' local currency pricing

Figure 6: Welfare gains under sellers' local currency pricing

Figure 7: Welfare gains under buyers' local currency pricing

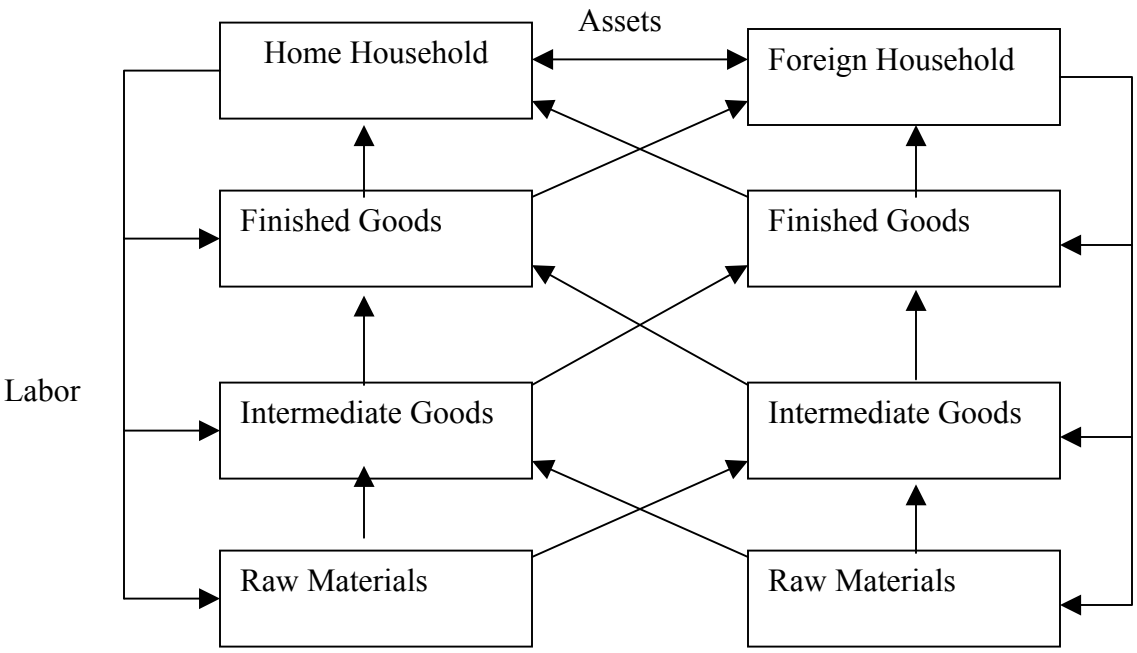


Figure 1: ---The international production and trading structure

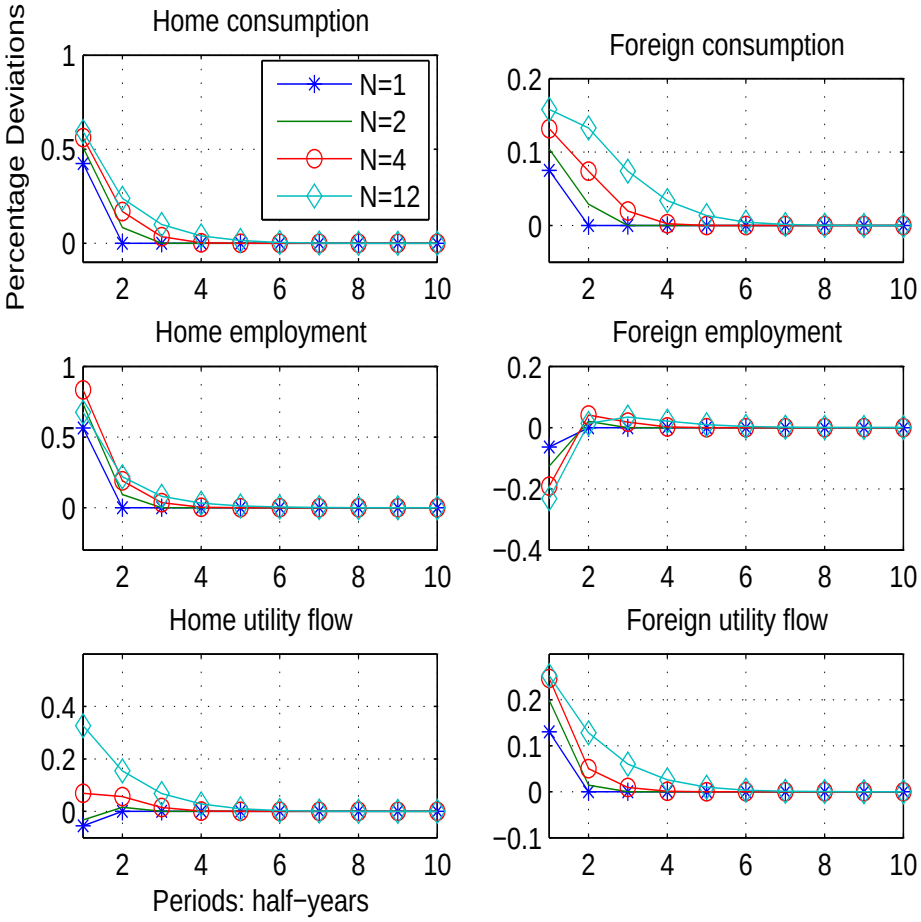


Figure 2:—The impulse responses of consumption, employment, and utility flows under sellers' local currency pricing

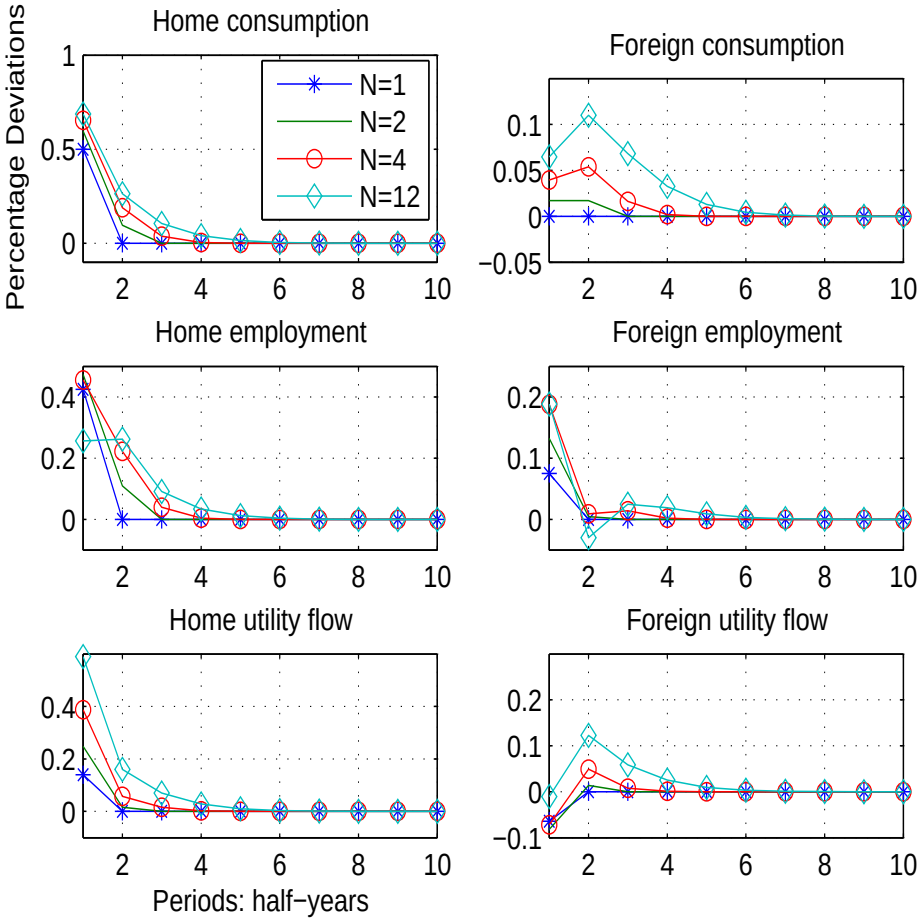
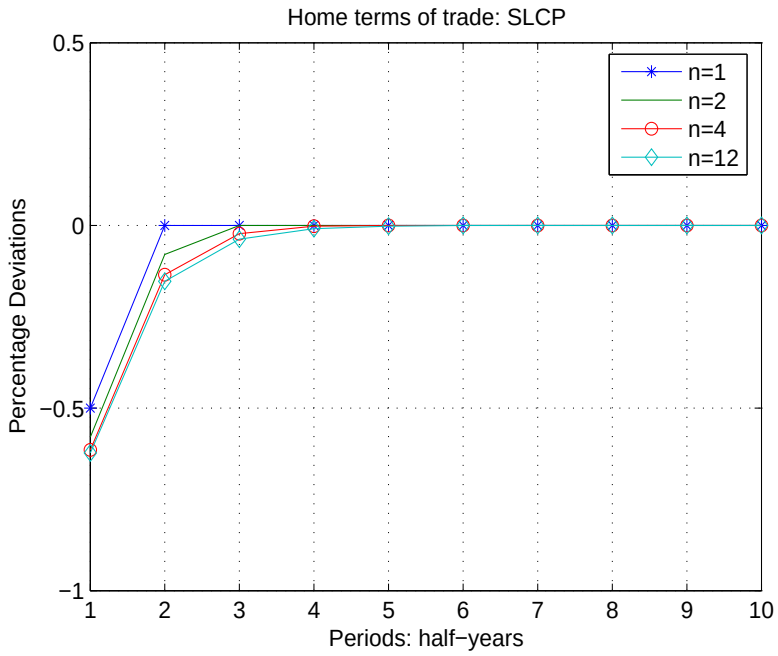


Figure 3:—The impulse responses of consumption, employment, and utility flows under buyers' local currency pricing



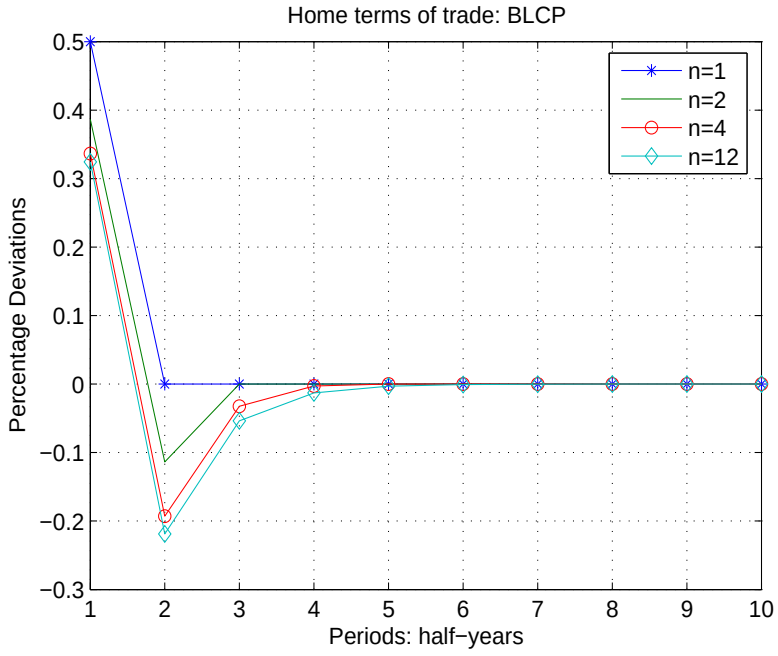
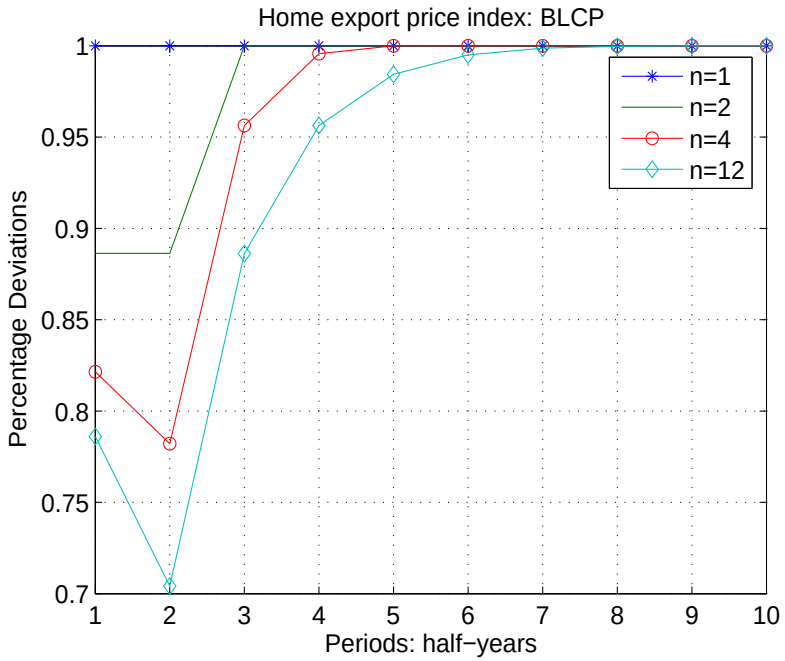


Figure 4:—The impulse responses of the home country's terms of trade



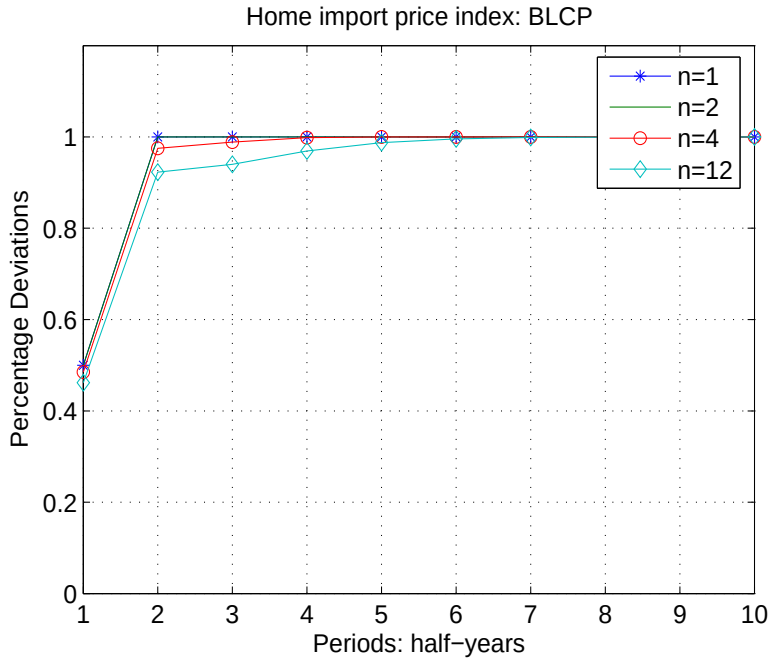


Figure 5:—The impulse responses of the home country's export price index and import price index under buyers' local currency pricing

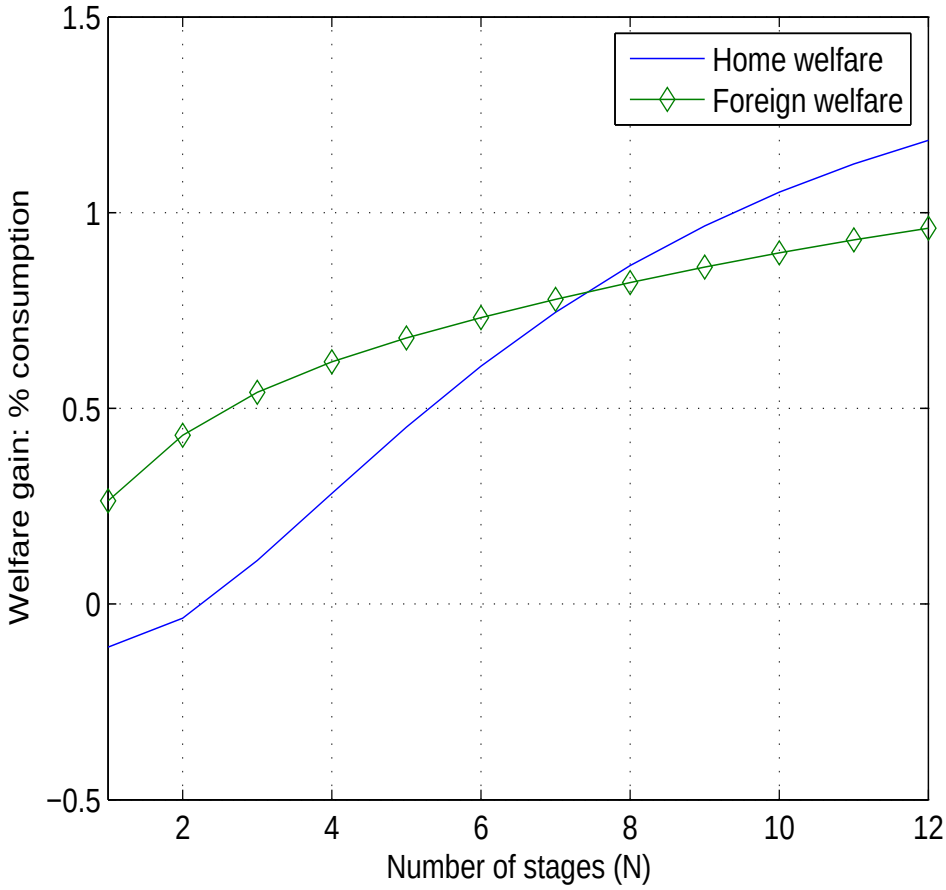


Figure 6:—Welfare gains under sellers' local currency pricing

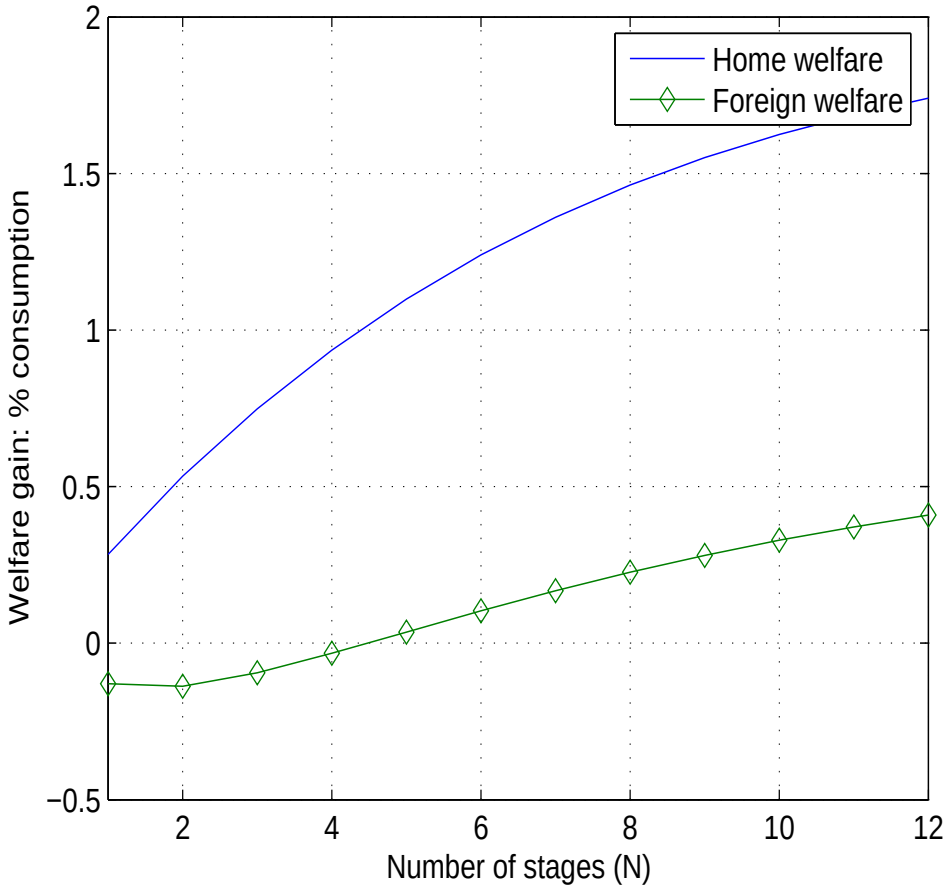


Figure 7:—Welfare gains under buyers' local currency pricing