Fickle Consumers versus Random Technology: Explaining Domestic and International Comovements

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Abstract

Viewing technology shocks as the primary source of business cycles has resulted in many "puzzles" or counter-factual predictions of general equilibrium theory with respect to international movements of output, consumption, investment, employment, and net exports (Backus, Kehoe and Kydland, JPE 1992). There are few puzzles, however, when aggregate demand rather than aggregate supply is the source of uncertainty. In particular, the stylized open-economy business cycle regularities are what standard general equilibrium theory predicts once the usual suspect - fickle consumers - is held responsible for the business cycle. The finding that preference shocks explain both domestic and international business cycles suggests the possibility of a unified explanation of the business cycle and the seasonal cycle, as both types of fluctuations share a common source: recurrent shifts in preferences.

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One of the most salient features of business cycles, argued by Lucas (1977), is the persistent and positive comovements in aggregate economic activities, such as consumption, hours, investment, and output over each business cycle. The real business cycle (RBC) theory introduced by Kydland and Prescott (1982) and Long and Plosser (1983) has so far accounted for such comovements by relying on technology shocks. Demand shocks have not played a major role in RBC models. The heavy reliance of RBC models on technology shocks to explain the business cycle has met many criticisms (see for example, Blanchard, 1989 and 1993; Cochrane, 1994; Evans, 1992; Gordon, 1993; Mankiw, 1989; and Summers, 1986). In the real world, presumably, it is not random technology but fickle consumption demand that is the principal cause of economic fluctuations. Booms and recessions, for example, are understood by central bankers and business people as being driven primarily by consumer spending. This understanding has defined aggregate demand management as the central goal of US monetary policy.[1] This is why despite the "spectacular failures" of traditional Keynesian macroeconometric models and the Phillips curve since the 70s (Lucas and Sargent, 1979), the IS-LM model and its open economy analogue remain popular as a paradigm for business cycle analysis in undergraduate textbooks and among policy makers, as it allows aggregate demand to play an important role in explaining the business cycle.

In this paper I show that RBC models do not need to rely on technology shocks to explain the business cycle. Indeed, perceiving technology shocks as the key source of business cycle comovements has led to many counterfactual predictions of general equilibrium business cycle theory, particularly with respect to international economic fluctuations. For example, Backus, Kehoe, and Kydland (1992) point out that standard general equilibrium models driven by technology shocks cannot explain the observed high cross-country correlations for output and low cross-country correlations for consumption, as well as the positive cross-country comovements for employment and investment; Specifically, predicted cross-country correlations are much higher for consumption than for output and strongly negative for employment and investment in general equilibrium models while the opposite is true in the data. These counter-factual predictions of dynamic general equilibrium theory are so robust to parameter specifications and model modifications that they have been called "puzzles" or "anomalies" in the international finance literature (see Kehoe and Perri, 2000). This literature suggests that market frictions or market incompleteness that inhibit international exchange and risk sharing may be responsible for these anomalies. Yet none of the explanations based on market frictions advanced to date can completely resolve these "puzzles". Some explanations tend to fix one puzzle at the expense of creating others. For

[1] Namely, "to bring the growth of aggregate demand and potential supply into better alignment." (Monetary Policy Report to the Congress, pursuant to section 2B of the Federal Reserve Act, February 13, 2001).

example, Backus, Kehoe, and Kydland (1992) show that imposing trade frictions (transport costs) to inhibit both physical trade across countries and trade in state-contingent claims does not resolve the aforementioned puzzles. Baxter and Crucini (1995) show that assuming random-walk technology shocks in conjunction with incomplete financial markets and capital adjustment costs helps improve predicted cross-country correlations for consumption and output, but it cannot resolve the negative cross-country correlation puzzles for investment and hours and it creates a new puzzle that domestic savings appear to be uncorrelated with domestic investment.[2] Stockman and Tesar (1995) point out that nontraded goods can reduce predicted cross-country correlations for aggregate consumption. However, in a model with both traded and nontraded goods predicted cross-country correlations remain higher for consumption than for output, and predicted relative price movements for traded and nontraded goods are at odds with data. Although they show that country-specific taste shocks in addition to technology shocks can help explain the relative-price movement puzzle, within-country correlations between trade balance and output deteriorate when taste shocks are added. Kehoe and Perri (2000) show that allowing for endogenous incompleteness in international credit markets due to limited enforcement constraints improves the model's goodness of fit in many dimensions but still leaves predicted cross-country correlations higher for consumption than for output. Furthermore, this financial market friction leads to another type of discrepancy: the predicted correlation between net export and output is positive while it is negative in the data. Kollmann (2001) shows that allowing for nominal rigidities and monetary shocks in conjunction with technology shocks cannot completely resolve the output-consumption correlations puzzle.[3]

However, the observed international business cycle patterns are precisely what standard equilibrium theory predicts once we assume that it is shocks to consumption demand that constitute the primary source of aggregate fluctuations. The standard two-country general equilibrium model of Backus, Kehoe, and Kydland (1992), for example, can predict the business cycle comovements for both closed and open economies if the main source of uncertainty is from preferences. In particular, the model can predict: 1) Domestic output, consumption, investment and hours are highly

[2]That national saving rates are highly correlated with national investment rates is one of the most stable regularities observed in the data (Feldstein and Horioka, 1980).

[3]Also see Heathcote and Perri (2000) for discussions on incomplete financial markets and see Chari, Kehoe and McGrattan (2001) for discussions on sticky price models. Obtsfeld and Rogoff (2000) argue that transport costs can resolve six major puzzles in international macroeconomics, including the aforementioned low cross-country consumption correlations puzzle. It is clear from the analysis of Backus, Kehoe and Kydland (1992), however, that transport costs cannot resolve the puzzle that predicted international correlations are higher for consumption than for output and negative for investment and employment in general equilibrium.

persistent and highly correlated with each other over the business cycle (Kydland and Prescott, 1982). 2) Changes in output are more volatile than changes in consumption but less volatile than changes in investment (Kydland and Prescott, 1982). 3) National output, investment and hours are positively correlated with their counterparts in other countries; and the cross-country correlations are much stronger for output than for consumption (Backus, Kehoe, and Kydland, 1992). 4) National saving rates and national investment rates are strongly positively correlated (Feldstein and Horioka, 1980). 5) Net export is less volatile than output and net-export to output ratio is negatively correlated with output (Backus, Kehoe, and Kydland, 1992).[4]

These predictions hold qualitatively regardless of market completeness. The only crucial assumption needed is that the effects of preference shocks on consumption demand be highly persistent. The intuition for consumption demand to be capable of explaining the business cycle comovements is simple. Although transitory shocks to consumption demand tend to have strong crowding-out effects on investment (which result in countercyclical movements in investment), persistent shocks to consumption demand can nevertheless generate positive changes in investment. This is so because the only way to sustain a persistent increase in consumption demand by a representative agent is to build up future capital stocks by investing more. This not only renders investment positively correlated with consumption but also reinforces the initial increase in aggregate demand. Such increases in aggregate demand necessarily result in higher employment and higher output. Consequently, standard equilibrium theory predicts that domestic consumption, investment, output and employment are positively correlated under persistent consumption demand shocks.[5]

In open economies, the same "demand-pull" mechanism applies. Consider a two-country model with full risk sharing. An increase in consumption demand in the home country raises aggregate demand for goods in the world. International risk sharing implies that consumption goods are

[4]The importance of consumption demand shocks for explaining business cycles has been emphasized by the literature studying externalities and increasing returns to scale. Notable examples include Baxter and King (1991), Benhabib and Wen (2000), Farmer and Guo (1994), Guo and Sturzenegger (1998) and Wen (1998). I show in this paper that market failures are not preconditions for understanding domestic and international comovements. Stockman and Tesar (1995) also emphasize the importance of consumption shocks in explaining international business cycles. However, since technology shocks play a major role while taste shocks play only a minor role in their analysis, adding taste shocks in their model does not change the fact that the predicted cross-country correlations are higher for consumption than for output. Apparently they fail to study whether taste shocks alone can generate the correct predictions for domestic and international business cycle comovements.

[5]Consumption shocks do not have to be exogenously persistent in order to generate positive investment growth. I show in the paper that under habit formation even purely transitory shocks (*i.i.d.* shocks) to preferences can generate highly persistent and positive comovements in investment, employment and output.

transferred to the home country, causing a "spillover" demand effect in other countries. Production and employment therefore increase both at home and abroad, resulting in their positive comovements across borders. Investment in both countries must also increase if the change in consumption demand is persistent, leading to increases in world-wide production capacities so as to sustain the persistent rise in world demand. Since consumption shocks are country-specific, consumption expenditures are less synchronized across countries than output. Consequently, standard theory predicts higher cross-country correlations for output than for consumption, as well as positive cross-country correlations for both employment and investment. Since fluctuations are demand-driven (no differences in technologies), there is no incentive for shifting capital across borders when a higher demand for output in one country raises also the demand for output in another country under international risk sharing. Consequently, national saving rates rise due mainly to the increases in national investment rates, not to changes in net exports. Hence predicted national savings and national investment are highly positively correlated, giving rise to the apparent "home-bias puzzle" in international capital allocation (Feldstein and Horioka, 1980).

Calibrated analyses show that consumption shocks explain the bulk of the business cycle even after market frictions and technology shocks are taken into consideration. A key contribution of the paper is therefore to show that business cycles, whether domestic or international, can be explained by a common economic mechanism in general equilibrium - risk sharing based on shocks to consumption demand. A clear implication of this is that it suggests the possibility of a unified explanation of the business cycle and the seasonal cycle, as the two seemingly very different types of fluctuations share a common source: shifts in preferences.[6]

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 studies business cycle implications of consumption demand shocks for closed economies. Section 4 studies business cycle implications of consumption shocks for open economies with complete markets. Section 5 examines the robustness of the consumption-driven business cycles with respect to market frictions and market incompleteness. Section 6 carries out calibrated analysis and measures the quantitative contributions of consumption shocks to business cycles. Section 7 concludes the paper.

[6] As is shown by Miron and Beaulieu (1996), the seasonal cycle is primarily driven by Christmas. Although Christmas spending is highly predictable and short-lived, it is nonetheless expected to have effects on production and employment similar to that of persistent consumption demand shocks.

1 The Model

This is a simplified version of the two-country model studied by Backus, Kehoe and Kydland (1992). Features such as inventory investment and time-to-build in the original model are omitted without loss of generality. To keep the model as simple as possible, I also assume logarithmic utility functions for consumption. The only novel feature of the model is that consumption is (possibly) habit-forming.[7] The theoretical world economy consists of two identical countries, each represented by a large number of identical consumers and an identical production technology. The countries produce the same good and have the same preferences. The labor input in each country consists only of domestic labor, and consumption is subject to country-specific shocks.

In the home (h) and foreign (f) countries, the representative consumer maximizes the expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln \left(c_t^j - b c_{t-1}^j - \Delta_t^j \right) - a \frac{\left(n_t^j \right)^{1+\gamma}}{1+\gamma} \right\}, \quad \text{for } j = h, f, \tag{1.1}$$

where $b \in [0, 1)$ measures the degree of habit formation in consumption, $\gamma \geq 0$ measures the inverse labor supply elasticity, c is consumption of the produced good, n is labor supply, and Δ represents a country-specific random shock to the marginal utility of consumption or to the habitual consumption level, which generates the urge to consume (Baxter and King, 1991). I assume that Δ follows a stationary $AR(1)$ process in log:

$$\log \Delta_t^j = (1-\rho) \log \Delta^* + \rho \log \Delta_{t-1}^j + \varepsilon_t^j, \qquad \text{for } j = h, f;$$

where $0 \leq \rho < 1$ measures the persistence of the consumption shocks.

Production of the single good takes place in each country according to the constant-returns-to-scale technology

$$y_t^j = \left(k_t^j \right)^{\alpha} \left(n_t^j \right)^{1-\alpha}, \quad \text{for } j = h, f. \tag{1.2}$$

World output from the two processes, $y_t^h + y_t^f$, is allocated to consumption and fixed investment:

$$\sum_j \left[c_t^j + k_{t+1}^j - (1-\delta) k_t^j \right] = \sum_j \left(k_t^j \right)^{\alpha} \left(n_t^j \right)^{1-\alpha}. \tag{1.3}$$

Next exports is $nx_t^j = y_t^j - \left[c_t^j + k_{t+1}^j - (1-\delta) k_t^j \right]$.

By exploiting the equivalence between competitive equilibria and Pareto optima, an equilibrium in this world economy can be computed as the solution to a planning problem of the following

[7] The reason for incorporating habit formation will become clear later.

form:

$$\max_{\{c_t^j, n_t^j, \tau_t^j, K_{t+1}\}_{t=0}^{\infty}} \sum_j \left\{ E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln\left(c_t^j - bc_{t-1}^j - \Delta_t^j\right) - a\frac{\left(n_t^j\right)^{1+\gamma}}{1+\gamma} \right\} \right\} \tag{1.4}$$

subject to

$$\sum_j c_t^j + [K_{t+1} - (1-\delta)K_t] \leq \sum_j \left(\tau_t^j K_t\right)^{\alpha} \left(n_t^h\right)^{1-\alpha}, \tag{1.5}$$

$$\sum_j \tau_t^j \leq 1, \tag{1.6}$$

and $K_0 > 0$ given for $j = h, f$; where K denotes the world capital stock and $\tau^j \in [0,1]$ denotes the fraction of the world capital stock allocated to production in country j. Without loss of generality, an equal weight is assumed in the objective function.

The first-order conditions are given by:

$$\frac{1}{c_t^j - bc_{t-1}^j - \Delta_t^j} - E_t \frac{\beta b}{c_{t+1}^j - bc_t^j - \Delta_{t+1}^j} = \lambda_t, \tag{1.7}$$

$$a\left(n_t^j\right)^{\gamma} = (1-\alpha)\lambda_t \left(\tau_t^j K_t\right)^{\alpha} \left(n_t^j\right)^{-\alpha}, \tag{1.8}$$

$$\alpha \left(\tau_t^j\right)^{\alpha-1} K_t^{\alpha} \left(n_t^j\right)^{1-\alpha} = \mu_t, \tag{1.9}$$

$$\lambda_t = \beta E_t \lambda_{t+1} \left[\sum_j \alpha \left(\tau_{t+1}^j\right)^{\alpha} K_{t+1}^{\alpha-1} \left(n_{t+1}^j\right)^{1-\alpha} + (1-\delta) \right], \tag{1.10}$$

$$\sum_j c_t^j + [K_{t+1} - (1-\delta)K_t] = \sum_j \left(\tau_t^j K_t\right)^{\alpha} \left(n_t^h\right)^{1-\alpha}, \tag{1.11}$$

$$\sum_j \tau_t^j = 1; \tag{1.12}$$

where $\{\lambda, \mu\}$ are Lagrangian multipliers associated with the world-wide resource constraints (1.5) and (1.6) respectively. The resource constraints support international risk sharing via three channels of cross-country transfers: transfer of consumption goods, transfer of investment goods, and transfer of fixed assets (i.e., factors of production). Equation (1.7) shows that the (expected) marginal utilities of current consumption are equalized across countries due to transfer of consumption goods. Equation (1.8) is the labor-market equilibrium condition for each country. Equation (1.9) shows that the marginal products of capital are equalized across countries due to transfer of fixed assets (capital mobility). Equation (1.10) equates the marginal cost of current savings to the expected marginal returns to investment in the world capital market due to transfer of investment goods. Due to international transfers of capital and investment goods, capital used in production in a specific country is not necessarily owned by residents of that country; thus, gross investment in a specific country (j) can be defined as

$$\begin{aligned} i_t^j &= \pi^j K_{t+1} - (1-\delta)\pi^j K_t + (\tau_t^j - \pi^j) K_t \\ &= \pi^j I_t + (\tau_t^j - \pi^j) K_t, \end{aligned}$$

where I_t denotes the aggregate world investment, and π^j denotes the fraction of the world population residing in country j, which is also the steady state value for τ_t^j. The last term in the above expression for national investment, $(\tau_t^j - \pi^j)K_t$, indicates the size of foreign capital operating in country j during period t, and is called foreign direct investment.[8] Foreign direct investment for country j is positive if $\tau^j > \pi^j$ and negative if $\tau^j < \pi^j$. Consequently, gross investment in a specific country consists of net increases in both home-owned capital stock $(\pi^j I_t)$ and foreign direct investment. Net exports is $nx_t^j = y_t^j - c_t^j - i_t^j$.

2 Autarky

The existing literature seems to embrace a notion that a closed-economy RBC model must rely on technology shocks to explain domestic business cycle comovements. This perception is due in part to the fact that closed-economy real business cycle models with technology shocks have accounted for many of the features of postwar U.S. business cycles (Kydland and Prescott, 1982), and in part to the fact that nontechnology shocks such as government spending or consumption demand shocks generate countercyclical movement in investment due to strong crowding out. Baxter and King (1991), for example, show that in order for consumption shocks to generate positive movements in investment in a closed-economy general equilibrium model, the degree of increasing returns to scale has to be very strong; Otherwise, consumptions shocks generate countercyclical movements in investment with respect to output and employment.

I show here that consumption shocks *can* generate positive movements in investment in closed-economy RBC models with constant returns to scale production technology provided that the effect of shocks are sufficiently persistent. It is therefore incorrect to believe that general equilibrium theory must rely on technology shocks to explain domestic business cycle comovements. This result applies also to open economies (which will be considered in the next section).

In autarky, all channels of international transfers are turned off, hence the first-order conditions

[8] Note that although the next-period world capital stock (K_{t+1}) is known at time t, the next-period capital stock operating in a specific country, $k_{t+1}^j = \tau_{t+1}^j K_{t+1}$, cannot be determined in time period t because τ_{t+1}^j can be determined only in period $t+1$.

(1.7)-(1.12) become:

$$\frac{1}{c_t - bc_{t-1} - \Delta_t} - E_t \frac{\beta b}{c_{t+1} - bc_t - \Delta_{t+1}} = \lambda_t, \tag{2.1}$$

$$a\,(n_t)^{\gamma} = (1-\alpha)\lambda_t\,(k_t)^{\alpha}\,(n_t)^{-\alpha}\,, \tag{2.2}$$

$$\lambda_t = \beta E_t \lambda_{t+1}\left[\alpha\,(k_{t+1})^{\alpha-1}\,(n_{t+1})^{1-\alpha} + (1-\delta)\right], \tag{2.3}$$

$$c_t + k_{t+1} - (1-\delta)k_t = (k_t)^{\alpha}\,(n_t)^{1-\alpha}\,; \tag{2.4}$$

where all variables are country-specific; In particular, λ is the multiplier associated with country-specific resource constraint (2.4) and k is the country-specific capital stock.

A. Exogenous Persistence

I first prove that exogenously persistent consumption shocks can generate positive and persistent movements in investment (as well as output, consumption and hours) without habit formation (i.e., $b = 0$). I then show that with habit formation even *i.i.d.* consumption shocks can generate positive and persistent movements for investment and output.

Proposition 1. Output, consumption, and hours always respond positively to consumption shock Δ. Investment, however, responds positively to consumption shock Δ if and only if the shock is persistent enough. For example, when $\gamma = 0$, positive responses for investment are possible if and only if

$$\rho > \frac{\alpha}{\alpha + (1-\alpha)\,(1-\beta(1-\delta))}.$$

Proof. (See Appendix).[9]

The first part of proposition 1 is well known (e.g., see Baxter and King, 1991). The second part of proposition 1 regarding investment behavior, however, has gone unnoticed in the literature. The intuition for proposition 1 is as follows. An increase in Δ creates an urge to consume by increasing the marginal utility of consumption. However, the resulting increase in consumption is smaller in proportion than the increase in Δ, otherwise the original consumption allocation would not have been optimal. Consequently, the price of leisure (or the utility value of real wage) goes up, rendering it optimal to increase labor supply. Hence in equilibrium, employment and output also increase in response to Δ. When the shock is transitory, however, the marginal utility of current consumption exceeds the marginal utilities of future consumption, hence savings (investment) are crowded out. When the shock is highly persistent, on the other hand, the marginal utilities of

[9] The analytical proof is carried out for the special case $\gamma = 0$ (Hansen's (1985) indivisible labor). Cases for $\gamma > 0$ can be proved analogously but the analytical expressions become very tedious and do not add any new insight. Cases for $\gamma > 0$ are confirmed by numerical analysis later in the paper.

future consumption increase, rendering optimal to increase savings (investment). This results in still higher output and employment, generating persistent and positive comovements in output, consumption, employment and investment.

Note that the required degree of persistence for consumption shocks depends on other parameters in the model. For example, when $\delta = 1$, a positive change for investment is optimal even when the shock is short lived (it requires only $\rho > \alpha$). Given that α is between 0.3 to 0.4 in the data, very mild persistence of consumption shocks is able to induce positive responses from investment. The intuition is that a higher value of δ increases the marginal impact of investment on the capital stock, hence the marginal rate of return to investment increases despite the fact that the average rate of return to investment decreases as δ gets larger. Hence, less persistent shocks are required to induce positive investment. On the other hand, when δ is very small (say 0.025), $\rho > 0.925$ is required to induce positive investment in the model if $\alpha = 0.3, \beta = 0.99, \gamma = 0$.[10]

Figure 1 presents the impulse responses of output, consumption, investment and hours to one standard deviation consumption shock when the parameters are calibrated at $\alpha = 0.3, \beta = 0.99, \gamma = 0, \delta = 0.025$, $\frac{\Delta}{c} = 0.01$, and when the persistence parameter takes two possible values: $\rho = 0.90$ and $\rho = 0.98$. The left window of figure 1 presents the case for $\rho = 0.90$. It shows that both employment and output respond positively to the consumption shock. Investment responds negatively, however, to the consumption shock due to crowding out, which confirms the analysis of Baxter and King (1991). The right window of figure 1, in contrast, shows that the responses of investment become strongly positive when the consumption shock is highly persistent. This is so because the only way to sustain such highly persistent increases in consumption demand is to build up larger production capacity by investing more. Therefore, three salient features of the business cycle emerge. First of all, the responses of output, consumption, investment and hours are all positively correlated with each other. Secondly, consumption is less volatile than output and investment is more volatile than output (diversifying preference risk intertemporally results in consumption smoothing). Thirdly, all variables exhibit substantial amount of serial correlation in transitional dynamics. These features of the business cycle are well documented in the RBC literature (e.g., see Kydland and Prescott, 1982).

The phenomenon that the predicted volatility of consumption relative to output decreases as preference shocks become more persistent is interesting. Intertemporal risk diversification suggests that consumption volatility relative to income increases as income shocks become more

[10] Interestingly, Baxter and King (1991) show that investment respond negatively to consumption shocks when $\rho = 0.97$ without externalities. But given the parameter specifications in their model, $\rho > 0.97$ is required to generate positive investment.

persistent. For example, with present parameter specifications, consumption volatility is only about 10% of output volatility when technology shocks are *i.i.d.* and consumption becomes as volatile as output when technology shocks are permanent. In contrast, consumption is about 10 times more volatile than output when preference shocks are *i.i.d.* and its volatility is only about 40% of output volatility when preference shocks are permanent. This is so because the principle of risk diversification works differently under preference shocks than under technology shocks. When the urgency to consume is transitory, agents opt to use up savings to satisfy current needs, leaving production level roughly constant. When the urgency to consume is permanent, however, individuals opt to produce more than currently needed so as to increase savings to satisfy future needs. This means that in an endowment economy where the income level is constant, current savings decrease less when the urgency to consume is more persistent. In other words, consumers are willing to pay a risk premium to avoid a less severe but more persistent urge to consume.

B. Endogenous Persistence

The requirement that consumption shocks be highly persistent in order to generate positive investment may call into question the empirical plausibility of preference shocks as the primary source of the business cycle.[11] In this section I show that rational habit formation has a powerful effect on enhancing the propagation mechanism of general equilibrium business cycle models – it renders transitory preference shocks endogenously persistent. Consequently, in order to generate the positive and persistent comovements among consumption, output, hours, and investment, consumption shocks need not be serially correlated.

Habit formation has a long history in the study of consumption dynamics (see Deaton, 1992, for an overview). Recently, it has been used by Constantinides (1990), Abel (1990), Campbell and Cochrane (1999), and Boldrin, Christiano and Fisher (2001) to explain asset markets business cycles. The habit-formation parameter b has been estimated by many people in the empirical literature and the results change substantially depending on the instrument variables used and whether monthly or quarterly data are used. According to Ferson and Constantinides (1991), best point estimates of b for U.S. quarterly data lie between 0.95 and 0.97 with standard errors of 0.05 and 0.01 respectively, depending on the number of lags chosen for the financial instrument variables.[12] Through out the paper, I choose $b = 0.95$ as my benchmark value for habit persistence.

[11] The required persistence (ρ) to generate highly volatile investment in the model depends on the other parameters in the model, since the minimum level of ρ required for positive investment increases as α and γ increase. For example, $\rho^{min} = 0.95$ if $\alpha = 0.42$ and $\rho^{min} = 0.96$ if $\gamma = 0.25$. To generate investment responses that are more volatile than consumption requires $\rho > 0.97$ when $\gamma = 0.25$.

[12] Using quarterly data from other industrial countries, Braun, Constantinides and Ferson (1992) find that the

The dynamic effects of habit formation are shown in figure 2 (with $b = 0.95$).[13] The left window presents the responses of output, consumption, hours and investment to an *i.i.d.* consumption shock. It shows that investment responds positively to the shock despite the fact that the shock is transitory. This is so because the representative agent anticipates the impact of the shock on consumption to persist due to rational habit formation, rendering it optimal to increase investment so as to meet the anticipated increases in future consumption demand. Thus, habit formation effectively renders the impact of transitory consumption shocks *endogenously* persistent. The right window presents impulse responses of the variables to a persistent consumption shock ($\rho = 0.9$). It shows that habit formation and persistent shocks interact to generate more complicated dynamics, so that consumption and output start to exhibit hump-shaped response pattern and investment becomes far more volatile than consumption.

To evaluate the plausibility of preference shocks as the main source of business cycles, I simulate the closed economy model and compare the simulated time series with the actual U.S. data. I choose the University of Michigan Index for Consumer Confidence as a proxy for preference shocks.[14] OLS autoregression gives the following estimates:

$$x_t = 0.33(0.13) + 0.92(0.03)x_{t-1} + v_t, \tag{2.5}$$

where x is the log of the Index and the numbers in parentheses are standard errors. The estimated persistence parameter is consistent with my specification $\rho = 0.9$. The residual variable (v_t) is taken as innovations of consumption shocks and is fed into the model to generate artificial data. Figure 3 presents the Hodrick-Prescott (H-P) filtered artificial data and U.S. data.[15] Given the simplicity of the model, the pictures indicate that the model preforms surprisingly well in explaining postwar U.S. economic fluctuations with respect to output, consumption, investment and total hours. The

point estimates of b are 0.82 (U.K.), 0.69 (France), 0.93 (Canada), 0.63 (Germany), and 0.64 (Japan) with relatively large standard errors. They also find that the log unity function is not rejected by most of these countries.

[13]The other parameter values are kept the same except that $\frac{\Delta}{c}$ is decreased from 0.1 to 0.045 in order to satisfy the condition: $1 - b - \frac{\Delta}{c} > 0$. The value of $\frac{\Delta}{c}$ affects the volatilities of consumption and other variables, but the relative second moments of the model are not sensitive to the values of $\frac{\Delta}{c}$.

[14]The data is taken from Citibase (1953:1 - 1996:4).

[15]The estimated standard deviation of v_t is 0.0685, slightly larger than required. In order to match the standard deviation of the U.S. output, I have scaled down v_t by a rescaling parameter $s = \frac{1}{1.7}$. The U.S. data are taken from Citibase (1960:1 - 1994:4). Total hours is defined as total employment times average hours worked weekly by household survey ($LHEM \times LHCH$); Investment is defined as total private fixed investment ($GIFQ$); Consumption is defined as total consumption expenditures on nondurable goods and services ($GCNQ + GCSQ$); And output is defined as the sum of investment and consumption. The model generated time series shown in figure 1 are shifted backward for 2 quarters since the University of Michigan Index strongly leads the business cycle by 2-3 quarters at the business cycle frequencies.

quality of the predictions is comparable to that obtained using the estimated Solow residual as the source of shocks (e.g., see Plosser, 1989). The statistical properties of the time series in figure 3 are summarized in Table 1, which shows that the model does a very good job in predicting the relative volatilities of consumption and investment. The model overpredicts the volatility of hours relative to output due to diminishing marginal product of labor. Regarding the correlations with output as well as the autocorrelations of these variables, the model does a reasonably good job.

Table 1. Selective Moments

	σ_x	σ_x/σ_y			$cor(x_t, y_t)$			$cor(x_t, x_{t-1})$			
	y_t	c_t	i_t	n_t	c_t	i_t	n_t	y_t	c_t	i_t	n_t
U.S.	0.016	0.53	3.36	0.87	0.92	0.96	0.82	0.90	0.86	0.89	0.82
Model	0.016	0.56	3.68	1.38	0.65	0.90	0.99	0.80	0.95	0.74	0.78

3 Open Economy

To understand why consumption demand shocks can help resolve the international comovement puzzles, I illustrate how technology shocks created these puzzles in the first place. Without loss of generality, assume no habit formation and consider only country-specific technology shocks (A^j) in the production functions. The first-order conditions for the open economy, equations (1.7)-(1.12), can be rewritten as (let $\Delta^j = 0$ for $j = h, f$):

$$\frac{1}{c_t^h} = \frac{1}{c_t^f} \tag{3.1}$$

$$A_t^h (\tau_t)^\alpha \left(n_t^h\right)^{-\alpha-\gamma} = A_t^f (1-\tau_t)^\alpha \left(n_t^f\right)^{-\alpha-\gamma} \tag{3.2}$$

$$A_t^h (\tau_t)^{\alpha-1} \left(n_t^h\right)^{1-\alpha} = A_t^f (1-\tau_t)^{\alpha-1} \left(n_t^f\right)^{1-\alpha}, \tag{3.3}$$

where τ_t denotes the home-country's share of the world capital stock. These first-order conditions imply the following cross-country ratios:

$$\frac{c_t^h}{c_t^f} = 1 \tag{3.4}$$

$$\frac{y_t^h}{y_t^f} = \frac{\tau_t}{1-\tau_t} = \left(\frac{A_t^h}{A_t^f}\right)^{\frac{1+\gamma}{\gamma(1-\alpha)}} \tag{3.5}$$

$$\frac{n_t^h}{n_t^f} = \left(\frac{A_t^h}{A_t^f}\right)^{\frac{1}{\gamma(1-\alpha)}}. \tag{3.6}$$

These cross-country ratios indicate a perfect cross-country correlation for consumption and imperfect cross-country correlations for other variables such as output, investment and labor (due to the assumption that technology shocks are country specific). In particular, since the capital share τ_t is completely dictated by technology ratios across countries, the predicted cross-country correlations for output, investment and labor are all negative under country specific technology shocks.[16]

Consider a positive technology shock in the home country. Consumption increases both at home and abroad because of an international income effect supported by the channel of transfer of consumption goods. Employment increases at home and decreases abroad for two reasons. The first is an international substitution effect of leisure supported by risk sharing, which causes the high-productivity country to decrease leisure and the low-productivity country to increase leisure. This substitution effect exists regardless of capital mobility, as long as countries can trade in currently produced goods. The second is capital mobility, which permits existing capital to flow to the highest returns, thus increasing demand for labor at home and decreasing labor demand abroad. Consequently, cross-country correlations for employment (as well as output) are negative. Investment increases at home and decreases in the foreign country also for two reasons. Firstly, the ability to transfer investment goods across national borders induce national savings flow to the highest expected returns; Secondly, capital mobility implies that the direct foreign investment is positive in the home country and negative in the foreign country (capital drain). Hence, general equilibrium theory predicts that cross-country correlations for output, employment and investment are all negative under technology shocks unless these shocks are highly positively correlated across countries.

Thus puzzles arise: the predicted cross-country correlations are much higher for consumption than for output, while in the data the opposite is true; and the predicted cross-country correlations of employment and investment are negative, while in the data they are positive. Furthermore, the predicted volatilities for both investment and net exports relative to output are excessively large

[16] The cross-country ratios indicate that the volatilities of the model are very sensitive to the inverse labor supply elasticity parameter γ. As γ approaches zero, for example, even a very small technology shock can generate extremely volatile movements in output and labor due to factor mobility across countries. The volatility of factor mobility can be determined by log-linearizing equation (3.5), which gives

$$\left(\frac{1}{1-\tau}\right)\hat{\tau}_t = \frac{1+\gamma}{\gamma a(1-\alpha)}\left(\hat{A}_{ht} - \hat{A}_{ft}\right),$$

where circumflex variables denote percentage changes around the steady state. Assuming that country specific technology shocks have identical variances (σ_A^2) and are uncorrelated, we have

$$\sigma_\tau = \sqrt{2}(1-\tau)\frac{1+\gamma}{\gamma(1-\alpha)}\sigma_A.$$

For example, let the steady-state value of the world capital share $\tau = 0.5$, and let $\gamma = 0.25$ and $\alpha = 0.3$, we then have $\sigma_\tau \approx 5\sigma_A$. It is also clear that σ_τ approaches infinity as γ approaches zero.

compared to the observed values.[17] There has been no shortage of explanations in the literature for these puzzles, with most of them focusing on market frictions and market incompleteness that inhibit international risk sharing. The problem is that some of these puzzles, especially the cross-country consumption correlations puzzle, are extremely robust to model modifications such that none of the explanations advanced to date in the literature can completely resolve these puzzles at once.

There is no puzzle, however, if the primary source of shocks causing short-run economic fluctuations in international trade comes from the demand side (consumption) rather than from the supply side (technology). Under consumption demand shocks, the first-order conditions for the open economy implies the following cross-country ratios:

$$\frac{c_t^h - \Delta_t^h}{c_t^f - \Delta_t^f} = 1, \tag{3.7}$$

[17]To see this, consider the percentage changes in the home-country's quantities relative to the steady state. Log-linearizing equation (3.5) and the definition of national investment around the steady state and simplifying gives:

$$\hat{y}_t^h - \hat{y}_t^f = \frac{1}{1-\tau}\hat{\tau}_t$$

$$\hat{\imath}_t = \frac{1}{\delta}\hat{K}_{t+1} - \frac{1-\delta}{\delta}\left(\hat{K}_t - \hat{\tau}_t\right) = \hat{I}_t + \frac{1}{\delta}\hat{\tau}_t,$$

where $\hat{I}$ denotes the percentage changes in total world investment. Denote σ_x as the standard deviation for x and $\rho(x_1, x_2)$ as the correlation between x_1 and x_2. The first equation implies:

$$\sigma_{y^h}^2 + \sigma_{y^f}^2 - 2\rho(y^h, y^f)\sigma_{y^h}\sigma_{y^f} = 4\sigma_\tau^2.$$

Suppose county-specific technology shocks are symmetric and are uncorrelated, then we can have the approximations, $\sigma_{y^h}^2 = \sigma_{y^f}^2$ and $\rho(y^h, y^f) \leq 0$. Hence, $2\sigma_{y^h}^2 \leq 4\sigma_\tau^2$, which implies $\sigma_{y^h} \leq \sqrt{2}\sigma_\tau$.

On the other hand, the investment equation implies

$$\sigma_i^2 = \sigma_I^2 + \left(\frac{1}{\delta}\right)^2 \sigma_\tau^2 + 2\rho(I,\tau)\sigma_I\sigma_\tau.$$

Given that the quarterly rate of capital depreciation $\delta = 0.025$, we have $\left(\frac{1}{\delta}\right)^2 = 160$. Hence the variance of i is clearly dominated by the variance of τ, which gives the approximation $\sigma_i \approx 40\sigma_\tau$. These results imply that $\sigma_i \gtrapprox 28\sigma_y$, namely, investment is at least 28 times more volatile than output under country-specific technology shocks. In the data, however, investment is only about as 3 times volatile as output. Such an extremely volatile investment leads also to an extremely volatile net exports. To see this, note that the percentage changes in net exports are given by

$$\widehat{nx}_t = \hat{y}_t - s_c\hat{c}_t - s_i\hat{\imath}_t,$$

where $s_c + s_i = 1$ are the steady-state shares of consumption and investment in output. Clearly the volatility of net exports is dominated by that of investment, hence we have $\sigma_{nx}^2 \approx s_i^2\sigma_i^2$ (consumption is much less volatile than output due to consumption smoothing and risk sharing under income shocks). Assuming that investment share $s_i = 0.2$, we have $\sigma_{nx} \approx 0.2\sigma_i \gtrapprox 5.6\sigma_y$; namely, net exports is at least about 6 times more volatile than output. In the data, however, net exports is less volatile than output.

$$\frac{y_t^h}{y_t^f} = \frac{n_t^h}{n_t^f} = 1, \tag{3.8}$$

$$\frac{\tau_t}{1 - \tau_t} = 1. \tag{3.9}$$

The last equation implies that the optimal foreign direct investment (capital mobility) is zero (i.e., τ_t is constant).[18] Hence,

$$\frac{i_t^h}{i_t^f} = 1. \tag{3.10}$$

These cross-country ratios imply that output, investment and labor are perfectly synchronized across countries while consumption is imperfectly correlated across countries (due to country-specific demand shocks). Thus, unless consumption shocks are perfectly correlated across countries, the predicted cross-country correlations are higher for output than for consumption (as observed in the data); and the predicted cross-country correlations for employment and investment are positive (as observed in the data).

The intuition is simple. It is a typical story of aggregate demand. Consider an increase in consumption demand in the home country due to a high urgency to consume. This raises demand for both domestic output and foreign output under international risk sharing. Hence production increases both at home and abroad in response to the higher world demand. In the mean time, investment may also rise both at home and abroad if the increase in demand is persistent, so that each country can build up more production capacities to sustain the persistent increases in world demand.[19] The higher investment demand across countries reinforces the initial rise in total world demand. Consequently, we observe strongly positive movements in output, investment and employment in both countries (perfect correlations). On the other hand, if the urge to consume (demand shock) is country specific, consumption will be less correlated across countries than output.[20] Furthermore, since capital does not flow across borders, national savings arise due mainly to the increases in national investment demand, hence the predicted domestic saving-investment correlations are positive, as they are in the data.[21] In addition, given that τ_t does not respond to Δ_t, the predicted volatilities of investment and net exports are substantially lower

[18] The reason for τ_t being constant under demand shocks is that domestic investment possibilities offer sufficient scope for self-insurance through intertemporal domestic reallocations when the two countries have identical technologies. Hence foreign direct investment is not optimal unless there are technology shocks which create differentials in returns to capital across countries.

[19] The increases in world demand are persistent either due to persistent demand shocks or due to habit formation in consumption.

[20] Risk sharing maximizes the cross-country correlations for $(c_t - \Delta_t)$, not for c_t.

[21] Under symmetric consumption demand shocks across countries, net exports of newly produced goods can be either positive or native (with zero mean) and is not closely correlated with world investment (which is always

than they are under technology shocks.[22]

Thus, general equilibrium theory predicts that when urges to consume arise in a specific country, international risk sharing causes a world-wide production synchronization, giving rise to the apparently puzzling phenomenon that "When an economic boom produces high output, employment, and investment in the United States, there is usually a simultaneous boom in other industrialized countries." (Baxter and Farr, 2001). This phenomenon is puzzling, however, only if we assume that international business cycles are driven primarily by technological differentials across countries. With consumption demand shocks as the main driving force of business cycles, the aforementioned phenomenon is expected and all the international comovements "puzzles" disappear at once.

The above discussions can be quantified by impulse response analysis. Let the capital-income share $\alpha = 0.3$, the time-discount factor $\beta = 0.99$, the labor supply elasticity parameter $\gamma = 0$, the capital depreciation rate $\delta = 0.025$, the steady state habit-demand to consumption ratio $\frac{\Delta}{c} = 0.045$, and the habit formation parameter $b = 0.95$. Figure 4 shows the impulse responses of output, consumption, hours and investment ($1 =$ home country and $2 =$ foreign country) to an *i.i.d.* technology shock at home. It is seen there that output, investment and employment increase in the home country and decrease in the foreign country in response to the shock at home, indicating negative cross-country correlations for these variables. In the meantime consumption increases in both countries and shows perfect correlations across countries. Highly persistent technology shocks give qualitatively similar results.

The dynamic effects of consumption shocks are dramatically different. Figure 5 shows the impulse responses of the same variables to an *i.i.d.* consumption demand shock at home. It is seen there ($1 =$ home country and $2 =$ foreign country) that movements of output, investment and employment are not only highly persistent in each country but also highly correlated across countries, indicating the "demand-pull" cross-country effects of consumption shocks. It shows

positive). Hence,

$$Cov(s^j, i^j) = Cov(nx^j + I, I) = \sigma_I^2,$$

and

$$\sigma_s^2 = \sigma_{nx}^2 + \sigma_I^2,$$

for $j = h, f$. These imply

$$\rho(s^j, i^j) = \frac{\sigma_I}{\sigma_s} = \frac{\sigma_I}{\sqrt{\sigma_{nx}^2 + \sigma_I^2}} \in (0, 1).$$

It is clear then that the saving-investment correlation is not only positive but also close to one since the volatility of net exports is small relative to that of investment under persistent consumption shocks.

[22]When τ_t is constant, the volatility of investment for each country becomes the same as that of the aggregate world investment.

how an economic boom in one country can lead to a simultaneous boom in another country (production synchronization). It also shows that consumption movements are less synchronized across countries due to the shock being country specific.

It is worth noting that the endogenous propagation mechanism created by habit formation in one country can induce similar propagation mechanism in another country through the "demand-pull" channel of business cycle transmissions, even if the other country does not have endogenous propagation mechanisms. For example, let the habit formation parameter in the foreign country be zero ($b^f = 0$). Then a negative *i.i.d.* consumption shock in the foreign country generates only a temporary drop in output in that country. However, a negative *i.i.d.* consumption shock in the home country can lead to a prolonged recession in the foreign country because the endogenous propagation mechanism in the home country generates persistently lower consumption demand for goods produced both at home and abroad (see figure 6). Hence, there is the well-known phenomenon that the whole world catches cold when the U.S. economy sneezes; And the cold is never cured before the sneezes are over.[23]

4 Robustness

Although market frictions are not preconditions for explaining international business cycle puzzles, they are by no means unrealistic features of actual open economies. This section discusses whether the predicted consumption-driven business cycles are robust to market frictions. This discussion also helps understand the acknowledged robustness of the anomalies created by technology shocks.

There are three types of markets in the one-good model to support international risk sharing: markets for currently produced consumption goods, markets for currently produced investment goods and markets for fixed assets. The first two types of markets provides risk sharing via transfer of consumption goods or future capital goods across borders, and the third type of markets provides risk sharing via transfer of factors of production across borders. The frictions introduced so far in the literature, whether they be transportation costs (Backus, Kehoe and Kydland, 1992), nontraded goods (Stockman and Tesar, 1995), or incomplete financial markets (Baxter and Crucini, 1995; Kollmann, 1996; and Kehoe and Perri, 2000), all amount to inhibiting transactions in the

[23] This raises a knotty identification problem for the nature of shocks using national data, as any apparent serial correlations and highly persistent movements in national data, suggesting a source of permanent shocks in that nation, could be driven entirely by neighboring countries' transitory shocks. The converse is also true; Namely, the lack of serial correlations in national data does not imply the lack of endogenous propagation mechanisms if the main source of shocks comes from a foreign country which lacks endogenous propagation mechanisms.

three types of markets in one way or another.

A. Frictions in Asset markets

Consider first frictions in the capital-good market. Assume that there exists a transport cost associated with shipping fixed capital across the border with the cost function,

$$\frac{\theta}{2}(\tau_t - \tau)^2 K_t,$$

so that the marginal transport cost is proportional to foreign direct investment.[24] Assume that the transport cost is shared equally by the two countries. The resource constraint, equation (1.5), becomes

$$\sum_j c_t^j + [K_{t+1} - (1-\delta)K_t] \leq \sum_j \left(\tau_t^j K_t\right)^\alpha \left(n_t^h\right)^{1-\alpha} - \frac{\theta}{2}(\tau_t - \tau)^2 K_t. \tag{4.1}$$

It is clear that the transport cost has no effects under consumption shocks (since the optimal value of τ_t is constant under demand shocks). It is nevertheless worthwhile to discuss why the cost also offers little help in resolving the international business cycle "puzzles" created by technology shocks. To sharpen the analysis, consider the extreme case where the transport cost parameter θ is infinity so that capital mobility is eliminated entirely in every period (i.e., $\tau_t = \tau$ for all t). With τ_t fixed, the first-order conditions for the open economy with technology shocks, equations (3.1) and (3.2), imply the following cross-country ratios:

$$\frac{c_t^h}{c_t^f} = 1, \tag{4.2}$$

$$\frac{n_t^h}{n_t^f} = \left(\frac{A_t^h}{A_t^f}\right)^{\frac{1}{\alpha+\gamma}}, \tag{4.3}$$

$$\frac{y_t^h}{y_t^f} = \left(\frac{A_t^h}{A_t^f}\right)^{\frac{1+\gamma}{\alpha+\gamma}}. \tag{4.4}$$

These ratios are very similar to those of the complete-market economy (3.4)-(3.6). Thus, open economies with incomplete asset markets behave qualitatively the same as open economies with complete markets: Under technology shocks, the cross country correlations remain higher for consumption than for output, and the cross-country correlations for output and employment remain negative.[25]

[24] An alternative restriction is that τ_t must be determined one period in advance. Under this restriction, τ_t cannot respond to technology shocks in time period t but τ_{t+1} will respond if the shocks are expected to be persistent.

[25] Baxter and Crucini (1995) consider a model in which agents are restricted to trade only goods and noncontingent real debt. Since the channel for international transfer of currently produced goods is kept intact, their model is similar to models with adjustment costs in τ_t.

The intuition is as follows. International risk sharing under technology shocks gives rise to both a cross-country income effect on consumption and a cross-country substitution effect on leisure. The income effect leads to higher consumption across countries (via transfers of consumption goods from a more productive country to a less productive country). The substitution effect leads to higher economic activity in the more productive country and lower activity in the less productive country (so that countries enjoy less leisure when productivity is high and more leisure when productivity is low, implying negative correlations for employment across countries). Capital immobility dampen but does not undo these two effects. Consequently, the structure of asset markets does not resolve the puzzles created by technology shocks.

Risk sharing under preference shocks, on the other hand, gives rise to a different substitution effect of leisure. It works through consumption-good transfers from the less urgent country to the more urgent country, leading to higher consumption demand in both countries. Consequently, both countries opt to enjoy less leisure when world demand is high and more leisure when world demand is low, rendering production activities highly synchronized across countries. Since there is no technology differentials involved, this mechanism does not generate unbalanced demand for capital goods across countries. Consequently, the structure of asset markets is irrelevant under consumption shocks.[26]

The only significant difference the absence of capital mobility makes under technology shocks is that the elasticities of the cross-country ratios with respect to cross-country technology differentials are reduced, hence the volatility of economic activities is smaller. In particular, the volatilities of investment and net exports relative to output are substantially lowered due to the absence of foreign direct investment.[27]

Table 2 reports the quantitative effects of the transport cost on volatilities of investment and net exports under technology shocks. It shows that the excess volatility of investment and the excess volatility of net exports go hand in hand - all are driven by the technology-induced international capital movements (foreign direct investment) in the model. In order for the predicted relative volatility ratio of net export and output to be less than one (or for investment volatility to be

[26] Cross-country capital movements will be observed under consumption shocks, however, if the production technologies differ across countries. In this case, the structure of asset markets or capital adjustment costs can be effective in reducing international capital mobility under consumption shocks. For analysis on capital movements in a deterministic two-country model with different production technologies, see Wan (1971).

[27] The elasticities measure how sensitive international comovements are to technology shocks. For example, comparing equations (4.3)-(4.4) with equations (3.5)-(3.6), the elasticity of cross-country output ratio with respect to cross-country technology ratio is reduced from $\frac{1+\gamma}{\gamma(1-\alpha)}$ to $\frac{1+\gamma}{\gamma+\alpha}$. Suppose $\gamma = 0.25, \alpha = 0.3$, then the reduction in aggregate volatilities in the model due to incomplete asset markets is more than 3 times.

roughly consistent with the data), θ has to be greater than one; Namely, the marginal cost of shipping fixed capital across the border, $\theta\left(\tau_t - \tau\right) K_t$, has to be greater than the total value of foreign direct investment.

Table 2. Relative Volatilities of Investment and Net Exports (A_t)

	U.S. Data	$\theta = 0$	$\theta = 0.1$	$\theta = 0.5$	$\theta = 1$	$\theta = 2$	$\theta = 10$
σ_i/σ_y	3.36	39.5	22.4	8.27	4.88	3.10	2.12
$\sigma_{nx/y}/\sigma_y$	$0.25^a \sim 0.86^a$	8.44	4.79	1.77	1.04	0.66	0.46

a : Reported by Backus, Kehoe and Kydland (1992).

B. Frictions in Currently-Produced Goods Markets

The above discussion suggests that the most effective restrictions to reduce cross-country correlations for consumption and to increase cross-country correlations for output under technology shocks must involve frictions in the currently-produced goods markets. To avoid autarky, obviously, the possibility of trade for certain goods is needed. To ensure maximum possible cross-country correlation for output and minimum possible cross-country correlation for consumption under technology shocks (so as to best resolve the international comovements puzzles), assume that international borrowing for fixed assets and consumption goods are both prohibited, but borrowing for investment goods are possible. Furthermore, assume that real debt contracts can be written in a way such that investment in each country are perfectly synchronized. This amounts to maximize cross country correlations for national income (output) under technology shocks.[28] Under these restrictions, capital is essentially "public" (shared with fixed proportions), and each country is forced to absorb its own output by domestic consumption and "public" investment:

$$c_t^j + \pi^j I_t = y_t^j, \qquad j = h, f;$$

for all t.

Due to the restrictions, the income effect of technology shocks can no longer take place in the form of transfer of consumption goods, rendering cross-country synchronization for consumption extremely difficult. On the other hand, the income effect can take place in the form of production activities, rendering cross-country synchronization for output possible. To see why, note that cross-country synchronization for consumption (risk sharing) is still the ultimate goal of the planner (representative world agent) under technology shocks. But the absence of markets for transfer

[28] These assumptions do not mean to be realistic. The point is to show how far one has to go in order to resolve the international comovements "puzzles" created by the technology shocks. It is therefore not important to specify the exact underling market structure giving rise to such risk-sharing arrangements.

of consumption goods forces the planner to achieve this goal by synchronizing productions across countries (so as to increase cross-country correlations for consumption). Thus, international risk sharing in the current context amounts essentially to maximize cross-country correlations for consumption subject to the constraints:

$$c_t^j = y_t^j - \pi^j I_t, \tag{4.5}$$

for $j = h, f$. Hence we have

$$\begin{aligned} Cov(c^h, c^f) &= Cov\left(y^h - \pi I, y^f - (1-\pi)I\right) \\ &= Cov(y^h, y^f) + \pi(1-\pi)\sigma_I^2 - \pi Cov(y^f, I) - (1-\pi)Cov(y^h, I). \end{aligned}$$

Using the fact that the two countries are symmetric and identical, we can simplify the equation as

$$\rho(c^h, c^f)\sigma_c^2 = \rho(y^h, y^f)\sigma_y^2 + \frac{1}{4}\sigma_I^2 - \rho(y^j, I)\sigma_y\sigma_I.$$

Given that $\left\{\rho(y^h, y^f), \rho(y^j, I)\right\}$ are all nonnegative in the current context, so clearly $\rho(c^h, c^f)$ is maximized when $\rho(y^h, y^f)$ is maximized. Hence, $\rho(c^h, c^f) < \rho(y^h, y^f)$ is possible provided that $\rho(y^j, I)$ is large enough. Then the cross-country consumption-output correlation puzzle can be resolved.

However, risk sharing by production synchronization does not necessarily resolve the problem of negative cross-country correlation for employment. To see this, consider a scenario in which national output in the two countries are perfectly synchronized ($y_t^h = y_t^f$). This implies

$$1 = \frac{A^h}{A^f}\left(\frac{n^h}{n^f}\right)^{1-\alpha},$$

which implies that cross-country correlation for labor is negative in order to support perfect production synchronization under technology shocks. Namely, countries with high productivity opt to use less labor and countries with low productivity opt to use more labor in order to synchronize national income across countries.

This illustrates just how difficult it is to resolve the international comovement puzzles with market frictions. Such difficulties do not arise under consumption shocks, however. With consumption shocks, production synchronization is the only natural mechanism for international risk sharing. Without technology shocks, synchronization in output automatically implies synchronization in labor and vice versa. In the current context, however, the absence of markets for transfer of consumption goods hinders the consumption-demand-pull channel for production synchronization. But, risk sharing via investment on public capital creates an investment-demand-pull channel for production synchronization. Consequently, when there is an urge to consume in a specific country, investment in all countries increase, creating a higher world demand for output in each country. As a result, cross-country correlations are expected to be higher for output than for consumption and to be positive for output, employment and investment, despite the severe restrictions imposed on market transactions.[29]

C. Numerical Analysis

The above discussions can be confirmed by numerical analysis. Table 3 reports means and standard deviations of sample moments computed from 500 simulations of the world economies of different types of frictions, with sample length of 100 periods in each simulation. Following the existing literature, all statistics reported are based on H-P filtered time series. Three types of economies are simulated, one pertaining to complete markets, the second pertaining to incomplete asset markets and the third pertaining to the economy with both incomplete asset markets and incomplete good markets.[30]

The first column in table 3 reports the puzzles created by technology shocks. The cross-country correlations are negative for output, employment and investment and are higher for consumption than for output. Furthermore, the predicted investment and net exports are excessively volatile. These puzzles do not exist under consumption demand shocks. Namely, the cross-country correlations are positive for output, employment and investment and are lower for consumption than for output. Furthermore, the predicted investment and net exports volatilities are consistent with the data.

The second column in table 3 shows that while the assumption of incomplete asset markets is quite effective in bringing down the excess volatilities of investment and trade balance under

[29] It is certainly possible to create hypothetical situations in which the predicted cross-country correlations are inconsistent with data under consumption shocks. But this is not the point. The point is to show that frictions frequently proposed for explaining the international comovements "puzzles" under technology shocks (including even the extremely unrealistic assumptions adopted here) can hardly diminish the explanatory power of consumption shocks for business cycles.

[30] Most parameter values are kept the same as in previous sections. Namely, the time-discount factor $\beta = 0.99$, the capital depreciation rate $\delta = 0.025$, the steady state habit-demand to consumption ratio $\frac{\Delta}{c} = 0.045$, the habit formation parameter $b = 0.95$, the transport cost parameter is set at infinity (τ_t is constant for all t). Both technology shocks and consumption shocks are assumed to be uncorrelated with each other and across countries. The persistent parameters of these shocks are set at 0.9. The only exception is the inverse labor supply elasticity γ. To avoid singularity under technology shocks, I follow the existing literature by setting the labor supply elasticity parameter $\gamma = 0.25$ under both technology shocks and consumption shocks, which implies steady-state hours worked as fraction of time endowment $\bar{n} = 0.2$.

technology shocks, it has little effect however on altering the negative cross-country correlations for output and employment implied by the complete-markets model. Asset market frictions have no effects on the model when the source of shocks is from consumption demand.

The third column in table 3 shows that goods-market frictions are very effective in resolving the consumption-output anomaly created by technology shocks. In particular, the frictions can substantially reduce the cross-country correlation for consumption and substantially increase the cross-country correlation for output (due to production synchronization), so that the predicted cross-country correlations become much higher for output (0.99) than for consumption (0.1). But, the cross-country correlation for employment remains negative (-0.73) under technology shocks. On the other hand, despite of the severe trading restrictions in both the asset markets and the goods markets, the predictions of consumption shocks remain consistent with all qualitative features of domestic and international business cycles. Namely, the predicted cross-country correlations are positive for output, investment and employment, and the correlations are higher for output (0.59) than for consumption (0.01); Domestic consumption, investment and employment are all positively correlated with domestic output; And domestic output is less volatile than domestic investment but more volatile than domestic consumption.[31]

Table 3. Predicted Open-Economy Business Cycle Moments (std. errors in parentheses)

	Complete Market		Incomplete Asset Market		Incomplete Goods Market	
	A_t	Δ_t	A_t	Δ_t	A_t	Δ_t
International comovement						
$\rho(y^h, y^f)$	-0.93(0.03)	1.00	-0.49(0.13)	same	0.99(0.00)	0.59(0.16)
$\rho(c^h, c^f)$	1.00	0.002(0.31)	1.00	same	0.10(0.31)	0.01(0.28)
$\rho(i^h, i^f)$	-0.99(0.00)	1.00	1.00	same	1.00	1.00
$\rho(n^h, n^f)$	-0.98(0.01)	1.00	-0.82(0.06)	same	-0.73(0.09)	0.57(0.16)
Domestic Comovement						
$cor(c, y)$	0.01(0.20)	0.45(0.16)	0.003(0.19)	same	0.01(0.16)	0.72(0.09)
$cor(i, y)$	0.99(0.01)	0.87(0.03)	0.50(0.14)	same	0.99(0.00)	0.78(0.08)
$cor(n, y)$	0.99(0.00)	0.99(0.00)	0.95(0.02)	same	0.28(0.17)	0.99(0.00)
$cor(s, i)$	0.99(0.01)	0.84(0.07)	0.50(0.14)	same	1.00	1.00
$cor(nx/y, y)$	-0.99(0.01)	-0.88(0.05)	-0.50(0.14)	same	-1.00	-1.00
Relative Volatility						
σ_c/σ_y	0.002(0.00)	0.91(0.18)	0.005(0.00)	same	0.01(0.00)	0.80(0.11)
σ_i/σ_y	38.4(1.12)	3.63(0.16)	2.37(0.37)	same	4.68(0.01)	3.26(0.37)
σ_{nx}/σ_y	7.21(0.24)	0.51(0.13)	0.86(0.08)	same	0.00	0.00
Autocorrelation						
$\rho(y_t, y_{t-1})$	0.65(0.08)	0.72(0.07)	0.65(0.08)	same	0.64(0.08)	0.75(0.07)

Note: The statistics are based on 500 simulations with sample lenth of 100. All series are H-P filtered.

[31]Note that under technology shocks, consumption is too smooth and is only weakly positively correlated with output in all cases. This is due to habit formation.

5 The Quantitative Importance of Consumption Shocks

A. Calibrating Consumption Shocks

Like technology shocks, preference shocks are unobservable. The existing literature estimate technology shocks (the Solow residual) using specified production functions. In a similar spirit, Baxter and King (1991) and Stockman and Tesar (1995) estimate preference shocks using a model's first-order conditions derived from specified utility functions.[32] Since preferences are time-nonseparable in my model, it is difficult to use the first order conditions directly. Instead, I choose to use the equilibrium decision rules to back-solve (deduce) the unobservable shock variables from the observable decision variables.[33] In particular, the decision rules for output and investment in the closed-economy model satisfy:

$$\begin{pmatrix} \hat{y}_t^j \\ \hat{\imath}_t^j \end{pmatrix} = \Pi_1 \hat{c}_{t-1}^j + \Pi_2 \begin{pmatrix} \hat{k}_t^j \\ \hat{\Delta}_t^j \end{pmatrix}, \qquad \text{for } j = h, f;$$

where Π_2 is a 2×2 matrix with full rank.[34] Thus, I can invert the equation to solve for the unobservable shocks and the capital stock by

$$\begin{pmatrix} \hat{k}_t^j \\ \hat{\Delta}_t^j \end{pmatrix} = \Pi_2^{-1} \begin{pmatrix} \hat{y}_t^j \\ \hat{\imath}_t^j \end{pmatrix} - \Pi_2^{-1} \Pi_1 \hat{c}_{t-1}^j.$$

This approach depends on iteration methods to find consistent values for the persistence parameters ρ_Δ^j so that the estimated shock processes have $AR(1)$ coefficients that are consistent with the calibrated values used in computing the coefficient matrices Π_1 and Π_2.[35] Using real GDP, fixed investment and consumption from the U.S. and Europe respectively as the observables,[36] I found:

$$\begin{aligned} \hat{\Delta}_t^{US} &= 0.80 \hat{\Delta}_{t-1}^{US} + \hat{\varepsilon}_t^{US} \\ \hat{\Delta}_t^{ER} &= 0.88 \hat{\Delta}_{t-1}^{ER} + \hat{\varepsilon}_t^{ER} \end{aligned}$$

[32] Similarly, Burnside and Eichenbaum (1996) deduce capacity utilization rate using a model's first-order conditions relating capacity utilization to the output-capital ratio.

[33] This approach is proposed by Ingram, Kocherlakota and Savin (1994, 1997).

[34] Due to symmetry, the open economy model involves singularity when this approach is used to back-solve the two country-specific consumption shocks. Namely, Π_2 does not have full rank when both Δ^h and Δ^f are included in the state vector. Hence I choose to use the closed economy model to solve for Δ_t for each country separately.

[35] Namely, I start with an initial guess for ρ. I then back solve for the shocks and estimate their persistence values $\hat{\rho}$. I then use the estimated persistence values in a second round of estimation for the shocks, and so on so forth until the values converge.

[36] All data are from OECD (1972:2 - 1996:2). To be consistent with the models, the variables are logged and their time trends are removed by OLS regressions.

where the estimated correlation between the two residuals is 0.11.[37]

An alternative approach for estimating consumption demand shocks is to use measures for consumer sentiment as a proxy for preference shocks. Using the University of Michigan Index from the U.S. and the Harmonized Consumer Survey from Europe respectively as measures of consumer confidence in a bivariate VAR regression, Guo and Sturzenegger (1998) find the estimated persistence parameters ranging from 0.9 to 0.5 for the U.S. economy and from 0.7 to 0.5 for Europe with mild spillover effects, and the innovations (shocks) are positively correlated with correlation equal to 0.45. Univariate autoregressions on the other hand reveal higher persistence. For example, it is about 0.92 with a standard error of 0.03 for the U.S. (see equation 2.5).

These empirical studies suggest that consumption demand shocks may be highly persistent and positively correlated across countries. I therefore choose $\rho^h = \rho^f = 0.9$ and $corr(\varepsilon^h, \varepsilon^f) = 0.3$ as my benchmark.[38] The other parameters in the model remain the same as before; Namely, the time-discount factor $\beta = 0.99$, the labor supply elasticity parameter $\gamma = 0.25$, the capital depreciation rate $\delta = 0.025$, the steady state habit-demand to consumption ratio $\frac{\Delta}{c} = 0.045$, and the habit formation parameter $b = 0.95$. Empirical estimates of the size of the transport cost is not available. I choose two possible values, $\theta = \{0, 1\}$, in my simulation analysis.

B. The Contribution of Consumption Shocks

Since consumption shocks and technology shocks give exactly opposite predictions for the cross-country correlations and since the data lie somewhere in between quantitatively, I add technology shocks in the simulations so as to see how much of a technology shock is needed in the model in order to bring the cross-country correlations into closer conformity with the data quantitatively. This provides an informal measure on the relative importance of consumption shocks. Consistent with Backus, Kehoe and Kydland (1992), I assume that technology shocks in both countries follow stationary $AR(1)$ processes,

$$\log A_t^j = 0.9 \log A_{t-1}^j + \varepsilon_{at}^j,$$

with $cor(\varepsilon_{at}^H, \varepsilon_{at}^F) = 0$.[39]

[37]Baxter and King (1991) obtain an estimate of 0.97 for the persistence parameter of the consumption shocks using Euler equations in a standard closed-economy RBC model.

[38]Choosing other values for the persistence parameters (e.g., $\rho^h = \rho^f = 0.8$) produces little difference in the results. None of the statistics except the cross-country correlations for consumption is sensitive to $corr(\varepsilon^h, \varepsilon^f)$. The cross-country correlation for consumption is determined by $corr(\varepsilon^h, \varepsilon^f)$. For example, the point estimate varies between zero and 0.43 when $corr(\varepsilon^h, \varepsilon^f)$ changes between zero and 0.45.

[39]The following results are not sensitive to this specification.

Table 4 reports the predicted moments of the model under both technology and consumption shocks along with the estimated data moments taken from the existing literature.[40] Table 4 shows that regardless of market frictions, the predictions of the model are qualitatively consistent with the data. In particular, the predicted cross-country correlations are positive for output, investment and employment; and the correlations are higher for output than for consumption. With regard to domestic movements, consumption, investment and employment are all positively correlated with output, and net exports are negatively correlated with output. Consistent with the data, the predicted correlations between domestic saving rates and investment rates are strongly positive. Also, domestic output is less volatile than investment but more volatile than consumption and net exports. Furthermore, output (as well as the other variables) in the model are all strongly serially correlated.

The relative importance of consumption shocks in explaining the data is found by comparing the total variance of output in the presence of both shocks and the total variance of output in the absence of one of the two shocks. The proportionality of the two types of shocks is determined by holding the standard deviation of consumption shocks constant while increasing the standard deviation of technology shocks until a point beyond which the predicted cross-country correlations for output, consumption and investment are no longer in agreement with the data. For example, in the second column of table 4 ($\theta = 0$) the proportion of technology shocks is given by the standard deviation ratio between the innovations of the two type of shocks, $\frac{\varepsilon_{At}}{\varepsilon_{\Delta t}} = 0.002$. With this proportionality between the two type of shocks, the contribution of technology shocks to the total variance of output is only 1%. When the contribution of technology shocks to the variance of output is increased to 3% or above by increasing the standard deviation ratio to 0.003 or higher, the cross-country correlations for investment become zero and even negative (inconsistent with the data). In the third column of table 4 ($\theta = 1$), the proportion of technology shocks is given by the standard deviation ratio $\frac{\varepsilon_{At}}{\varepsilon_{\Delta t}} = 0.05$. With this proportionality, the contribution of technology

[40] The estimated second moments reported by existing literature vary quite a lot depending on the particular countries and sample periods selected as well as on the specific definitions of variables adopted. For example, the estimated cross-country correlations for output range from 0.81 (reported by Baxter and Farr, 2001) to 0.51 (reported by Kehoe and Perri, 2000) or even much lower (reported by Backus, Kehoe and Kydland, 1992), and the reported cross-country correlations for consumption range from 0.67 (reported by Baxter and Farr, 2001) to 0.32 (reported by Kehoe and Perri, 2000) or even negative (reported by Backus, Kehoe and Kydland, 1992). What remain as robust features of the data, therefore, are not the quantitative but qualitative characteristics of the data; Namely, given the sample periods and the countries chosen the cross country correlations are positive and significantly higher for output than for consumption, and they are positive for hours and investment. Similar caveats apply to statistics characterizing domestic business cycles.

shocks to the total variance of output is 13%. When the contribution of technology shocks to the variance of output is increased to 20% or above by increasing the standard deviation ratio to $\frac{\varepsilon_{At}}{\varepsilon_{\Delta t}} = 0.07$ or higher, the cross-country correlations for investment become zero and negative. When the adjustment cost is infinity ($\theta = 10^7$), the maximum contribution of technology shocks to the variance of output is still less than 27% (the maximum standard-deviation ratio is $\frac{\varepsilon_{At}}{\varepsilon_{\Delta t}} = 0.09$), beyond which the cross-country correlations for output become smaller than that for consumption (inconsistent with the data).[41]

This sensitivity analysis suggests that consumption demand shocks are the dominant force behind economic fluctuations. What remains to be explained by general equilibrium theory, however, is the procyclical labor productivity over the business cycle. This stylized fact about productivity is what makes the technology-shock view attractive. Under demand shocks only, labor productivity is countercyclical due to diminishing marginal product of labor. With technology shocks explaining less than 27% of output variance, the predicted labor productivity in the current model is not procyclical enough to account for the data. However, labor hoarding, capacity utilization, externalities or increasing returns to scale may also help explain the procyclical labor productivity. See Burnside, Eichenbaum and Rebelo (1993) and Benhabib and Wen (2000) for analyses along these lines.

[41] Choosing other values of the persistence parameters for consumption demand shocks produces little difference in the results. For example, when $\rho^h = \rho^f = 0.8$, with the standard-deviation ratio $\frac{\varepsilon_{At}}{\varepsilon_{\Delta t}} = 0.035$, the implied contribution of technology shocks to the total variance of output is 13%. The corresponding point estimates for sample moments are: $\rho(y^h, y^f) = 0.58$, $\rho(c^h, c^f) = 0.29$, $\rho(i^h, i^f) = 0.21$, $\rho(n^h, n^f) = 0.82$ for international comovements, and $\sigma_c/\sigma_y = 0.89$, $\sigma_i/\sigma_y = 3.61$, $\sigma_{nx}/\sigma_y = 0.43$, $corr(s, i) = 0.87$, and $corr(nx/y, y) = -0.92$ for domestic movements. Allowing for higher proportion of technology shocks produces cross-country correlations for investment and output that are inconsistent with the data.

The standard deviation of the U.S. output is about 0.017. To match this value, the standard deviation required for innovations of consumption shocks (ε_Δ) in the model with $\theta = 0$ is 0.023, and the required value is 0.022 in the model with $\theta = 1$. These required standard deviations for consumption innovations are reasonable. For example, the estimated standard deviations of innovations $\{\varepsilon^h, \varepsilon^f\}$ based on the equilibrium-decision-rule approach are $\{0.032, 0.020\}$. And the estimated standard deviation of consumption innovations based on the University of Michigan Index (1953:1 - 1996:4) is 0.069. And the estimates obtained by Guo and Sturzenegger (1998) are 0.049 for both the U.S. and Europe. Hence the data suggest that the variance of consumption shocks is high enough to account for the observed volatilities in aggregate output.

Table 4. Predicted Moments with Both Δ_t and A_t Shocks

	Data	Complete Markets ($\theta = 0$)	Trade Friction ($\theta = 1$)
International comovement			
$\rho(y^h, y^f)$	0.81^a, 0.51^b	0.99(0.003)	0.63(0.11)
$\rho(c^h, c^f)$	0.67^a, 0.32^b	0.26(0.29)	0.30(0.28)
$\rho(i^h, i^f)$	0.73^a, 0.29^b	0.42(0.15)	0.42(0.14)
$\rho(n^h, n^f)$	0.84^a, 0.43^b	0.99(0.001)	0.85(0.05)
Domestic Comovement			
$cor(c, y)$	0.81^a	0.52(0.13)	0.46(0.15)
$cor(i, y)$	0.81^a	0.76(0.06)	0.90(0.04)
$cor(n, y)$	0.78^a	0.99(0.001)	0.97(0.01)
$cor(s, i)$	0.94^c, 0.89^c	0.79(0.08)	0.93(0.04)
$cor(nx/y, y)$	-0.66^d, -0.03^d	-0.87(0.06)	-0.95(0.02)
Relative Volatility			
σ_c/σ_y	0.79^b	0.80(0.15)	0.69(0.14)
σ_i/σ_y	3.24^b	4.30(0.46)	3.95(0.27)
σ_{nx}/σ_y	0.23^a	0.58(0.13)	0.33(0.12)
Autocorrelation			
$\rho(y_t, y_{t-1})$	0.89^a	0.71(0.08)	0.71(0.07)

Note: The predicted statistics are based on 500 simulations with sample lenth of 100. All series are H-P filtered. a : Reported by Baxter and Farr (2001). b : Reported by Kehoe and Peri (2000). c : Reported by Feldstein and Horioka (1980). d : Reported by Backus, Kehoe and Kydland (1992).

6 Conclusion

This paper showed that preference shocks could be the primary force behind economic fluctuations. The observed domestic and international synchronization of economic activities could just be the manifestation of risk sharing based on demand uncertainty. Increases in aggregate demand in time period t raise aggregate demand in the future via habit-formation, hence production and investment activities increase accordingly to diversify intertemporal risk even if demand shocks are *i.i.d.* Similarly, increases in aggregated demand in one country raise economic activity in other countries through international risk sharing. Hence productions are synchronized across countries even if demand shocks are country specific and are completely uncorrelated across countries. Sticky prices, which may exacerbate the business cycle, are thus not the preconditions for demand shocks to explain business cycle comovements, in contrast to what has been suggested by the IS-LM model for both closed and open economies,

Several important issues remain to be investigated. The literature (e.g., Barsky and Miron, 1989) has documented that the seasonal cycle displays similar characteristics to that of the business cycle. For example, output, consumption, investment and employment are highly synchronized at the seasonal frequency, but with investment raising more than output and consumption during the second and third quarter of a year and starting to decrease during the fourth quarter, while consumption and final-goods production rise sharply during the fourth quarter and drop sharply during the first quarter along with investment, suggesting that the seasonal cycle is caused primarily by Christmas spending. As an anticipated but short-lived high urgency to consume during the fourth quarter, general equilibrium theory suggests that investment opts to rise a couple of quarters earlier before Christmas so as to build up production capacities for the fourth quarter consumption boom. When the high consumption demand arrives in the fourth quarter, production and employment increase sharply to meet the urge to consume. If this conjecture is correct, general equilibrium theory with preference shifts may provide an unified explanation for both types of fluctuations. Another important issue is the policy and welfare implications of stabilization under preference shocks. When short-run output fluctuations are primarily caused by the urgency to consume, it may be desirable to smooth real interest rates to accommodate demand for credits, resulting in a higher output volatility. Consequently, smoothing output over the business cycle maybe counter-productive and welfare reducing. This may also explain and justify why the U.S. Fed smooths nominal interest rates over the seasonal cycle. These important issues are beyond the scope of the paper and are left for future investigation.

7 Appendix 1

A. Proof of Proposition 1

It suffices to show that Proposition 1 holds near the steady state. Using circumflex variables to denote percentage deviations from their steady-state values, the log linearized first order conditions for the closed economy without habit formation are given by:

$$(1-\omega)\hat{\Delta}_t - \omega\hat{c}_t = \hat{\lambda}_t \tag{A}$$

$$\alpha\hat{n}_t = \hat{\lambda}_t + \alpha\hat{k}_t \tag{B}$$

$$\hat{\lambda}_t = E_t\left[\hat{\lambda}_{t+1} - \eta\hat{k}_{t+1} + \eta\hat{n}_{t+1}\right] \tag{C}$$

$$\delta(1-s)\hat{c}_t + s\left[\hat{k}_{t+1} - (1-\delta)\hat{k}_t\right] = \delta\alpha\hat{k}_t + \delta(1-\alpha)\hat{n}_t, \tag{D}$$

$$\hat{\Delta}_t = \rho\hat{\Delta}_{t-1} + \varepsilon_t; \tag{E}$$

where $\omega > 1$ denotes $1/(1-\frac{\Delta^*}{c^*})$, $\eta > 0$ denotes $(1-\alpha)(1-\beta(1-\delta))$, and $s \in (0,1)$ denotes the steady state saving ratio. The solutions of the model have the form:

$$\begin{pmatrix} \hat{k}_{t+1} \\ \hat{y}_t \\ \hat{c}_t \\ \hat{n}_t \\ \hat{\imath}_t \end{pmatrix} = \begin{pmatrix} \pi_{kk} & \pi_{k\Delta} \\ \pi_{yk} & \pi_{y\Delta} \\ \pi_{ck} & \pi_{c\Delta} \\ \pi_{nk} & \pi_{n\Delta} \\ \pi_{ik} & \pi_{i\Delta} \end{pmatrix} \begin{pmatrix} \hat{k}_t \\ \hat{\Delta}_t \end{pmatrix}.$$

The sign and magnitudes of initial responses of output, consumption, hours, and investment to a consumption shock are determined by the coefficients $\{\pi_{y\Delta}, \pi_{c\Delta}, \pi_{n\Delta}, \pi_{i\Delta}\}$. Equations (A) and (B) imply

$$\begin{pmatrix} \hat{c}_t \\ \hat{n}_t \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{\omega} & \frac{\omega-1}{\omega} \\ 1 & \frac{1}{\alpha} & 0 \end{pmatrix} \begin{pmatrix} \hat{k}_t \\ \hat{\lambda}_t \\ \hat{\Delta}_t \end{pmatrix}. \tag{F}$$

Substituting out $\{c_t, n_t\}$ in equations (C)-(E), we obtain

$$\begin{pmatrix} \hat{k}_{t+1} \\ \hat{\lambda}_{t+1} \\ \hat{\Delta}_{t+1} \end{pmatrix} = \begin{pmatrix} \frac{s(1-\delta)+\delta}{s} & -\delta\frac{s\alpha-\alpha-\omega+\omega\alpha}{s\omega\alpha} & (s-1)\frac{\delta}{s}\frac{\omega-1}{\omega} \\ 0 & \frac{\alpha}{\alpha+\eta} & 0 \\ 0 & 0 & \rho \end{pmatrix} \begin{pmatrix} \hat{k}_t \\ \hat{\lambda}_t \\ \hat{\Delta}_t \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \varepsilon_{t+1}. \tag{G}$$

The 3 eigenvalues of the coefficient matrix are given by $\left\{1-\delta+\frac{\delta}{s}, \frac{\alpha}{\alpha+\eta}, \rho\right\}$. Since the steady state saving ratio is less than one, it is clear that the first eigenvalue, $\left(1-\delta+\frac{\delta}{s}\right) > 1$ and the other two eigenvalues are less than one in absolute values, implying that the steady state is a saddle and the equilibrium of the model is unique.

Decomposing the coefficient matrix in equation (G) as $W = P\Lambda P^{-1}$, where Λ is a diagonal matrix with eigenvalues of W as diagonal elements and where P is the corresponding eigenvector matrix. Arranging the eigenvalues in ascending order in absolute values, it can be shown that

$$P^{-1} = \begin{pmatrix} 0 & 0 & \frac{1}{(\rho s-s+s\delta-\delta)\omega}\delta(s\omega-s-\omega+1) \\ 0 & 1 & 0 \\ 1 & \delta(\alpha+\eta)\frac{s\alpha-\alpha-\omega+\omega\alpha}{\omega\alpha(-s\eta+\delta s\alpha+s\delta\eta-\delta\alpha-\delta\eta)} & \frac{1}{(\rho s-s+s\delta-\delta)\omega}\delta(s-s\omega+\omega-1) \end{pmatrix}.$$

Applying the transversality condition on the third equation (solving the system forward), we have

$$\begin{pmatrix} 1 & \frac{\delta(\alpha+\eta)(\alpha s-\alpha-\omega+\omega\alpha)}{\omega\alpha(-s\eta+\delta\alpha s+s\delta\eta-\delta\alpha-\delta\eta)} & \frac{\delta(1-s)(\omega-1)}{\omega(\rho s-s+s\delta-\delta)} \end{pmatrix} \begin{pmatrix} \hat{k}_t \\ \hat{\lambda}_t \\ \hat{\Delta}_t \end{pmatrix} = 0,$$

which implies

$$\hat{k}_t + \frac{\delta(\alpha+\eta)(\alpha s-\alpha-\omega+\omega\alpha)}{\omega\alpha(-s\eta+\delta\alpha s+s\delta\eta-\delta\alpha-\delta\eta)}\hat{\lambda}_t + \frac{\delta(1-s)(\omega-1)}{\omega(\rho s-s+s\delta-\delta)}\hat{\Delta}_t = 0.$$

The solution for λ_t is then given by

$$\hat{\lambda}_t = \pi\hat{k}_t + \phi\hat{\Delta}_t,$$

where

$$\pi = \frac{\omega\alpha(s\eta-\delta\alpha s-s\delta\eta+\delta\alpha+\delta\eta)}{\delta(\alpha+\eta)(\alpha s-\alpha-\omega+\omega\alpha)}$$

$$\phi = \frac{\alpha(1-s)(\omega-1)(s\eta(1-\delta)+\alpha\delta(1-s)+\delta\eta)}{(s(1-\rho)+\delta(1-s))(\alpha+\eta)(\alpha(1-s)+\omega(1-\alpha))} > 0.$$

Since $\phi > 0$, the shadow price responds positively to Δ_t. Equation (F) then implies

$$\begin{pmatrix} \hat{c}_t \\ \hat{n}_t \end{pmatrix} = \begin{pmatrix} -\frac{1}{\omega}\pi & \frac{\omega-(1+\phi)}{\omega} \\ 1+\frac{1}{\alpha}\pi & \frac{1}{\alpha}\phi \end{pmatrix} \begin{pmatrix} \hat{k}_t \\ \hat{\Delta}_t \end{pmatrix}.$$

It is clear then that labor responds positively to Δ_t. Therefore, output also responds positively to Δ_t.

To show that consumption always responds positively to Δ_t, we need to show that $\omega-(1+\phi) > 0$, or $\phi < \omega - 1$, which is equivalent to

$$\frac{\alpha(1-s)(s\eta(1-\delta)+\alpha\delta(1-s)+\delta\eta)}{(s(1-\rho)+\delta(1-s))(\alpha+\eta)(\alpha(1-s)+\omega(1-\alpha))} < 1.$$

Since the left-hand side increases with ρ, without loss of generality let $\rho = 1$, we have

$$\alpha(s\eta(1-\delta)+\alpha\delta(1-s)+\delta\eta) < \delta(\alpha+\eta)(\alpha(1-s)+\omega(1-\alpha)),$$

which implies

$$s\alpha\eta < \delta\omega(1-\alpha)(\alpha+\eta).$$

Since $\omega > 1$, without loss of generality let $\omega = 1$, we have

$$s\alpha\eta < \delta(1-\alpha)(\alpha+\eta).$$

Since $s = \delta\frac{\beta\alpha}{1-\beta(1-\delta)}$ and $\eta = (1-\alpha)(1-\beta(1-\delta))$, we have $s\eta = \delta\beta\alpha(1-\alpha)$. Substituting this into the above inequality gives

$$\alpha^2\beta < (\alpha+\eta).$$

This is true since $\eta > 0$ and $\alpha^2\beta < \alpha$. Hence, it has been proven that consumption, hours, and output all respond positively to consumption shocks.

It remains to show the condition under which investment responses positively to consumption shocks. The first equation in (G) and the solution for λ_t together imply

$$\begin{pmatrix} \hat{k}_{t+1} \end{pmatrix} = \begin{pmatrix} 1-\delta+\frac{\delta}{s}+\delta\frac{\alpha(1-s)+\omega(1-\alpha)}{s\omega\alpha}\pi & \delta\left[\frac{(s-1)}{s}\frac{\omega-1}{\omega}+\frac{\alpha(1-s)+\omega(1-\alpha)}{s\omega\alpha}\phi\right] \end{pmatrix} \begin{pmatrix} \hat{k}_t \\ \hat{\Delta}_t \end{pmatrix}.$$

Investment responds positively to Δ_t if and only if k_{t+1} responds positively to Δ_t. Hence we need to show

$$\frac{\alpha(1-s)+\omega(1-\alpha)}{s\omega\alpha}\phi > \frac{(1-s)}{s}\frac{\omega-1}{\omega}.$$

Using the definition of ϕ, this inequality implies

$$(s\eta(1-\delta)+\alpha\delta(1-s)+\delta\eta) > (s(1-\rho)+\delta(1-s))(\alpha+\eta),$$

which implies

$$\eta > (1-\rho)(\alpha+\eta)$$

or

$$\rho > \frac{\alpha}{\alpha+\eta} = \frac{\alpha}{\alpha+(1-\alpha)(1-\beta(1-\delta))}.$$

■

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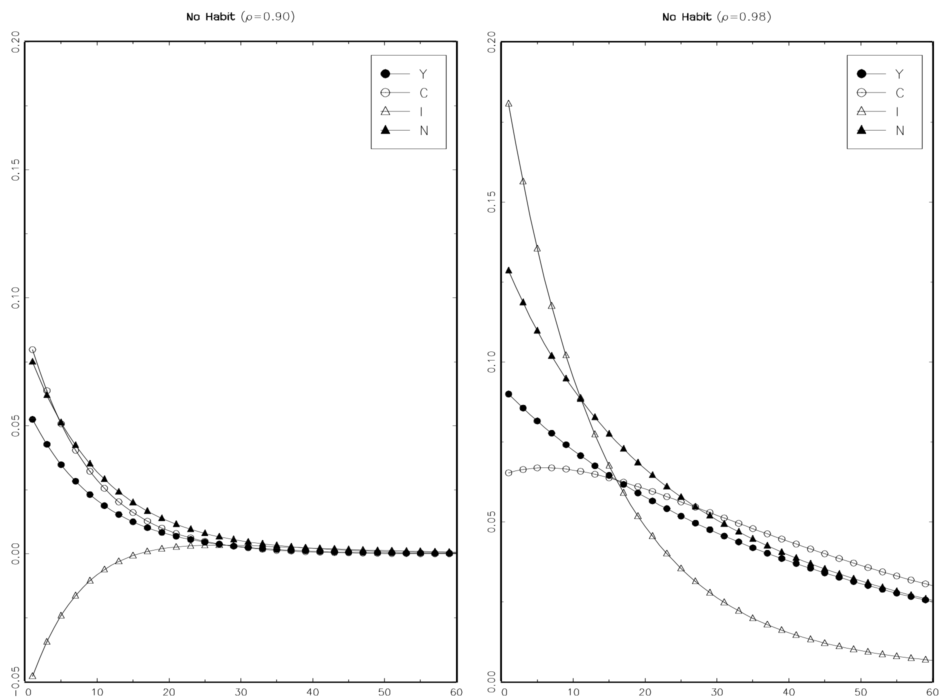

Figure 1. Impulse Responses to Consumption Shocks without Habit Formation (left window: $\rho = 0.9$; right window: $\rho = 0.98$).

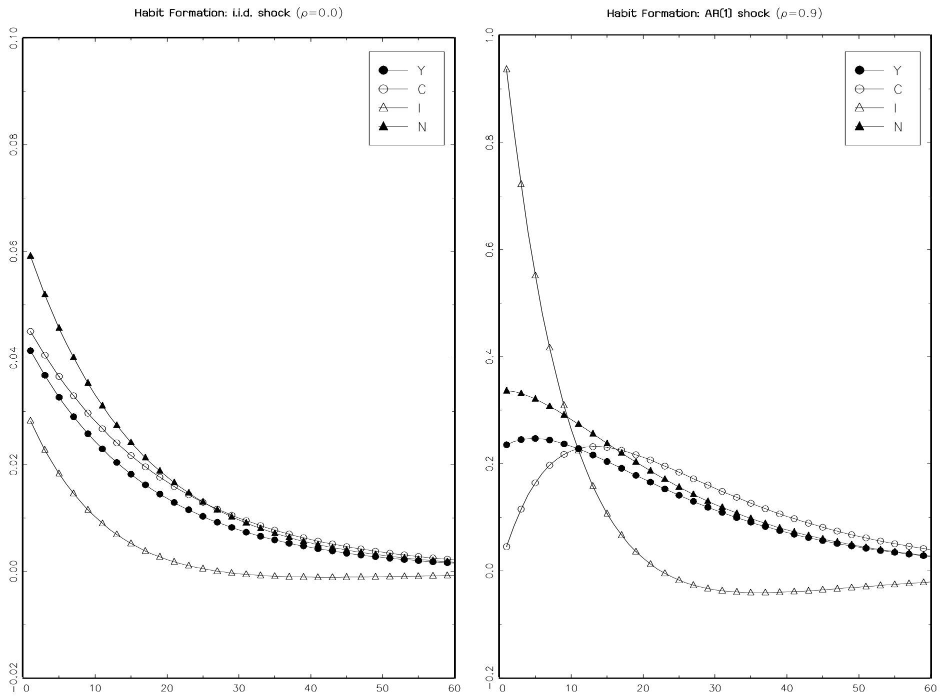

Figure 2. Impulse Responses to Consumption Shocks with Habit Formation (left window: $\rho = 0.0$; right window: $\rho = 0.9$).

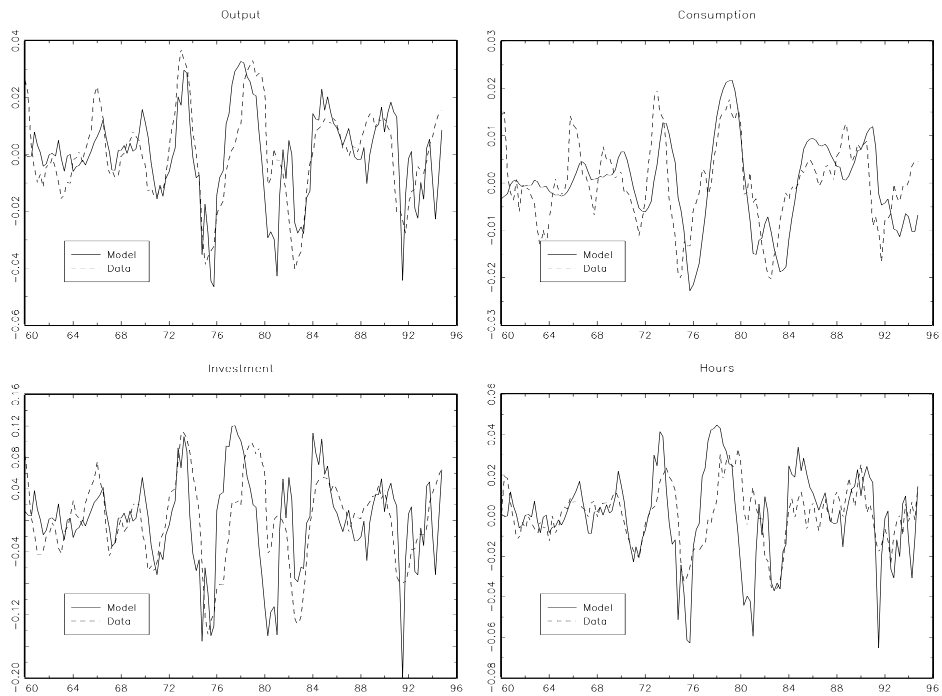

Figure 3. Predictions of Close-Economy Business Cycles with Consumption Shocks.

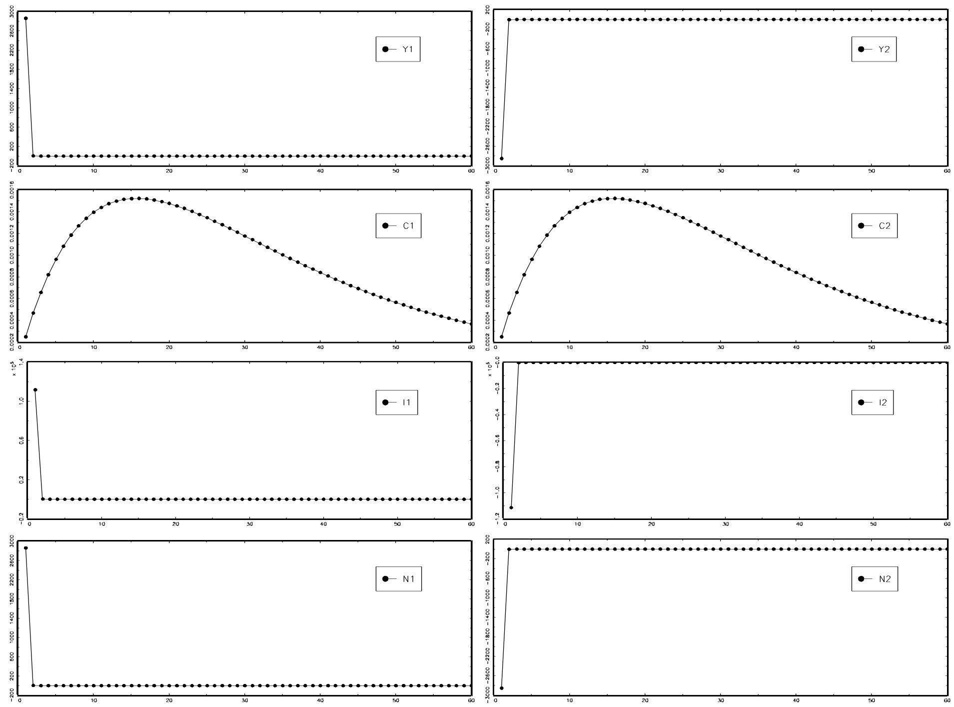

Figure 4. Impulse Responses of Home Country (left) and Foreign Country (right) to *i.i.d.* Technology Shocks in the Home Country.

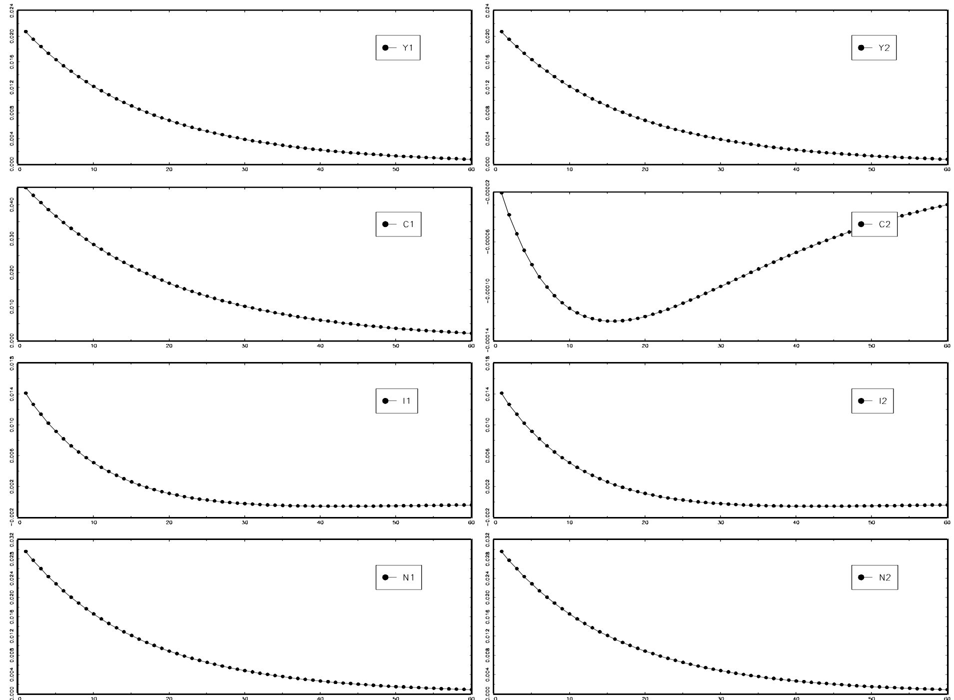

Figure 5. Impulse Responses of Home Country (left) and Foreign Country (right) to *i.i.d.* Preference Shocks in the Home Country.

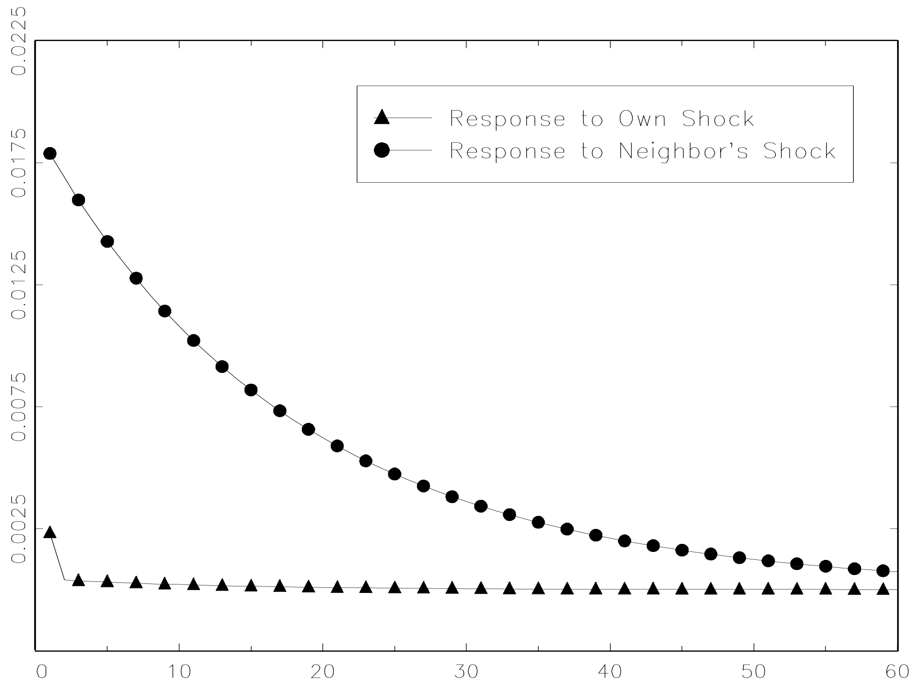

Figure 6. International Propagation of Business Cycles (*i.i.d.* shocks).