

# HABIT PERSISTENCE AND INTERNATIONAL COMOVEMENTS

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Theoretically, two-country real business cycle models with time-separable preferences and complete markets predict that cross-country investment correlations will be negative. The opposite is true in the data. This phenomenon has been described by Backus et al. [in Cooley (ed.), *Frontiers of Business Cycle Research*, pp. 331–356 (Princeton, NJ: Princeton University Press, 1995)] as a quantity anomaly. This paper proposes to address this discrepancy by allowing the nonseparability of preferences over time. Here, we incorporate internal habit formation into consumption. Our model predicts the empirically plausible value of cross-country investment correlation without sacrificing other business cycle statistics. The results are robust to the degree of spillovers and persistence in the specification of the productivity shocks.

**Keywords:** International Real Business Cycles, Time-Nonseparable Preferences, Habit Persistence, Investment Comovements

## 1. INTRODUCTION

Two-country real business cycle models with time-separable preferences and complete markets predict that cross-country investment correlations will be negative. The opposite is true in the data. This phenomenon has been described by Backus et al. (1995) as a quantity anomaly. In this paper, we address the discrepancy by allowing time nonseparability in preferences. To do so, we incorporate habit formation into consumption. Our model predicts an empirically plausible value of cross-country investment correlation without sacrificing other

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business-cycle statistics. Our results are robust the degree of spillovers and the persistence in the specification of the productivity stocks.

The origins of the quantity anomaly can be traced back to Backus et al. (1992) (henceforth BKK), who first identified this discrepancy between the data and the predictions of the standard international RBC model. The comovement puzzle turned out to be remarkably robust to modifications in parameter and model structure. Baxter (1995) emphasized the importance of this phenomenon by proclaiming that “a major challenge to the theory is to develop a model which can explain international comovement in labor input and investment” (p. 1859). Canova and Ubide (1998) make a similar point by arguing that “the magnitude and the sign of the cross-country investment correlations constitute an important regularity previously under-emphasized by the literature” (p. 558).

Most of the contributions that followed Baxter’s challenge focused on the role of financial frictions.<sup>1</sup> Our approach is different. We retain the assumption of complete international markets, and ask whether relaxing the assumption of time-separable preferences can improve the properties of a canonical two-country one-good RBC model.

We depart from the assumption of time-separability by introducing habit formation into consumption. There are several reasons to do so. First, empirical evidence presented in Fuhrer and Klein (2006) suggests that habit formation characterizes consumption behavior among most of the G-7 countries. Second, habits have been used somewhat successfully to address asset pricing puzzles [Boldrin et al. (2001)] and monetary phenomena [Christiano et al. (2005)], as well as in the growth literature [Carroll et al. (2000)]. Finally, the notion of habits has been embraced by the behavioral sciences. As noted by Campbell and Cochrane (1999), “Habit formation captures a fundamental feature of psychology: repetition of a stimulus diminishes the perception of the stimulus and responses to it” (p. 208).

To see the role of habits in international comovements, consider the origin of the anomaly. When international markets are complete, productivity differentials, induced by idiosyncratic shocks, make capital flows rush toward the most productive location. This results in counterfactually high volatility, of investment and negative cross-country investment correlation. Most two-country models restrain international capital movements by introducing sluggish capital adjustment.<sup>2</sup> Restricting capital movements delivers plausible investment volatility, but it fails to get the sign or the magnitude of cross-country investment correlations right.

In a model with time-nonseparable preferences, consumers react differently to productivity innovations. Habit-forming households strive to smooth not only consumption but also changes in consumption. In the periods following the shock, they increase consumption gradually and allow their habits to adjust. Therefore, on impact, an increase in domestic output compels domestic agents to increase their savings drastically. Because rapid changes in capital stock at home are increasingly costly, the domestic economy responds by increasing net exports. At the same time, the wealth effect makes foreign agents want to consume more, but habit formation punishes rapid changes in consumption. As a

result, world output rises with minor changes to world consumption. An increase in world savings raises investment abroad, provided that the adjustment cost at home exceeds the opportunity cost of not investing in the most productive location.

The way we model habits has three distinct features. First, we consider internal habits in consumption. This specification implies that an agent's utility depends on his or her current consumption relative to a reference level determined by his or her own consumption history. Our main alternative, the "Catching up with the Joneses" preferences described by Abel (1990), does not seem to reconcile with business cycle facts in a closed-economy setting [Lettau and Uhlig (2000)]. In addition, econometric studies in the financial literature tend to conclude that internal habit formation is more consistent with observed asset and bond returns than external habits [Ferson and Constantinides (1991); Grishchenko (2010)].

Second, in our setup, agents are interested in smoothing quasi-differences between consumption and the stock of habits. This specification, known as additive habits, has been popularized by Constantinides (1990). We prefer this specification because, unlike the multiplicative habits of Abel (1990), additive habits preserve the usual concavity properties of the consumer's objective function.<sup>3</sup>

Third, we assume that habits change gradually in response to changes in consumption. In contrast to specifications where habit stock is proportional to the previous period's consumption, we incorporate habit persistence. This feature is motivated by the empirical evidence provided by Heaton (1995) and Grishchenko (2010).

Our analysis is related to previous studies that highlight potential channels that contribute to resolving the quantity anomaly. These channels include exogenously incomplete markets [Kollmann (1996); Baxter and Crucini (1995)], variable factor utilization [Baxter and Farr (2005)], labor market frictions [Yakhin (2007); Hairault (2002)], and limited enforcement of international borrowing contracts [Kehoe and Perri (2002)].

Following Kollmann (1996), most of these studies allow trade only in one-period risk-free real debt contracts. Furthermore, they analyze near-steady state dynamics using a linearized system of equations. These simplifications might be problematic. As shown by Boileau and Normandin (2008), international RBC models with exogenously incomplete markets do not possess a unique deterministic steady state, and linearization methods yield nonstationary systems of linear difference equations. Our approach is not subject to this critique, for two reasons. First, we restrict our analysis to complete markets. Second, we solve the model with an Euler equation method that does not require linearization of the first-order conditions.<sup>4</sup>

International business cycle models are known to be sensitive to parameterization of the stochastic process for productivity [Baxter and Crucini (1995)]. In the words of Raffo (2008), "shocks need to have unit root persistence with no spillover effects for the asset structure to matter for business cycle properties" (p. 22). Simulations of our model suggest that our results exhibit little sensitivity

to the degree of spillovers and the persistence of the shocks. In fact, our model performs best when the models with financial frictions perform worst.

The remainder of the paper is organized as follows. In the next section we describe the model economy. In Section 3, we discuss the parameterization of the model. In Section 4, we present our quantitative results and discuss the implications of habits for international comovements. In Section 5, we offer some concluding remarks.

**2. THE ECONOMIES**

The world consists of two countries. The same parameters describe technology and preferences in both countries. Each country  $j = 1, 2$  is populated by a continuum of identical infinitely lived individuals. The two countries produce a single good that can be either consumed or invested. Labor is immobile across countries. In each period  $t$ , the world economy experiences an event  $s_t$  drawn from the countable set of events,  $S$ . Let  $s^t = (s_0, s_1, \dots, s_t) \in S^t$  be the history of events from time 0 to time  $t$ . The probability at time 0 of any given history  $s^t$  is denoted by  $\pi(s^t)$ .

**2.1. Consumers**

Let  $c_{jt}(s^t)$  denote household consumption at time  $t$  in country  $j$  after history  $s^t$  has been realized. Following Ferson and Constantinides (1991), we define the stock of habits  $h_{jt+1}(s^t)$  with which the agent begins the period as a convex combination of her past consumption and her past stock of habits:

$$h_{jt+1}(s^t) = \lambda c_{jt}(s^t) + (1 - \lambda) h_{jt}(s^{t-1}). \tag{1}$$

Under this specification, habit stock depreciates at a constant rate, as in Campbell and Cochrane (1999). The parameter  $\lambda \in [0, 1]$  determines the degree of habit persistence. The higher the  $\lambda$ , the more weight agents place on recent consumption history relative to the past. When  $\lambda = 1$ , the next period's habit stock is at just the level of current consumption.

Habit-forming agents have their preferences defined over stochastic sequences of consumption, habits, and leisure,

$$U = \sum_{t=0}^{\infty} \beta^t \sum_{s^t \in S^t} \pi(s^t) u(c_{jt}(s^t), h_{jt}(s^{t-1}), l_{jt}(s^t)), \tag{2}$$

where  $\beta \in (0, 1)$  is the discount factor and  $l_{jt}(s^t) \in [0, 1]$  denotes individual labor supply. Time endowment per period is normalized to one. The instantaneous utility function takes the following form:

$$u(c, h, l) = \frac{[(c - bh)^\gamma (1 - l)^{1-\gamma}]^{1-\sigma} - 1}{1 - \sigma},$$

where  $\sigma$  is the curvature parameter, and  $\gamma$  determines relative importance of leisure,  $1 - l$ , and habit-adjusted consumption,  $c - bh$ . The parameter  $b \in (0, 1)$

denotes the intensity of habit formation and introduces time-nonseparability of preferences.

**2.2. Producers**

The households supply labor and capital to the firms, which have access to constant-returns to scale technology. Production is subject to country-specific exogenous random shocks,  $z_{jt}(s^t)$ , to total factor productivity. Output in country  $j$  after history  $s^t$  is given by

$$y_{jt}(s^t) = f(k_{jt}(s^{t-1}), l_{jt}(s^t), z_{jt}(s^t)), \tag{3}$$

where  $k_{jt}(s^{t-1})$  denotes the capital stock used at time  $t$  by the firms in country  $j$ . The production function is Cobb–Douglas:  $f(k, l, z) = k^\alpha(zl)^{1-\alpha}$ . The  $2 \times 1$  vector of productivity shocks is assumed to follow a stationary autoregressive process in logs:

$$\begin{bmatrix} \log(z_{1t}(s^t)) \\ \log(z_{2t}(s^t)) \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{12} & A_{11} \end{bmatrix} \begin{bmatrix} \log(z_{1t-1}(s^{t-1})) \\ \log(z_{2t-1}(s^{t-1})) \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t}(s^t) \\ \varepsilon_{2t}(s^t) \end{bmatrix}.$$

Diagonal elements of the transition matrix,  $A_{11}$ , determine the degree of persistence in productivity within each country. When off-diagonal elements,  $A_{12}$ , are different from zero, productivity innovations originating in one country spill over national borders. The innovations to the productivity process,  $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t})'$ , are zero-mean serially uncorrelated bivariate normal random variables with contemporaneous covariance matrix

$$E[\varepsilon_t \varepsilon_t'] = \sigma_\varepsilon^2 \cdot \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}.$$

Capital accumulation is subject to convex adjustment costs as described in Hayashi (1982). Capital stock in each economy evolves over time according to the law of motion

$$k_{jt+1}(s^t) = (1 - \delta)k_{jt}(s^{t-1}) + \phi\left(\frac{i_{jt}(s^t)}{k_{jt}(s^{t-1})}\right)k_{jt}(s^{t-1}), \tag{4}$$

where  $\delta$  is the depreciation rate of capital. An adjustment cost function  $\phi$  satisfies  $\phi(\cdot) > 0$ ,  $\phi'(\cdot) > 0$ , and  $\phi''(\cdot) < 0$ . The restrictions  $\phi(\delta) = \delta$  and  $\phi'(\delta) = 1$  ensure that incorporation of the adjustment cost does not affect the deterministic steady state of the model. This formulation has been used by Baxter and Crucini (1995), Baxter and Farr (2005), and Yakhin (2007) in the context of international business cycle models.

### 2.3. Asset Markets

Agents have access to a complete set of state-contingent claims. The budget constraint faced by the residents in country  $j$  at time  $t$ , after history  $s^t$  is given by

$$\begin{aligned}
 c_{jt}(s^t) + i_{jt}(s^t) + \sum_{s_{t+1}} Q(s^t, s_{t+1}) B_{jt}(s^t, s_{t+1}) \\
 = r_{jt}(s^t) k_{jt}(s^{t-1}) + w_{jt}(s^t) l_{jt}(s^t) + B_{jt-1}(s^{t-1}, s_t),
 \end{aligned} \tag{5}$$

where  $w_{jt}(s^t)$  is the wage,  $r_{jt}(s^t)$  is the rental rate on capital in country  $j$ ,  $B_{jt}(s^t, s_{t+1})$  is the quantity of the claims for a unit of time  $t + 1$  consumption contingent on the realization of  $s_{t+1}$ , and  $Q(s^t, s_{t+1})$  is the claim's period- $t$  price.

### 2.4. Equilibrium

In this environment the equilibrium is defined in a standard way. It consists of the state-contingent sequences of prices  $\{r_{jt}(s^t), w_{jt}(s^t), \{Q(s_{t+1}, s^t)\}_{s_{t+1} \in S}\}_{t=0}^\infty$  and allocations  $\{c_{jt}(s^t), i_{jt}(s^t), l_{jt}(s^t), k_{jt+1}(s^t), \{B(s_{t+1}, s^t)\}_{s_{t+1} \in S}\}_{t=0}^\infty$  that satisfy the following conditions:

- (i) Given prices, consumers in country  $j \in \{1, 2\}$  choose state-contingent sequences of consumption,  $\{c_{jt}(s^t)\}_{t=0}^\infty$ , labor supply,  $\{l_{jt}(s^t)\}_{t=0}^\infty$ , gross investment,  $\{i_{jt}(s^t)\}_{t=0}^\infty$ , and bond-holding,  $\{\{B(s_{t+1}, s^t)\}_{s_{t+1} \in S}\}_{t=0}^\infty$ , to maximize (2) subject to budget constraint (5) and equations of motion (1) and (4), as well as the initial conditions  $\{k_{j0}, h_{j0}, z_{j0}\}_{j=1,2}$ .
- (ii) Given prices, the firms in country  $j \in \{1, 2\}$  choose  $l_{jt}(s^t)$  and  $k_{jt}(s^{t-1})$  to maximize profits,

$$y_{jt}(s^t) - r_{jt}(s^{t-1})k_{jt}(s^{t-1}) - w_{jt}(s^t)l_{jt}(s^t),$$

subject to the production technology (3) and nonnegativity constraints  $l_{jt}(s^t) \geq 0$ ,  $k_{jt}(s^{t-1}) \geq 0$ .

- (iii) Asset market clearing requires that for all  $t \geq 0$  and all  $s^t \in S^t$  it holds that

$$B_{1t}(s^t, s_{t+1}) + B_{2t}(s^t, s_{t+1}) = 0, \quad \text{for all } s_{t+1} \in S.$$

Because our environment is free from distortions or externalities, both welfare theorems hold. Consequently, an equilibrium allocation in this economy can be computed as a solution to the social planner's problem. The planner chooses state-contingent plans of consumption,  $c_{jt}(s^t)$ , investment,  $i_{jt}(s^t)$ , and employment,  $l_{jt}(s^t)$ , to maximize the expected discounted sum of weighted utilities of the two countries,

$$\sum_{t=0}^\infty \beta^t \sum_{s^t \in S^t} \pi(s^t) \sum_{j=1}^2 \omega_j u(c_{jt}(s^t), h_{jt}(s^{t-1}), l_{jt}(s^t)),$$

subject to equations of motion (1) and (4), the world resource constraint

$$\sum_{j=1}^2 c_{jt}(s^t) + \sum_{j=1}^2 i_{jt}(s^t) = \sum_{j=1}^2 f(k_{jt}(s^{t-1}), l_{jt}(s^t), z_{jt}(s^t)),$$

and the initial values  $\{k_{j0}, h_{j0}, z_{j0}\}_{j=1,2}$ . Because we abstract from differences in country size or initial distributions, symmetry requires us to equate the planner’s weights by setting  $\omega_1 = \omega_2 = 1/2$ .

Optimality requires that for all  $t \geq 0$ , all  $s^t \in S^t$ , and  $j = 1, 2$ , the following conditions hold:

$$\Lambda_{1t}(s^t) = \Lambda_{2t}(s^t), \tag{6}$$

$$\Lambda_{jt}(s^t) = \beta \sum_{s_{t+1} \in S} \pi(s_{t+1} | s^t) \Lambda_{j,t+1}(s^t, s_{t+1}) R_{j,t+1}(s^t, s_{t+1}), \tag{7}$$

$$-\frac{\partial u(c_{jt}(s^t), h_{jt}(s^{t-1}), l_{jt}(s^t))}{\partial l_{jt}(s^t)} = \Lambda_{jt}(s^t) \frac{\partial f(k_{jt}(s^{t-1}), l_{jt}(s^t), z_{jt}(s^t))}{\partial l_{jt}(s^t)}, \tag{8}$$

where  $\Lambda_{jt}(s^t)$  is the marginal utility of consumption after history  $s^t$ ,  $\pi(s_{t+1} | s^t)$  is the conditional probability of  $s_{t+1}$  given  $s^t$ , and  $R_{j,t+1}(s^t, s_{t+1})$  is the one-period gross return in country  $j$  from history  $s^t$  to  $(s^t, s_{t+1})$ .

The interpretation of the necessary conditions is standard. In complete markets the risk-sharing condition (6) requires that marginal utilities of consumption be equated across countries for every possible state of nature. The intertemporal condition (7) is the Euler equation, and (8) is the intratemporal condition that controls labor supply. Still, two nonstandard features are worth noting. First, under habit-formation preferences, the marginal utility of consumption is forward-looking, in the sense that it depends on expected future endogenous variables,

$$\Lambda_{jt}(s^t) = u_c(c_{jt}(s^t), h_{jt}(s^{t-1}), l_{jt}(s^t)) + \lambda \beta \sum_{\tau=t+1}^{\infty} \sum_{s^\tau} \pi(s^\tau | s^t) \times [\beta(1 - \lambda)]^{\tau-t-1} u_h(c_{j\tau}(s^\tau), h_{j\tau}(s^{\tau-1}), l_{j\tau}(s^\tau)), \tag{9}$$

where  $\pi(s^\tau | s^t)$  denotes the conditional probability of  $s^\tau$  given  $s^t$ , and  $\pi(s^t | s^t) = 1$ . Second, one-period gross return on capital reflects costly capital

**TABLE 1.** Parameterization of the benchmark model

Preferences:	Discount factor	$\beta$	0.989
	Consumption share	$\gamma$	0.361
	Utility curvature	$\sigma$	3.772
	Habit intensity	$b$	0.73
	Habit persistence	$\lambda$	0.75
Technology:	Capital income share	$\alpha$	0.36
	Depreciation rate	$\delta$	0.025
	Adjustment cost parameter	$\xi$	7.91
Productivity:	Persistence of productivity shocks	$A_{11}$	0.95
	Spillover parameter	$A_{12}$	0
	St. dev. of innovations to productivity	$\sigma_\varepsilon^2$	0.007
	Correlation of innovations to productivity	$\rho$	0.25

*Notes:* The time period is a quarter of a year. The values for  $\beta$  and  $\delta$  are set to yield the steady-state values for the investment-to-output ratio and the capital-to-output ratio of 0.25 and 10, respectively. These values correspond to the long-run averages in the postwar U.S. economy [Cooley (1997)]. The share of consumption in the composite good,  $\gamma$ , is chosen so that hours worked in the steady state equal 1/3. The values of the curvature parameter,  $\sigma$ , and the elasticity parameter,  $\xi$ , in the capital adjustment cost function vary across models. The former ensures that the elasticity of intertemporal substitution in consumption is equated to 1/2 across the models. The latter is set to match the relative standard deviation of investment in the data.

adjustment:

$$\begin{aligned}
 R_{jt+1}(s^t, s_{t+1}) = & \phi' \left( \frac{i_{jt}(s^t)}{k_{jt}(s^{t-1})} \right) f_k(k_{jt+1}(s^t, s_{t+1}), l_{jt+1}(s^t, s_{t+1}), \\
 & z_{jt+1}(s^t, s_{t+1})) + \left( 1 - \delta + \phi \left( \frac{i_{jt+1}(s^t, s_{t+1})}{k_{jt+1}(s^t)} \right) - \phi' \left( \frac{i_{jt+1}(s^t, s_{t+1})}{k_{jt+1}(s^t)} \right) \right) \\
 & \times \frac{i_{jt+1}(s^t, s_{t+1})}{k_{jt+1}(s^t)} \phi' \left( \frac{i_{jt}(s^t)}{k_{jt}(s^{t-1})} \right) / \phi' \left( \frac{i_{jt+1}(s^t, s_{t+1})}{k_{jt+1}(s^t)} \right). \tag{10}
 \end{aligned}$$

### 3. CALIBRATION AND SOLUTION

To facilitate comparison with existing studies, most parameter values are taken from the literature (see Table 1). We refer to Backus et al. (1992) for the empirical rationale underlying this choice of parameters. In parameterization of the stochastic process for the technology shocks, we follow Kehoe and Perri (2002).

We adopt the following functional form for capital adjustment cost from Boldrin et al. (2001):

$$\phi(x) = \frac{a_1}{1 - 1/\xi} (x)^{1-1/\xi} + a_2,$$

where  $\xi$  represents elasticity of investment with respect to Tobin’s  $q$ . The parameter  $\xi$  is chosen to match the observation that the standard deviation of investment is 2.88 times higher than that of output. The constants  $a_1$  and  $a_2$  are set to ensure that the deterministic steady state is invariant to changes in the concavity parameter  $\xi$ .<sup>5</sup>



The weight of leisure in the composite good,  $1 - \gamma$ , follows from the labor supply equation (8) in the deterministic steady state. Following Cooley (1997), we assume that the fraction of time endowment devoted to market activities equals  $1/3$ , and that investment/output share equals 0.25. With the chosen functional forms, the steady state version of the intratemporal condition (8) reads as

$$1 - \frac{\bar{i}}{\bar{y}} = \frac{\gamma}{(1 - \gamma)}(1 - \alpha) \frac{(1 - \bar{l})}{\bar{l}} \kappa,$$

where

$$\kappa = \frac{1 - b\lambda\beta \sum_{\tau=0}^{\infty} \beta^{\tau} (1 - \lambda)^{\tau}}{(1 - b)} = \frac{1}{1 - b} \left( 1 - \frac{b\lambda\beta}{1 - \beta + \lambda\beta} \right),$$

and the bars above the variables refer to their steady-state values. In general, the value for  $\gamma$  depends on the values of the habit intensity,  $b$ , and the habit persistence parameter,  $\lambda$ . Notice that in the case of time-separable preferences  $\kappa = 1$ , whereas in the case of nonpersistent habits  $\kappa = (1 - \beta b)/(1 - b)$ .

We calibrate the utility curvature parameter,  $\sigma$ , to ensure that the intertemporal elasticity of substitution of consumption in a deterministic model,  $\text{IES} = 1/(1 - \gamma(1 - \sigma))$ , equals  $1/2$ . This value corresponds to curvature 2, which is usually assumed in business cycle models with inelastic labor supply. In other words, we compare model economies adjusted to have the same intertemporal elasticity of substitution of consumption.

Parameterization of the model with habit formation requires choosing values for the habit intensity parameter,  $b$ , and the persistence parameter,  $\lambda$ . Several studies estimate the parameters of consumption habits [see Diaz et al. (2003) and references therein]. It appears that the heterogeneity of data, techniques, and research objectives results in a very wide range of possible values for habit parameters. Asset-pricing literature has shown that consumption habits characterized by values in the range from 0.69 to 0.9 help to explain the equity premium puzzle [see Boldrin et al. (2001), Constantinides (1990), or Jermann (1998)]. Because the purpose of our exercise is to examine investment behavior, we will resort to the estimate from the asset-pricing literature. In particular, we adopt the value of habit intensity from Jermann (1998), who considered a closed-economy counterpart to our model with inelastic labor supply and nonpersistent habits. In the sensitivity analysis, we report the results from simulations of the model with different values of habit parameters.

## 4. FINDINGS

### 4.1. Baseline Parameterization

This section compares the quantitative predictions of the model with the data. The two main results can be summarized as follows. First, our model predicts positive cross-country investment correlations. They are no longer at odds with

**TABLE 2.** International business cycle statistics: Baseline parameterization

	Model economy with				
	Adjustment cost			No adjustment cost	
	Time-separable preferences	Nonpersistent habits	Persistent habits	Nonpersistent habits	
	( $b = 0$ , $\lambda = 0$ )	( $b = 0.73$ , $\lambda = 1$ )	( $b = 0.73$ , $\lambda = 0.75$ )	( $b = 0.73$ , $\lambda = 1$ )	
Data					
Output	0.56	0.06	0.03	0.01	-0.41
Consumption	0.46	0.72	0.77	0.77	0.31
Investment	0.43	-0.20	0.29	0.33	-0.90
Employment	0.31	-0.39	-0.62	-0.68	-0.65

*Notes:* The statistics in the data column are calculated from U.S. data and aggregated data for fifteen European countries. The sample consists of the quarterly time series covering the period 1970:1–2008:2. The model's statistics are computed from a single simulation of 100,000 periods. All the statistics are based on logged (except for net exports) and HP-filtered data with a smoothing parameter of 1,600.

the data. Second, the introduction of habits does not weaken within-country business cycle properties. This contradicts the conclusions of Lettau and Uhlig (2000), who considered the role of external habits in a closed-economy RBC model.

The international business cycle statistics reported in Table 2 refer to the correlations of the U.S. variable with the corresponding variable for an aggregate of 15 European countries. In Table 3, the statistics corresponding to U.S. quarterly time series are reported in the column labeled “Data.” The sample covers the period 1970:1 to 2008:2. The data sources are described in the Appendix.

*International comovements.* The column labeled “Time-Separable Preferences” reports the predictions of the canonical international RBC model for our parameterization. The “quantity anomaly” of Backus et al. (1995) appears in Table 2. The standard model predicts negative international correlations of investment and employment ( $-0.20$  and  $-0.39$ ), whereas they are positive in the data (0.43 and 0.31).

Columns (3) and (4) of Table 3 correspond to the model augmented with internal habit-formation preferences. Our model with habits contributes to the resolution of the “anomaly” by getting international comovements of investment right. When nonpersistent habits are incorporated, the cross-country investment correlation changes from  $-0.20$  to 0.29. Introducing even very weak habit memory increases the correlation to 0.33.

To focus on the role of time-nonseparability, we abstract from the other important mechanisms of international propagation and transmission of business cycles.<sup>6</sup> This comes at a cost, mainly that predicted labor comovements still remain at odds with the data. Predicted cross-country correlations of employment remain negative, whereas the opposite is true in the data. Furthermore, our

**TABLE 3.** Domestic business cycle statistics: Baseline parameterization

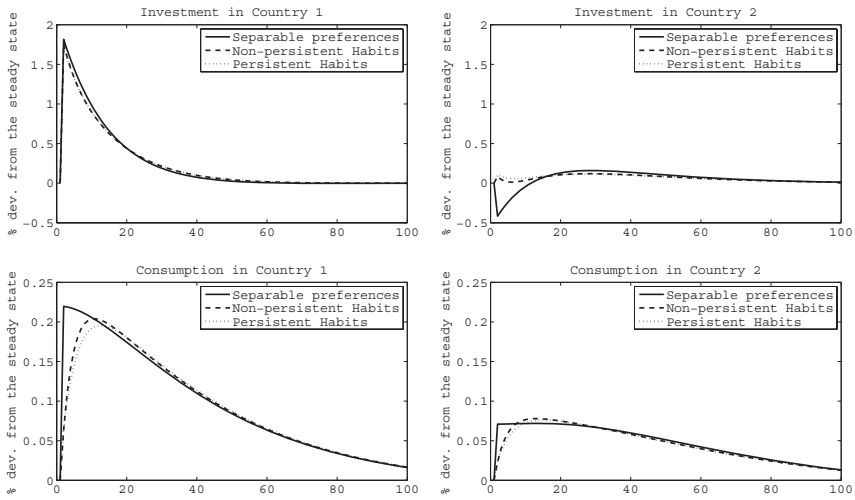
	Model economy with				
	Adjustment cost			No adjustment cost	
	Time-separable preferences ( $b = 0$ , $\lambda = 0$ )	Nonpersistent habits ( $b = 0.73$ , $\lambda = 1$ )	Persistent habits ( $b = 0.73$ , $\lambda = 0.75$ )	Nonpersistent habits ( $b = 0.73$ , $\lambda = 1$ )	
Data					
Panel A—volatilities—st. deviation (in %)					
Output	1.51	0.80	0.78	0.77	1.14
Net export/output	0.74	0.34	0.31	0.30	5.50
Standard deviations relative to output					
Consumption	0.81	0.41	0.30	0.27	0.23
Investment	2.88	2.88	2.88	2.88	21.41
Employment	0.84	0.43	0.40	0.40	0.48
Panel B—correlations with output					
Consumption	0.86	0.93	0.70	0.68	0.71
Investment	0.94	0.97	0.96	0.96	0.19
Employment	0.88	0.97	0.94	0.93	0.99
Net exports/output	-0.35	0.17	0.68	0.69	-0.01
Panel C—autocorrelations					
Output	0.87	0.73	0.73	0.73	0.83
Consumption	0.88	0.73	0.93	0.93	0.94
Investment	0.90	0.71	0.68	0.69	0.21
Employment	0.92	0.73	0.74	0.73	0.85
Net exports/output	0.86	0.96	0.71	0.72	0.21

*Notes:* Domestic statistics in the data column correspond to the U.S. quarterly time series sample 1970:1–2008:2. The model's statistics are computed from a single simulation of 100,000 periods. All the statistics are based on logged (except for the net exports) and HP-filtered data with a smoothing parameter of 1,600.

model inherits a well-known shortcoming of complete market models. It predicts international correlations of consumption that are too high (.77 vs. .46 in the data), and international correlations of output that are too low (.03 vs. .56 in the data).

*Domestic business cycle statistics.* Departure from time-separable preferences does not worsen within-country business cycle predictions. Improvements in matching some moments are offset by deteriorations in matching others. Consumption gets closer to the data in term of persistence (0.93 vs. 0.88 in the data) at the expense of becoming too smooth. Consumption, investment, and employment become less procyclical, whereas net export is more correlated with output.

As expected, most of the drawbacks of the canonical international RBC model are still present. First, the model predicts too little volatility in output, consumption, and employment. Second, net export is procyclical in the model, whereas the opposite is true in the data.



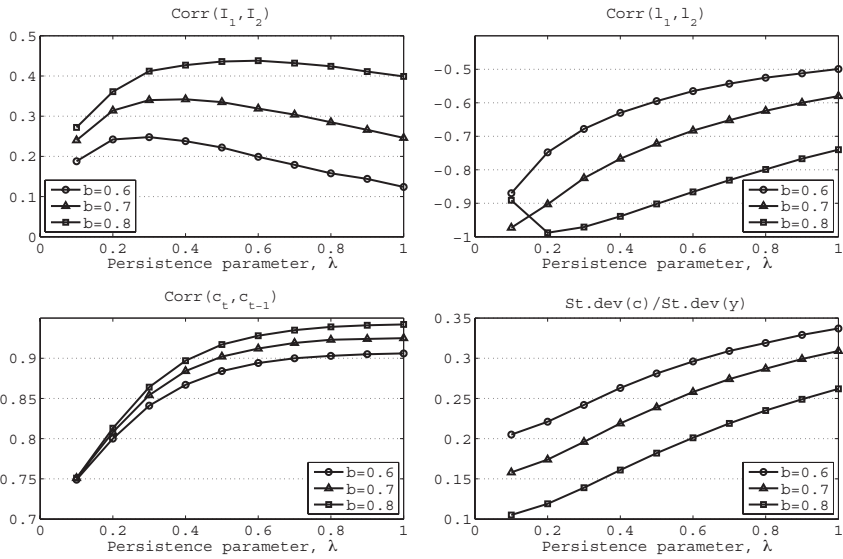
**FIGURE 1.** Impulse response functions. The figure plots the percentage changes in consumption and investment in response to one–standard deviation positive productivity shock in country 1.

*Responses to a productivity shock.* Impulse responses may help to understand the intuition for our result. Figure 1 plots the percentage changes in consumption and investment in response to a one–standard deviation positive productivity shock in country 1. The responses are shown for the three economies considered. We refer to country 1 as the home country and country 2 as the foreign country.

Consider the model with habit-formation preferences and capital adjustment costs. Following a positive productivity shock at home, domestic output rises. On impact, domestic investment will increase because the marginal productivity of capital is higher. At this point, another motive is present for raising domestic investment.

Following the shock, habit-forming consumers want to increase their consumption. However, they want to do so gradually and allow their stocks of habit enough time to rise. The desired consumption profile will be hump-shaped. Obtaining this profile gives consumers another motive for shifting consumption intertemporally. They have two channels for doing so: increasing domestic investment or increasing net exports. Changing domestic investment is costly, as rapid changes in capital stock are penalized through capital adjustment cost. To obtain the desired consumption profile, the consumers have to use international markets and increase net exports.

The net flow of goods to the most productive country diminishes in the immediate aftermath of the shock. Foreign consumers also need time to adjust their habits. The response of their consumption to the increase in wealth will be hump-shaped as well. The home country’s increased unwillingness to borrow from abroad



**FIGURE 2.** Sensitivity to the parameterization of habits. To examine the sensitivity of our model’s prediction to the parameterization of habits we vary persistence of habits,  $\lambda$ , for different levels of habit intensity,  $b$ . The figure depicts the moments most sensitive to habit intensity and persistence.

makes foreign consumers increase investment in order to shift their consumption intertemporally. Hence, investment rises simultaneously in both economies.

Note that both internal habits and capital adjustment cost are essential for this result. Habits induce households to want to smooth changes in consumption. Adjustment costs prevent households from intertemporally smoothing consumption domestically to the extent that they desire. As shown in Table 2, a model economy with costly capital adjustment and time-separable preferences generates negative cross-country investment correlations. As far as international comovements are concerned, a model with habit-formation preferences but without adjustment cost performs equally poorly. Both foreign and domestic agents are always able to obtain the desired consumption profile by investing in the most productive location. The last column of Table 2 reports negative investment comovements.

**4.2. Varying Intensity and Persistence of Habits**

This section considers how changes in the parameterization of habit intensity and its persistence affect the model’s prediction. Figure 2 summarizes the reactions of the most sensitive business cycle statistics to the choice of habit parameters. We study the sensitivity of the model’s predictions by varying the persistence of habits,  $\lambda$ , for different levels of habit intensity,  $b$ .

The consumer’s desire to smooth changes in consumption is determined by the two parameters in the specification of habits: the intensity of habits,  $b$ ,

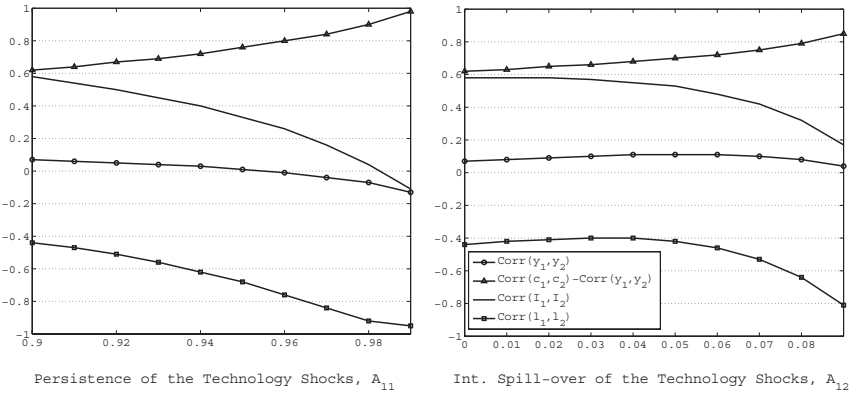
and their persistence,  $\lambda$ . When  $b$  is small, the forward-looking terms in the marginal utility of consumption matter little to the consumer. Hence, from the consumer's perspective, the model resembles the model with time-separable preferences.

Figure 2 shows that greater persistence of habits is associated with less volatile and less autocorrelated consumption streams. The explanation for this is as follows. When habits become more persistent, the relative weight of leisure in the instantaneous utility,  $1 - \gamma$ , must increase to maintain the steady state level of hours worked. Intuitively, with persistent memory, any change in consumption has long-lasting consequences. Higher consumption today sets a higher standard for all future periods. The lower the persistence parameter is, the more substantial are the negative effects of today's higher consumption on felicity in any given future period. Hence, an increase in habit persistence lowers the marginal utility of consumption by placing more weight on its negative forward-looking term. In equilibrium, the marginal rate of substitution between consumption and leisure equals the real wage. To maintain this equality in the steady state without changing the level of hours worked, the weight of habit-adjusted consumption,  $\gamma$ , must decrease. A higher relative weight of leisure in the instantaneous utility implies that the response of consumption to productivity shocks decreases whereas the response of hours worked increases. As a result, relative volatility of consumption and its autocorrelation falls.

As habit persistence rises, cross-country correlation of hours worked remains negative but increases in absolute value. For sufficiently high levels of habit intensity, Figure 2 documents an inverse U-shaped relation between international investment correlation and the degree of habit persistence. An interaction between two opposing forces is responsible for this outcome. The positive force stems from households' increased reluctance to change consumption rapidly and the growth of consumption in response to transitory shocks. The negative force comes from labor comovement. After a productivity shock, hours worked in the two countries move in opposite directions, primarily due to complete international markets and frictionless labor markets. If hours worked did not move in opposite directions, it would only reinforce our mechanism behind positive investment co-movements. Indeed, after a positive shock in the home country, the wealth effect reduces foreign agents' willingness to work. Hours worked and output abroad fall. If foreign labor input did not decrease, world output would rise ever more, in response to a positive shock. World savings would increase further and put greater pressure on raising foreign investment. As habits become more persistent, both forces are amplified. For sufficiently low  $\lambda$ , the negative force grows faster than the positive force, and therefore investment correlations decrease.

#### 4.3. Do Spillovers and Persistence of Shocks Matter?

In this section, we investigate the extent to which our model's predictions depend on the specification of the exogenous shocks. The main reason for doing so is that



**FIGURE 3.** Sensitivity to the persistence and spillovers of the shocks. The figure plots the cross-country correlations implied by the model with persistent habits. When the degree of persistence is varied, the remaining parameters are kept at the baseline level. When degree of technological spillovers is varied,  $A_{12}$ , the persistence parameter,  $A_{11}$ , is set to 0.9, whereas the remaining parameters are kept at the baseline level.

the predictions of the international RBC model are known to be sensitive to the specification of the forcing process (Baxter and Crucini, 1995). This is especially important for models with restricted international markets.

Figure 3 and Table 4 show that our model’s predictions under benchmark parameterization are robust to changes in the parameters governing productivity shocks. Our model predicts positive cross-country investment correlations, even when technological innovations spill over national borders. The intuition behind this result is apparent. When the spillover coefficients,  $A_{12}$ , are high, the role of financial markets and therefore their imperfections diminish. Thus, the predictions of the incomplete market models become closer to those for the frictionless economy.

As the persistence of technology shocks,  $A_{11}$ , increases, the extent of international borrowing possibilities becomes of greater importance. To isolate the effect of habits on international comovement, we assume a complete market setting. Only when the process for the shock approaches the unit root does the prediction of our model for international comovements deteriorate. On the other hand, when shocks are less persistent, habit-forming agents are more reluctant to change their consumption profiles in response to technology disturbances. In this case, the interplay between habits and costly capital adjustment becomes more important. To summarize, as far as parameterization of technological shocks is concerned, our model seems to perform best when models with financial frictions perform worst.

**5. CONCLUSION**

This paper considered the effect of nonseparability of preferences over time on international comovements in factors of production. We introduced internal

**TABLE 4.** Business cycle statistics: Sensitivity to the parameterization of the shocks

	Parameterizations of the forcing process					
	Data	Benchmark	Persistence		Positive spillovers	BKK
			Low	High		
Panel A—volatilities—st. deviation (in %)						
Output	1.51	0.77	0.78	0.75	0.73	0.88
Net export/output	0.74	0.30	0.32	0.30	0.27	0.32
Standard deviations relative to output						
Consumption	0.81	0.27	0.22	0.30	0.35	0.36
Investment	2.88	2.88	2.88	2.88	2.88	2.88
Employment	0.84	0.40	0.41	0.39	0.38	0.37
Panel B—correlations with output						
Consumption	0.86	0.68	0.67	0.68	0.66	0.66
Investment	0.94	0.96	0.95	0.97	0.95	0.95
Employment	0.88	0.93	0.96	0.88	0.88	0.85
Net exports/output	-0.35	0.69	0.68	0.70	0.64	0.64
Panel C—cross country correlations						
Output	0.56	0.01	0.07	-0.04	0.04	0.01
Consumption	0.46	0.77	0.69	0.81	0.89	0.90
Investment	0.43	0.33	0.58	0.16	0.17	0.09
Employment	0.31	-0.68	-0.44	-0.84	-0.81	-0.88
Panel D—autocorrelations						
Output	0.87	0.73	0.71	0.74	0.70	0.70
Consumption	0.88	0.93	0.92	0.93	0.93	0.93
Investment	0.90	0.69	0.67	0.69	0.65	0.65
Employment	0.92	0.73	0.71	0.74	0.67	0.67
Net exports/output	0.86	0.72	0.69	0.74	0.76	0.78

*Notes:* Domestic statistics in the data column (Panels A, B, and D) correspond to the U.S. quarterly time series sample 1970:1–2008:2. International business cycle statistics are calculated from U.S. data and aggregated data of 15 European countries. The model’s statistics are computed from a single simulation of 100,000 periods. All the statistics are based on logged (except for the net exports) and HP-filtered data with a smoothing parameter of 1600.

habit-formation preferences into a two-country stochastic growth model with an endogenous labor supply and costly capital adjustment. This innovation helps an otherwise standard international RBC model with complete markets to overcome its difficulty in accounting for positive cross-country investment correlations observed in the data. We show that internal habits in consumption provide a channel through which the capital adjustment costs exceed the opportunity costs of not investing in a more productive country. The improvement in terms of international comovements does not come at the expense of the domestic business cycle properties of the model.



To focus on the role of time-nonseparability, we abstract from the other potentially important mechanisms of international propagation and transmission of business cycles. This comes at some costs. Cross-country consumption correlations exceed those of output; furthermore, predicted labor comovements still remain at odds with the data.

To summarize, our study suggests that internal habit-formation preferences may be useful for understanding international comovements of factors of production. A possible alternative to our formulation of habits is a version of external habits. The most common formulations of external habits are “Keeping up with the Joneses” and “Catching up with the Joneses” [Ljungqvist and Uhlig (2000)]. In the context of two-country business cycle models, we are less than enthusiastic about external habits for two reasons. First, excess smoothness of consumption, documented by Lettau and Uhlig (2000) in a closed-economy setting, will only be exacerbated under perfect international risk-sharing. Second, in a multicountry setting, the introduction of external habits begs the question of who exactly “the Joneses” are. Does consumption externality induced by comparison utility cross national borders? To what extent does foreign consumption affect the reference level in domestic utility? These are interesting questions that deserve further investigation. Our explanation is not intended to be a substitute for others that focus on financial frictions and labor market imperfections. On the contrary, we consider examining the interaction of time nonseparable preferences with incomplete financial markets a promising avenue for future research.

## NOTES

1. See for example Kollmann (1996), Heathcote and Perri (2002), or Kehoe and Perri (2002).
2. For instance, Backus et al. (1992) use time-to-build technology, Kollmann (1996) relies on quadratic capital adjustment cost, and Baxter and Crucini (1995) adopt a version of convex capital adjustment cost introduced by Hayashi (1982). The comovement problem has proved very robust to variations in how sluggish capital adjustment is introduced. Most of the literature that followed BKK relied on Hayashi’s formulation of the adjustment cost function to deal with excessive volatility of investment. Recent examples include Maffezzoli (2000), Baxter and Farr (2005), Yakhin (2007), and Boileau and Normandin (2008).
3. When habits are additive, the instantaneous utility function is concave. Theorems in Chapter 4 of Stokey et al. (1989) establish that the latter is sufficient for the consumer’s objective function to be concave. However, Alonso-Carrera et al. (2005) demonstrate that under a multiplicative specification of habits, the consumer’s objective function may fail to be concave. In this case, the consumer’s optimization problem is not convex and therefore the interiority of the solution is not guaranteed.
4. We solve the social planner’s problem numerically using a version of the parameterized expectations approach (PEA) introduced by Den Haan and Marcat (1990).
5. The restrictions  $\phi'(\delta) = 1$  and  $\phi(\delta) = \delta$  require that  $a_1 = \delta^{1/\xi}$  and  $a_2 = \delta/(1 - \xi)$ .
6. Labor market frictions seem to be a promising avenue for getting labor comovements right. For instance, Yakhin (2007) demonstrated that real wage rigidity helps to account for positive cross-country correlation of hours worked when international markets are incomplete. Household production is another mechanism that enjoyed a degree of success in dealing with labor comovements,

as well as with lack of variability in consumption and output. Canova and Ubide (1998) introduced it by explicitly modeling a household production sector, whereas Raffo (2008) considered preferences that embed home production in reduced form. Baxter and Farr (2005) emphasize yet another propagation mechanism that increases volatility of output and potentially relative volatilities of consumption and hours worked. They focus on variable capital utilization, which is incorporated through a depreciation-in-use specification.

## REFERENCES

- Abel, Andrew B. (1990) Asset prices under habit formation and catching up with the Joneses. *American Economic Review* 80, 38–42.
- Alonso-Carrera, Jaime, Jordi Caballe, and Xavier Raurich (2005) Growth, habit formation, and catching-up with the Joneses. *European Economic Review* 49, 1665–1691.
- Backus, David K., Patrick J. Kehoe, and Finn E. Kydland (1992) International real business cycles. *Journal of Political Economy* 100, 745–775.
- Backus, David K., Patrick J. Kehoe, and Finn E. Kydland (1995) International business cycles: theory and evidence. In Thomas F. Cooley (ed.), *Frontiers of Business Cycle Research*, pp. 331–356. Princeton, NJ: Princeton University Press.
- Baxter, Marianne (1995) International trade and business cycles. In Gene Grossman and Kenneth Rogoff (eds.), *Handbook of International Economics*, Vol. 3, pp. 1801–1864. Amsterdam: Elsevier North Holland.
- Baxter, Marianne and Mario J. Crucini (1995) Business cycles and the asset structure of foreign trade. *International Economic Review* 36, 821–854.
- Baxter, Marianne and Dorsey D. Farr (2005) Variable capital utilization and international business cycles. *Journal of International Economics* 65, 335–347.
- Boileau, Martin and Michel Normandin (2008) Closing international real business cycle models with restricted financial markets. *Journal of International Money and Finance* 27, 733–756.
- Boldrin, Michele, Lawrence J. Christiano, and D. M. Fisher Jonas (2001) Habit persistence, asset returns, and the business cycle. *American Economic Review* 91, 149–166.
- Campbell, John Y. and John Cochrane (1999) By force of habit: A consumption-based explanation of aggregate stock market behavior. *Journal of Political Economy* 107, 205–251.
- Canova, Fabio and Angel J. Ubide (1998) International business cycles, financial markets and household production. *Journal of Economic Dynamics and Control* 22, 545–572.
- Carroll, Christopher D., Jody Overland, and David N. Weil (2000) Saving and growth with habit formation. *American Economic Review* 90, 341–355.
- Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans (2005) Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy* 113, 1–45.
- Constantinides, George M. (1990) Habit formation: A resolution of the equity premium puzzle. *Journal of Political Economy* 98, 519–43.
- Cooley, Thomas F. (1997) Calibrated models. *Oxford Review of Economic Policy* 13, 55–69.
- Den Haan, Wouter J. and Albert Marcet (1990) Solving the stochastic growth model by parameterizing expectations. *Journal of Business and Economic Statistics* 8, 31–34.
- Diaz, Antonia, Josep Pijoan-Mas, and Jose-Victor Rios-Rull (2003) Precautionary savings and wealth distribution under habit formation preferences. *Journal of Monetary Economics* 50, 1257–1291.
- Ferson, Wayne E. and George M. Constantinides (1991) Habit persistence and durability in aggregate consumption: empirical tests. *Journal of Financial Economics* 29, 199–240.
- Fuhrer, Jeffrey C. and Michael W. Klein (2006) Risky habits: On risk sharing, habit formation, and the interpretation of international consumption correlations. *Review of International Economics* 14, 722–740.
- Grishchenko, Olesya V. (2010) Internal vs. external habit formation: The relative importance for asset pricing. *Journal of Economics and Business* 62, 176–194.

- Hairault, Jean-Olivier (2002) Labor-market search and international business cycles. *Review of Economic Dynamics* 5, 535–558.
- Hayashi, Fumio (1982) Tobin's marginal  $q$  and average  $q$ : A neoclassical interpretation. *Econometrica* 50, 213–224.
- Heathcote, Jonathan and Fabrizio Perri (2002) Financial autarky and international business cycles. *Journal of Monetary Economics* 49, 601–627.
- Heaton, John (1995) An empirical investigation of asset pricing with temporally dependent preference specifications. *Econometrica* 63, 681–717.
- Jermann, Urban J. (1998) Asset pricing in production economies. *Journal of Monetary Economics* 41, 257–275.
- Kehoe, Patrick J. and Fabrizio Perri (2002) International business cycles with endogenous incomplete markets. *Econometrica* 70, 907–928.
- Kollmann, Robert (1996) Incomplete asset markets and the cross-country consumption correlation puzzle. *Journal of Economic Dynamics and Control* 20, 945–961.
- Lettau, Martin and Harald Uhlig (2000) Can habit formation be reconciled with business cycle facts? *Review of Economic Dynamics* 3, 79–99.
- Ljungqvist, Lars and Harald Uhlig (2000) Tax policy and aggregate demand management under catching up with the Joneses. *American Economic Review* 90, 356–366.
- Maffezzoli, Marco (2000) Human capital and international real business cycles. *Review of Economic Dynamics* 3, 137–165.
- Raffo, Andrea (2008) Net exports, consumption volatility and international business cycle models. *Journal of International Economics* 75, 14–29.
- Stokey, Nancy L., Robert E. Lucas, Jr. with Edward C. Prescott (1989) *Recursive Methods in Economic Dynamics*. Cambridge, MA: Harvard University Press.
- Yakhin, Yossi (2007) Staggered wages, financial frictions, and the international comovement problem. *Review of Economic Dynamics* 10, 148–171.

## APPENDIX

Data on GDP, consumption, investment, and net exports come from *OECD Quarterly National Accounts*. European data cover the following fifteen countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom. The data are in quarterly frequency, in constant prices, and seasonally adjusted. The sample period is 1970:1–2008:2. The data are aggregated at the source.