W – 23

april 2010

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Habit Persistence and International Comovements

CROATIAN NATIONAL BANK

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April 2010

CROATIAN NATIONAL BANK

Publisher:
Croatian National Bank
Publishing Department
Trg hrvatskih velikana 3, 10002 Zagreb
Phone: 385-1-4564-555
Contact phone: 385-1-4565-006
Fax: 385-1-4564-687

Website:
http://www.hnb.hr

Editor-in-chief:
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Printed by:
Denona d.o.o., Zagreb

Printed in 350 copies

ISSN 1331–8586

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Abstract

Two-country real business cycle models with time-separable preferences and complete markets predict that cross-country investment correlations are negative. The opposite is true in the data. Backus et al (1995) coined the term quantity anomaly for this phenomenon. This paper proposes to address this discrepancy by allowing the nonseparability of preferences over time. We incorporate internal habit formation in consumption. Our model predicts empirically plausible values of cross-country investment correlation without deteriorating other business cycle statistics. The results are robust to the degree of spillovers and persistence in the specification of productivity shocks.

JEL: E32, F41, G15

Keywords: international real business cycles, time nonseparable preferences, habit persistence, investment comovements

We are most grateful to Jordi Caballé, Juan Carlos Conesa, and Albert Marcet for their encouragement, their patience, many helpful comments and discussions. We have also benefited from the comments and suggestions of Mario Crucini, Chris Edmond and participants of CEF2009, Econometric Society Australiasian Meeting 2009, Southern Macroeconomics Workshop 2009, AMW 2009, Sydney-Melbourne Workshop on Macro Theory and seminar attendants at Universitat Autonoma de Barcelona, U. of Barcelona and U. of Graz. Financial support from ASBRG is gratefully acknowledged. The usual disclaimer applies.

Contents

1 Introduction

Two-country real business cycle models with time-separable preferences and complete markets predict that cross-country investment correlations are negative.[1] The opposite is true in the data. Backus et al (1995) coined the term quantity anomaly for this phenomenon. In this paper we propose to address this discrepancy by allowing time nonseparability in preferences. To do so we incorporate habit formation into consumption. Our model predicts empirically plausible values of cross-country investment correlation without a concomitant deterioration of other business cycle statistics. Our results are robust to the degree of spillovers and 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" (Baxter 1995, p. 1859).

Most contributions that followed Baxter's challenge focused on the role of financial frictions. Baxter and Crucini (1995) and Kollmann (1996) investigated the quantitative impact of the elimination of trade in state-contingent assets on the properties of international real business cycles. They found that the exogenous limit on the assets that may be traded was not severe enough in terms of risk sharing, investment flows and working effort to resolve correlation puzzles. Kehoe and Perri (2002) examined the model in which limited risk sharing arises endogenously from the limited ability to enforce international credit arrangements between countries. They find that this contract enforcement friction goes a long way in reconciling the IRBC theory and data (although not all the way in terms of the consumption puzzle). Recently, Yakhin (2007) show that exogenous market incompleteness can also generate positive employment and investment crosscorrelations once additional nominal rigidities are introduced (staggered wages and monopolistic behavior of households with respect to supply of labor).

Our approach is different. We retain the assumption of complete international markets. We ask the question of whether relaxing the assumption of time separable preferences could improve the properties of a canonical two-country one-good RBC model.

We depart from the assumption of time-separability by introducing habit formation in consumption. There are several reasons for doing 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 enjoyed some degree of success in addressing asset pricing and monetary

1 See Krznar (2008) for an extensive review of two-country RBC models.

phenomena as well as in the growth literature. Finally, the notion of habits has been embraced by behavioral sciences. As noted by Campbell and Cochrane (1999:208) "Habit formation captures a fundamental feature of psychology: repetition of a stimulus diminishes the perception of the stimulus and responses to it".

The way we model habits has three distinct features. First, we consider internal habits in consumption. This specification implies that agents' utility depends on their current consumption relative to a reference level determined by the history of their own past consumptions. Our main alternative, "Catching up with the Joneses" preferences of Abel (1990), does not seem to reconcile well with business cycle facts in a closed economy setting (Lettau and Uhlig, 2000). In addition, econometric studies in 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; Grishenko 2008).

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.

Third, we assume that habits change gradually in response to changes in consumption. Contrary to specifications in which 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 (2008).

Our analysis is related to the previous studies that highlight potential channels contributing to resolution of 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), 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 non-stationary 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 a Euler equation method that does not require linearization of the first order conditions.

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 $s^t = (s_0, s_1, ..., s_t)$ denote the history of events from time 0 to time 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 households stock of habits at time t as a weighted sum of all their past consumptions

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

Under this specification, habit stock depreciates at a constant rate as in Campbell and Cochrane (1999). Alternatively, the level of habits $h_{jt+1}(s^t)$ with which the agent begins the period can be defined recursively as a convex combination of their past consumption and their past stock of habits

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

The parameter $\lambda \in [0,1]$ determines the degree of habit persistence. The higher the λ the more weight agents place on recent consumption history relative to the past. When $\lambda = 1$, the next period's habit stock is just the level of current consumption.

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

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

where $\beta \in (0,1)$ is the discount factor, and $l_{jt}(s^t) \in (0,1]$ denotes the individual labor supply. Time endowment per period is normalized to one. The instantaneous utility of an individual in country j after history s^t is given by

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

where σ is the curvature parameter, and γ 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-non-separability of preferences.

2.2 Producers

The households supply labor and capital to the firms that have access to constant returns-to-scale technology. Production is subject to country-specific exogenous random shock, $z_{jt}(s^t)$, 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 capital stock used at time t by the firms in country j. Production function is Cobb-Douglas: $f(k,l,z)=k^{\alpha}(zl)^{1-\alpha}$. The 2×1 vector of productivity shocks is assumed to follow a stationary autoregressive process in logs:

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

The innovations to the productivity process are zero mean serially independent bivariate normal random variables with contemporaneous covariance matrix

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

Capital stock in each economy evolves over time according to the following law of motion

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

where δ is the depreciation rate of capital and ϕ is an increasing convex adjustment cost function described in Hayashi (1982). 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 real 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

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

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 realization of s_{t+1}, and $Q(s^t,s_{t+1})$ is their 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 $\left\{r_{jt}\left(s^t\right), w_{jt}\left(s^t\right), \left\{Q\left(s_{t+1}, s^t\right)\right\}_{s_{t+1}\in S}\right\}_{t=0}^{\infty}$ and allocations $\left\{c_{jt}\left(s^t\right), i_{jt}\left(s^t\right), l_{jt}\left(s^t\right), k_{jt+1}\left(s^t\right), \left\{B\left(s_{t+1}, s^t\right)\right\}_{s_{t+1}\in S}\right\}_{t=0}^{\infty}$ that satisfy the following conditions:

1. Given prices, consumers in country $j \in \{1,2\}$ choose state contingent sequences of consumption, $\left\{c_{jt}\left(s^t\right)\right\}_{t=0}^{\infty}$, labor supply, $\left\{l_{jt}\left(s^t\right)\right\}_{t=0}^{\infty}$, gross investment, $\left\{i_{jt}\left(s^t\right)\right\}_{t=0}^{\infty}$, and bond holding, $\left\{\left\{B\left(s_{t+1}, s^t\right)\right\}_{s_{t+1}\in S}\right\}_{t=0}^{\infty}$, to maximize (2) subject to the budget constraint (5), equations of motion (1) and (4), as well as the initial conditions $\left\{k_{j0}, h_{j0}, z_{j0}\right\}_{j=1,2}$.
2. 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 non-negativity constraints $l_{jt}(s^t) \geq 0$, $k_{jt}(s^{t-1}) \geq 0$.
3. Asset markets clearing requires that for all $t \geq 0$, and all $s^t \in S^t$ it holds that $B_{1t}(s^t, s_{t+1}) + B_{2t}(s^t, s_{t+1}) = 0$, for all $s_{t+1} \in S$.

Since 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

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

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

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

and the initial values $\left\{k_{j0}, h_{j0}, z_{j0}\right\}_{j=1,2}$. Since 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:

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

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

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

where $R_{jt+1}(s^t, s_{t+1})$ is one period real return in country j from history s^t to (s^t, s_{t+1}), and $\Lambda_{jt}(s^t)$ is marginal utility of consumption after history s^t.

The interpretation of the necessary conditions is standard. Under 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 equation (8) is the intratemporal condition that controls labor supply. Still, two non-standard features are worth noting. First, under habit formation preferences, marginal utility of consumption is forward-looking in the sense that it depends on expected future endogenous variables

$$\begin{aligned}\Lambda_{jt}\left(s^t\right) &= u_c\left(c_{jt}\left(s^t\right),h_{jt}\left(s^{t-1}\right),l_{jt}\left(s^t\right)\right)\\ &+\lambda\beta\sum_{\tau=t+1}^{\infty}\sum_{s^\tau}\pi\left(s^\tau\middle|s^t\right)\left[\beta(1-\lambda)\right]^{\tau-1}u_h\left(c_{jt}\left(s^\tau\right),h_{jt}\left(s^{\tau-1}\right),l_{jt}\left(s^\tau\right)\right). \end{aligned} \tag{9}$$

Second, one-period gross return on capital reflects costly capital adjustment

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

3 Calibration and Solution

3.1 Parametrization of the Model

To facilitate comparison with existing studies, most parameter values are taken from the literature. 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) (See Table 1).

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 ξ represents elasticity of investment with respect to Tobin's q. The parameter ξ 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_{12} are set to make sure that deterministic steady state is invariant to changes in the concavity parameter ξ.

The share of leisure in the composite good, $1-\gamma$, follows from the labor supply equation (8) in the deterministic steady state. Following Cooley1997OREP we assume that fraction of time endowment devoted to market activities is equal to 1/3, and that investment/output share is equal to 0.25. With the chosen functional forms, the steady state version of the intratemporal condition (8) reads as:

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

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 bar above the variable refers to their steady state values. In general, the value for γ depends on the values of the habit intensity, b, and the habit persistence parameter λ. Notice that in the case of time-separable preferences $\kappa=1$, while in the case of non-persistent habits $\kappa=\frac{1-\beta b}{1-b}$.

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

Parametrization of the model with habit formation requires choosing a value for the habit intensity parameter, b, and the persistence parameter, λ. There are several studies that estimate the parameters of consumption habits (see Diaz et al (2003) and references therein). It appears that heterogeneity of data, techniques and research objectives gives rise to a very wide range of possible values for habit parameters. Asset pricing literature found that consumption habits characterized by values in the range of 0.69 to 0.9 help to explain equity premium puzzle.[2] Since the purpose of our exercise is to examine behavior of investment, 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 of our model with inelastic labor supply and non-persistent habits. In the sensitivity analysis we report the results from simulation of the model with different values of habits parameters.

3.2 Numerical Solution of the Model

We solve the social planner's problem numerically using the parameterized expectations approach (PEA) introduced by den Haan and Marcet (1990). The idea of PEA is to replace the conditional expectations in (7), and (9) by smooth parametric

2 See Boldrin, Christiano and Fisher (2001), Constantinides (1990), or Jermann (1998).

approximation functions of the current state variables and a vector of parameters and then iterate on the values of parameters until the rational expectation equilibrium is achieved. The details of implementation of the algorithm to our framework are reported in the Computational Appendix.

The choice of PEA as a solution algorithm can be justified on several grounds. First, PEA is not as vulnerable to the "curse of dimensionality" as state-space discretization methods due to its reliance on Monte Carlo integration and endogenous oversampling. This is of particular importance here since we are dealing with numerous state and co-state variables.

Second, some authors, e.g. Diaz et al (2003), reported facing difficulties in getting a numerical solution to a version of stochastic growth model augmented with additive habits in consumption. This is because the algorithm that relies on value function iteration can not rule out ex ante the values of decision variables that an agent will try very hard to avoid (so that actually agents end up consuming negative habit adjusted consumption!). Since PEA features endogenous oversampling it only pays attention to those points that actually happen in equilibrium. In other words, by focusing on the economically relevant region of the state space, PEA overcomes this problem.

4 Findings

4.1 Baseline Parametrization

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

In Table 3, the statistics reported in the Data columns correspond to US quarterly time series. The international business cycle statistics reported in Table 2 refer to the correlations of the US variable with the corresponding variable for an aggregate of 15 European countries. The sample coverers the period 1970:1 to 2008:2. The data sources are described in Appendix A.

4.1.1 International Comovements

The column labeled 'Time-Separable Preferences' reports 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) while they are positive in the data (0.43 and 0.31).

The last two columns of Table 3 correspond to the model augmented with internal habit formation preferences. Our model with habits contributes to resolution of the 'anomaly' by getting international comovements of investment right.

When non-persistent habits are incorporated, cross-country investment correlation changes from –0.20 to 0.29. Introducing even a very weak habit memory increases the correlation to 0.33.

To focus on the role of time non-separability we abstract from other important mechanisms of international propagation and transmission of business cycles. This comes at a cost, the main one of which is that predicted labor comovements still remain at odds with the data. Predicted cross country correlations of employment remain negative while the opposite is true in the data. Furthermore, our model inherits a well-known shortcoming of complete market models. It predicts too high international correlations of consumption (0.77 vs. 0.46 in the data) as a result of perfect risk sharing and too low international correlations of output (0.03 vs. 0.56 in the data). Our model solves the investment puzzle but aggravates the labor puzzle. The former will give rise to a positive output correlation. However, the latter will push output correlation back to zero.

4.1.2 Domestic Business Cycle Statistics

Departure for 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 getting too smooth. Consumption, investment and employment become less procyclical whereas net export becomes more correlated with output.

As expected, most 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 while the opposite is true in the data.

4.1.3 Responses to a Productivity Shock

Impulse responses are helpful to understand the intuition for our result. Figure 1 plots the percentage changes in consumption and investment in response to 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 cost. Following a positive productivity shock at home, domestic output rises. On impact, domestic investment will rise since marginal productivity of capital is higher. This time, another motive for raising domestic investment is present.

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 export.

Changing domestic investment is costly since rapid changes in capital stock are penalized through the 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 in the immediate aftermath of the shock diminishes. 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 abroad makes foreign consumers increase investment in order to shift their consumption intertemporally. Hence, investment rises simultaneously in the two economies.

Notice that both internal habits and capital adjustment cost are essential for this result. Habits induce a household's desire to smooth changes in consumption. Adjustment costs prevent households from intertemporally smoothing consumption domestically to the extent that they want. As shown in Table 2, a model economy with costly capital adjustment and time-separable preferences generate negative cross-country investment correlations.

4.2 Varying Intensity and Persistence of Habits

This section considers how changes in 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, λ, 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, λ. When b is small, the forward-looking terms in the marginal utility of consumption matter little to the consumer. Hence, from their perspective, the model resembles that with time-separable preferences.

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 predictions of international RBC model are known to be sensitive to the specification of the forcing process (Baxter and Crucini,1995). This is especially important for the 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. Unlike models with incomplete markets, ours predicts positive cross country investment correlations even when technological innovations spill over the national borders. The intuition behind this is apparent. When the spillover coefficients, A_{12}, are high, the role of financial markets and therefore of their imperfections diminish. Therefore, the predictions of the incomplete market models become closer to those of the frictionless economy.

As persistence of technology shocks, A_{11}, increases, the extent of international borrowing possibilities becomes more important. To isolate the effect of habits on international comovement we assumed a complete market setting. Only when the process for the shock becomes near unit-root, will the prediction of our model for cross-country correlation deteriorate. On the other hand, when shocks are less persistent, habit forming agents become more reluctant rapidly to change their consumption profile.

As far as parameterization of the technological shocks is concerned, our model performs best when the models with financial friction perform worst.

5 Conclusion

This paper considered the effect of non-separability of preferences over time on international comovements in factors of production. We introduced internal habit formation preferences in a two-country stochastic growth model with 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 the 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 become larger than 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 deteriorating domestic business cycle properties of the model.

To focus on the role of time non-separability we abstract from other important mechanisms of international propagation and transmission of business cycles. This comes at a cost, the main one of which is that cross-country consumption correlations exceed those of output. Furthermore, predicted labor comovements still remain at odds with the data.

To conclude, our study suggests that internal habit formation preferences may be useful for understanding international comovements of factors of production. Our explanation is not intended to be a substitute for those that focus on financial fictions and labor market imperfections. On the contrary, we consider examining the interaction of time non-separable preferences with incomplete financial markets as a promising avenue for future research.

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6 Data Appendix

Data for GDP, consumption, investment and net export come from *OECD Quarterly National Accounts*. European data cover the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom. The data are in quarterly frequency, in constant prices, seasonally adjusted. The sample period is 1970:1–2008:2. The data are aggregated at the source.

7 Appendix: Tables and Figures

Table 1 Parametrization of the Benchmark Model

Preferences:	Discount factor	β	0.989
	Consumption share	γ	0.361
	Utility curvature	σ	3.772
	Habit intensity	b	0.73
	Habit persistence	λ	0.75
Technology:	Capital income share	α	0.36
	Depreciation rate	δ	0.025
Productivity:	Persistence of the productivity shocks	A_{11}	0.95
	Spillover parameter	A_{12}	0
	St. dev. of innovations to productivity	σ^2_ε	0.007
	Correlation of innovations to productivity	ρ	0.25

Note: The time period is a quarter of a year. The adjustment cost parameter is set to match the relative standard deviation of investment in the data.

Table 2 International Business Cycle Statistics: Baseline Parameterization

	Data	**Time separable preferences**	**Non-persistent habits**	**Persistent habits**
		(λ=0)	**(b=0.73, λ=1)**	**(b=0.73, λ=0.75)**
Output	0.56	0.06	0.03	0.01
Consumption	0.46	0.72	0.77	0.77
Investment	0.43	–0.20	0.29	0.33
Employment	0.31	–0.39	–0.62	–0.68

Note: The statistics of the Data column are calculated from U.S. data and aggregated data of 15 European countries. The sample consists of the quarterly time series covering the period of 1970:1–2008:2. The model's statistics are computed from a single simulation on a 100,000 period time series. All the statistics are based on logged (except for the net exports) and HP-filtered data with the smoothing parameter of 1600.

Table 3 Domestic Business Cycle Statistics: Baseline Parameterization

	Data	Time separable preferences	Non-persistent habits	Persistent habits
		(λ=0)	(b=0.73, λ=1)	(b=0.73, λ=0.75)
Panel A – Volatilities – Standard deviation (in %)				
Output	1.51	0.80	0.78	0.77
Net export/Output	0.74	0.34	0.31	0.30
Standard deviations relative to output				
Consumption	0.81	0.41	0.30	0.27
Investment	2.88	2.88	2.88	2.88
Employment	0.84	0.43	0.40	0.40
Panel B – Correlations with output				
Consumption	0.86	0.93	0.70	0.68
Investment	0.94	0.97	0.96	0.96
Employment	0.88	0.97	0.94	0.93
Net exports/Output	–0.35	0.17	0.68	0.69
Panel C – Autocorrelations				
Output	0.87	0.73	0.73	0.73
Consumption	0.88	0.73	0.93	0.93
Investment	0.90	0.71	0.68	0.69
Employment	0.92	0.73	0.74	0.73
Net exports/Output	0.86	0.96	0.71	0.72

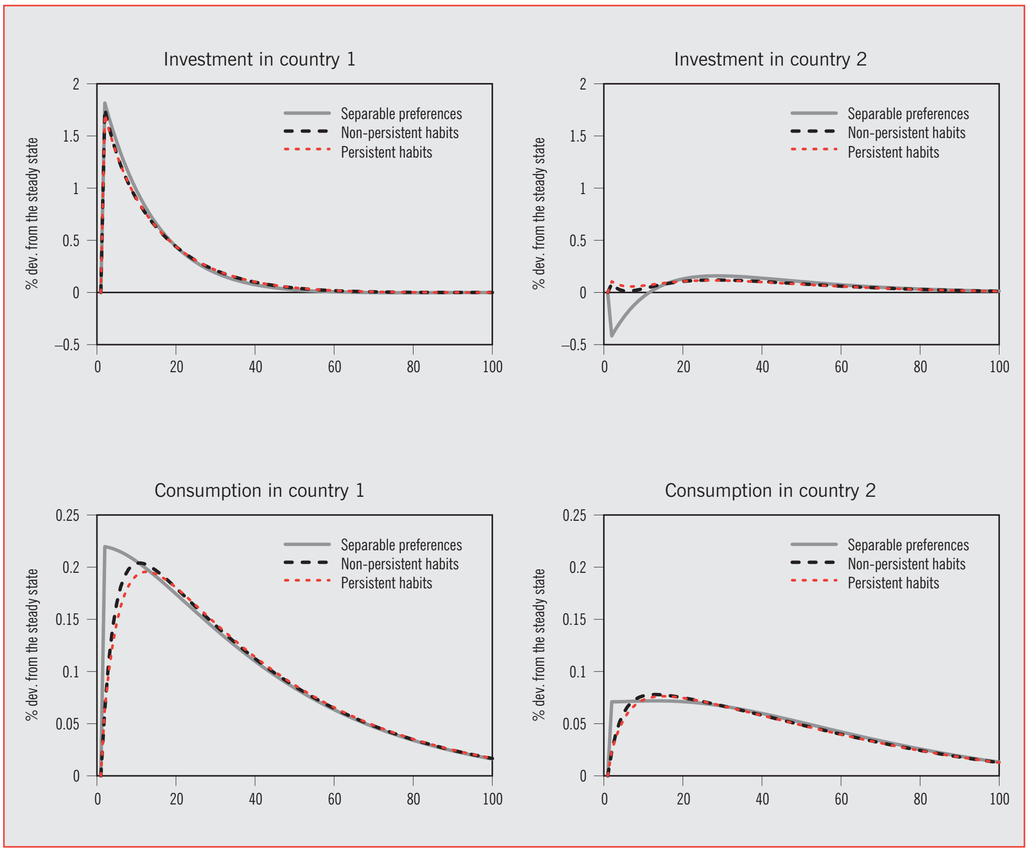
Note: Domestic statistics of the Data column correspond to the U.S. quarterly time series sample 1970:1–2008:2. The model's statistics are computed from a single simulation on a 100,000 period time series. All the statistics are based on logged (except for the net exports) and HP-filtered data with the smoothing parameter of 1600.

Table 4 Business Cycle Statistics: Sensitivity to the Parametrization of the Shocks

	Data	Parameterizations of the forcing process				
		Benchmark	Persistence		Positive	BKK
			Low	High	Spillovers	
Panel A – Volatilities – Standard 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

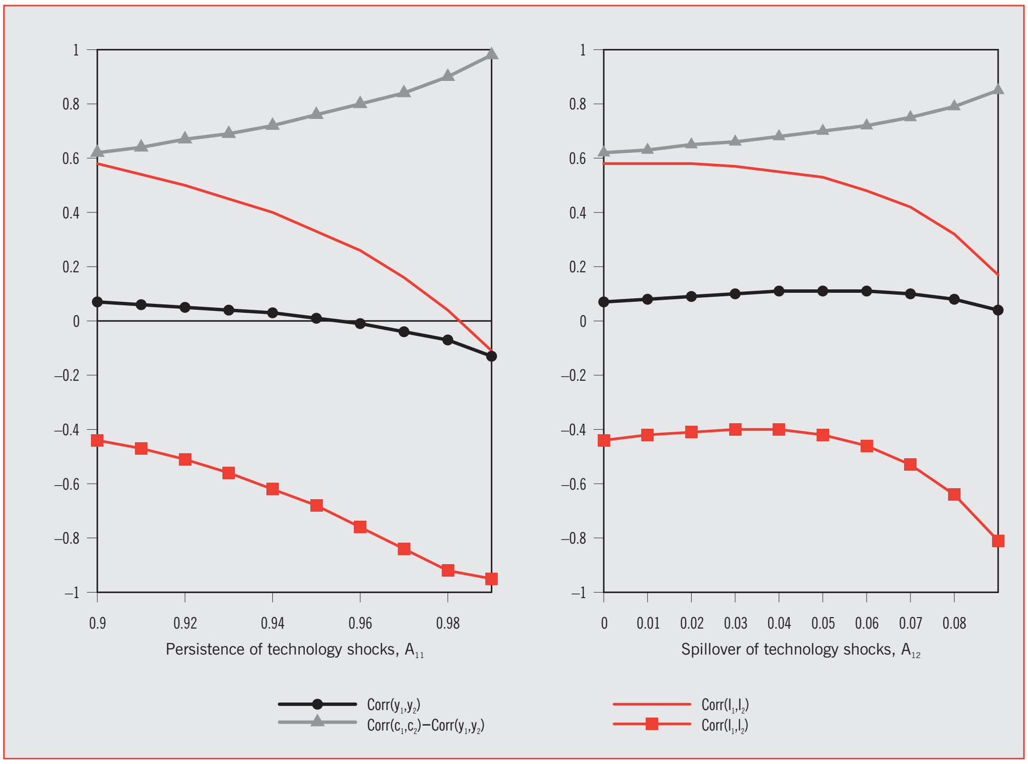
Note: Domestic statistics of the Data column (Panel A, B, and D) correspond to the U.S. quarterly time series sample 1970:1–2008:2. International business cycle statistics are calculated from U.S. data and aggregated data of 15 European countries. The model's statistics are computed from a single simulation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

Figure 1 Impulse Response Functions



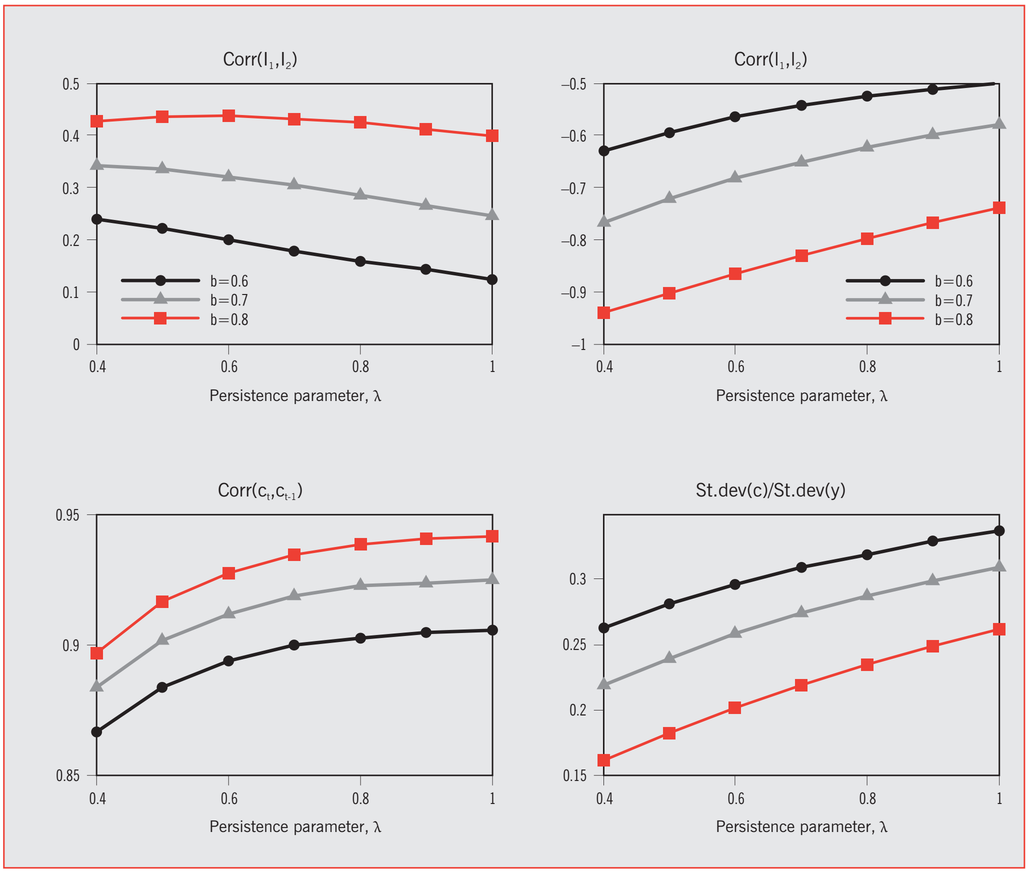
Note: The figure plots the percentage changes in consumption and investment in response to one standard deviation positive productivity shock in country 1.

Figure 2 Sensitivity to the Parameterization of Habits



Note: To examine the sensitivity of our model's prediction to the parameterization of habits we vary the persistence of habits, λ, for different levels of habit intensity, b. The figure depicts the moments most sensitive to habit intensity and persistence.

Figure 3 Sensitivity to the Persistence and Spillovers of the Shocks



Note: The figure plots the cross-country correlations implied by the model with persistent habits. When the of degree of persistence is varied, the remaining parameters are kept at the baseline level. When the degree of technological spillovers, A_{12}, is varied, the persistence parameter, A_{11}, is set to 0.9, while the remaining parameters are kept at the baseline level.

8 Appendix: The Optimality Conditions

An equilibrium allocation in this economy can be computed as the solution to a social planner's problem. The planner seeks to maximize the expected discounted sum of weighted utilities of the countries $j \in \{1,2\}$ subject to equations of motion for capital, habits as well as the world budget constraint.

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

$$h_{jt+1}(s^t) = \lambda c_{jt}(s^t) + (1-\lambda) h_{jt}(s^{t-1}), \text{ for } j = 1,2,$$

$$k_{jt+1}(s^t) = (1-\delta) k_{jt}(s^{t-1}) + \phi\left(\frac{i_{jt}(s^t)}{k_{jt}(s^{t-1})}\right) k_{jt}(s^{t-1}), \text{ for } j = 1,2,$$

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

with the initial condition k_{j0}, h_{j0}, z_{j0} given.

The Lagrangian for the planner's problem is given by

$$\begin{aligned} L = \sum_{t=0}^{\infty} \sum_{s^t \in S^t} \Big[& \beta^t \pi(s^t) \sum_{j=1}^{2} \omega_j u\left(c_{jt}(s^t), h_{jt}(s^{t-1}), l_{jt}(s^t)\right) \\ & - \sum_{j=1}^{2} m_j(s^t) \left(k_{jt+1}(s^t) - (1-\delta) k_{jt}(s^{t-1}) + \phi\left(\frac{i_{jt}(s^t)}{k_{jt}(s^{t-1})}\right) k_{jt}(s^{t-1}) \right) \\ & - \sum_{j=1}^{2} n_j(s^t) \left(h_{jt+1}(s^t) - \lambda c_{jt}(s^t) + (1-\lambda) h_{jt}(s^{t-1}) 0pt19pt \right) \\ & - \gamma(s^t) \left(\sum_{j=1}^{2} c_{jt}(s^t) + \sum_{j=1}^{2} i_{jt}(s^t) - \sum_{j=1}^{2} f\left(k_{jt}(s^{t-1}), l_{jt}(s^t), z_{jt}(s^t)\right) \right) \Big] \end{aligned}$$

The corresponding first order conditions are

$$\beta^t \pi(s^t) \omega_j u_c\left(c_{jt}(s^t), h_{jt}(s^{t-1}), l_{jt}(s^t)\right) + \lambda n_j(s^t) = \gamma(s^t),$$

$$m_j(s^t) \phi'\left(\frac{i_{jt}(s^t)}{k_{jt}(s^{t-1})}\right) = \gamma(s^t),$$

$$\beta^t \pi(s^t) \omega_j u_l\left(c_{jt}(s^t), h_{jt}(s^{t-1}), l_{jt}(s^t)\right) + \gamma(s^t) f_l\left(k_{jt}(s^{t-1}), l_{jt}(s^t), z_{jt}(s^t)\right) = 0,$$

$$\begin{aligned} m_j(s^t) = \sum_{s_{t+1} \in S} m_j(s^t, s_{t+1}) \Bigg(& 1 - \delta + \phi\left(\frac{i_{jt+1}(s^t, s_{t+1})}{k_{jt+1}(s^t)}\right) \\ & - \phi'\left(\frac{i_{jt+1}(s^t, s_{t+1})}{k_{jt+1}(s^t)}\right) \frac{i_{jt+1}(s^t, s_{t+1})}{k_{jt+1}(s^t)} \Bigg) \\ & + \sum_{s_{t+1} \in S} \gamma(s^t, s_{t+1}) f_k\left(k_{jt+1}(s^t, s_{t+1}), l_{jt+1}(s^t, s_{t+1}), z_{jt+1}(s^t, s_{t+1})\right), \end{aligned}$$

$$n_j\left(s^t\right)=(1-\lambda)\sum_{s_{t+1}\in S}n_j\left(s^t,s_{t+1}\right)$$
$$+\sum_{s_{t+1}\in S}\beta^{t+1}\pi\left(s^t,s_{t+1}\right)\omega_j u_h\left(c_{jt+1}\left(s^{t+1}\right),h_{jt+1}\left(s^t\right),l_{jt+1}\left(s^{t+1}\right)\right).$$

The intertemporal conditions can be rearranged as

$$\frac{n_j\left(s^t\right)}{\beta^t\pi\left(s^t\right)}=(1-\lambda)\sum\nolimits_{s_{t+1}\in S}\frac{n_j\left(s^t,s_{t+1}\right)}{\beta^{t+1}\pi\left(s^t,s_{t+1}\right)}\frac{\beta^{t+1}\pi\left(s^t,s_{t+1}\right)}{\beta^t\pi\left(s^t\right)}$$
$$+\sum\nolimits_{s_{t+1}\in S}\frac{\beta^{t+1}\pi\left(s^t,s_{t+1}\right)}{\beta^t\pi\left(s^t\right)}\omega_j u_h\left(c_{jt+1}\left(s^{t+1}\right),h_{jt+1}\left(s^t\right),l_{jt+1}\left(s^{t+1}\right)\right),$$

$$\frac{m_j\left(s^t\right)}{\beta^t\pi\left(s^t\right)}=\sum\nolimits_{s_{t+1}\in S}\frac{m_j\left(s^t,s_{t+1}\right)}{\beta^{t+1}\pi\left(s^t,s_{t+1}\right)}\frac{\beta^{t+1}\pi\left(s^t,s_{t+1}\right)}{\beta^t\pi\left(s^t\right)}$$
$$\times\left(1-\delta+\phi\left(\frac{i_{jt+1}\left(s^t,s_{t+1}\right)}{k_{jt+1}\left(s^t\right)}\right)-\phi'\left(\frac{i_{jt+1}\left(s^t,s_{t+1}\right)}{k_{jt+1}\left(s^t\right)}\right)\frac{i_{jt+1}\left(s^t,s_{t+1}\right)}{k_{jt+1}\left(s^t\right)}\right)$$
$$+\sum\nolimits_{s_{t+1}\in S}\frac{\gamma\left(s^t,s_{t+1}\right)}{\beta^{t+1}\pi\left(s^t,s_{t+1}\right)}\frac{\beta^{t+1}\pi\left(s^t,s_{t+1}\right)}{\beta^t\pi\left(s^t\right)}f_k\left(k_{jt+1}\left(s^t,s_{t+1}\right),l_{jt+1}\left(s^t,s_{t+1}\right),z_{jt+1}\left(s^t,s_{t+1}\right)\right).$$

By denoting $\tilde{n}_j\left(s^t\right)=n_j\left(s^t\right)/\beta^t\pi\left(s^t\right);\tilde{m}_j\left(s^t\right)=m_j\left(s^t\right)/\beta^t\pi\left(s^t\right);\tilde{\gamma}\left(s^t\right)=\gamma\left(s^t\right)/\beta^t\pi\left(s^t\right)$ we can rewrite the optimality conditions as

$$\tilde{n}_j\left(s^t\right)=\beta\sum\nolimits_{s_{t+1}\in S}\pi\left(s_{t+1}\middle|s^t\right)\left[\omega_j u_h\left(c_{jt+1}\left(s^t,s_{t+1}\right),h_{jt+1}\left(s^t\right),l_{jt+1}\left(s^t,s_{t+1}\right)\right)+\right.$$
$$\left.+(1-\lambda)\tilde{n}_j\left(s^t,s_{t+1}\right)\right],$$

$$\omega_j u_c\left(c_{jt}\left(s^t\right),h_{jt}\left(s^{t-1}\right),l_{jt}\left(s^t\right)\right)+\lambda\tilde{n}_j\left(s^t\right)=\tilde{\gamma}\left(s^t\right),$$
$$\omega_j u_l\left(c_{jt}\left(s^t\right),h_{jt}\left(s^{t-1}\right),l_{jt}\left(s^t\right)\right)+\tilde{\gamma}\left(s^t\right)f_l\left(k_{jt}\left(s^{t-1}\right),\mathrm{l}_{jt}\left(s^t\right),\mathrm{z}_{jt}\left(s^t\right)\right)=0,$$
$$\tilde{m}_j\left(s^t\right)=\beta\sum\nolimits_{s_{t+1}\in S}\pi\left(s_{t+1}\middle|s^t\right)\tilde{m}_j\left(s^t,s_{t+1}\right)$$
$$\times\left(1-\delta+\phi\left(\frac{i_{jt+1}\left(s^t,s_{t+1}\right)}{k_{jt+1}\left(s^t\right)}\right)-\phi'\left(\frac{i_{jt+1}\left(s^t,s_{t+1}\right)}{k_{jt+1}\left(s^t\right)}\right)\frac{i_{jt+1}\left(s^t,s_{t+1}\right)}{k_{jt+1}\left(s^t\right)}\right)$$
$$+\beta\sum\nolimits_{s_{t+1}\in S}\pi\left(s_{t+1}\middle|s^t\right)\tilde{\gamma}\left(s^t,s_{t+1}\right)f_k\left(k_{jt+1}\left(s^t,s_{t+1}\right),l_{jt+1}\left(s^t,s_{t+1}\right),z_{jt+1}\left(s^t,s_{t+1}\right)\right).$$

Let $\Lambda_{jt}(s^t)$ denote marginal utility of consumption of agent j after history s^t. Recursive substitution and the law of iterated expectations allow us to write it as

$$\Lambda_{jt}\left(s^t\right)=u_c\left(c_{jt}\left(s^t\right),h_{jt}\left(s^{t-1}\right),l_{jt}\left(s^t\right)\right)$$
$$+\lambda\beta\sum\nolimits_{\tau=t+1}^{\infty}\sum\nolimits_{s^\tau}\pi\left(s^\tau\middle|s^t\right)\left[\beta(1-\lambda)\right]^{\tau-1}u_h\left(c_{j\tau}\left(s^\tau\right),h_{j\tau}\left(s^{\tau-1}\right),l_{j\tau}\left(s^\tau\right)\right),$$

where $\pi(s^\tau|s^t)$ denotes the conditional probability of s^τ given s^t, and $\pi(s^\tau|s^t)=1$.

Let $R_{jt+1}(s^t,s_{t+1})$ denote the realized one-period gross rate of return on capital after realization of history (s^t,s_{t+1}).

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

then the first order conditions can be reformulated as

$$\Lambda_{1t}\left(s^t\right)=\frac{\omega_2}{\omega_1}\Lambda_{2t}\left(s^t\right),$$
$$\Lambda_{jt}\left(s^t\right)=\beta\sum_{s_{t+1}\in S}\pi\left(s_{t+1}\middle|s^t\right)\Lambda_{jt}\left(s^t,s_{t+1}\right)R_{jt+1}\left(s^t,s_{t+1}\right),$$
$$u_l\left(c_{jt}\left(s^t\right),h_{jt}\left(s^{t-1}\right),l_{jt}\left(s^t\right)\right)+\Lambda_{jt}\left(s^t\right)f_l\left(k_{jt}\left(s^{t-1}\right),l_{jt}\left(s^t\right),z_{jt}\left(s^t\right)\right)=0.$$

The following Working Papers have been published:

No.	Date	Title	Author(s)
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W–2	January 2000	Is Unofficial Economy a Source of Corruption?	Michael Faulend and Vedran Šošić
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After the submission, the manuscripts shall be subject to peer review and classification by the Manuscript Review and Classification Committee. The authors shall be informed of the acceptance or rejection of their manuscript for publication within two months following the manuscript submission.

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ISSN 1331–8586