Review of Economic Dynamics **3,** 79–99 (2000)
doi:10.1006/redy.1998.0035, available online at http://www.idealibrary.com on IDEAL®

Can Habit Formation Be Reconciled with Business Cycle Facts?*

Martin Lettau

Federal Reserve Bank of New York and CEPR, Research Department, New York, New York 10045
E-mail: Martin.Lettau@ny.frb.org

and

Harald Uhlig

Tilburg University and CEPR, 5000 LE Tilburg, The Netherlands
E-mail: uhlig@kub.nl

Received September 18, 1997

Many asset pricing puzzles can be explained when habit formation is added to standard preferences. We show that utility functions with a habit then gives rise to a puzzle of consumption volatility in place of the asset pricing puzzles when agents can choose consumption and labor optimally in response to more fundamental shocks. We show that the consumption reaction to technology shocks is too small by an order of magnitude when a utility includes a consumption habit. Moreover, once a habit in leisure is included, labor input is counterfactually smooth over the cycle. In the case of habits in both consumption and leisure, labor input is even countercyclical. Consumption continues to be too smooth. *Journal of Economic Literature* Classification Numbers: E13, E21, E32.
Key Words: habit formation; real business cycles; consumption

1. INTRODUCTION

In recent years, models with habit formation[1] have been quite successful in linking consumption with asset prices. In particular, Constantinides

* We thank John Campbell, an anonymous referee, and the participants of seminars at Maastricht, Mannheim, Tilburg, the CEPR summer symposium in finance 1996, and the AEA 1996 meetings for helpful comments. The views expressed in this paper are those of the authors and are not necessarily those of the Federal Reserve Bank of New York or the Federal Reserve System. Any errors and omissions are the responsibility of the authors.

[1] The term ‘‘habit’’ refers here to external habits, or in Abel’s (1990) words, ‘‘keeping up with the Joneses.’’

1094-2025/00 $35.00

(1990) has shown that once a habit is added to the standard model with power utility and log normal distribution, the equity premium puzzle of Mehra and Prescott (1985) disappears. More recently, Campbell and Cochrane (1995) presented a different habit formation model that avoids some of the drawbacks of earlier models, such as a high and very volatile risk-free rate. See also Weil (1992) for a discussion on how habit formation changes the volatility bounds of Hansen and Jagannathan (1991). Typically these models specify an exogenously given consumption process and use the first-order condition of a representative consumer to derive the implication for asset prices. This approach leaves the following question open: How does the consumption path look when consumers choose consumption optimally in response to some more fundamental shock in the presence of habit formation?

In this spirit we study versions of Hansen's (1985) real business cycle model with shocks to technology and preferences which include habit formation following Campbell and Cochrane (1995). Consider first a model with habit only in consumption. One feature of the model is that agents can adjust consumption and labor input in response to technology shocks. We find that this labor−leisure channel provides an avenue for adjusting to the aggregate shock, enabling the agent to drastically smooth consumption. The intuition is that the habit formation makes the agent (locally) very risk averse, which implies a very low (local) elasticity of substitution. Hence the agents want to smooth consumption extremely, making consumption very unresponsive to shocks. This low elasticity of substitution has also an effect on the optimal labor choice after a positive technology shock. There are two effects. First, labor is more productive, and hence wages are higher. This induces the worker to work more now to take advantage of the higher wages as long as the technology shock has not died out yet. Second, workers are induced to work less because they earn more per unit worked, and the low elasticity of substitution implies that they do not want to adjust consumption by much. Hence, they can reduce their labor input. The sign of the net effect depends on parameters of the models, such as the persistence of the technology shock and elasticity of substitution for consumption and labor. When the technology shock is very persistent and the intertemporal elasticity of substitution of labor is not too large, we find that labor input decreases after a positive technology shock. Moreover, the consumption responses are still very small when the persistence of technology shocks is high or risk aversion is decreased.

The key insight is that agents use labor input to smooth consumption extremely. Since the Hansen (1985) model is very restrictive in assuming that labor enters the utility function in a linear fashion, we consider several extensions of the benchmark model. In particular, we allow for a separate habit in leisure. Since agents are reluctant to adjust labor input much when their preferences include a leisure habit, the volatility of labor input decreases substantially. Interestingly, the volatility of consumption is not affected very much by the leisure habit. When we allow for habits in both consumption and leisure, agents choose to decrease their input slightly after a positive shock, causing labor input to move countercyclically. Consumption is still extremely smooth.

Studying the dynamic responses of other real variables, such as output and investment, productivity shocks reveals that the pattern of dynamic behavior is not affected very much by habit formation, although their volatilities are dampened substantially by habit formation.

After we completed an earlier version of this paper, two related working papers came to our attention: Jermann (1998) and Boldrin *et al*. (1995). Both papers consider real business cycle models with habit formation as we do, but they focus on the implications for the equity premium instead of the variability of consumption, as in our paper. Jermann (1998) looks at a model where labor input is fixed and there are adjustment costs in capital accumulation. He finds that the equity premium is fairly large as long as the adjustment costs are substantial. Boldrin *et al*. (1995) study a two-sector model with limited resource flexibility across sectors. They find that the model with habit formation is not able to match the high equity premium in the data, even when capital goods cannot be moved between sectors and the labor inputs are predetermined before the shock is realized. Our paper differs from theirs in several ways. First, they consider a special case of Constantinides' (1990) habit, which is known to produce a high and volatile risk-free rate. We consider the habit of Campbell and Cochrane (1995), which matches the asset pricing data better. Second, we look at a one-sector model, while Boldrin *et al*. (1995) consider a two-sector model. The two papers have in common that agents have to be restricted in their labor, investment, and/or consumption choice in order to get a high equity premium or large consumption fluctuations. Boldrin *et al*. (1995) accomplish this through rigidities between sectors, while we concentrate on the labor market. Third, in the last version of their model, consumption, which is the focus of our study, is essentially determined by the technology shock alone, since all substitution between sectors is switched off and labor input is chosen before the shock is realized.

The next section contains the specification of the utility function. Section 3 describes the model. Section 4 contains the results for the model with only a habit in consumption, and Section 5 allows for separate habits in both consumption and leisure. In Section 6, we briefly discuss alternative preferences. Section 7 concludes.

2. HABIT FORMATION FOLLOWING CAMPBELL AND COCHRANE

The specification of the habit in the utility function follows Campbell and Cochrane (1995). Capital letters denote levels, and small letters natural logs of a variable. Let $(X_t)_{t=0}^{\infty}$ denote a (stochastic) sequence of habits. X_t is a function of past consumption and will be defined below. Define a discount factor $0 < \beta < 1$ and a curvature parameter $\gamma > 0$. The utility of an individual agent for a stochastic sequence of individual consumption $(C_t)_{t=0}^{\infty}$ is given by

$$U\big((C_t)_{t=0}^{\infty}\big) = E_0 \sum_{t=0}^{\infty} \beta^t u(C_t; X_t), \tag{1}$$

where

$$u(C; X) = \frac{(C - X)^{1-\gamma} - 1}{1 - \gamma}.$$

The stochastic sequence of habits $(X_t)_{t=0}^{\infty}$ is regarded as exogenous by the individual agents and tied to the stochastic sequence of aggregate consumption $(C_t)_{t=0}^{\infty}$ as follows (note that we use the same symbol for individual as well as for aggregate consumption, as we are only going to study environments with a representative agent). Let

$$S_t = \frac{C_t - X}{C_t} \tag{2}$$

denote the surplus consumption ratio and $s_t = \log S_t$ its natural logarithm. Instead of specifying how the habit component X_t depends on past consumption, Campbell and Cochrane choose to specify the surplus ratio S_t as a function of past consumption. Of course, the habit can be recovered from (2) for any given S_t. Let lowercase letters denote logs, e.g., $c_t = \log(C_t)$. Let g be the average consumption growth rate, $g = E[\Delta c_{t+1}]$, and let σ_ν^2 denote the conditional variance of consumption growth, $\sigma_\nu^2 = \mathrm{Var}_t[\Delta c_{t+1}]$. Campbell and Cochrane (1995) assume that the log-surplus ratio is an autoregressive process, with the innovation depending on unexpected consumption growth:

$$s_{t+1} = (1 - \phi)\bar{s} + \phi s_t + \lambda(s_t)(\Delta c_{t+1} - g), \tag{3}$$

where $0 < \phi < 1$ is a persistence parameter, and $\lambda(s)$ defines a sensitivity function which controls how the surplus ratio (and hence the current habit) is affected by current consumption shocks. Note that habit depends on consumption in the same period, in contrast to, e.g., the model of Constantinides (1990), where habits depend only on past consumption. The AR structure of the surplus ratio implies that the log-habit x_t is (approximately) a moving average process of past log consumption. See Campbell and Cochrane (1995) for more details of this habit specification. The marginal rate of substitution can be written in terms of consumption and the surplus ratio:

$$\begin{aligned} M_{t+1} &= \beta \frac{u'(C_{t+1}; X_{t+1})}{u'(C_t; X_t)} \\ &= \beta \left(\frac{S_{t+1}}{S_t} \frac{C_{t+1}}{C_t} \right)^{-\gamma} \\ &= \beta e^{-\gamma[(1-\phi)(\bar{s}-s_t)+(1+\lambda(s_t))\Delta c_{t+1}+\lambda(s_t)g]}. \end{aligned} \tag{4}$$

Campbell and Cochrane (1995) use (4) to compute asset prices in an exchange economy. They are able to generate a set of asset pricing relations which are consistent with the data while avoiding some of the problems of earlier habit models. They generate a procyclical variation of stock prices, a countercyclical stock market volatility, as well as long-horizon predictability of excess stock returns.

The specification of the sensitivity function $\lambda(s)$ plays a crucial role for the asset pricing implications of (4). On a priori grounds, $\lambda(s)$ can take any form. Campbell and Cochrane (1995) specify $\lambda(s)$ so that the risk-free interest rate is constant over time. Hence they use the degree of freedom of choosing $\lambda(s)$ to avoid an implausibly volatile risk-free rate usually associated with habit formation models. Let $\bar{S}$ be the steady-state surplus ratio; the restriction of a constant risk-free rate implies the following $\lambda(s)$ function:

$$\lambda(s) = \frac{1}{\bar{S}} \sqrt{1 - 2(s - \bar{s})} - 1, \tag{5}$$

if the term under the root is positive and zero otherwise. See Campbell and Cochrane (1995) for a detailed discussion of the properties of (5). In particular, $\lambda(s)$ is decreasing in s; hence consumption surprises affect the habit more if consumption is close to the habit, i.e., in ‘‘bad’’ times. These properties of $\lambda(s)$ drive most of the results in Campbell and Cochrane (1995), including the countercyclical price of risk. Campbell and Cochrane (1995) use the following parameter values to calibrate their model: $g = 0.0044$, $\sigma_\nu = 0.00555$, $\phi = 0.97$, $\gamma = 2.37$, $\beta = 0.973$. This implies that the steady-state surplus ratio $\bar{S}$ is 5% or, equivalently, that the share of habit in total consumption is 95%. Moreover, $\lambda(\bar{s}) = 1/\bar{S} - 1 = 19$. The quarterly risk-free rate equals 0.23%.

In this paper, we are interested in the macroeconomic implications of habit formation. For aggregate real variables, the particular shape of $\lambda(s)$ turns out to be much less important than for asset prices. A nonconstant $\lambda(s)$ implies that the elasticity of intertemporal substitution (EIS) is changing over time. In macroeconomic models, the EIS determines how reluctant agents are to change their consumption in response to interest changes. It is easy to show that EIS $= 1/(\gamma(\lambda(s) + 1)$. Using the parameter values in Campbell and Cochrane (1995), the steady-state EIS is $1/(20\gamma))$. For $\gamma = 2.37$, the value in Campbell and Cochrane (1995), EIS $= 0.02$. Hence, consumers with Campbell–Cochrane preferences are extremely reluctant to change their consumption profile. In Campbell and Cochrane (1995) the EIS is time-varying, since λ is a function of the surplus ratio. However, the movements in λ, while important for asset prices, are too small to have a major effect on macroeconomic variables in the context of this paper. The behavior of the macroeconomic variables is almost unchanged when we fix λ at various levels within a plausible range implied by Campbell and Cochrane (1995) (e.g., adding or subtracting one standard deviation from the steady-state value of λ). Therefore, since we are interested in the role of habit formation on dynamic responses of real variables to exogenous fluctuations, we are confident that nothing is lost for the macroeconomic analysis in the constant λ case. Hence we fix λ at its steady-state value. Substituting for $\lambda(\bar{s})$ yields the following process for the log surplus ratio:

$$s_{t+1} = (1 - \phi)\bar{s} + \phi s_t + \left(\frac{1}{\bar{S}} - 1\right)(\Delta c_{t+1} - g). \tag{6}$$

Note that (6) reduces to the no-habit case for $\bar{S} = 1$ and $s_0 = 0$.

3. A REAL BUSINESS CYCLE MODEL WITH HABIT PREFERENCES

The goal of this paper is to study how habit formation affects real macroeconomic variables in a standard real business cycle (RBC) model. In particular, we are interested in seeing whether the success of preferences in reproducing asset market facts in an exchange economy survives in an economy with production and storage technologies. Apart from the preferences, we consider a standard RBC model, e.g., following Hansen

(1985). The representative agent solves

$$\max_{C_t, L_t} E_0 \sum_{t=0}^{\infty} \beta^t U\big(C_t, X_t^{\mathrm{c}}, L_t, X_t^{\mathrm{l}}\big) \tag{7}$$

s.t.

$$C_t + K_t = \big(d_t + (1-\delta)\big)K_{t-1} + w_t N_t + \pi_t.$$

Agents derive utility from consumption C_t and leisure L_t. In general, we allow for habits in the consumption good, X_t^{c}, as well in leisure, X_t^{l}. K_t denotes the capital stock chosen at date t and owned by the agents, d_t are dividends per unit of old capital, $N_t = 1 - L_t$ is labor, w_t are wages, π_t are firm profits, and δ is the depreciation rate. The representative firm maximizes profit:

$$\pi_t = \max_{(K_{t-1}^d, N_t)} Y_t - d_t K_{t-1}^d - w_t N_t^d,$$

where

$$Y_t = \tilde{Z}_t\big(K_{t-1}^d\big)^{\rho}\big(N_t^d\big)^{1-\rho}$$

is output and K_{t-1}^d, N_t^d are demanded capital and labor. Market clearing requires that $C_t + K_t = Y_t + (1-\delta)K_{t-1}$, $N_t^d = N_t$ and that $K_{t-1}^d = K_{t-1}$. At steady state, technology $\tilde{Z}_t$ grows at rate g. The stochastic fluctuations of technology around the growth path Z_t are assumed to follow an AR(1) in logs:

$$z_t = \tilde{z} + \psi z_{t-1} + \epsilon_t, \quad \epsilon_t \sim \text{i.i.d.}\,\mathcal{N}\big(0; \sigma_\epsilon{}^2\big) \tag{8}$$

for $z_t = \log Z_t$, where $0 < \psi \leq 1$.

We consider the following functional form for the period utility function in (7):

$$U\big(C_t, X_t^{\mathrm{c}}, L_t, X_t^{\mathrm{l}}\big) = \frac{\big(C_t - X_t^{\mathrm{c}}\big)^{1-\gamma} - 1}{1-\gamma} + A\frac{\big(L_t - X_t^{\mathrm{l}}\big)^{1-\chi} - 1}{1-\chi}, \tag{9}$$

where A is a parameter. Utility is additive in consumption and leisure, and we allow for separate habits in both variables. Notation for all variables concerning habits is extended, using a superscript “c” for the consumption habit an an “l” superscript for the habit in leisure. We use the additive structure in (9) as our benchmark case in order to preserve the asset pricing implications in Campbell and Cochrane (1995) as much as possible.

The marginal rate of substitution implied by (9) is unchanged from the original Campbell–Cochrane specification (4), hence keeping the successful asset pricing implications intact (given consumption). If utility were multiplicative in leisure, the marginal rate of substitution would be not only a function of consumption, but also of leisure. Hence asset prices would be different from Campbell and Cochrane (1995), even given the same consumption sequence. We will discuss this alternative below in Section 6. Specification (9) is also flexible enough to study the relative importance of habit formation in consumption and leisure for the macroeconomic response to productivity shocks.

King *et al.* (1988) point out that $\gamma = 1$ is required to obtain a balanced growth path when consumption and leisure are additively (and time) separable. This results extends to habit preferences as in (9). There are several ways to make (9) consistent with a balanced growth path without restricting γ to unity. A ratio model replacing $C - X^{\mathrm{c}}$ with C/X^{c} is consistent with balanced growth for general γ, but it has less appealing asset pricing implications, as mentioned in Campbell and Cochrane (1995). Second, multiplying the term involving $C - X^{\mathrm{c}}$ by $q_t^{-\gamma}$, where q_t is a sequence that grows at rate g, would restore a balanced growth path.

To analyze the dynamic implications, we log-linearize the equations characterizing equilibrium, a technique proposed in particular by Campbell (1994). The linearized equations can be solved, using the method of undetermined coefficients with the techniques in Uhlig (1995). The state of the economy is given by the vector $[k_{t-1}, s_{t-1}, c_{t-1}, z_t]$. The solution for this dynamic system is a (linear) vector function f: $[k_t, s_t, c_t, y_t, n_t] = f([k_{t-1}, s_{t-1}, c_{t-1}, z_t])$. More on the details can be found in Uhlig (1995). Of particular interest for us are the reactions of consumption and labor following a technology shock. Let η_c and η_n denote the respective elasticities with respect to technology. Besides these elasticities, we will also report HP-filtered standard deviations as well as cross-correlations for output, consumption, labor, and investment.

4. HABIT IN CONSUMPTION

We start by analyzing the effect of a habit in consumption on macroeconomic variables. Habit formation in leisure will be considered below. Furthermore, we assume linear disutility in labor as in Hansen (1985), i.e., $\chi = 0$. Following Campbell and Cochrane (1995), we choose a steady-state value for the surplus ratio $\bar{S}$ of 5%. In Tables I–III we vary γ and the persistence of the technology shocks ψ. We compare the model data to the relevant numbers from the U.S. economy, which we take from Cooley and Prescott (1994). The data are quarterly and cover 1954:I to 1992:II.

TABLE I
Impulse Responses, Consumption Habit

γ	ψ	With habit ($\bar{S}^c = 0.05$)) η_c	η_n	Figure	Without habit η_c	η_n	Figure
2.37	0.95	0.02%	0.16%	2	0.30%	0.80%	1
47.64	0.95				0.02%	0.15%	3
0.1	0.95	0.27%	1.02%		−2.86%	3.72%	
2.37	0.80	0.00%	1.46%		0.16%	1.75%	
2.37	0.99	0.03%	−0.98%		0.43%	−0.04%	
2.37	0.999	0.03%	−1.41%		0.48%	−0.35%	

$\bar{S}^c = 0.05$, $\chi = 0$, $X_l = 0$.

TABLE II
Hodrick−Prescott Filter, Consumption Habit

γ	ψ	With habit ($\bar{S}^c = 0.05$)) σ_c	σ_y	σ_n	σ_i	Without habit σ_c	σ_y	σ_n	σ_i
2.37	0.95	0.02%	1.09%	0.41%	4.21%	0.32%	1.50%	0.85%	4.98%
47.64	0.95					0.02%	0.88%	0.41%	4.18%
0.12	0.95	0.29%	1.62%	1.02%	5.59%	3.74%	3.66%	3.87%	21.26%
2.37	0.80	0.01%	1.80%	1.46%	6.96%	0.20%	1.96%	1.67%	7.24%
2.37	0.99	0.03%	0.37%	0.99%	1.34%	0.43%	0.96%	0.96%	2.53%
2.37	0.999	0.03%	0.09%	1.39%	0.27%	0.47%	0.76%	0.76%	1.62%

$\bar{S}^c = 0.05$, $\chi = 0$, $X_l = 0$. U.S. data: $\sigma_c = 0.86\%$, $\sigma_y = 1.72\%$, $\sigma_n = 1.59\%$, $\sigma_i = 8.24\%$.

TABLE III
Cross-Correlations, Consumption Habit

Habit?	x	$corr(x_{t+j}, y_t)$ −5	−4	−3	−2	−1	0	1	2	3	4	5
No	y	−0.03	0.10	0.26	0.46	0.71	1.00	0.71	0.46	0.26	0.10	−0.03
	c	0.23	0.35	0.48	0.62	0.77	0.92	0.57	0.28	0.06	−0.11	−0.23
	n	−0.26	−0.14	0.03	0.26	0.56	0.93	0.74	0.56	0.41	0.27	0.16
	i	−0.08	0.05	0.22	0.43	0.68	1.00	0.72	0.49	0.29	0.14	0.01
Yes	y	−0.04	0.09	0.25	0.46	0.70	1.00	0.70	0.46	0.25	0.09	−0.04
	c	0.24	0.35	0.47	0.60	0.74	0.89	0.51	0.21	−0.02	−0.19	−0.30
	n	−0.57	−0.52	−0.40	−0.21	0.07	0.45	0.52	0.55	0.54	0.51	0.47
	i	−0.04	0.09	0.25	0.45	0.70	1.00	0.71	0.46	0.26	0.09	−0.03

$\bar{S}^c = 0.05$, $\gamma = 2.37$, $\psi = 0.95$, $\chi = 0$, $X_l = 0$.

First, consider the benchmark case, where we have used the benchmark parameters stated in the previous section: $\gamma = 2.37$, $\psi = 0.95$. A positive 1% shock ϵ_t moves the technology parameter, and therefore output at the steady-state values, given K_{t-1} and N_t, up by 1%. If the agent decided never to change its level of capital and labor, the entire output change would be consumed, resulting in an increase of consumption by 1.36%, compared to the steady-state level.[2] The models imply, of course, that the agent will usually not leave his gross investment levels and his labor input unchanged. The effect on consumption is decreased, if gross investment is increased or if the agent takes the opportunity of higher productivity to enjoy more leisure, i.e., if the labor input is decreased. The first row of Table I lists the actual reaction of consumption in the model with and without habit at the standard parameters. In the model without habit consumption moves up by 0.3% rather than 1.36%. The effect is more dramatic by an order of magnitude in the model with habit, however. There, consumption moves up by merely 0.02%, not even a tenth of the movement in the model without habit formation. Figures 1 and 2, which correspond to these parameter choices, show what happens: capital is increased by about the same amount in both models, but the essential difference is in the labor input. This is confirmed by the fact that investment is only a little lower in the habit case than in the no-habit case.

While the agent in the model without habit formation (Fig. 1) uses the opportunity of increased productivity to work a lot harder to build up capital, the agent in the model with habit formation will do so a lot less. There two reasons for this. First, a habit formation consumer does not like to adjust consumption by much in response to a shock. Since she prefers a flat consumption path, she chooses to increase her labor input less, since she does not need to build up the capital stock as much to sustain the higher consumption as in the no-habit case. Second, habit formation leads to substitution through leisure, since it is costly to increase consumption. The tiny reaction of consumption in Fig. 2 is no surprise, of course. With the habit formulation, the intertemporal elasticity of substitution is reduced strongly and is locally around the steady state close to $\overline{S}/\gamma$.[3] Since $\overline{S} = 0.05$, this means that a version of the model without habit formation but with $\gamma = 2.37/0.05 = 47.64$ should show a similar responsiveness of consumption to a technology shock, and indeed it does: compare Fig. 3 to Fig. 1 and row 2 to row 1 in the table.

[2] Note that these numbers do not depend on choices for γ or ψ, or on whether one considers the steady state in the model with or without habit formation.

[3] To see this, examine the derivative of the per-period utility function, given by $u'(C_t; X_t) = (C_t - X_t)^{-\gamma}$. Write $C_t = \overline{C}e^{c_t}$, let $X_t \equiv \overline{X}$, and take a first-order Taylor approximation in c_t to find $\log u'(C_t; X_t) \approx -(\gamma/\overline{S})c_t$ and $u'(C_t; X_t) \approx (C_t/\overline{C})^{-\gamma/\overline{S}}$.

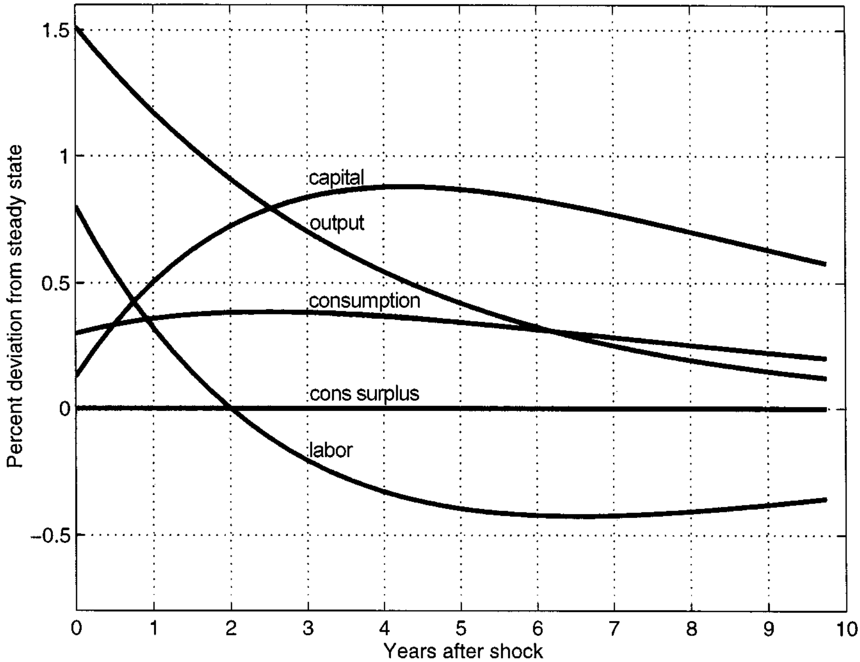

FIG. 1. Impulse responses to a positive 1% shock in technology, preferences without consumption, and leisure habits. $\gamma = 2.37$, $\chi = 0$, $\psi = 0.95$.

These results are also reflected by the Hodrick−Prescott filtered series presented in Table II. The standard deviation of consumption is too small by an order of magnitude in the model with habit and the benchmark parameter values. Even the model excluding habit does not produce enough variation in consumption. The volatility of output is reduced by about half after the habit is introduced. The HP filtered volatility of labor is higher in the no-habit case as well. Habit consumers increase labor input by less than consumers without the habit, since they do not have to build up as much capital to afford higher consumption in the future. Hence labor input is less volatile over the cycle. As mentioned in the last paragraph, the habit model with $\gamma = 2.37$ behaves approximately similarly to the nonhabit model with $\gamma = 47.64$, as documented by the HP filtered volatilities, although output and investment are slightly more volatile in the habit case.

Table III shows the cross-correlations of output, consumption, labor, and investment with $\gamma = 2.37$ and $\psi = 0.95$ for economies with and without the consumption habit. Interestingly, the correlations of most real

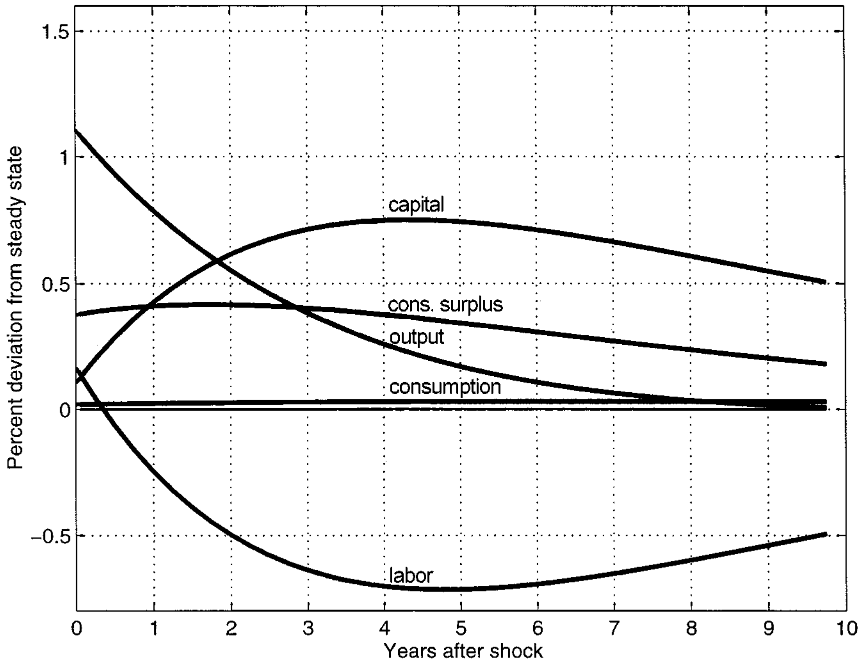

FIG. 2. Impulse responses to a positive 1% shock in technology, preferences with consumption habit and without leisure habit. $\gamma = 2.37$, $\chi = 0$, $\psi = 0.95$.

variables are not affected very much by the habit. The cross-correlation pattern for output, investment, and, most surprisingly, consumption in the habit case are very close to those in the no-habit case. Only labor input differs substantially. It is generally much more weakly correlated with output in the habit case. In particular, the correlations are negative after a lag of two periods. This inconsistent with U.S. data, as reported, e.g., by Cooley and Prescott (1994). We conclude, therefore, that the habit basically damps the response of, in particular, consumption to a technology shock, but has only a small effect on the dynamic pattern of the impulse responses of real variables, with the exception of labor input.

The low volatility of consumption in the case with habit formation is a serious problem for the model. First, asset premia will be much lower than in the exchange economy studied by Campbell and Cochrane (1995). Second, the macroeconomic implications are much worse than in the RBC model with standard time-separable preferences. Is it possible to improve the performance of the model? In Tables I and II we first decrease the exponent γ and second, increase the persistence of the technology shock

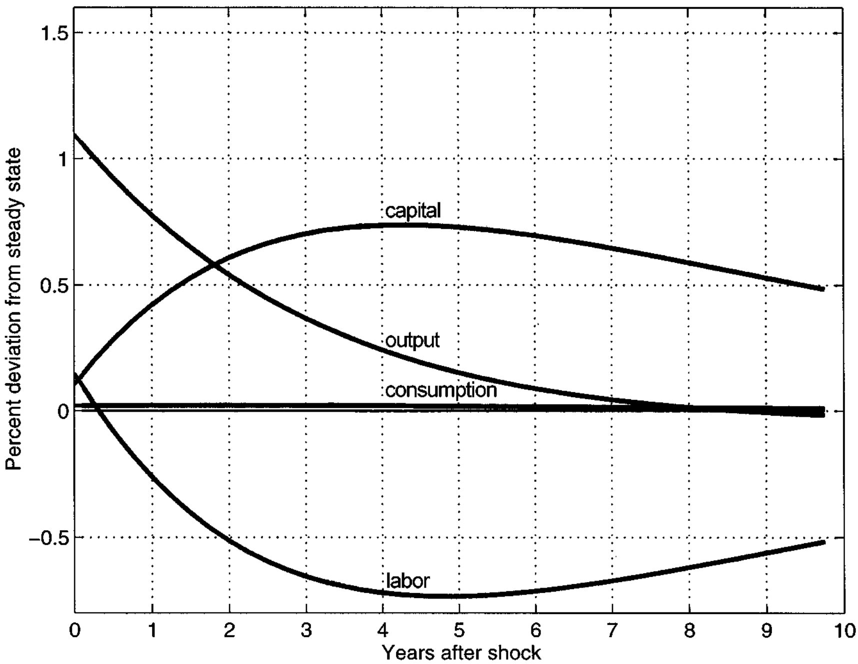

FIG. 3. Impulse responses to a positive 1% shock in technology, preferences without consumption, and leisure habits. $\gamma = 47.64$, $\chi = 0$, $\psi = 0.95$.

as possible avenues to increasing the volatility of consumption. First, consider lowering γ. Recall that the elasticity of intertemporal substitution EIS is $\overline{S}/\gamma$. We choose a such that the EIS equals $1/2.37$, which is the same value as for time-separable CRRA with an exponent of 2.37 (studied in the first row in Table I). The implied value for γ is 0.12. As expected, the dynamic behavior of the economy is similar to that in the case without habit formation and $\gamma = 2.37$. Initially consumption goes up by 0.27%, while labor input increases by about 1%. The HP filtered volatilities are also close to the corresponding no-habit case. Of course, this resolution of the problem is not satisfying for asset prices, since a low γ implies low-risk premia.

One may suspect that consumption does not react much in the habit models, since perhaps the shocks are too transitory. Shouldn't it make more sense to raise consumption levels even in the habit model, if productivity changes are permanent? After all, Hall (1978) has taught us that a 1% increase in permanent income should be accompanied by a 1% increase in permanent consumption. Thus, we have increased the persistence of the technology shock in rows 6 and 7 of the table to the near unit-root values $\psi = 0.99$ and even $\psi = 0.999$. As reported in Table I, the consumption reaction only increases from 0.2% in the benchmark case to 0.3% for almost permanent shocks. The reason is that in the model with habit, the agent does not expect to change his consumption much in the future. With a permanent increase in productivity, he thus simply takes this opportunity to increase his consumption of leisure. While this effect is certainly present even without habit, it is even more dramatic in the model with habit. While Hall's logic still holds true, the rise in productivity simply does not correspond to a rise in income. An interesting feature of high persistence of shocks is that the labor input reaction is much smaller than with less persistent shocks. With a risk aversion coefficient of 2.37, $\eta_n = -0.04\%$ for $\gamma = 0.99$, and $\eta_n = -0.35\%$ for $\gamma = 0.999$ in the model without habit. When a habit is included, the numbers are even more negative. Hence, the persistence of shocks must not be too large when labor input should be procyclical, as suggested by the data. Again, the HP filtered standard deviations confirm the intuition. Increasing the persistence of the technology shock has only a minor effect on consumption variability in the habit model. However, increasing ψ drastically decreases the volatility of output and investment. This effect is particularly strong in the habit case. Hence increasing the persistence of the shock has a negative overall effect on the performance of the model.

For completeness we also have included the number for less persistent shocks, i.e., $\gamma = 0.80$ (see row 5). The labor reaction is fairly large in both models with and without habit, as the agent wants to take advantage of the high productivity as long as it is high. However, the consumption path is not changed by much.

5. HABIT IN CONSUMPTION AND LEISURE

Next, we allow for a separate habit in leisure. To conserve space, we only report the results for $\psi = 0.95$ and $\gamma = 2.37$. The surplus ratios for both habits are set to 5%, as suggested in Campbell and Cochrane (1995). To cover all possible cases we consider economies with leisure habit but no consumption habit, as well as with both habits. Tables IV−VI report the results for three different values of the curvature parameter in leisure, χ. The first row considers the case of $\chi = 2.37$, i.e., the same curvature as in the utility of consumption, and no habit in consumption. Figures 4 and 5 report the impulse response functions for the model without and with leisure habit. Figure 4 corresponds to a standard RBC model with additively separable utility in consumption and leisure. The initial reaction of labor is smaller than in the case with linear utility in leisure, as considered

TABLE IV
Impulse Responses, Leisure Habit

		With leisure habit ($\bar{S}^l = 0.05$))			Without leisure habit		
C habit?	χ	η_c	η_n	Figure	η_c	η_n	Figure
No	2.37	0.34%	0.01%	5	0.31%	0.17%	4
No	47.64				0.35%	0.01%	
No	0.12	0.30%	0.18%				
Yes	2.37	0.07%	−0.09%	6	0.03%	−0.25%	
Yes	47.64				0.08%	−0.12%	
Yes	0.12	0.03%	−0.15%				

$\psi = 0.95$, $\gamma = 2.37$.

TABLE V
Hodrick−Prescott Filter, Leisure Habit

		With leisure habit ($\bar{S}^l = 0.05$))				Without leisure habit			
C-habit?	χ	σ_c	σ_y	σ_n	σ_i	σ_c	σ_y	σ_n	σ_i
No	2.37	0.35%	0.99%	0.01%	2.89%	0.32%	1.10%	0.19%	3.15%
No	47.64					0.36%	0.99%	0.01%	2.88%
No	0.12	0.32%	1.11%	0.20%	3.45%				
Yes	2.37	0.66%	0.93%	0.09%	3.44%	0.03%	0.83%	0.29%	3.15%
Yes	47.64					0.08%	0.91%	0.12%	3.29%
Yes	0.12	0.03%	0.90%	0.20%	3.43%				

$\psi = 0.95$, $\gamma = 2.37$. U.S. data: $\sigma_c = 0.86\%$, $\sigma_y = 1.72\%$, $\sigma_n = 1.59\%$, $\sigma_i = 8.24\%$.

TABLE VI
Cross-Correlations, Habits in Consumption and Leisure

	$corr(x_{t+j}, y_t)$										
x	−5	−4	−3	−2	−1	0	1	2	3	4	5
y	−0.02	0.11	0.27	0.47	0.71	1.00	0.71	0.47	0.27	0.11	−0.02
c	0.11	0.24	0.38	0.55	0.75	0.98	0.65	0.38	0.16	−0.01	−0.14
n	−0.14	−0.26	−0.40	−0.57	−0.76	−0.97	−0.63	−0.35	−0.13	0.04	0.16
i	−0.02	0.10	0.27	0.47	0.71	1.00	0.72	0.48	0.28	0.12	−0.01

$\bar{S}^c = 0.05$, $\gamma = 2.37$, $\bar{S}^l = 0.05$, $\chi = 2.37$, $\psi = 0.95$.

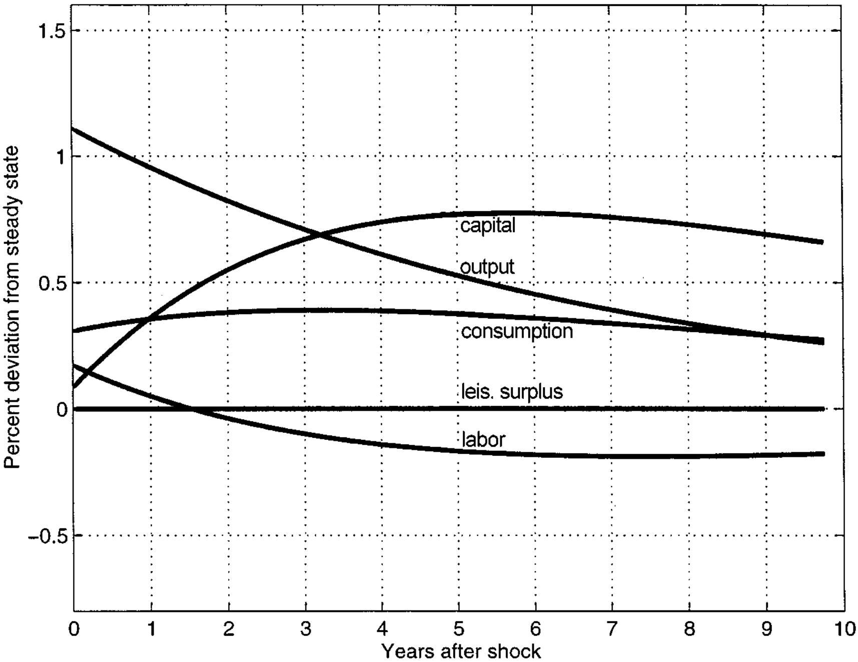

FIG. 4. Impulse responses to a positive 1% shock in technology, preferences without consumption, and leisure habits. $\gamma = 2.37$, $\chi = 2.37$, $\psi = 0.95$.

in Table I. Introducing the leisure habit makes the agent more reluctant to adjust leisure (and therefore labor input) than in the no-habit case with the same curvature parameter. Agents increase labor input by 0.17% in the no-habit case compared to 0.01% in the case with the leisure habit. Consumption increases slightly more in the habit case. The reason is that although agents work more initially in the case without leisure habit, they also decrease their labor input by more about 3 years after the shock. Agents with a leisure habit are more reluctant to adjust their consumption of leisure, as demonstrated in Figs. 4 and 5. Investment and capital accumulation are not affected very strongly by the leisure habit. HP-filtered volatilities for consumption, output, and investment are of the same magnitude in both cases. Of course, labor input varies much less in the case with a habit in leisure.

Next, we study an economy without leisure habit but with a higher curvature parameter, so that the elasticities of intertemporal leisure substitution are the same as in the leisure habit case with $\chi = 2.37$. This implies $\chi = 47.64$ (recall the argument in the preceding section). The second rows

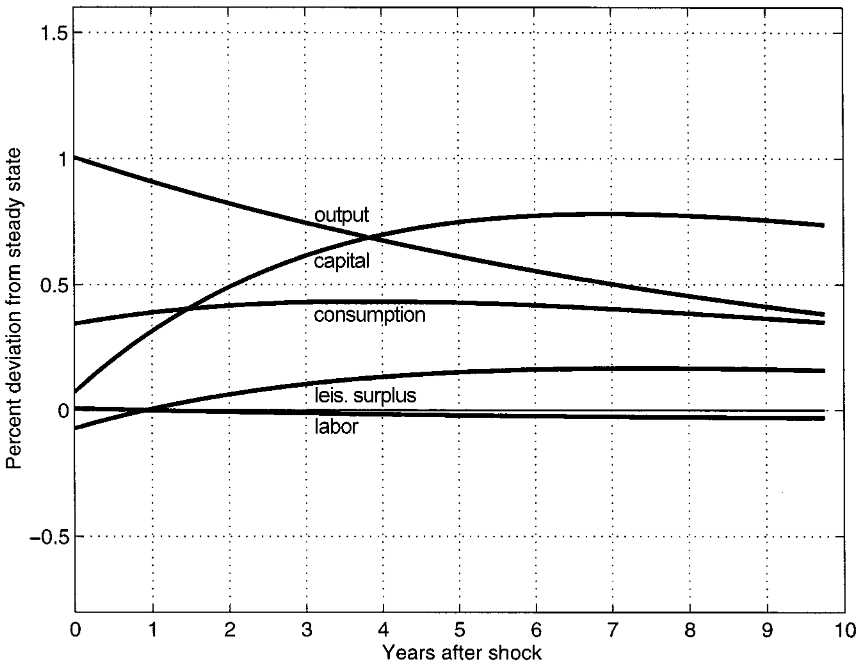

FIG. 5. Impulse responses to a positive 1% shock in technology, preferences without consumption habit and with leisure habit. $\gamma = 2.37$, $\chi = 2.37$, $\psi = 0.95$.

in Table IV and V show that this economy behaves very much like the economy with leisure habit and $\chi = 2.37$. Agents are very reluctant to change their leisure consumption after a shock. Finally, we report the results for a leisure habit economy with a lower χ. As in the preceding section, we choose χ so that the elasticities of intertemporal leisure substitution equal 2.37, implying $\chi = 0.12$. We find that the dynamic response to shocks in this case is very close to the no-habit case and $\chi = 2.37$. In summary, including a habit in leisure has a surprisingly small effect on the behavior of real variables in response to a technology shock. Only the response in labor input is much lower than in the no-habit case.

Now we allow for habits in consumption and leisure. We start with setting both curvature parameters, γ and χ, to our benchmark values of 2.37 (Fig. 6). Results with and without leisure habit are reported in the bottom panel of Tables IV and V. The case without leisure habit is, of course, close to the model studied in Section 4 (there we assumed $\chi = 0$). Introducing the consumption habit has again a major influence on the reaction in labor, which hardly reacts at all after a shock. Note that

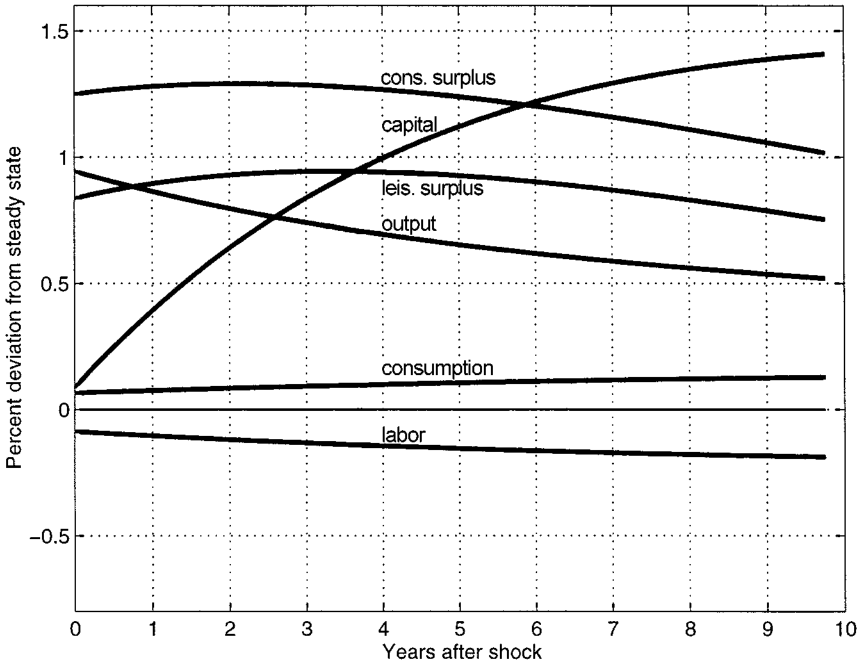

FIG. 6. Impulse responses to a positive 1% shock in technology, preferences with consumption, and leisure habits. $\gamma = 2.37$, $\chi = 2.37$, $\psi = 0.95$.

consumption is slightly more volatile after introducing the habit in leisure. Since agents choose to adjust labor input less in this case, it is optimal for agents to increase consumption a little more, even though they prefer a smooth consumption path, since they also have a habit in consumption. However, allowing for a habit in leisure does not change the counterfactually low variability in consumption when we assume a habit in this variable as well. Moreover, it is inconsistent with the procyclical labor input which we observe in the data.

Last, we study the economy with a higher χ of 47.64 as well as a lower value of 0.12. We find that in both cases, the dynamic response is close to the corresponding cases with and without leisure habit, confirming the result that the habit itself has only a low impact on the behavior of the economy after a shock once the curvature parameter is adjusted.

To complete the analysis, we present the cross-correlations for the case with both habits included and the curvature parameters set to 2.37. Compared to the case with only a consumption habit reported in Table III, we find that the autocorrelation of output and investment is hardly affected by the leisure habit at all. However, the correlation of lagged consumption with output is somewhat lower once the habit in leisure is introduced. The contemporaneous and led correlation of consumption increases in the leisure habit case. The effect is even stronger for labor input. It is negatively correlated with output at all lags, which is grossly inconsistent with the data. Hence habit formation in leisure causes the behavior of labor input over the cycle to be counterfactual.

6. ALTERNATIVE PREFERENCES

In this section we discuss some possible extensions to the model discussed above. Instead of the additive structure of consumption and leisure in (9) of preferences, consider the following multiplicative specification of the period utility function:

$$U(C_t, L_t) = \frac{\left(C_t^{\rho} L_t^{1-\rho}\right)^{1-\gamma}}{1-\gamma}, \tag{10}$$

where $0 \leq \rho \leq 1$. We will ignore habit formation for the moment, but it is straightforward to allow for a habit in the composite of consumption and leisure. While the macroeconomic effects of the multiplicative and additive specifications have been studied, for example, in Campbell (1994), the implications for asset prices are less favorable. The reason is that the marginal rate of substitution for (10) contains not only consumption, but also leisure:

$$M_{t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{\rho(1-\gamma)-1} \left(\frac{L_{t+1}}{L_t} \right)^{(1-\gamma)(1-\rho)}. \tag{11}$$

In the data, labor input and consumption are positively correlated; hence consumption and leisure are negatively correlated. If $\gamma > 1$, both exponents in (11) are negative. Therefore a negative (conditional) correlation of C and L lowers the conditional volatility of the marginal rate of substitution, which in turns lowers asset premia. So the multiplicative preferences have even more counterfactual asset pricing implications than the additive preferences we considered in (9). The same argument holds, of course, if we define a habit for the multiplicative specification (10). A similar argument holds for preferences in which the habit is defined over an index which is the sum of consumption and leisure:

$$U\left(F_t, X_t^f\right) = \frac{\left(F_t - X_t^f\right)^{1-\gamma} - 1}{1 - \gamma}, \tag{12}$$

where

$$F_t = \left(C_t^{\alpha} + AL_t^{\alpha}\right)^{1/\alpha}, \tag{13}$$

and X^f represents the habit. Again the marginal rate of substitution, which prices assets, is a function not only of consumption but also of leisure. Since we intended to study preferences which have been proved to produce sensible asset pricing facts, we restricted ourselves to the additive structure in (9).

7. CONCLUSIONS

In this paper we studied how habit formation in the utility function affects the optimal responses of consumption, labor input, output, and investment to exogenous shocks. We chose the habit formulation of Campbell and Cochrane (1995) because it is able to explain a wide range of asset pricing puzzles when consumption is assumed to be exogenous. We showed that once a habit is included in Hansen's (1985) RBC model with adjustable labor, consumption is extremely smooth and unresponsive to shocks. The intuition is that the habit makes the consumer (locally) very risk averse, hence lowering the elasticity of intertemporal substitution of consumption dramatically. Since agents can choose their labor input, they decide to consume more leisure following a positive technology shock. Thus agents do not have to adjust consumption by much. We considered various extensions to this benchmark model. First, we allowed for a habit in leisure. In this case, agents are reluctant to adjust labor input after a shock. The consumption reaction is not affected much by the leisure habit. Next, we studied a model with two separate habits in consumption and leisure. We found that agents decrease their labor input slightly after a positive shock, causing labor input to be countercyclical. Consumption rises only slightly after the shock. Hence, introducing habit formation in consumption and leisure yields counterfactual cyclical behavior or an otherwise standard real business cycle model. Going down this route thus must require more drastic changes to the model, e.g., to the production technologies (this is the strategy pursued by Boldrin *et al*. (1995). The point of our paper was to document this fundamental difficulty when simultaneously explaining financial market facts and business cycle facts with habit formation.

REFERENCES

Abel, A. (1990). ''Asset Prices under Habit Formation and Catching up with the Joneses,'' *American Economic Review* **80**, 38–42.

Boldrin, M., Christiano, L., and Fisher, J. (1995). *Macroeconomic Lessons for Asset Pricing*. NBER working paper no. 5262, Cambridges, MA.

Campbell, J. Y. (1994). ''Inspecting the Mechanism: An Analytical Approach to the Stochastic Growth Model,'' *Journal of Monetary Economics* **33**, 463–506.

Campbell, J. Y., and Cochrane, J. (1995). ''By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior,'' *Journal of Political Economy*, to appear.

Constantinides, G. (1990). ''Habit Formation: A Resolution of the Equity Premium Puzzle,'' *Journal of Political Economy* **98**, 519–543.

Cooley, T. F., and Prescott, E. C. (1994). Economic growth and business cycle, *in* ''Frontiers of Business Cycle Research'' (Thomas F. Cooley, Ed.), pp. 2–38, Princeton Univ. Press, Princeton, NJ.

Hall, R. (1978). ''Stochastic Implications of the Life Cycle Permanent Income Hypothesis: Theory and Evidence.'' *Journal of Political Economy* **86**, 971–987.

Hansen, G. D. (1985). ''Indivisible Labor and the Business Cycle,'' *Journal of Monetary Economics* **16**, 309–327.

Hansen, L. P., and Jagannathan, R. (1991). ''Implications of Security Market Data for Models of Dynamic Economies,'' *Journal of Political Economy* **99**, 225–262.

Jemann, U. (1998). ''Asset Pricing in Production Economics,'' *Journal of Monetary Economics* **41**, 257–275.

King, R., Plosser, C., and Rebelo, S. (1988). ''Production, Growth and Business Cycles. I. The Basic Neoclassical Model,'' *Journal of Monetary Economics* **21**, 195–232.

Mehra, R., and Prescott, E. C. (1985). ''The Equity Premium Puzzle,'' *Journal of Monetary Economics* **15**, 145–161.

Prescott, E. C. (1985). ''Theory Ahead of Measurement,'' *Federal Reserve Bank Minnesota Quarterly Review* **10**, 9–22.

Uhlig, H. (1995). A toolkit for solving dynamic stochastic models easily, draft, Tilburg University.

Weil, P. (1992). Comment on ''Asset pricing lessons for macroeconomics,'' by John Cochrane and Lars Peter Hansen, NBER Macroeconomic Annual, MIT Press, Cambridge, MA.