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Real business-cycle model with habits: Empirical investigation

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ABSTRACT

This paper empirically investigates the ability of a real business-cycle model with nonseparabilities in consumption and leisure and external habits both in consumption and leisure to fit the postwar US data. The results indicate a strong but fast-dying habit in leisure, and a somewhat weaker but more persistent habit in consumption. Intratemporal nonseparabilities in consumption and leisure play an important role in driving the response of real variables to a productivity shock. Adding capital adjustment costs to the model with nonseparabilities in consumption and leisure and external habits both in consumption and leisure changes the responses of real variables to a productivity shock, however, in a way similar to that documented for the models with capital adjustment costs and habit formation in consumption. The estimated persistence of the productivity shock is quite modest, which may be the factor that drives a procyclical response of hours worked to the positive productivity shock even when habit in consumption is strong.

Since the influential works of Constantinides (1991), Campbell and Cochrane (1999), and Heaton (1995), the use of models with habit formation in consumption is common in macroeconomic and financial literature because of their ability to match both asset-pricing and business-cycle facts.[1] The use of habits in consumption, however, comes at a cost of producing the countercyclical response of hours worked to the positive productivity shock. Researchers have argued that mainly due to the presence of habit formation and capital adjustment costs, positive productivity shocks lead to an immediate decrease in hours worked (see Francis and Ramey, 2005; Smets and Wouters, 2007). The countercyclical response of hours worked to the positive productivity shock is at odds with the observed procyclicality of aggregate hours worked and the anticipated co-movement of consumption and hours worked in the same direction in response to technology shocks. Whereas some studies have argued that the empirical evidence on the effect of a productivity shock on the labor input can also support a positive impact (e.g., Christiano et al., 2005), the problem of the countercyclical response of hours worked to the positive productivity shock remains a valid drawback of habit-formation models.

Although macroeconomic literature routinely uses models with habit formation in consumption, it does not give equal attention to models with habit formation in leisure. Researchers have shown empirically that habit formation in leisure is non-negligible (e.g., Eichenbaum et al., 1988; Kennan, 1988); however, they have left largely unexplored the ability of models with habit formation in leisure to match business-cycle facts. When the model with preferences additively separable in consumption and leisure and with exogenous habits in both variables is put to test how agents adjust consumption and labor input in response to technology shocks, Lettau and Uhlig (2000) demonstrate that the results are in contrast to favorable properties of habit-formation models claimed by earlier studies. Consumption is extremely smooth and unresponsive to shocks, whereas labor input is counterfactually smooth over the cycle, and, as discussed earlier, might even be countercyclical. Uhlig (2007) indicates that habit-formation models coupled with intratemporal nonseparabilities in preferences between consumption and leisure have the potential to provide a better match to both the observed asset markets and basic macroeconomic statistics. However, how agents adjust consumption and labor input in response to technology shocks remains unclear when preferences contain external habit-formation and intratemporal nonseparabilities in consumption and leisure.

My objective is to extend this exercise by applying the model with external habits in both consumption and leisure and with intratemporal nonseparabilities in consumption and leisure similar to the one used in Uhlig (2007) directly to the postwar US data, and estimating its parameters using maximum likelihood. The parameter values calibrated in Uhlig (2007) provide good starting values for the optimization procedure. The estimated model fits the data well. The empirical results suggest that (i) both consumption and leisure appear to be strongly habit forming (the parameter of habit strength in consumption is 0.83, whereas the one for leisure is 0.96), and (ii) habit formation in consumption is estimated to be persistent, whereas habit in leisure is not.

I investigate whether the model with habits in consumption and leisure is capable of producing meaningful responses of real variables

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[1] See Otrok et al. (2002) for challenging habit-formation models to provide a robust account for the equity premium puzzle.

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to a productivity shock. Using the estimated parameters, I conduct model simulations to investigate how the consumption and labor-input paths look when consumers choose consumption and hours worked optimally in response to a more fundamental shock in the presence of habit formation. The strength and persistence of the habit-formation process greatly influence the impulse responses of the real macroeconomic variables. Consistent with Christiano et al. (2005), I obtain the hump-shaped response of consumption to a productivity shock. Including habit formation in leisure allows for augmenting the immediate effect realized because of a strong but fast-dying habit in leisure with a somewhat weaker but more persistent effect of habit in consumption. Ignoring habit in consumption while allowing for habit in leisure can generate responses of real variables similar to those that we observe in the full model. Interestingly, it is possible to obtain the hump-shaped response of consumption as in Christiano et al. (2005) by allowing for habit formation in leisure only. This result is driven by the complementarity effect of consumption and leisure. The next experiment examines how the findings change with the inclusion of capital adjustment costs in the model. Once the model is augmented with capital adjustment costs, the responses of real variables to a productivity shock change dramatically, with the key result that hours worked immediately decline in response to a positive productivity shock. The negative reaction of labor input in the model with adjustment cost disappears once habit in consumption is ruled out but habit in leisure remains. These findings suggest that in the presence of nonseparabilities in consumption and leisure, habit in leisure is an important model feature for a procyclical response of hours worked to a positive productivity shock; however, it may not be strong enough to counteract a substantial instantaneous negative impact of a combination of habit in consumption and adjustment cost on labor input.

Along with joint estimation of the parameters of the strength and persistence of habits in leisure and consumption, I also estimate other standard parameters of real business-cycle models, including the persistence of the productivity shock. The estimated persistence of the shock is moderate, similar to the value found in Otrok (2001). I show that it is possible to obtain a positive reaction of hours worked after a positive productivity shock, if the shock is not too persistent, even with a strong habit formation in consumption or a high adjustment cost of investment, but not with a combination of those. Further, I find that the persistence parameter of the productivity shock is one of the important factors that determines the sign of the effect of hours worked on the positive productivity shock.

The plan of the paper is as follows. Section 1 describes the model. Section 2 outlines the estimation procedure. Section 3 discusses results and examines the business-cycle implications for the model. Section 4 concludes.

1. Model

The infinitely lived representative household has preferences described by the expected utility function:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\left((\mathrm{C}_t - \mathrm{H}_t)\left(a + (\mathrm{L}_t - \mathrm{F}_t)^{\nu}\right)\right)^{1-\gamma} - 1}{1-\gamma}, \tag{1}$$

where a, ν, and γ are parameters satisfying $\nu > 0$, $\gamma > \nu/(\nu+1)$ to ensure monotonicity and concavity on the domain, and $0 < \beta < 1$ is a discount factor. C_t and L_t denote consumption and leisure of the representative household, and H_t and F_t are exogenous habits in consumption and leisure, respectively. The representative household maximizes its preferences over the choice of consumption and leisure, taking as given exogenous habits that evolve according to

$$\mathrm{H}_{t+1} = (1-\zeta)\phi C_t + \zeta \mathrm{H}_t, \tag{2}$$

$$\mathrm{F}_{t+1} = (1-\xi)\varphi \mathrm{L}_t + \xi \mathrm{F}_t, \tag{3}$$

where $0 < \zeta < 1$ and $0 < \xi < 1$ are the persistence parameters, and ϕ and φ are habit-strength parameters on consumption and leisure accordingly.

The representative household is endowed with initial capital and one unit of time per period to be used as leisure (L) or labor (N):

$$1 = \mathrm{L}_t + \mathrm{N}_t. \tag{4}$$

The economy consists of a large number of identical, price-taking firms that hire labor (N) and rent capital (K) from households, and produce output (Y) according to the Cobb–Douglas technology:

$$\mathrm{Y}_t = \mathrm{K}_t^{\alpha}(\mathrm{Z}_t \mathrm{N}_t)^{1-\alpha}, \tag{5}$$

where $0 < \alpha < 1$. The technological innovation $\mathrm{Z}_t = e^{gt}e^{z_t}$ grows at rate g at steady state, and its stochastic fluctuations around the growth path are assumed to follow an AR(1) process:

$$z_t = \rho z_{t-1} + \varepsilon_t, \tag{6}$$

where $0 < \rho < 1$ and ε_t are i.i.d. $\mathcal{N}\left(0, \sigma_\varepsilon^2\right)$. Output is divided among consumption (C) and investment (I), with the latter being used to finance next-period capital for the firms:

$$\mathrm{Y}_t = \mathrm{C}_t + \mathrm{I}_t \tag{7}$$

$$\mathrm{K}_{t+1} = (1-\delta)\mathrm{K}_t + \mathrm{I}_t, \tag{8}$$

where $0 < \delta < 1$ denotes the depreciation rate.

One can show that there exists a steady state in the detrended variables. I transform the variables as $c_t = \ln\left(\mathrm{C}_t/\overline{\mathrm{C}}\right)$ and similarly, h_t, y_t, k_t, i_t, l_t, f_t, and n_t, where bars denote steady states. To analyze the dynamic implications of the model, I log-linearize the system of equations characterizing the equilibrium. The linearized equations can be solved using the method developed by Sims (2001). The state of the economy is given by the vector $[h_t, f_t, k_t, z_t]$. The solution for the dynamic system is a linear vector function Ψ, such that $[y_t, c_t, i_t, n_t, l_t, h_{t+1}, f_{t+1}, k_{t+1}] = \Psi([h_t, f_t, k_t, z_t])$.

2. Estimation procedure

To estimate the model, I use quarterly US data, drawn from the Federal Reserve Bank of St. Louis' FRED website. The sample period runs from 1948:I through 2004:IV. Data on real personal consumption expenditures in chained 2000 dollars provide the measure of C. Data on real gross private investment in chained 2000 dollars provide the measure of I. Data on hours worked by all persons in the nonfarm business sector provide the measure of N. All data series are seasonally adjusted, expressed in per capita terms, and HP-filtered. I construct three observable stationary variables: hours worked, the growth rate of aggregate consumption, and the growth rate of aggregate investment.

I estimate the model's structural parameters via maximum likelihood using the Kalman filtering algorithm. I link the behavior of three observable series on consumption, investment, and hours worked to a vector of unobservable state variables that assumes a single structural shock. To incorporate additional shocks, I allow for measurement errors in the observable series. Following Sargent (1989) and Ireland (2004), I impose serial correlation on the measurement errors in the observable data:

$$u_{jt} = \rho_j u_{jt-1} + {}_{jt}, \quad E\left(jt\,{}^t jt\right) = \sigma_j^2, \quad j = c, i, n,$$

where ϵ_{ct}, ϵ_{it}, and ϵ_{nt} are mutually orthogonal white noises with variances chosen to yield standard deviations of u_{ct}, u_{it}, and u_{nt} indicating the presence of moderate measurement error in the observed data. The estimation results reveal that the structural parameter estimates do not significantly differ for the various reasonable levels of measurement errors in the data; therefore, σ_c^2, σ_i^2, and σ_n^2 were fixed to yield up to 3% measurement errors for the observed consumption, investment, and hours-worked series. Therefore, along with the structural parameters of the model, three extra parameters related to the measurement-error process (ρ_c, ρ_i, ρ_n) are to be estimated.

In total, the model includes 16 parameters, which describe preferences and technology, stochastic behavior of exogenous technological shock, and measurement errors: α, β, δ, γ, a, ν, g, ζ, ξ, ϕ, φ, ρ, σ_ε, ρ_c, ρ_i and ρ_n. The starting values for the parameters are taken from the related study of Uhlig (2007): $\alpha = 0.33$, $\delta = 0.015$, $\beta = 0.99$, $\gamma = 7.0$, $a = 0.01$, $\nu = 1.5$, $\zeta = 0.5$, $\xi = 0.9$, $\phi = 0.97$ and $\varphi = 0.9$. Pinning down the growth rate g and the standard deviation of the technology shock σ_ε was found difficult. I set $g = 0.005$, the average quarterly growth rate of consumption and output in the data. I also fix $\sigma_\varepsilon = 0.0065$, the value widely adopted in RBC literature.

3. Results

In Table 1, I report the maximum likelihood estimation results of a real business-cycle model with non-separabilities in consumption and leisure and habits both in consumption and leisure. Recall that the parameters ζ and ϕ characterize habit formation in consumption. The estimate of strength of habit in consumption, $\phi = 0.83$, provides evidence for the strong habit formation in aggregate consumption, the result commonly found in macroeconomic literature. I also find that habit formation in consumption is relatively persistent, measured by $\zeta = 0.64$. Parameters φ and ξ characterize habit formation in leisure. Similar to Uhlig (2007), I find a strong habit in leisure, measured by $\varphi = 0.96$. However, I find the estimate of the persistence in leisure habits, ξ, is statistically insignificant, which indicates habit in leisure is not persistent. Other structural parameters, such as α, β, δ, and γ, are estimated well inside the range used in macroeconomic literature. The estimate of $\gamma = 6.9$ is consistent with the value of $\gamma = 7$ used in Uhlig (2007) for a similar model. The estimate of $\delta = 0.036$ implies that the depreciation rate is about 14% on the annual basis, which is slightly larger than the standard 10% typically used in the literature. The estimation results are robust to various starting values.

Table 2 reports summary statistics for the series of consumption, investment, and labor observed in the data and implied by the solution of the benchmark model. I report standard deviations of the variables (σ_j, $j = [c, i, n]$), standard deviations relative to output $\left(\frac{\sigma_j}{\sigma_y}, j = [c, i, n]\right)$, first-order autocorrelations ($\rho(1)$, $j = [c, i, n]$), and contemporaneous correlations ($\rho_{j,y}(0)$, $j = [c, i, n]$) as well as lagged correlations ($\rho_{j,y}(1)$, $j = [c, i, n]$) between the variables and the output.

Table 1
Maximum likelihood estimates and standard errors.

Parameter	Estimates	Std. errors
α	0.381	0.017
β	0.982	0.001
δ	0.036	0.006
γ	6.886	1.148
a	0.014	0.007
ν	1.550	0.241
ζ	0.645	0.006
ξ	0.026	0.017
ϕ	0.832	0.004
φ	0.956	0.020
ρ	0.552	0.056
ρ_c	0.574	0.008
ρ_i	0.223	0.005
ρ_n	0.449	0.009

Standard errors, reported in brackets, are computed by means of a parametric Monte Carlo simulation procedure.

Table 2
Data vs. estimated benchmark model: Summary statistics.

j	$\frac{j}{y}$	σ_j	$\frac{\sigma_j}{\sigma_y}$	$\rho(1)$	$\rho_{j,y}(0)$	$\rho_{j,y}(1)$
A. HP-filtered data						
c	0.825	0.008	0.44	0.82	0.81	0.76
i	0.175	0.080	4.40	0.79	0.95	0.79
n	0.006	0.018	1.03	0.89	0.83	0.62
Simulated data at the solution						
B. Habits in consumption and leisure						
c	0.825	0.007	0.65	0.98	0.87	0.82
i	0.174	0.037	3.44	0.79	0.89	0.74
n	0.414	0.003	0.32	0.89	0.84	0.70
C. Habit in consumption						
c	0.825	0.004	0.58	0.99	0.79	0.73
i	0.174	0.030	3.96	0.65	0.90	0.66
n	0.414	0.001	0.09	0.61	0.91	0.67
D. Habit in leisure						
c	0.825	0.007	0.62	0.87	0.91	0.80
i	0.174	0.036	3.26	0.83	0.92	0.74
n	0.414	0.005	0.50	0.83	0.86	0.67
E. No habits						
c	0.825	0.005	0.58	0.88	0.93	0.71
i	0.174	0.027	3.35	0.59	0.95	0.64
n	0.414	0.003	0.34	0.56	0.90	0.59

It is important to obtain such parameterization of the model that endogenously delivers moments similar to those that are observed in the data. Panel A reports summary statistics for HP-filtered data; panels B, C, D, and E report summary statistics of the data, simulated at the estimated values of parameters provided in Table 1. Panel B corresponds to the model with external habits in consumption and leisure; panel C corresponds to the model with external habits in consumption only; panel D corresponds to the model with external habits in leisure only; and panel E describes data simulated by the model with no habit formation.

3.1. Habit formation in consumption and leisure

Results in Table 2 indicate that the model with habits in consumption and leisure (panel B) performs well in characterizing the patterns of serial correlation observed in the data. The model replicates the patterns of volatility observed in consumption and investment relative to output. Consumption is implied to be smoother relative to output, whereas the volatility of investment is much larger than that of output. However, as in many RBC models, this model performs poorly in characterizing the relative volatility of labor, measured by hours worked.

Results from panels C, D, and E in Table 2 indicate that if one does not account for habits in consumption or in leisure, the summary statistics do not improve in general, but show an even bigger discrepancy with the patterns observed in the data. The tendency is clear though: the model with habits in leisure can improve some statistics relative to the behavior of hours worked (absolute and relative volatility labor input), whereas the model with habits in consumption only (as reported in Table 2, panel C) shows a better match of the correlation pattern in consumption series.

Volatility in hours worked, which many RBC models routinely find is lower than in the data, is substantially greater than the one reported for a time-separable model with habits in consumption and leisure (e.g., Lettau and Uhlig, 2000). This difference is likely to be driven by non-separabilities in preferences over consumption and leisure. The results reported in Table 2 reveal that for the model without habits, the volatility of hours worked does not differ from the volatility implied by the model when habits are present both in consumption and leisure. Allowing for habit only in consumption substantially reduces the volatility of hours worked, whereas habit in leisure magnifies it considerably. Two opposing effects are compensated in the specification with two habits, producing similar volatility of hours worked in the model with and without habits. The findings in Lettau and Uhlig (2000) suggest that in a time-separable model, the effect is reversed: the extremely low volatility generated by habits in leisure largely affects the resulting low volatility of hours worked.

After having shown that the estimated model fits the US macroeconomic data quite well, I use the model to investigate the effect of a productivity shock on the consumption path and hours worked. To understand the persistence properties of the model, I consider the role of habits in dynamic responses of real macroeconomic variables to exogenous fluctuations of productivity shock. Fig. 1 displays the response of the model variables y, c, i, and n to a positive one-standard-deviation shock to technology in period 0. The response of consumption and hours worked following a positive technology shock is of particular interest. The impulse responses of the real macroeconomic variables are primarily driven by the strength of habit formation in consumption and leisure and the persistence of habit formation. Fig. 1 shows that after a positive productivity shock, consumption increases following the growth in output. Individuals are taking advantage of an increase in productivity and keep increasing labor input for a while. Because of the complementarity between consumption and leisure, consumption falls while labor input increases. The reaction of consumption to the movement in hours worked is not immediate, because of the presence of habit formation in consumption. Gradually, the effect of the shock dies out, and habit in consumption starts showing up in the hump-shaped consumption path (see Christiano et al., 2005; Smets and Wouters, 2007). The slow-developing hump in the consumption path is due to the moderate persistence of habit in consumption, measured by $\zeta = 0.65$. When this parameter is set to zero, consumption shows a short-term hump-shaped response, consistent with findings in Christiano et al. (2005) and Smets and Wouters (2007). Interestingly, the model with habits only in leisure generates impulse–response patterns similar to those observed in the full model. Fig. 2 shows that in the model with habits in leisure, when a positive productivity shock starts dying out and individuals reduce labor input, consumption increases again slightly before it gradually returns to its pre-shock level. The summary statistics in Table 2 support this observation: the volatility and correlation patterns in the model with habit in leisure are similar to the model with habits in consumption and leisure.

The model allows addressing the effect of a productivity shock on labor input, which is a subject of sharp interest in current literature that studies the implications of a productivity shock in the US business cycles. Researchers have argued that in a model with habit formation (Francis and Ramey, 2005; Smets and Wouters, 2007), a positive productivity shock leads to an immediate decrease in hours worked. The current analysis shows that obtaining a positive reaction of labor input to the shock is possible even with strong habit formation. In RBC literature (including the papers cited above), the productivity shock is traditionally modeled as persistent. By contrast, the estimate of the persistence of the productivity shock obtained in this study is 0.55. Although the value of this parameter is similar to the one reported in Otrok (2001), it is more moderate than the typical persistence level used in the literature. As soon as the persistence of the productivity shock is increased to $\rho = 0.99$, the reaction of hours worked changes from positive to negative. Fig. 3 addresses the issue. A positive productivity shock leads to expansion of aggregate consumption, but also to an immediate and significant reduction in hours worked. Because of habit formation in leisure, individuals continue reducing their labor input for a while before it starts increasing again to the pre-shock level. With a persistent productivity shock, no observable short-term

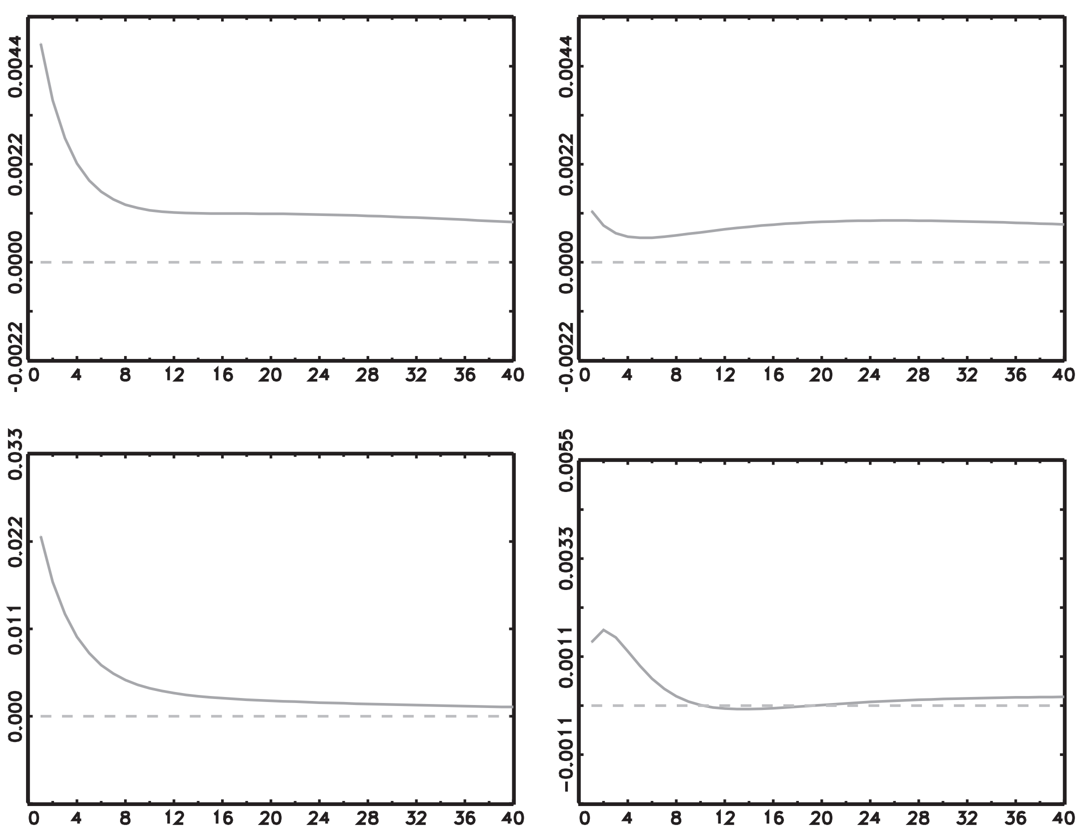

Fig. 1. Model with external habits in consumption and leisure. Impulse responses to a positive one-standard-deviation shock to technology. Periods after shock represent quarters. From left to right: y, c, i, and n.

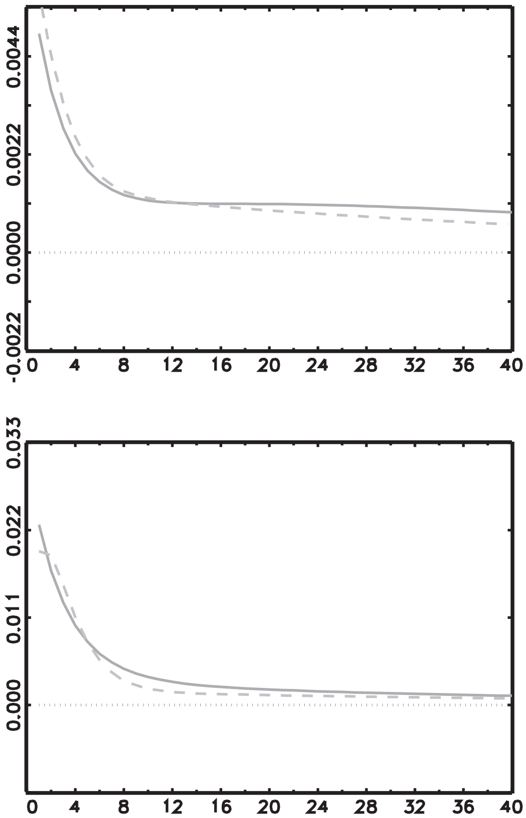

Fig. 2. External habits in leisure. Impulse responses to a positive one-standard-deviation shock to technology. Periods after shock represent quarters. From left to right: *y*, *c*, *i*, and *n*. The bold line corresponds to the benchmark model, and the dashed line denotes the model with external habits in leisure.

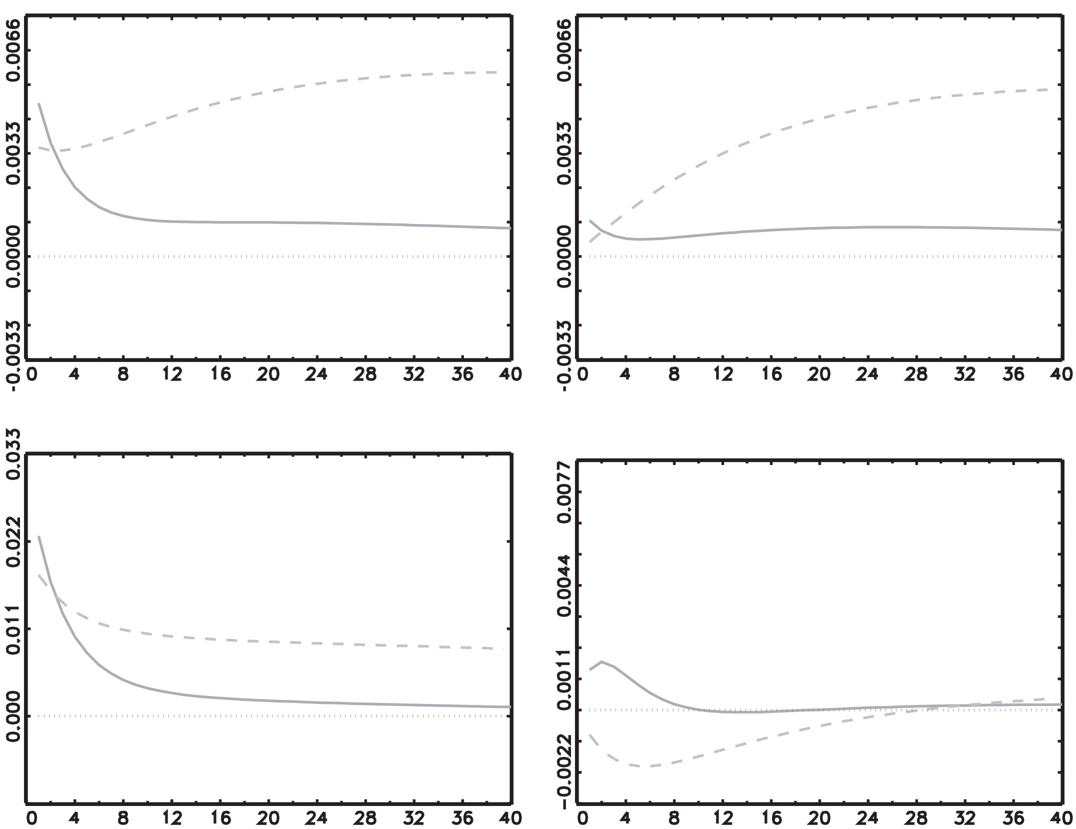

Fig. 3. Persistence of the technology shock. Model with external habits in consumption and leisure. Impulse responses to a positive one-standard-deviation shock to technology. Periods after shock represent quarters. From left to right: *y*, *c*, *i*, and *n*. The bold line corresponds to the benchmark model, and the dashed line denotes the model with a very persistent technology shock.

response of consumption to the immediate move in hours worked occurs. The response of consumption is similar to the model with habits in consumption (not reported, available upon request) and is consistent with the hump-shaped consumption response of Christiano et al. (2005), with the only difference being that it realizes more slowly, because of the high persistence in the habit-formation process.

3.2. Habit formation and adjustment costs

The next experiment examines how the data moments and the responses of real macroeconomic variables to fluctuations of productivity shock change with the inclusion of capital adjustment costs in the model. Coupling habit-formation specifications with capital adjustment costs became standard in general equilibrium models (for influential examples, see Jermann, 1998; Boldrin et al., 2001; Francis and Ramey, 2005; Smets and Wouters, 2007). As an alternative to the standard capital accumulation Eq. (8), the equation for capital accumulation can be augmented with adjustment costs of investment:

$$K_{t+1} = (1-\delta)K_t + \kappa\left(\frac{I_t}{K_t}\right)K_t, \tag{9}$$

where $\kappa\left(\frac{I_t}{K_t}\right) = \frac{a_1}{1-\theta}\left(\frac{I_t}{K_t}\right)^{1-\theta} + a_2$, and parameters a_1 and a_2 are chosen so that the balanced growth path is invariant to θ. The adjustment–cost parameter θ is set to render $1/\theta = 0.23$, the value used in Jermann (1998) and subsequent studies.

Summary statistics in Table 3, panel B, show that the model with habit formation and adjustment costs does not improve on summary statistics of consumption, as reported for the model without adjustment costs (Table 2, panel B). Furthermore, it substantially reduces volatility and autocorrelation in investment. However, the model with habit formation and adjustment costs allows for improving on selected summary statistics of hours worked: the model performs markedly better at replicating the volatility observed in hours worked relative to output. This improvement comes at a cost of large negative correlations of hours worked and output. Labor input is now negatively correlated with output contemporaneously and at lagged values, which goes against the patterns observed in the data.

If the habit in leisure is ruled out, so that habit in only consumption affects preferences (panel C of Table 3), summary statistics show some improvement for consumption and investment relative to the results reported in panel B. Hours worked, however, vary much less and retain a negative correlation with output. This reaction of labor input is corrected in the model with habits in leisure only (panel D in Table 3), although hours worked relative to output remain excessively smooth. Excluding habits in consumption increases absolute and relative volatility of consumption and dramatically reduces volatility of investment. The model with no habits (panel E of Table 3) combines all unfavorable features of models with eliminated habits either in consumption or in leisure: overly smoothed investment and hours worked, negatively correlated output and hours worked, and counterfactual autocorrelation pattern in investment, whereas consumption is more volatile than output.

I now turn to the persistence properties of the model with adjustment costs and habits, and consider the responses of real macroeconomic variables to exogenous fluctuations of productivity shock. The response of the model variables y, c, i, and n to a positive one-standard-deviation shock to technology in period 0 is displayed in Fig. 4. This figure shows that the model with capital adjustment costs produces weaker and more short-lived responses of output and investment relative to the model without adjustment costs. Consumption does not jump following the productivity shock, but increases gradually, forming a hump-shaped response, and returns to the pre-shock level faster. In contrast to the responses of output, investment, and consumption, hours worked respond more dramatically and in a contrasting way to the model without adjustment costs. In the environment where habit formation prohibits immediate adjustment of consumption, and high adjustment costs on investment prohibit spending resources on investment, increasing leisure is the only alternative for consumers. Gali (1999), Francis and Ramey (2005), and Smets and Wouters (2007) documented a similar response of labor input. Nonseparabilities in consumption and leisure play a magnifying role for this effect.

The negative response of hours worked, shown in Fig. 4, disappears once habit in consumption is ruled out but habit in leisure remains (see Fig. 5). However, the gradual increase in responses of consumption, investment, and hours worked, followed by a subsequent decline back to the pre-shock level, which empirical studies document, is not present. In the absence of habit formation in consumption, consumers immediately increase their level of consumption following a positive productivity shock, whereas the response of investment is positive, but rather weak due to costly adjustment. Following a positive productivity shock, labor input increases immediately, albeit only slightly, and returns quickly to the pre-shock level. The responses of consumption, investment, and hours worked are supported by the autocorrelation patterns, reported in panel D of Table 3. Summary statistics in Table 3 also suggest that habit only in leisure is able to alleviate the effect of adjustment costs on hours worked, whereas habit in consumption reduces the effect, not only through a negative effect of both adjustment cost and habit in consumption on the reaction of hours worked, but also because of non-separability between consumption and leisure.

In the exercise, similar to the one conducted in the previous subsection and reported in Fig. 3, I set the persistence of the productivity shock at 0.99. The results are reported in Fig. 6. Analogously to the model without capital adjustment costs, a positive, extremely persistent productivity shock leads to expansion of aggregate output and consumption and to an immediate and even more dramatic reduction in hours worked.

The model presented in this paper has extensions that future work can pursue. One such consideration is to allow for richer model specification with two sectors. As shown in Ireland and Schuh (2008), a two-sector model with habit formation and adjustment costs produces different responses of real variables, including hours worked, to distinct sector-specific technology shocks, and, therefore has capacity for reconciling habit formation and adjustment cost to the observed procyclicality of hours worked. Another potentially fruitful direction for future work is to employ the model with Christiano and Todd's

Table 3
Data vs. model with capital adjustment costs: Summary statistics.

j	$\frac{\bar{j}}{\bar{y}}$	σ_j	$\frac{\sigma_j}{\sigma_y}$	$\rho(1)$	$\rho_{j,y}(0)$	$\rho_{j,y}(1)$
A. HP-filtered data						
c	0.825	0.008	0.44	0.82	0.81	0.76
i	0.175	0.080	4.40	0.79	0.95	0.79
n	0.006	0.018	1.03	0.89	0.83	0.62
Simulated data at the solution						
B. Habits in consumption and leisure						
c	0.825	0.003	0.74	0.96	0.82	0.77
i	0.174	0.015	3.48	0.35	0.82	0.57
n	0.414	0.004	0.84	0.66	−0.33	−0.11
C. Habit in consumption						
c	0.825	0.003	0.61	0.93	0.92	0.76
i	0.174	0.018	3.26	0.59	0.94	0.67
n	0.414	0.001	0.19	0.52	−0.45	−0.21
D. Habit in leisure						
c	0.825	0.005	0.91	0.62	0.99	0.63
i	0.174	0.008	1.43	0.71	0.98	0.65
n	0.414	0.001	0.10	0.87	0.88	0.63
E. No habits						
c	0.825	0.005	1.04	0.65	0.98	0.49
i	0.174	0.007	1.35	−0.02	0.66	0.32
n	0.414	0.001	0.14	0.40	−0.10	−0.07

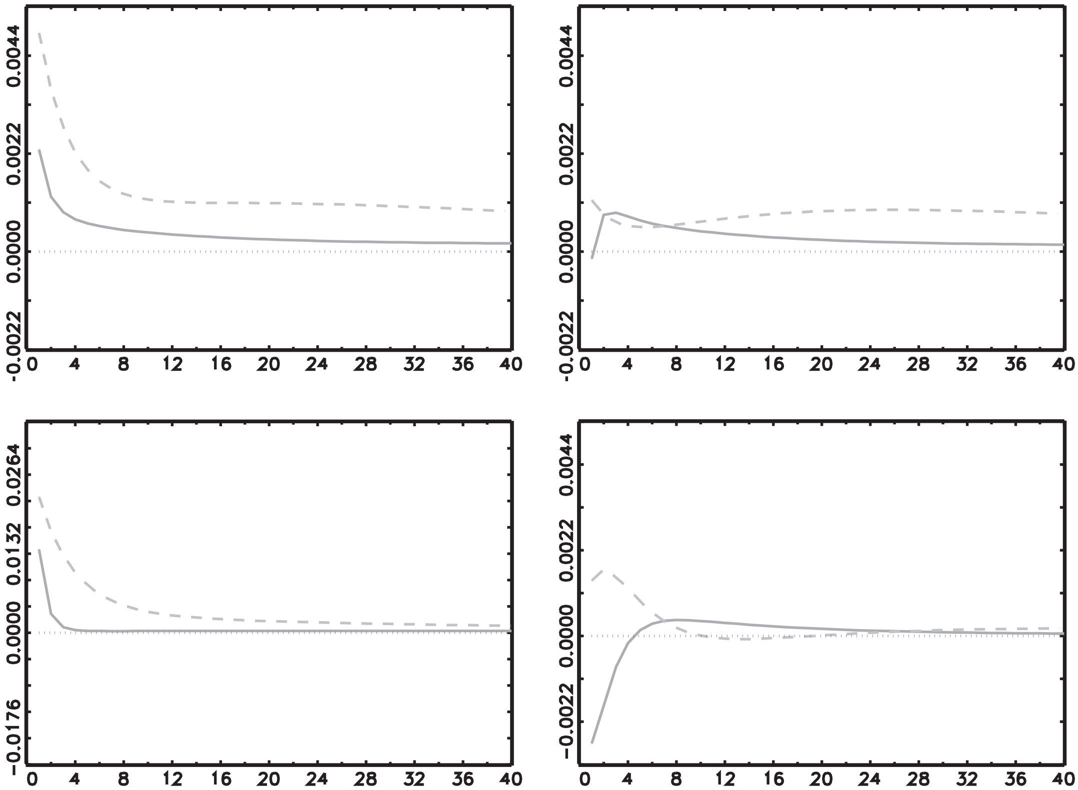

Fig. 4. Model with external habits in consumption and leisure and capital adjustment costs. Impulse responses to a positive one-standard-deviation shock to technology. Periods after shock represent quarters. From left to right: *y*, *c*, *i*, and *n*. The bold line corresponds to the model with capital adjustment costs, and the dashed line denotes the model without.

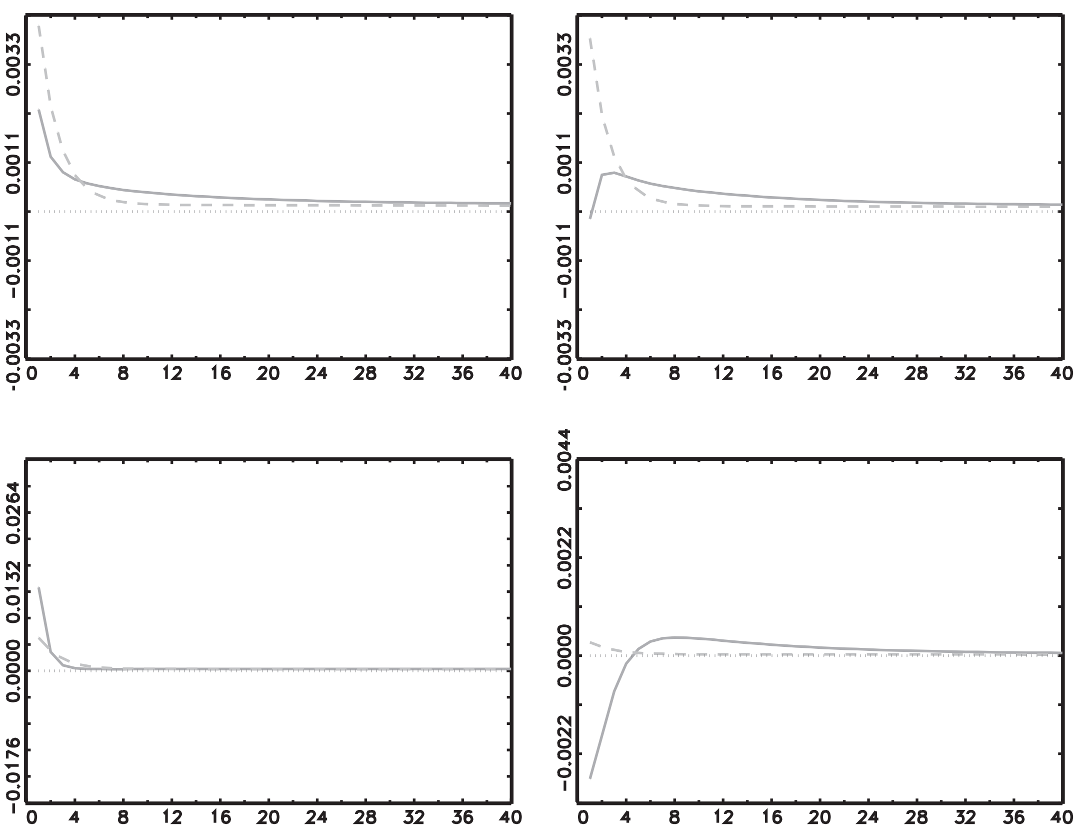

Fig. 5. Habits in leisure and capital adjustment costs. Impulse responses to a positive one-standard-deviation shock to technology. Periods after shock represent quarters. From left to right: *y*, *c*, *i*, and *n*. The bold line corresponds to the model with habits in consumption and leisure and adjustment costs, and the dashed line denotes the model with external habits in leisure and adjustment costs.

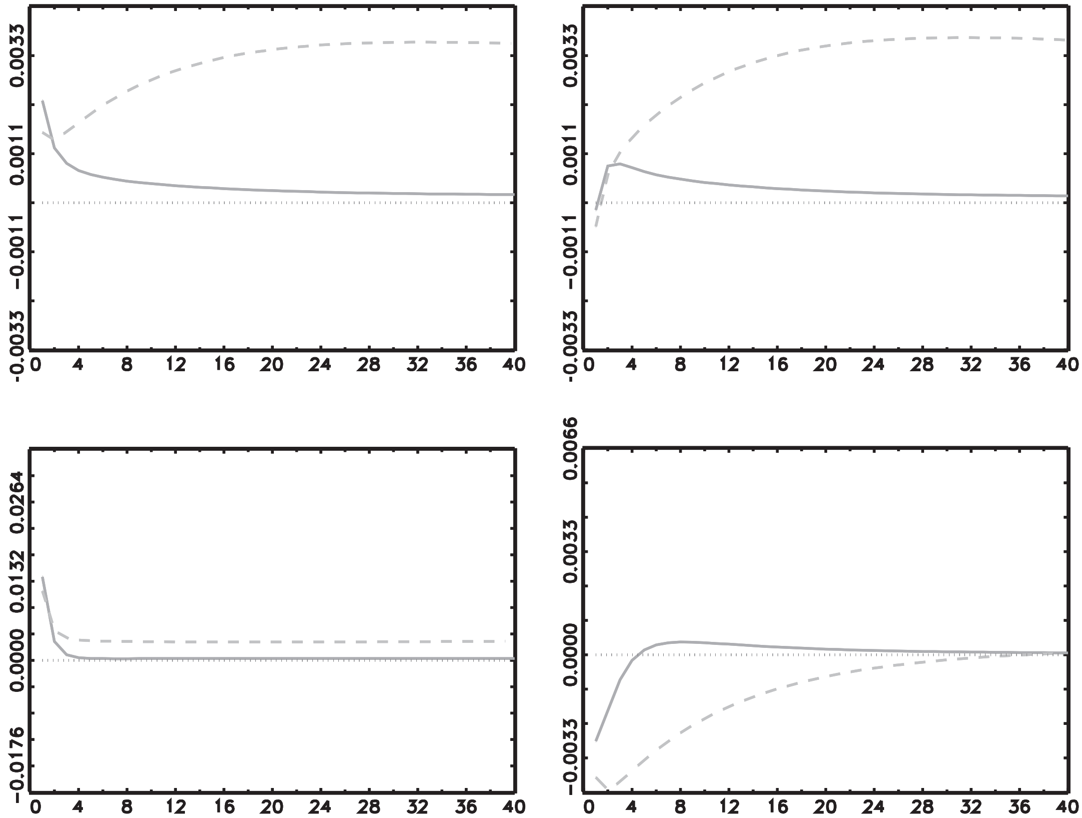

Fig. 6. Persistence of the technology shock. Model with external habits in consumption and leisure and adjustment costs. Impulse responses to a positive one-standard-deviation shock to technology. Periods after shock represent quarters. From left to right: *y*, *c*, *i*, and *n*. The bold line corresponds to the model with a moderate shock to technology, and the dashed line denotes the model with a very persistent technology shock.

(1996) time-to-plan as an alternative to capital adjustment cost. This modeling feature is supported empirically (Christiano and Vigfusson, 2003). It creates an observed delayed response of hours worked to a positive productivity shock, but also is able to improve on the volatility of labor relative to output, which is, however, not so different from what a model with capital adjustment costs often generates.

4. Conclusion

In this paper, I estimate a flexible model that allows for habit formation in both consumption and leisure as well as intratemporal nonseparability in consumption and leisure, to investigate how external habit formation in consumption, and leisure affects the optimal responses of output, investment, consumption, and hours worked to an exogenous productivity shock. The real business-cycle model with habits in leisure and consumption provides a reasonable fit to the data and delivers plausible business-cycle implications. Habit formation in leisure allows for improving the response of hours worked in the model with and without capital adjustment costs. For the models, when frictionless and instantaneous adjustment of capital stock is ruled out, further analysis is necessary to reconcile capital adjustment costs with the patterns of labor response observed in the data. I show that the persistence parameter of the productivity shock is an important factor that determines the sign of the effect of hours worked on the positive productivity shock.

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