NBER WORKING PAPER SERIES

A MODEL OF HOUSING IN THE PRESENCE OF ADJUSTMENT COSTS: A STRUCTURAL INTERPRETATION OF HABIT PERSISTENCE

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Working Paper 10458
http://www.nber.org/papers/w10458

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
April 2004

For helpful comments we thank Elena Bisagni, James Hamilton, Bruce Lehmann, and especially Takashi Yamashita. This is a revised version of the October, 2001 paper circulated under the title "Owner-Occupied Housing in the Presence of Adjustment Costs: Implications for Asset Pricing and Nondurable Consumption". The views expressed herein are those of the author(s) and not necessarily those of the National Bureau of Economic Research.

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April 2004
JEL No. E21, G12, G11

ABSTRACT

The paper generalizes the Grossman and Laroque (1990) model of optimal consumption and portfolio allocation in the context in which a durable good (or house) subject to adjustment costs is both an argument of the utility function and a component of wealth. Because the Grossman and Laroque model abstracts completely from nondurable consumption, their analysis cannot address either a) the potential spillover effects of the adjustment costs of the durable good on the dynamics of nondurable consumption, or b) the implications for portfolio allocation of housing risk arising from variation in the relative price of housing.

By introducing an endogenously determined but infrequently adjusted state variable, the housing model generates many of the implications of the habit persistence model, such as smooth nondurable consumption, state-dependent risk aversion, and a small elasticity of intertemporal substitution despite moderate risk aversion. Using a specification of the utility function which nests both the housing model and habit persistence, the Euler equation for nondurable consumption is estimated with household level data on food consumption and housing from the PSID. The habit persistence model (without housing effects) can be decisively rejected, while the housing model (without habit effects) is not rejected.

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The paper generalizes the Grossman and Laroque (1990) model of optimal consumption and portfolio allocation in the context in which a durable good (or house) subject to adjustment costs is both an argument of the utility function and a component of wealth. Because the Grossman and Laroque version of the model considers a utility function in which the durable good is the sole argument, and thus abstracts completely from nondurable consumption, their analysis cannot address either a) the potential spillover effects of the adjustment costs of the durable good on the dynamics of nondurable consumption, or b) the implications for portfolio allocation of housing risk arising from variation in the relative price of housing. By incorporating a utility function that includes nondurable consumption goods as well as the durable good as arguments, the model nests both the Grossman and Laroque model and the standard consumption-beta model.[1]

Like Grossman and Laroque, we assume that the household incurs an adjustment cost when altering the holding of the durable good (or house), although financial assets can be bought and sold costlessly. Consumption of the nondurable good can also be adjusted costlessly. When choosing a new house, the consumer takes into account the fact that the consumption of housing services will be constant at the new level until the subsequent stopping time, when it is again worthwhile to incur the adjustment cost. Thus the home purchase decision is endogenous and fully rational, but, because of the adjustment cost, infrequent. In this continuous time setting, the household's decision process has a

[1] Beaulieu (1993) also develops a generalization of Grossman and Laroque (1990) in which the utility function depends on nondurable goods as well as a house. In Beaulieu's model, the relative price of the house in terms of the nondurable good is fixed. Due to the simplifying assumption that the relative price of the two goods is constant, housing is "risky" only because the household may be confronted with paying the adjustment cost; his approach does not allow for housing risk in the form of appreciation or depreciation of the value of the house relative to nondurable goods. Nevertheless, Beaulieu's analysis makes several of the points discussed below; in particular, he points out that adding the durable good (subject to costly adjustment) to the standard consumption-beta model drives a wedge between the elasticity of intertemporal substitution and the reciprocal of the coefficient of relative risk aversion. He also points out that while the Euler equation for nondurable consumption holds in the more general model, the fact that the marginal utility of nondurable consumption depends, at the household level, on the holding of the durable good, aggregation issues will preclude empirical applications of the model based on representative agent specifications.

recursive structure; at each instant, the household first decides whether it is optimal to sell the house immediately. On those rare occasions that it is optimal to incur the adjustment cost, the household sells the old house and buys a new one instantaneously. If the household decides that it is not optimal to sell the house immediately, it then determines its optimal holdings of financial assets and optimal level of nondurable consumption conditional on the current housing stock. In essence, because of the adjustment costs associated with the durable good, the current house stock becomes a state variable that affects both the nondurable consumption choice and portfolio allocation.

The analytical model shows that if the covariance matrix of asset returns is block diagonal in the sense that the return to housing is uncorrelated with the returns to financial assets, all households will hold a single optimal portfolio of risky financial assets, despite differences among households in terms of preferences or in terms of the state variables faced. The paper provides some empirical evidence, and cites other evidence, that the block diagonality assumption required by the model is consistent with the data. While the state variables do not affect the composition of the optimal risky portfolio, they do affect the household's degree of risk aversion and therefore the allocation of the portfolio between the optimal risky portfolio and the riskless asset. Further, in the absence of nonnegativity constraints on the holdings of financial assets, asset pricing is consistent with the standard Capital Asset Pricing Model (CAPM).

Unlike the standard model in which utility is a function of a single, nondurable consumption good, the model does not imply an exact inverse relationship between the curvature of the utility function and the elasticity of intertemporal substitution. Depending on the degree of substitutability of the two goods, the elasticity of intertemporal substitution can in theory be greater than, equal to, or less than, the reciprocal of the curvature parameter. Under the plausible assumption of imperfect intratemporal substitutability between the two goods, the model can generate a low elasticity of intertemporal substitution of nondurable consumption without assuming a high value of the curvature parameter.

Along many dimensions, the housing model looks a lot like the habit persistence model. Both models explain the smoothness of nondurable consumption by introducing an additional state variable to the household's optimization problem. Because the state variable moves slowly (when the state variable is interpreted as the habitual level of consumption) or is unchanged for substantial periods of time (when the state variable is interpreted as the house), both models can generate a low elasticity of intertemporal substitution without requiring a high degree of curvature of the utility function. However, since the two models differ in their specification of the crucial state variable, it is possible to discriminate between the models empirically. In the final section of the paper, we consider a general utility function which nests the restricted utility functions consistent with the habit persistence model, the housing model, and the standard model. Using data from the PSID and the American Housing Survey, estimates of the parameters of the utility function are obtained by estimating the Euler equation for nondurable consumption. The empirical results confirm the finding of Dynan (2000) that very little evidence of habit persistence is found at the household level. Further, the parameter restrictions implied by the habit persistence model and the standard model are rejected decisively, while the parameter restrictions imposed by the housing model are not rejected. The parameter estimates imply that 1) the utility function exhibits only a modest degree of curvature and 2) intratemporal substitutability between housing and nondurable consumption is substantially less than perfect.

Section 1: Analytical model

In an important paper, Grossman and Laroque (l990) analyze optimal consumption and portfolio allocation in a context in which utility is derived solely from an illiquid durable good. They show that even modest transactions costs associated with adjustment of the quantity of the durable good will prevent the household from continuously equating the marginal utility of consumption with the marginal utility of wealth and therefore cause the consumption based CAPM to fail. Consumption (that is, consumption of the flow of services from the durable good) and marginal utility are constant for significant periods of time, despite fluctuations in the marginal utility of wealth, because the transactions costs preclude continuous, or even frequent, adjustment of the stock of the durable good.

Flavin and Yamashita (1999) consider a generalization of the Grossman and Laroque model in which current utility is a function of both a durable good, that is, a house, H, and a nondurable good, C. The nondurable good, C, has the ideal attributes of being infinitely divisible and costlessly adjustable. As in Grossman and Laroque, once the household purchases a particular house, no adjustments to the size (or any other attribute such as location) can be made without selling the existing house and incurring an adjustment cost proportional to the value of the house, then purchasing a new house.

The household maximizes expected lifetime utility:

$$(1) \qquad U = E_0 \int_0^\infty e^{-\delta t} u(H_t, C_t) dt$$

The instantaneous utility function, $u(H_t, C_t)$, depends on the flow of housing services, which in turn is assumed proportional to the housing stock, H. By choice of units, the factor of proportionality relating housing services to the housing stock is normalized to unity, so that the utility function can be written as a function of the housing stock. The household's rate of time preference is denoted by δ.

Much of Grossman and Laroque (l990) is devoted to analytical and numerical characterization of the optimal stopping times, $\tau_1, \tau_2, \tau_3, \ldots$, at which the household optimally incurs the adjustment cost and reoptimizes over H. In Grossman and Laroque, the stopping times are endogenous in the sense that the household adjusts its holding of the durable good when the stochastic evolution of wealth creates too great a disparity between the existing stock of the durable and the frictionless optimal stock. In addition to the endogenous stopping times modeled by Grossman and Laroque, our version of the model permits "exogenous stopping" in the sense that the adjustment of H may be caused by some event which is exogenous with respect to the evolution of wealth. Examples of exogenous events which might induce stopping are: a) death, in which the house is sold and the proceeds transferred to the heirs, b) change in job location, c) retirement, d) change in marital status, and e) acquisition or emancipation of children.

Each house is a distinct good, differing from every other house (at a minimum) in terms of its exact location. For the purposes of the analytical model, we assume that the house is not subject to physical depreciation.[2] Using the nondurable good as numeraire, define:

(2)
P_t = house price (per square foot) in the household's current market

P_t' =house price (per square foot) in the region to which the household relocates in the next move

As in Grossman and Laroque, we abstract from labor income or human wealth, and assume that wealth is held only in the form of financial assets and the durable good. The household can invest in a riskless asset and in any of n risky financial assets. Unlike the durable good, holdings of the financial assets can be adjusted with zero transaction cost.

Thus wealth is given by:

(3) $$W_t = P_t H_t + B_t + \underline{X}_t \underline{\ell}$$

where $\underline{X}_t$ = (1xn) vector of amounts (expressed in terms of the nondurable good) held of the risky assets and $\underline{\ell}$ = (nx1) vector of ones. B_t is the amount held in the form of the riskless asset. All financial assets, including the riskless asset, may be held in positive or negative amounts.[3]

Assuming that dividends or interest payments are reinvested so that all returns are received in the form of appreciation of the value of the asset, let b_{it} = the value (per share) of the ith risky asset, and assume that asset prices follow an n-dimensional Brownian motion process:

(4) $$db_{it} = b_{it}\left((\mu_i + r_f)dt + d\omega_{it}\right)$$

The vector $\underline{\omega}_{Ft} \equiv (\omega_{1t}, \omega_{2t}, \ldots, \omega_{nt})$ follows an n-dimensional Brownian motion with zero drift and with instantaneous covariance matrix Σ, the corresponding vector of expected excess returns on risky financial assets is $\underline{\mu} \equiv (\mu_1, \mu_2, \ldots, \mu_n)$, and r_f is the riskless rate. The ith element of $\underline{X}_t$ is given by $X_{it} \equiv N_{it} b_{it}$ where N_{it} is the number of shares held of asset i. The household takes asset prices, b_{it}, as exogenous, and determines X_{it} by its choice of N_{it}. To simplify the notation, the model is expressed using X_{it} rather than N_{it} as the choice variable representing the portfolio decision.

House prices also follow a Brownian motion:

(5) $$\begin{aligned} dP_t &= P_t\left((\mu_H + r_f)dt + d\omega_{Ht}\right) \\ dP_t' &= P_t'\left((\mu_{H'} + r_f)dt + d\omega_{H't}\right) \end{aligned}$$

where ω_{Ht} and $\omega_{H't}$ are Brownian motions with zero drift, instantaneous variance σ_P^2 and $\sigma_{P'}^2$, respectively, and instantaneous covariance σ_H.

Stacking equations (4) and (5), and defining the ((n+2)x1) vector $d\underline{\omega}_t$ as:

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[2] Generalizing the model to allow for a constant rate of depreciation is straightforward. By assuming a depreciation rate of zero, the model is simplified slightly without changing the basic implications of interest.

[3] Flavin and Yamashita (1999) considers the model under the alternative assumption that the household must hold nonnegative amounts of all financial assets other than mortgages. Since the household can borrow only in the form of a mortgage, and only up to the value of the house, the house becomes collateral in that model. Lustig and Van Nieuwerburgh

$$(6) \qquad d\underline{\omega}_t = \begin{bmatrix} d\omega_{1t} \\ \vdots \\ d\omega_{nt} \\ d\omega_{Ht} \\ d\omega_{H't} \end{bmatrix}$$

The vector $d\varpi_t$ has instantaneous ((n+2)x(n+2)) covariance matrix Ω:

$$(7) \qquad \Omega = \begin{bmatrix} \Sigma & 0 & 0 \\ 0 & \sigma_P^2 & \sigma_H \\ 0 & \sigma_H & \sigma_{P'}^2 \end{bmatrix}$$

Note that, in order to simplify the optimization problem, the covariance matrix Ω is assumed to be block diagonal. The block diagonality of Ω implies that housing prices both in the current market and in the next market are uncorrelated with the returns to financial assets. It is important to note that the block diagonality does not require an absence of correlation in regional house prices; the covariance matrix Ω allows for an arbitrary $\sigma_H \equiv \mathrm{cov}(P_t, P'_t)$. Because the covariance matrix does not place any restrictions on the correlation of regional housing prices, the model is sufficiently general to incorporate the role of housing investment in providing a hedge against the risk arising from variability in future housing costs. For given σ_P^2 and $\sigma_{P'}^2$, the extent to which homeownership provides a hedge against future housing costs will be increasing in σ_H .

Flavin and Yamashita (2002) present empirical evidence that the block diagonality assumed in equation (7) is consistent with data on US house prices and asset returns. Table 1 reports an estimate of the covariance matrix using data from Case and Shiller (1989) based on repeat sales transactions

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(2002) also studies the role of housing collateral and provides empirical evidence based on aggregate data that a decrease in the ratio of housing collateral to human wealth increases the market price of risk.

prices for four cities – Atlanta, Chicago, Dallas, and San Francisco – and returns to four financial assets – T-bills, Treasury bonds, a stock index, and fixed-rate mortgages.[4] The correlation

Table 1: Expected Returns and Covariance Matrix – Case-Shiller Price Indices

	T-Bills	Bonds	Stocks	Atlanta	Chicago	Dallas	SF
Mean Return	-0.0038	0.0060	0.0824	0.05356	0.05363	0.07196	0.09787
Standard Deviation	0.0435	0.0840	0.2415	0.04200	0.06079	0.04872	0.06540
				Covariance Matrix			
T-Bills	0.001892						
Bonds	0.002505	0.007061					
Stocks	0.000201	0.004038	0.058329				
Atlanta	0.000525	0.002038	0.003202	0.001764			
Chicago	0.000277	0.002859	0.002211	0.001006	0.003696		
Dallas	-0.000127	-0.000769	-0.000825	0.000851	0.001327	0.002373	
San Francisco	-0.000580	0.000415	-0.000223	-0.000159	0.001931	0.000796	0.004277
				Correlation Matrix			
T- Bills	1.0000						
Bonds	0.68533	1.0000					
	(0.09103)						
Stocks	0.01912	0.19897	1.0000				
	(0.12498)	(0.12251)					
Atlanta	0.41871	0.38527	0.42041	1.0000			
	(0.24271)	(0.24663)	(0.23970)				
Chicago	0.15244	0.37332	0.20051	0.39412	1.0000		
	(0.26414)	(0.24794)	(0.26001)	(0.24563)			
Dallas	-0.08701	-0.12527	-0.09341	0.41585	0.44796	1.0000	
	(0.26625)	(0.26516)	(0.26632)	(0.24306)	(0.23895)		
San Francisco	-0.29702	0.05041	-0.01879	-0.05794	0.48567	0.24987	1.0000
	(0.25520)	(0.26692)	(0.26721)	(0.26681)	(0.23362)	(0.25878)	

Standard errors are in parentheses.

Source: Flavin and Yamashita (2002).

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[4] Case and Shiller (1989) used data from the Society of Real Estate Appraisers to construct a Weighted Repeated Sales Index for each of the four cities by extracting the date and sales price of houses that sold twice during the sample period (1970-1986). Using weighted least squares, the change in the log of the individual house price is regressed on a set of dummy variables to obtain an index for average house appreciation in each city.

between the housing returns and financial asset returns is not statistically significantly different from zero for any of the four cities.[5] Flavin and Yamashita (2002) also use house price data from the Panel Study of Income Dynamics to check the assumption of zero correlation between returns to financial assets and housing returns. With the much larger sample size of the PSID, the estimates of the correlation between housing returns and financial asset returns are essentially zero, in terms of numerical magnitude as well as statistical significance.

Let $V(H, W, P, P')$ denote the supremum of household expected utility, conditional on the current values of the state variables (H, W, P, P'). At every moment, the household considers whether the disparity between the current size house and the frictionlessly optimal size house is sufficiently large to justify paying the transactions cost and reoptimizing over the house. House sales of this type are referred to as "endogenous" sales because they are triggered by the evolution of wealth, and therefore endogenous to the model. At time t=0, the Bellman equation is:

$$(8) \qquad V(H_0, W_0, P_0, P_0') = \sup_{\{C_t\},\{\underline{X}_t\},\tau} E_0\left[\int_0^{\tau} e^{-\delta t} u(H_0, C_t)dt + e^{-\delta\tau} V(H_\tau, W_\tau, P_\tau, P_\tau')\right]$$

where τ denotes the next stopping time.

Since the quantity of housing will change discontinuously at a stopping time, the notation $H_{\tau-}$ is used to distinguish the quantity of housing immediately prior to the sale from the quantity of housing immediately after the sale, H_τ. At the instant the house is sold, the household pays a transactions cost proportional to the value of the house sold, so that wealth also changes

[5] With the partial exception of San Francisco, the correlation between housing returns in two different cities is positive and approaching statistical significance at the 5% level. For all city pairs, the correlation of housing returns is statistically significantly different from unity, and for most pairs is about 0.4. Note, however, that the assumption of block diagonality does not require the absence of correlation of housing returns in different regions (i.e., does not require $\sigma_H = 0$).

discontinuously. Wealth is denoted $W_{\tau-}$ immediately prior to a sale, and denoted W_{τ} immediately after a sale. Thus at a stopping time, τ, wealth evolves according to:

(9) $$W_{\tau} = W_{\tau-} - \lambda P_{\tau} H_{\tau-}$$

where λ is the proportional transaction cost. The household faces a "no bankruptcy constraint", $W_t > \lambda P_t H_t$, which says that wealth must always be at least sufficient to pay the transactions cost to sell the current house. If wealth ever drops to a level just equal to the transactions cost on the current house, the house is sold and consumption of both housing and the nondurable good drop to zero.

Consider the time t=0. If the house were sold at t=0, the value of the program is $\sup_{\tilde{H}} V(\tilde{H}, W_{0-} - \lambda P_0 H_{0-}, P_0, P_0^{'})$. At each instant, the household first decides whether it is optimal to sell the house immediately by comparing the value of the program conditional on selling to the value of the program conditional on not selling. That is, if

(10) $$\sup_{\tilde{H}} V(\tilde{H}, W_{0-} - \lambda P_0 H_{0-}, P_0, P_0^{'}) < V(H_{0-}, W_{0-}, P_0, P_0^{'})$$

it is not optimal to sell the house at t=0. If, on the other hand, the values on each side of equation (10) are equal, then it is optimal to sell the house; that is, t=0 is a stopping time. For the version of the model studied by Grossman and Laroque, a conservative estimate of transactions costs equal to 5% of the value of the house implies that the average time between house purchases is 20 to 30 years. Thus the home purchase decision is endogenous and fully rational, but, because of the transactions cost, infrequent.

Suppose that at time t=0, the household decides that it is not optimal to sell the house immediately (i.e., $\tau \neq 0$), so that the value function $V(H_0, W_0, P_0, P_0^{'})$ strictly exceeds the maximum value attainable if the house were sold immediately. By continuity, there must be a time interval (0,s) sufficiently small that the possibility of stopping within that small interval can be ignored.[6] During such a time interval, wealth evolves according to:

$$(11) \qquad dW_t = \left[P_t H_0(\mu_H + r_f) + \underline{X}_t(\underline{\mu} + r_f) + r_f B_t - C_t\right]dt + \underline{X}_t d\underline{\omega}_{Ft} + P_t H_0 d\omega_{Ht}$$

or, rewriting in order to eliminate the term representing risk-free bonds,

$$(12) \qquad dW_t = \left[r_f W_t + P_t H_0 \mu_H + \underline{X}_t \underline{\mu} - C_t\right]dt + \underline{X}_t d\underline{\omega}_{Ft} + P_t H_0 d\omega_{Ht}$$

and the Bellman equation is:

$$(13) \qquad V(H_0, W_0, P_0, P_0^{'}) = \sup_{\{\underline{X}_t\},\{C_t\}} E\left[\int_0^s e^{-\delta t} u\left(H_0, C_t\right)dt + e^{-\delta s} V(H_0, W_s, P_s, P_s^{'})\right]$$

subject to the budget constraint (12), and the process for house prices (5) and the "no bankruptcy constraint". Subtracting $V(H_0, W_0, P_0, P_0^{'})$, dividing by s and taking the limit as $s \to 0$ gives:

$$(14) \qquad 0 = \lim_{s \to 0} \sup_{\{\underline{X}_t\}\{C_t\}} E\left[\frac{1}{s}\int_0^s e^{-\delta t} u\left(H_0, C_t\right)dt + \frac{1}{s}\left(e^{-\delta s} V(H_0, W_s, P_s, P_s^{'}) - V(H_0, W_0, P_0, P_0^{'})\right)\right]$$

Evaluating the integral and using Ito's lemma, equation (14) can be rewritten as:

$$\begin{aligned} 0 = \sup_{\underline{X}_0, C_0} \Big\{ & u(H_0, C_0) - \delta V(H_0, W_0, P_0, P_0^{'}) + \frac{\partial V}{\partial W}(r_f W_0 + P_0 H_0 \mu_H + \underline{X}_0 \underline{\mu} - C_0) \\ (15) \qquad & + \frac{\partial V}{\partial P} P_0 \mu_H + \frac{\partial V}{\partial P^{'}} P_0^{'} \mu_{H'} + \frac{1}{2}\frac{\partial^2 V}{\partial W^2}\left(\underline{X}_0 \Sigma \underline{X}_0^T + P_0^2 H_0^2 \sigma_P^2\right) + \frac{1}{2}\frac{\partial^2 V}{\partial P^2} P_0^2 \sigma_P^2 + \frac{1}{2}\frac{\partial^2 V}{\partial P^{'2}} P_0^{'2} \sigma_{P'}^2 \\ & + \frac{\partial^2 V}{\partial W \partial P} P_0^2 H_0 \sigma_P^2 + \frac{\partial^2 V}{\partial W \partial P^{'}} P_0 P_0^{'} H_0 \sigma_H + \frac{\partial^2 V}{\partial P \partial P^{'}} P_0 P_0^{'} \sigma_H \Big\} \end{aligned}$$

Nondurable consumption satisfies the usual first order condition:

$$(16) \qquad \frac{\partial u}{\partial C} = \frac{\partial V}{\partial W}$$

The vector of holdings of risky financial assets, $\underline{X}_0$, is chosen according to:

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[6] See Grossman and Laroque (1990), page 31.

$$(17) \qquad 0 = \text{constant} + \frac{\partial V}{\partial W}\left(r_f W_0 + P_0 H_0 \mu_H - C_0\right) + \frac{1}{2}\frac{\partial^2 V}{\partial W^2} P_0^2 H_0^2 \sigma_P^2$$

$$+ \sup_{\underline{X}_0} \left\{ \frac{\partial V}{\partial W} \underline{X}_0 \underline{\mu} + \frac{1}{2}\frac{\partial^2 V}{\partial W^2} \underline{X}_0 \Sigma \underline{X}_0^T \right\}$$

Thus from the first order condition for $\underline{X}_0$, the optimal holding of risky financial assets, stated as shares of wealth, is given by:

$$(18) \qquad \left(\frac{1}{W_0}\right)\underline{X}_0^T = \left[\frac{-\dfrac{\partial V}{\partial W}}{\dfrac{\partial^2 V}{\partial W^2} W_0}\right]\Sigma^{-1}\underline{\mu}$$

and the amount held of the riskless asset is:

$$(19) \qquad B_0 = W_0 - P_0 H_0 - \underline{X}_0 \underline{\ell}$$

In equation (18), the expression in square brackets is the reciprocal of the coefficient of relative risk aversion:

$$(20) \qquad RRA \equiv -\frac{\dfrac{\partial^2 V(W_t, H_t, P_t, P_t^{'})}{\partial W_t^2}}{\dfrac{\partial V(W_t, H_t, P_t, P_t^{'})}{\partial W_t}} W_t > 0$$

Note that, because the household's degree of risk version depends on the curvature of the value function, behavior toward risk will depend not only on the curvature of the instantaneous utility function, $u(H_t, C_t)$ but also on all of the state variables. The property that risk aversion varies with the state is also a feature of the version of the model considered by Grossman and Laroque (1990). In particular, they find that the household is less risk averse (in terms of the allocation of its portfolio between the risky and risk-free asset) shortly before purchasing a new house, and relatively more risk averse immediately after purchasing a new house.[7]

Section 2: Implications for asset pricing: CAPM vs. consumption-beta

From equation (18), all consumers hold risky assets in exactly the same proportion, despite differences among households in terms of preferences (i.e., in the specification of u(H,C)) or in terms of the state variables faced. The result that there is a single optimal portfolio of risky financial assets held by all consumers is consistent with the more restricted version of the model considered by Grossman and Laroque (1990). Like the corresponding result in Grossman and Laroque, the result does not require a specific assumption, such as constant relative risk aversion, on the instantaneous utility function. Further, the result does not require a specific assumption about the degree of substitutability between H and C; all that is required is a general instantaneous utility function $u(H_t, C_t)$. Note, however, that the derivation of equation (18) required the assumption that the covariance matrix is block diagonal as specified in equation (7); in the absence of this restriction the Grossman and Laroque result that all consumers hold risky assets in the same proportion would not survive in the more general model. Under a completely general covariance matrix (i.e., one that is not block diagonal), risky financial assets could be used to hedge the risk associated with the current house, or to hedge the risk associated with the variability of future house prices. However, under the assumption of block diagonality, returns to financial assets are uncorrelated with both current house prices and with future house prices. In this case, even though the risk averse household will dislike the risk created by variability in P or P', the household is unable to hedge either of these types of risk with the portfolio of financial assets. Since, under block diagonality, there is no scope for using financial assets to hedge the risk from current or future house prices, the presence of the (risky) housing asset

[7] See Grossman and Laroque (1990), pages 38-40.

does not create any "distortion" of the optimal portfolio of risky financial assets as compared to the risky portfolio implied by the standard model which abstracts from housing altogether. While the composition of the optimal risky portfolio does not depend on the values of the state variables, the household's degree of risk aversion in general will depend on the values of the state variables. As in the standard model, the allocation of the overall portfolio between the optimal risky portfolio and the riskless asset will depend on the household's risk aversion.

In general equilibrium, the fact that all consumers hold risky assets in the same proportion implies that risk premia are determined by the standard CAPM. To see this, note that in equation (18), the expression in square brackets is a positive scalar that, for each household j, depends on preferences and on the household's vector of state variables. For household j, denote this scalar as s(j); denote the sum of s(j) across households as $S \equiv \sum_j s(j)$. Denote the total market value of risky asset i as M_i, and define the (nx1) vector $\underline{M} \equiv (M_1, M_2, ..., M_n)$. Market clearing requires:

$$\underline{M} = S\, \Sigma^{-1} \underline{\mu} \tag{21}$$

which implies

$$\begin{aligned} \underline{\mu} &= \frac{1}{S} \Sigma \underline{M} \\ S &= \frac{\underline{M}^T \Sigma \underline{M}}{\underline{M}^T \underline{\mu}} \end{aligned} \tag{22}$$

Eliminating S, (22) implies:

$$\underline{\mu} = \left[\frac{\underline{M}^T \underline{\mu}}{\underline{M}^T \Sigma \underline{M}} \right] \Sigma \underline{M} \tag{23}$$

Expressed in more familiar notation, equation (23) can be restated as:

$$E(r_i) - r_f = \frac{\mathrm{cov}(r_i - r_f, r_m - r_f)}{\mathrm{var}(r_m - r_f)} [E(r_m) - r_f] \tag{24}$$

since the matrix products in equation (23) have the following interpretations:

$\underline{M}^T\underline{\mu}$= expected excess return on the market portfolio = $\mu_m - r_f$

(25) $\underline{M}^T\Sigma\underline{M}$ = variance of return on the market portfolio = $\mathrm{var}\left(r_m - r_f\right)$

$\Sigma\underline{M}$ = vector whose ith element represents the covariance of the return to risky asset i with the return to the market portfolio, i.e., ith element = $\mathrm{cov}\left(r_i - r_f, r_m - r_f\right)$

Asset prices are also consistent with the consumption-beta model; the implications of the traditional CAPM and consumption-beta model exactly coincide in this setting. Because nondurable consumption is costlessly adjustable, households continuously equate the marginal utility of nondurable consumption with the marginal utility of wealth, and satisfy an Euler equation for each of the financial assets. Denoting the marginal utility of nondurable consumption of household j in period t as:

$$\lambda_{jt} = \frac{\partial u(H_t, C_t)}{\partial C_t} \tag{26}$$

the set of Euler equations for the time interval (t, t+s) imply:

$$\begin{aligned} E(r_{it+s}) - r_f &= \frac{-\mathrm{cov}(r_{it+s} - r_f, \lambda_{jt+s})}{E(\lambda_{jt+s})} \\ E(r_{mt+s}) - r_f &= \frac{-\mathrm{cov}(r_{mt+s} - r_f, \lambda_{jt+s})}{E(\lambda_{jt+s})} \end{aligned} \tag{27}$$

Even if households are identical in the sense that they have the same preferences (i.e., the same utility function $u(H_t, C_t)$), differences across households in the values of the state variables (including H_t and W_t) will create cross-sectional dispersion in the marginal utility of nondurable consumption, λ_{jt}. Nevertheless, since all households are satisfying the Euler equations for nondurable consumption, equation (27) will hold for all households. Rewriting equation (27) to express the risk premium on an individual risky asset in terms of the risk premium on the market portfolio gives:

$$(28) \qquad E(r_{it+s}) - r_f = \frac{\operatorname{cov}(r_{it+s} - r_f, \lambda_{jt+s})}{\operatorname{cov}(r_{mt+s} - r_f, \lambda_{jt+s})}[E(r_{mt+s}) - r_f]$$

Comparing equations (24) and (28), the model implies that

$$(29) \qquad \beta_i \equiv \frac{\operatorname{cov}(r_{it+s} - r_f, \lambda_{jt+s})}{\operatorname{cov}(r_{mt+s} - r_f, \lambda_{jt+s})} = \frac{\operatorname{cov}(r_{it+s} - r_f, r_{mt+s} - r_f)}{\operatorname{var}(r_{mt+s} - r_f)}$$

Thus the basic implication of the model is that risk premia on individual assets will be proportional to the risk premium on the market portfolio, and that an asset's beta can be expressed either in terms of the covariance of the asset's return with the marginal utility of consumption or in terms of the covariance of the asset's return with the market portfolio; in theory, equation (29) provides two alternative ways of obtaining empirical estimates of a unique vector of betas. In practice, of course, either approach to estimating the betas is compromised by serious measurement issues. In terms of the traditional CAPM approach, we do not observe the return on the complete market portfolio and consequently rely on a proxy (such as the return to a broad stock index). In terms of the consumption-beta approach, we do not directly observe the marginal utility of nondurable consumption at the household level, λ_{jt}. To estimate the risk premia using the consumption-beta approach in (29), we would need a) to make an assumption about the functional form of the utility function $u(H_t, C_t)$ and b) to have data on the state variable H_t as well as data on nondurable consumption at the household level. Thus it is not necessary to conclude that the consumption-beta model should be rejected on the basis of the extensive empirical evidence that the traditional CAPM outperforms the consumption-based CAPM in terms of predicting asset premia. In this setting, households behave in exactly the manner prescribed by the consumption-beta model. Instead, one can interpret the poor empirical performance of the consumption-beta model as an indication that, in practice, we cannot infer the marginal utility of nondurable consumption with sufficient accuracy to exploit the empirical implications of the model.

None of the preceding analytical results depend on any specific assumptions on the functional form of the utility function. In order to study the relationship between risk aversion and intertemporal substitution, we now assume that the instantaneous utility function is of the CES form:

$$\text{(30)} \qquad u(H_t, C_t) = \frac{\left[\gamma H_t^{\alpha} + C_t^{\alpha}\right]^{\frac{1-\rho}{\alpha}}}{1-\rho} \qquad \alpha \leq 1, \quad 0 \leq \gamma, \qquad 1 \neq \rho > 0$$

The parameter α governs the degree of intratemporal substitutability between housing and nondurable consumption goods. If α=1 the two goods are perfect substitutes. The limiting case of $\alpha \to -\infty$ implies Leontief preferences, i.e., no substitutability between goods:

$$\text{(31)} \qquad u(H_t, C_t) = \frac{\left[\min(\gamma H_t, C_t\right]^{1-\rho}}{1-\rho}$$

The parameter ρ determines the degree of curvature of the utility function with respect to the composite good. The coefficient of relative risk aversion does not, in general, coincide with the parameter governing the curvature of the instantaneous utility function. For this reason, the parameter ρ will be referred to as "the curvature parameter" rather than "the risk aversion parameter". There are, however, two special cases in which the coefficient of relative risk aversion will be equal to the curvature parameter. The obvious special case arises when we assume that $\gamma = 0$, i.e., nondurable consumption is the sole argument of the utility function. In this case the utility function reduces to $u(C) = (1-\rho)^{-1} C^{1-\rho}$ and the curvature of the value function immediately inherits the curvature of the utility function, which yields the familiar result that the coefficient of relative risk aversion is equal to the curvature parameter, ρ.

For the second special case, consider the general CES utility function given in equation (30), but assume that the housing stock is costlessly adjustable ($\lambda = 0$). The result that the value function $V(H_t, W_t, P_t, P_t^{'})$ is homogeneous of degree (1-ρ) in H and W can be established by an argument parallel to that in Theorem 2.1 of Grossman and Laroque (1990). However, if the stock of housing is costlessly adjustable, the value function at t depends on H_t only to the extent that H_t is a component of wealth; H_t does not appear in the value function as a separate state variable. Thus, in the absence of adjustment costs, the value function can be written in the form:

$$V(H_t, W_t, P_t, P_t^{'}) = k(P_t, P_t^{'}) W_t^{1-\rho} \tag{32}$$

where $k(P_t, P_t^{'})$ is a function of house prices which does not depend on W_t, which implies

$$RRA \equiv - \frac{\frac{\partial^2 V(W_t, H_t, P_t, P_t^{'})}{\partial W_t^2}}{\frac{\partial V(W_t, H_t, P_t, P_t^{'})}{\partial W_t}} W_t = \rho \tag{33}$$

To summarize, it is the curvature of the value function that reflects preferences toward risk and determines the composition of the optimal portfolio. If we assume that the instantaneous utility function has curvature with respect to the composite good as defined by the parameter ρ in equation (31), the coefficient of relative risk aversion coincides exactly with ρ if we consider special cases in which the stock of housing is not a state variable (i.e. the utility function does not depend on housing, or housing is costlessly adjustable). In the general case, however, the curvature of the value function and therefore the coefficient of risk aversion will depend on the values of the state variables as well as parameters such as ρ. The state-dependence of preferences toward risk and portfolio composition is examined through numerical simulation by Grossman and Laroque (1990) in the context of their simplified version of the model. Empirical evidence that the average share of housing in consumption expenditure helps to forecast excess stock returns is provided in Piazzesi, Schneider, and Tuzel (2002).

Section III: The elasticity of intertemporal substitution of nondurable consumption

In the standard version of the consumption-beta model, it is assumed that 1) the lifetime utility function is determined within an expected utility framework, 2) the one-period utility function is time-separable, and 3) the utility function depends solely on a single, costlessly adjustable nondurable good.[8] Under these assumptions, the curvature of the utility function immediately determines both risk aversion and the elasticity of intertemporal substitution. Further, it is an implication of the standard version of the model that the elasticity of intertemporal substitution is the reciprocal of the coefficient of relative risk aversion. In response to the large body of empirical work that demonstrated consistent rejection of this implication of the standard model, various authors have considered more general versions of the model by 1) relaxing the assumption of expected utility or by 2) relaxing the assumption of time-separable preferences. In both of these more general specifications, the model no longer has the implication that the elasticity of intertemporal substitution is equal to the reciprocal of the coefficient of relative risk aversion. In our model, we maintain assumptions 1) and 2) by using a standard time-separable expected utility framework, and consider the implications for the elasticity of intertemporal substitution after relaxing assumption 3) by making the utility function depend on the durable good subject to adjustment costs as well as nondurable consumption.[9]

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[8] Ogaki and Reinhart (1998) estimate the elasticity of intertemporal substitution in a model in which utility is a nonseparable function of durable and nondurable consumption. In their empirical work, durable goods are interpreted as durable goods in the NIPA sense (automobiles, furniture, appliances, etc), rather than as the house. Because they assume that both durables and nondurables are costlessly adjustable, their model does not exhibit the dynamics associated with the adjustment cost.

[9] The point that an adjustment cost associated with durable goods will in general effect the dynamics of nondurable consumption was made in Bernanke (1985). In the context of the Permanent Income model based on quadratic preferences, Bernanke allows utility to depend on durable goods as well as nondurable goods in a potentially nonseparable way. For tractability, he models the adjustment costs associated with durable goods as a quadratic function of the change in the stock

Consider a time t=0 such that, due to the transactions costs, it is not optimal for the household to sell the house immediately and reoptimize over H. Having decided, for the moment, to maintain the level of housing services at H_0, the elasticity of intertemporal substitution (EIS) of nondurable consumption is:

$$\text{(34)} \quad \text{EIS} \equiv \frac{-\dfrac{\partial u(H_0,C_t)}{\partial C_t}}{C_t \dfrac{\partial^2 u(H_0,C_t)}{\partial C_t^2}} = \frac{-1}{(\alpha-1)\left[1-\dfrac{C_t^\alpha}{\gamma H_0^\alpha + C_t^\alpha}\right] - \rho\left[\dfrac{C_t^\alpha}{\gamma H_0^\alpha + C_t^\alpha}\right]}$$

Using the notation $\varpi_t \equiv \dfrac{C_t^\alpha}{\gamma H_0^\alpha + C_t^\alpha}$, note that

$$\text{(35)} \quad 0 \le \varpi_t = \frac{C_t^\alpha}{\gamma H_0^\alpha + C_t^\alpha} \le 1$$

so that the EIS takes the form:

$$\text{(36)} \quad \text{EIS} = \frac{1}{(1-\varpi_t)(1-\alpha) + \varpi_t \rho}$$

In the special case in which the instantaneous utility function depends on nondurable consumption alone ($\tilde{u}(C_t) = \dfrac{C_t^{1-\rho}}{1-\rho}$), the EIS is ρ^{-1}, that is, we get the implication that the elasticity of intertemporal substitution is simply the inverse of the coefficient of relative risk aversion. In the more

of durables; given the quadratic specification of preferences and adjustment costs, he is able to derive and estimate closed form solutions for the behavior of durable and nondurable consumption goods. Quadratic adjustment costs will induce adjustment dynamics very different from the specification of adjustment costs used by Grossman and Laroque, in which the adjustment cost is proportional to the entire stock of the durable — under the quadratic specification the adjustment will take the form of a series of small adjustments over a number of periods, while under proportional adjustment costs, the household will maintain a given stock of the durable over a long period and ultimately make a single, large adjustment. When the durable good is interpreted as a house, as in the current paper, modeling the adjustment cost as proportional to the stock seems more plausible than the quadratic function of the change in the stock. However, in Bernanke's paper, "durable goods" refers to durable goods as defined in the NIPA classification; that is, vehicles, furniture, clothing, etc. Since "durable goods" in his model refers to a collection of smaller individual goods, as opposed to a single indivisible good, the specification of adjustment costs as quadratic in the change in the total stock of durable goods is more plausible. While general case in which housing appears as an argument of the utility function, the elasticity of intertemporal substitution will equal the inverse of the curvature parameter ρ only if α, which reflects the intratemporal substitutability of the two goods, happens to obey the restriction $\alpha=1-\rho$.

Consider a household with preferences characterized by modest curvature of the utility function with respect to the composite good; for example, assume $\rho=2$. Because the EIS is the reciprocal of a weighted average of ρ and $(1-\alpha)$, a low value of ρ does not necessarily imply a high elasticity of intertemporal substitution. As an extreme example, consider the EIS as $\alpha \to -\infty$ (that is, the limiting cases in which the intratemporal substitutability of the two goods approaches zero). In this case, the EIS of nondurable consumption approaches zero, regardless of the value of ρ. In the opposing extreme case of perfect intratemporal substitutability between the two goods ($\alpha = 1$), the EIS will generally exceed the inverse of the curvature parameter. Thus, depending on the parameter governing intratemporal substitution, the two good model implies the following relationship between the elasticity of intertemporal substitution and the curvature of the utility function:

$$
\begin{aligned}
&\text{EIS} \to 0 && \text{for} \quad \alpha \to -\infty \\
&\text{EIS} < \rho^{-1} && \text{for} \quad \alpha < 1-\rho \\
&\text{EIS} = \rho^{-1} && \text{for} \quad \alpha = 1-\rho \\
&\text{EIS} \geq \rho^{-1} && \text{for} \quad \alpha = 1
\end{aligned}
\tag{37}
$$

Thus even if the curvature of the utility function with respect to the composite good is modest (i.e., ρ is small), the plausible assumption of imperfect intratemporal substitutability between the two goods can easily generate a low elasticity of intertemporal substitution of nondurable consumption.

Bernanke's model allows for nonseparability between durable goods (as defined by the NIPA) and nondurable goods and services, empirical estimation of the model indicates that the restriction implied by separability cannot be rejected.

Section IV: Comparison with the recursive utility framework of Epstein and Zin

In an important series of papers, Epstein and Zin (1989, 1991) show that the tight link between risk aversion and intertemporal substitution which characterizes the standard model can be broken by replacing the time-additive expected utility preference model with a generalized model of preferences based on Kreps and Porteus (1978). In this approach, preferences toward risk are embodied in the function μ ($\mu_{t+1} = \mu\left(U_{t+1} \middle| I_{t+1}\right)$) which relates the conditional distribution of next period's value function (U_{t+1}) to its certainty equivalent, μ_{t+1}. Lifetime utility, U_t, is then defined with an aggregator function, θ:

(38) $$U_t = \theta\left(C_t, \mu_{t+1}\right)$$

as a function of current consumption and the certainty equivalent of lifetime utility in t+1. Preferences regarding intertemporal substitution are embodied in the aggregator function and may be varied independently of preferences toward risk. For example, the functional form for the aggregator function suggested in Epstein and Zin (1991) is:

(39) $$U_t = \left[(1-\beta)C_t^{\alpha_0} + \beta\mu_{t+1}^{\alpha_0}\right]^{\frac{1}{\alpha_0}} \qquad 0 \neq \alpha_0 < 1$$

The specification in (39) implies that, when future consumption is deterministic, the elasticity of intertemporal substitution is constant and equal to:[10]

(40) $$\text{EIS} = \frac{1}{1-\alpha_0}$$

After estimating Euler equations generated by their model under a general parameterization of risk aversion, Epstein and Zin conclude that "Risk preferences do not differ statistically from the

[10] See Epstein and Zin (1991), page 266.

logarithmic specification."[11] Under the log specification for risk aversion, their recursive utility model implies[12]

(41) $$E_t \Delta \ln C_{t+1} = \frac{1}{1-\alpha_0}\left[\ln\beta + E_t \ln(1+R_{t+1})\right]$$

The expected utility model can be obtained as a special case of Epstein and Zin's generalized preference model if (for the case of logarithmic risk preferences), $\alpha_0 = 0$. However, their empirical work suggests that $\alpha_0 < 0$, so that the expected utility model is rejected. Depending on the value of α_0 the recursive utility framework implies that consumers favor early resolution of uncertainty ($\alpha_0 > 0$), favor late resolution of uncertainty ($\alpha_0 < 0$) or are indifferent to the timing of the resolution of uncertainty ($\alpha_0 = 0$). Thus the estimates of the EIS reported by Epstein and Zin (1991) are interpreted as evidence that the expected utility framework can be rejected as too restrictive, and, further, that consumers prefer late resolution of uncertainty.

In essence, Epstein and Zin maintain the assumption of a single, nondurable good, and dispense with expected utility, then interpret the small empirical estimates of the elasticity of intertemporal substitution as evidence that preferences are inconsistent with the expected utility framework. In the housing model, the expected utility framework is maintained, and the estimates of a low elasticity of intertemporal substitution are interpreted as a consequence of imperfect substitutability between housing and the nondurable consumption good. To take a particularly simple case, consider the special case in which the curvature of the utility function with respect to the composite good is given by the log specification. In this case, the utility function (30) becomes:

(42) $$u(H_t, C_t) = \frac{1}{\alpha}\ln\left[\gamma H_t^{\alpha} + C_t^{\alpha}\right]$$

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[11] ibid, page 282.
[12] ibid, page 269.

and the elasticity of intertemporal substitution is:

$$\text{(43)} \qquad \text{EIS} = \frac{1}{1-\alpha(1-\varpi_t)}$$

In this approach, one can maintain both the expected utility framework and the log specification of the utility function and interpret small empirical estimates of the EIS as an indication that housing and nondurable consumption goods are imperfect substitutes (i.e., $\alpha < 0$).

Section V: Comparison with models of habit persistence

Models of habit persistence provide another approach for breaking the tight relationship between the elasticity of intertemporal substitution and risk aversion. In particular, papers by Abel (1990), Campbell and Cochrane (1998, 1999), Constantinides (1990), Ferson and Constantinides (1991), Heaton (1995) and Sundarson (1989) examine the macroeconomic and asset pricing implications of a variety of models incorporating preferences which exhibit habit persistence. Of the many models of habit persistence contained in the literature, the model posed by Constantinides (1990) provides a convenient comparison to the housing model, as Constantinides considers the effects of habit persistence in an infinite horizon, continuous time model that, like the housing model, incorporates a portfolio decision and abstracts from labor income. That is, Constantinides considers the lifetime utility function:

$$\text{(44)} \qquad U = E_0 \int_0^{\infty} e^{-\delta t} u(c_t, h_t) dt$$

where h_t is the state variable representing the "habit".

In particular, Constantinides parameterizes the instantaneous utility function as:

$$\text{(45)} \qquad u(c_t, h_t) = \frac{(c_t - h_t)^{1-\rho}}{1-\rho}$$

and models "habit" as an exponentially weighted distributed lag of past consumption:

(46) $$h_t = e^{-at}h_0 + b\int_0^t e^{a(s-t)}c_s ds$$

In this specification, the consumption habit, h_t, can be interpreted as the subsistence level of consumption in the sense that marginal utility becomes infinite at $c_t = h_t$. For the parameter values $h_0 = b = 0$, the model specializes to the standard time-separable case.

In the general case, the value function depends on the state variable representing habit, h_t, as well as wealth, W_t:

(47) $$V(W_t, h_t) = \max_{\alpha(s),c(s)} E_t \int_t^\infty e^{-\delta s} \frac{(c_s - h_s)^{1-\rho}}{1-\rho} ds$$

where $\alpha(s)$ denotes the fraction of the portfolio invested in the risky asset. Defining relative risk aversion as in equation (20) as the curvature of the value function, Constantinides shows that risk aversion is not constant across time, as in the time-separable case, but instead varies with the ratio of the two state variables, $\frac{h_t}{W_t}$. That is, the degree of relative risk aversion at time t is given by:

(48) $$RRA = -\frac{\frac{\partial^2 V(W_t, h_t)}{\partial W_t^2}}{\frac{\partial V(W_t, h_t)}{\partial W_t}} W_t = \frac{\rho}{1 - \left[\frac{h_t}{W_t(r+a-b)}\right]}$$

where a and b are the parameters which govern the strength of habit persistence and r denotes the risk-free rate of return.[13] Thus in contrast to the time-separable case, in which relative risk aversion is constant and completely determined by the curvature of the utility function, ρ, in the presence of habit persistence the household's degree of relative risk aversion depends on the ratio of habit to wealth. For

[13] The model imposes the restriction that $0<b<r+a$ so that the expression in square brackets is nonnegative.

a given value of ρ, relative risk aversion is an increasing function of the ratio of habit (or subsistence) to wealth.

Like the degree of relative risk aversion, Constantinides shows that the elasticity of intertemporal substitution will be time-varying and a function of the state variable, h_t, in addition to the curvature parameter, ρ. In the habit persistence model, the elasticity of intertemporal substitution is:

$$\text{(49)} \qquad \text{EIS} \equiv \frac{-\dfrac{\partial u(c_t,h_t)}{\partial c_t}}{c_t \dfrac{\partial^2 u(c_t,h_t)}{\partial c_t}} = \frac{1-\dfrac{h_t}{c_t}}{\rho}$$

Because h_t is the subsistence level of consumption, the specification of the utility function in equation (45) implies that $\frac{h_t}{c_t} < 1$ and therefore that habit persistence reduces the elasticity of intertemporal substitution.

To underscore the common elements of the housing model and the habit persistence approach, it is useful to consider a slightly more general CES utility function that nests the utility functions used in both models (i.e., equations (30) and (45)). That is, consider the utility function

$$\text{(50)} \qquad u(x_t,c_t) = \frac{\left[\theta_1 x_t^{\alpha} + \theta_2 c_t^{\alpha}\right]^{\frac{1-\rho}{\alpha}}}{1-\rho} \qquad \alpha \le 1, \quad 1 \ne \rho > 0$$

where x_t is an unspecified state variable and c_t is nondurable consumption. When the state variable is identified as the house ($x_t = H_t$), the assumption that utility is increasing in both goods implies the restriction $0 < \theta_i$. If, instead, the state variable is interpreted as the habitual level of consumption ($x_t = h_t$), the plausible parameter restriction would be $\theta_1 < 0$ and $\theta_2 > 0$, since the partial derivative of utility with respect to habit is negative. For the utility function in (50), the elasticity of intertemporal substitution is:

$$(51) \quad \text{EIS} \equiv \frac{-\dfrac{\partial u(x_t, c_t)}{\partial c_t}}{c_t \dfrac{\partial^2 u(x_t, c_t)}{\partial c_t^2}} = \frac{-1}{(\alpha - 1)\left[1 - \dfrac{\theta_2 c_t^\alpha}{\theta_1 x_t^\alpha + \theta_2 c_t^\alpha}\right] - \rho\left[\dfrac{\theta_2 c_t^\alpha}{\theta_1 x_t^\alpha + \theta_2 c_t^\alpha}\right]}$$

Constantinides assumes that utility depends on the difference between current consumption and habit, and therefore sets $\theta_1 = -1$, $\theta_2 = 1$, and $\alpha = 1$ to get equation (49). For a given value of ρ, the implied EIS is a decreasing function of the ratio of habit to current consumption. However, as Constantinides points out, under this specification, the degree of habit persistence required to explain the equity premium puzzle is extremely high; that is, to fit the data, the habitual, or subsistence level, of consumption, h_t, is, on average, equal to 80% of the level of consumption, c_t. When the state variable is interpreted as the house, the parameter assignment $\alpha = 1$ implies, implausibly, that housing and nondurable goods are perfect substitutes. Under the interpretation of equation (50) provided by the housing model, a high degree of curvature of the utility function with respect to nondurable consumption is the result of imperfect substitutability between the two goods (i.e., $\alpha < 0$). In light of the parallel implications of the two models in terms of household behavior toward risk, and in terms of the dynamics of nondurable consumption, the housing model might be thought of as a "structural"[14] model of behavior that looks like habit persistence at the aggregate level.

In summary, it is evident that the restriction that households' relative risk aversion and elasticity of intertemporal substitution are simply and exactly reciprocals of one another is not a robust implication of the basic consumption-beta framework, but instead requires three assumptions: expected utility preferences, time-separability of preferences, and an instantaneous utility function which depends only on a single, costlessly adjustable, consumption good. Relaxing any one of these three assumptions – by introducing recursive preference, habit persistence, or a durable good subject to adjustment costs – relaxes the tight link between these two crucial aspects of household behavior. While any of the three generalized models can be used to reconcile empirical evidence that households, while not highly risk averse, are nevertheless strongly averse to intertemporal substitution of consumption, the models generate different implications on other aspects of household behavior. For example, the habit persistence model and the housing model both generate consumption smoothness by introducing a state variable. In contrast to the model based on recursive preferences, the habit persistence and housing models both imply that the household's current choices (with respect to nondurable consumption and portfolio composition) will depend not only on current wealth, but also on the path of wealth. That is, in a comparison of two households that are identical in terms of their preferences and current wealth but differ in terms of the historical path of wealth, the two households may differ in terms of their optimal level of nondurable consumption and their optimal portfolio composition because the households may face different values of the state variables (habit or current housing stock). In contrast, the generalized model based on recursive preferences implies that optimal consumption and portfolio composition will depend on current wealth, but not on the path of wealth.

The habit persistence model and the housing model have a long list of common features: both retain the expected utility framework, both explain the smoothness of consumption of nondurable goods by introducing an additional state variable, and both imply that a household with stable preferences will nevertheless display variation over time in the degree of relative risk aversion and the elasticity of intertemporal substitution. However, the two approaches have important differences. To generate smooth consumption and a low elasticity of intertemporal substitution, the habit persistence model locates the "rigidity", or the cause of sluggish adjustment, in household preferences by

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[14] Pun intended.

assuming that utility depends on the level of current consumption relative to habitual consumption. In contrast, the housing model identifies costs of adjustment of the house as the source of the "rigidity". The testable implications of the two models are examined in the next section.

Section VI: Empirical tests of habit persistence vs. the housing model

In order to estimate the parameters of the utility function, and test the housing model against the habit persistence model, we consider a utility function which nests both models. Generalized to allow for habit persistence in nondurable consumption, the CES utility function for household i becomes:

$$u(C_{it}, C_{it-1}, H_{it}) = \frac{\left[(C_{it} - bC_{it-1})^{\alpha} + \gamma H_{it}^{\alpha}\right]^{\frac{1-\rho}{\alpha}}}{1-\rho} \qquad \alpha \leq 1,\ 1 \neq \rho > 0,\ \gamma \geq 0 \tag{52}$$

If γ=0 and α=1, the utility function in (52) is a simple habit persistence specification, with the stock of habit represented by last period's nondurable consumption. Conceptually, the parameter b could be positive, negative, or zero. A positive value of b indicates habit persistence in the sense that the utility associated with a given level of current nondurable consumption is decreasing in the previous level of consumption. A negative value of b indicates that the consumption good, although physically nondurable, exhibits durability in the utility flow in the sense that consumption of the nondurable good generates utility in both the current and subsequent periods.

Under the assumption that the nondurable consumption good is costlessly adjustable, the Euler equation for nondurable consumption holds. Since there is no reason, a priori, to rule out a role for both state variables, C_{it-1} and H_{it}, we estimate the Euler equation implied by the utility function in (52), then test the restrictions imposed by the various nested models: housing, habit persistence, or the standard model with neither habit persistence nor habit. The Euler equation for nondurable consumption is:

(53) $$1=\beta E_t\left[\frac{(C_{it+1}-bC_{it})^{\alpha-1}Q_{it+1}+\beta b(C_{it+2}-bC_{it+1})^{\alpha-1}Q_{it+2}}{(C_{it}-bC_{it-1})^{\alpha-1}Q_{it}+\beta b(C_{it+1}-bC_{it})^{\alpha-1}Q_{it+1}}(1+r_{it+1})\right]$$

where $$Q_{it}=\left[(C_{it}-bC_{it-1})^{\alpha}+\gamma H_{it}^{\alpha}\right]^{\frac{1-(\alpha+\rho)}{\alpha}},$$

β is the discount factor, and r_{it+1} is the real after-tax asset return from t to t+1.[15]

The Euler equation is estimated with data from the Panel Study of Income Dynamics (PSID), which contains data on housing in addition to the food consumption data used by many authors as a proxy for nondurable consumption.[16] That is, data on household food expenditure, defined as the sum of food expenditure at home and the value of food stamps (deflated by the CPI for food at home) plus food eaten out (deflated by the CPI for food away from home), was used to represent nondurable consumption, C_{it}. The after-tax real interest rate, r_{it}, is defined as:

(54) $$r_{it}=(1-\tau_{it})R_t-\pi_t$$

where R_{it} is the nominal interest rate on one-year Treasury bills, τ_{it} is the household's marginal tax rate, and π_{it} is the inflation rate as measured by the CPI.

The PSID provides data on the value of owner-occupied houses and annual rents paid by renters. However, as an argument of the utility function, the housing variable, H_{it}, reflects some measure of the physical *quantity* of housing consumed, rather than the *value* of housing consumed. In principle, one could start with the PSID data on the value of the house (as reported by the respondent)

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[15] Because of differences in marginal tax rates, r_{it+1} varies across households.

[16] Based on National Income and Product Accounts data for 1930-2002, the annual growth rate of total nondurable consumption expenditures and the growth rate of food consumption have a correlation coefficient of 0.9. Thus even though food consumption represents slightly less than half of total nondurable consumption expenditures, it seems to be a reasonable proxy for nondurable consumption.

and attempt to deflate the house value with an index of housing prices. In practice, there is substantial cross-sectional variation in housing prices within regions or cities, as well as across regions or cities. Since the region-wide price index provides only a crude approximation to the house price inflation within a particular neighborhood, deflating by the region-wide index would produce data that (inaccurately) indicates that even families who reside in the same physical house nevertheless are consuming different quantities of housing in different years. For this reason, we use a measure of housing consumption that is based on physical characteristics of the house, rather than attempting to deflate the reported house value by a price index. Of the many different metrics one could use to measure the quantity of housing, we start with the simplest quantity measure: square footage.[17]

While the PSID does not provide data on the square footage of homes, it does report, for both homeowners and renters, the number of rooms. To impute the square footage of the homes of PSID respondents, we first used data from the American Housing Survey (AHS) to estimate a model of square footage as a function of number of rooms and other housing variables common to both the AHS and the PSID. That is, AHS data was used to regress square footage on dummy variables representing whether the household was a) located in a suburb, b) located in a non-SMA region, c) a renter, d) living in a mobile home, and on a third order polynomial in the number of rooms. Separate models were estimated for each of the four regions (Northeast, Midwest, South, and West). The regional models estimated from the AHS data, reported in the data appendix, were then used to generate estimated square footage data for each PSID household.

[17] If the objective were to construct a measure of the quantity of housing at a single point in time, we recognize that the approach of deflating the house value by a regional price index would provide a better measure of real housing consumption because the house value will reflect many attributes other than square footage, such as location and construction materials. However, for this application, we are particularly interested in comparing the behavior of nondurable consumption across two periods in which housing consumption did not change against the behavior of nondurable consumption across two periods in which housing consumption did change. A simple physical measure of housing consumption like square footage has the important property that measured housing consumption is constant as long as the family stays in the same house.

Estimation was by GMM, for the 1975-1985 sample period.[18] To address the measurement error in C_{it} and H_{it}, as well as the expectation error in the Euler equation, the following instruments were used: the growth rate in real household income, the change in total annual hours worked by all family members, and the growth rate of housing square footage. The instruments were lagged two periods relative to the Euler equation; that is, the instruments reflected changes from t-2 to t-1 for the Euler equation linking marginal utility in t to t+1.

Table 2: Comparison of Housing, Habit Persistence, and Standard Models

	Unrestricted Form	Restricted Forms: Housing	Habit	Standard
Subjective discount factor (β)	0.98	0.98	0.98	0.98
Total number of observations	25,421	25,421	25,421	25,431
Parameters:				
Intratemporal Substitution (α)	-6.485	-6.668	1	1
	(1.751)	(1.689)		
Habit Formation (b)	0.007	0	0.009	0
	(0.006)		(0.007)	
Curvature (ρ)	1.846	1.799	7.520	7.778
	(0.267)	(0.244)	(2.804)	(2.301)
Weight on Housing (γ)	1.039	1.015	0	0
	(0.310)	(0.287)		
Implied EIS of C	0.133	0.131	0.132	0.129
Hypothesis Tests [p-values]:				
α=1	[0.00]	[0.00]		
ρ=1	[0.00]	[0.00]	[0.00]	[0.00]
α=1-ρ	[0.00]	[0.00]		
Overidentifying restrictions	[0.38]	[0.42]	[0.13]	[0.06]
LR Test Statistic		0.880	13.771	14.760
		[0.35]	[0.00]	[0.00]

Asymptotic standard errors are in parentheses. Probability values for hypothesis tests are in brackets. Sample period is 1975 to 1985. The EIS is calculated using the point estimates of the parameters and the 1974-87 sample averages of the variables. The subjective discount factor of .98 was imposed, not estimated.

[18] Because the food questions were not asked in 1973, or in 1988-89, the food data is only available for 1974-87. After allowing for required leads and lags, this left a sample period of 1975-85.

Table 2 reports parameter estimates for four versions of the model. The most general version (labeled “unrestricted”), allows for effects from both housing and habit persistence. In addition to restricted specifications for the housing model and the habit persistence model, Table 2 reports results for a restricted version of the model with neither housing nor habit persistence (labeled “standard”). For each version of the model, the elasticity of intertemporal substitution is calculated from the point estimates of the parameters and sample averages of the data. The various versions of the model all generate essentially the same value of the EIS of about .13, but differ in the mapping between the EIS and the underlying preference parameters. In the standard model, of course, a low EIS of .13 is interpreted as an implication of a fairly high value of the curvature parameter ($\rho = 7.8$). In the habit persistence model, the estimate of the parameter b, which reflects the importance of habit in the utility function, is indistinguishable from zero, both in terms of its magnitude (b=0.009), and in terms of statistical significance. Since the data do not attribute a quantitatively significant role to habit persistence, the estimate of the curvature parameter of 7.5 is essentially the same as in the standard model. In the specification for the housing model, the estimate of the intertemporal substitution parameter, α, is –6.7, and reasonably precisely estimated. The null hypothesis of perfect intratemporal substitutability between the two goods ($H_0 : \alpha = 1$) is rejected at high confidence levels. The estimate of the curvature parameter, ρ, is 1.8 . While the estimated value of the curvature parameter is only modestly greater than unity, it is sufficiently precisely estimated to reject the log specification of the utility function (i.e., the null hypothesis that $\rho = 1$). In the housing model, the reciprocal relationship between the EIS and the curvature parameter does not hold in general, but will hold in the special case that $\alpha = 1 - \rho$. However, the parameter restriction $\alpha = 1 - \rho$ is also rejected at high confidence levels. Further, the finding that the estimated value of α (-6.7) is smaller than the estimate of $1 - \rho$ (-0.8) attributes the low EIS of nondurable consumption to the substantially imperfect substitutability between the two goods, rather than to a high degree of curvature of the utility function with respect to the composite good.

The last two rows of Table 2 report the likelihood ratio test statistic, and the associated probability value, of each of the three restricted models against the general model. Both the standard model and the habit persistence model are decisively rejected, while the housing model survives with a probability value of only .35 .

Renters as well as homeowners incur a substantial transactions cost when adjusting their consumption of housing services. The adjustment costs for renters presumably are lower than for homeowners, since renters pay the pecuniary and nonpecuniary costs of moving but not the commissions and closing costs associated with real estate transactions. However, as long as nondurable consumption is costlessly adjustable, the Euler equation should hold for renters as well as homeowners despite likely differences between the two groups in terms of the magnitude of the adjustment cost and the frequency of moves.

The decision to own rather than rent will depend on the household's constraints (for example, on income, wealth, and the ability to borrow), on lifestyle and demographic considerations, and on preferences. Since the subset of the population which chooses to become homeowners may differ systematically from non-homeowners in terms their preferences over housing and nondurable consumption, we estimate a specification in which the preference parameters α, ρ, and γ are assumed to differ for renters as opposed to homeowners. The Euler equation for the housing model is:

$$(55) \qquad 1 = \beta E_t \left[(1 + r_{ij,t+1}) \left(\frac{C_{ij,t+1}}{C_{ij,t}} \right)^{\alpha_j - 1} \left(\frac{C_{ij,t+1}^{\alpha_j} + \gamma_j H_{ij,t+1}^{\alpha_j}}{C_{ij,t}^{\alpha_j} + \gamma_j H_{ij,t}^{\alpha_j}} \right)^{\frac{1-(\alpha_j+\rho_j)}{\alpha_j}} \right]$$

where i is the household index, and j indicates whether the household owns or rents. The preference parameters are assumed to be the same within the group (homeowners or renters), but differ across groups.

As reported in Table 3, the estimated value of γ, the weight on housing, is essentially the same for the two groups (1.023 for homeowners and 0.988 for renters). The estimates of the curvature parameter, ρ, are also very similar (1.795 for homeowners and 1.998 for renters). The point estimate of the intratemporal substitution parameter, α, is somewhat lower for homeowners (-7.383) for homeowners that for renters (-5.032). However, the likelihood ratio test of the joint restriction that the three preference parameters have common values across the two groups, reported at the bottom of Table 3, cannot be rejected.

Table 3: Housing model estimates: Homeowners vs. Renters

	Restricted Form	Unrestricted Forms Homeowners	Renters
Subjective discount factor (β)	0.98	0.98	0.98
Total number of observations	23,299	13,966	9,333
Average values (1974-87):			
C ($, per capita)	1,190	1,250	967
H (square feet)	1,499	1,624	1,178
Number of rooms	5.4	6.1	4.3
Estimated parameters:			
Intratemporal Substitution	-6.576	-7.383	-5.032
(α)	(1.768)	(2.069)	(1.341)
	1.701	1.795	1.998
Curvature (ρ)	(0.228)	(0.199)	(0.239)
	1.009	1.023	0.988
Weight on Housing (γ)	(0.278)	(0.256)	(0.231)
	0.132	0.120	0.153
Implied EIS of C			
Hypothesis Tests [p-values]:	[0.00]	[0.00]	[0.00]
α=1	[0.00]	[0.00]	[0.00]
ρ=1	[0.00]	[0.00]	[0.00]
α=1-ρ	[0.39]	[0.31]	
Overidentifying restrictions	4.111		
LR Test Statistic	[0.25]		

Notes: Asymptotic standard errors are in parentheses. Probability values for hypothesis tests are in brackets. Sample period is 1974 to 1986. The EIS is calculated using the point estimates of the parameters and the 1974-87 sample averages of the variables.

Whether we look at homeowners alone, renters alone, or the pooled sample of homeowners and renters, we can reject at very high levels of confidence the parameter restrictions which imply a) perfect substitutability between the two goods ($\alpha = 1$), b) the curvature of the utility function is consistent with the log specification ($\rho = 1$), and c) the reciprocal relationship between the EIS and the curvature parameter ($\alpha = 1 - \rho$).

Conclusions

Despite the quantitative importance of housing as a component of the household budget, and of the household portfolio, the dominant models in macro and in finance typically ignore housing entirely, and build their optimization problems on a utility function which takes as its argument a single, costlessly adjustable, nondurable good. This simplifying assumption, though drastic, would be reasonable if 1) abstracting from housing did not appreciably alter the implications of the model, and 2) the more plausible specification in which housing is treated as a separate good, imperfectly substitutable with nondurable consumption, were intractable. The paper provides a generalization of the important, but highly stylized, model of Grossman and Laroque (1990), and identifies the conditions under which the model remains tractable in a setting sufficiently general to incorporate variation in the price of housing relative to the nondurable good. The required assumption seems to be reasonably consistent with the data.

The housing model differs substantially from the standard model, but delivers many of the same implications as the habit persistence model, because the assumption that housing is subject to a nonconvex adjustment cost causes the current house to become one of the state variables which affect the household's optimal level of nondurable consumption and optimal portfolio allocation. While the housing model and the habit persistence model are both theoretically capable of explaining why nondurable consumption is "smooth", without invoking an implausibly large degree of risk aversion, empirical tests using household level data strongly favor the housing model.

Data Appendix

Food consumption data from the Survey Research Center (SRC) sample of the Panel Study of Income Dynamics (PSID) is used as a proxy for nondurable consumption. Since the food questions were not asked in the 1973, 1988, and 1989 waves, the sample period runs from 1974 to 1987. Observations were excluded from the sample if the household contained more than one family unit, if the household resided outside the US during the time of the interview, or if there was a change relative to the previous year in either the head or the spouse. Real food expenditures, C_{it} , represents the sum of 1) expenditures on food at home plus the value of food stamps, deflated by the CPI for food at home, and 2) expenditures on food eaten out, deflated by the CPI for food away from home. Since most of the PSID interviews are conducted between January and June, the CPI deflator for a given survey year is calculated as the average of the monthly values of the index for the first six months of the year. Observations were excluded if the data value fell in the top-coded range ("$9,999 or more" for either component), or if total household consumption was reported as zero. Total household food consumption was then converted to a per capita measure by dividing by the number of people in the family unit in order to control for changes in family composition.

The PSID provides data on the value of the home, as reported by the homeowner, the number or rooms (not counting bathrooms), and the annual rent paid by renters. Since the housing variable which appears as an argument of the utility function represents the physical quantity rather than the market value of the housing services consumed, we impute the square footage of the house of each PSID respondent using a model estimated from the American Housing Survey (AHS), which provides an extensive dataset on housing characteristics from 1975 through the present (annually prior to 1983 and biennially thereafter).

Table A1 reports the parameter estimates obtained from the 1993 AHS by regressing the house size in square feet on the following variables: dummy variables which indicate whether the house is located in a central city, suburb, or rural area (denoted "non-Metropolitan Statistical Areas"), dummy variables for rented homes and for mobile homes, and a third degree polynomial in the number of rooms. Separate models are estimated for four regions: North, Midwest, South and West. All of the explanatory variables used in the regressions are reported in the PSID as well as the AHS. Using the parameter estimates obtained from the AHS and the corresponding data on the explanatory variables form the PSID, we then impute the square footage of the house occupied by each PSID household, both renters and homeowners. Unlike the data on food consumption, the imputed house size is not converted to "per capita" terms by dividing by household size.

Table A1: Relationship between House Size and Housing Characteristics
Dependent variable: House size in square feet

	Northeast	Midwest	South	West
Dependent variable:				
House size in square feet				
Median	1700.000	1650.000	1386.000	1344.000
Mean	1831.580	1792.499	1574.084	1495.667
Standard Deviation	1038.022	923.669	829.836	793.820
Independent variables:				
Constant	455.937	644.271	1113.713	639.543
	(71.18)	(101.87)	(81.97)	(57.21)
Suburbs	81.051	63.775	68.910	21.794
	(23.48)	(18.42)	(12.46)	(12.86)
Non-MSA	153.706	14.452	37.151	30.938
	(33.70)	(20.29)	(14.67)	(19.86)
Renter	-405.376	-351.076	-236.472	-231.220
	(26.07)	(19.66)	(12.18)	(14.52)
Mobile Home	-638.203	-596.653	-356.816	-282.514
	(35.76)	(23.98)	(15.35)	(19.37)
# rooms	114.379	42.360	-170.826	-2.264
	(26.61)	(33.82)	(30.06)	(22.05)
$(\# \text{ rooms})^2$	10.151	16.933	35.299	17.928
	(3.18)	(3.65)	(3.45)	(2.70)
$(\# \text{ rooms})^3$	-0.427	-0.644	-1.033	-0.531
	(0.12)	(0.12)	(0.12)	(0.10)
Adjusted R^2	0.425	0.378	0.446	0.512
Log likelihood	-58282.33	-76536.98	-109678.80	-68869.75
AIC	16.176	16.020	15.691	15.475
SBIC	16.184	16.026	15.695	15.481
Number of Observations	7,207	9,556	13,981	8,902

Notes: Data is from the 1993 wave of the AHS. Standard errors, reported in parentheses, are estimated using White's heteroskedasticity consistent covariance matrix.

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