BORROWING COSTS AND THE DEMAND FOR EQUITY OVER THE LIFE CYCLE

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Abstract—We construct a life cycle model that delivers realistic behavior for both equity holdings and borrowing. The key model ingredient is a wedge between the cost of borrowing and the risk-free investment return. Borrowing can either raise or lower equity demand, depending on the cost of borrowing. A borrowing rate equal to the expected return on equity—which we show roughly matches the data—minimizes the demand for equity. Alternative models with no borrowing or limited borrowing at the risk-free rate cannot simultaneously fit empirical evidence on borrowing and equity holdings.

I. Introduction

BORROWING presents a problem for life cycle models of consumption and portfolio choice. In the classic Merton-Samuelson model, modified to include a realistic process for labor income, unsecured borrowing leads to huge, highly levered equity positions. For example, with relative risk aversion of 2 and standard specifications for income and asset returns, the model yields average equity holdings more than 20 times bigger than average annual income. To be sure, life-cycle models that preclude borrowing can generate realistic equity holdings, but they fly in the face of evidence that unsecured consumer credit is widely available and widely used. In fact, unsecured debt is much more prevalent than equity in the portfolios of younger households.

In this paper, we construct a life cycle model that resolves the tension between borrowing and equity holdings. Households can borrow in our setup—but at rates that exceed the risk-free investment return. Given realistic borrowing costs, the model yields both debt positions and equity holdings that fit the main features of the data.

Except for its treatment of borrowing, our preferred model is entirely standard. Agents have time-separable, isoelastic preferences with moderate risk aversion. They face realistic income processes and can invest in risky and risk-free assets. We do not rely on habit formation, self-control problems, myopia, or costs of participating and trading in equity markets to obtain sensible life cycle profiles for borrowing and equity holdings. Neither do we rely on informational barriers, time-varying asset returns or enforcement problems in loan markets. Instead, the key elements of our analysis are realistic borrowing costs and the life cycle structure. But, as we explain, realistic borrowing costs magnify the effect of certain other frictions—such as fixed costs of participating in equity markets or liquidity benefits from bondholdings—on participation rates and portfolio shares.

Table 1 reports data on the size of the wedge between borrowing costs and the risk-free return. The bottom two rows show that household borrowing costs on unsecured loans exceed the risk-free return by approximately 6 to 9 percentage points on an annual basis, after adjusting for tax considerations and charge-offs for uncollected loan obligations. Since 1987, roughly 2 percentage points has arisen from the asymmetric income tax treatment of household interest receipts and payments. However, the bulk of the wedge arises from transactions costs in the loan market. Despite the evident size of these costs, they have been largely ignored in theoretical analyses of life cycle consumption and portfolio behavior. They have also been ignored in most empirical studies of asset-pricing behavior.

The relationship between equity holdings and the cost of borrowing is nonmonotonic in our model. To see why, suppose initially that the borrowing rate equals the expected return on equity. No one borrows to buy equity in this case, because the net return is 0 and the investment would increase risk exposure. At a slightly lower borrowing rate, however, the net return is positive and the household adopts a small debt-financed equity position. Further reductions in the borrowing rate lead to greater leverage and further increases in equity demand. Now move in the other direction and consider a borrowing rate that slightly exceeds the equity return. In this case, households with debt hold no equity (because debt repayment offers a better return), so the borrowing rate has no immediate impact on their equity demand. But higher borrowing rates discourage borrowing for consumption-smoothing purposes. As a result, households borrow less at each age, achieve a positive financial position earlier in life, invest in equity at an earlier age, and hold more equity at later ages. Further increases in the borrowing rate imply a further upward shift in the life cycle equity profile, and sufficiently high borrowing costs choke off all borrowing. Hence, equity holdings and participation rates are minimized when the borrowing rate equals the expected return on equity—a scenario consistent with table 1.

We also develop several other points. First, our model implies high nonparticipation rates in equity markets, much higher than in otherwise identical models with no borrowing

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TABLE 1.—HOUSEHOLD BORROWING COSTS AND RISK-FREE RETURNS, SELECTED YEARS

	1972	1980	1984	1987	1990	1995	2001
(1) Average rate on two-year personal loans	12.5	15.5	16.5	14.2	15.5	13.9	13.2
(2) Average marginal tax subsidy on borrowing	.181	.247	.249	0	0	0	0
(3) After-tax borrowing cost (1 − row 2) × (row 1)	10.2	11.6	12.4	14.2	15.5	13.9	13.2
(4) Rate on three-year U.S. Treasury securities	5.7	11.5	11.9	7.7	8.3	6.3	4.1
(5) Average marginal tax rate on interest income	.313	.428	.330	.279	.250	.282	.297
(6) After-tax risk-free return (1 − row 5) × (row 4)	3.9	6.6	8.0	5.5	6.2	4.5	2.9
(7) Pretax wedge between borrowing cost and risk-free return (row 1 − row 4)	6.7	4.0	4.6	6.5	7.2	7.7	9.1
(8) After-tax wedge between borrowing cost and risk-free return (row 3 − row 6)	6.3	5.1	4.4	8.7	9.3	9.5	10.3
(9) Charge-off rate on loans, net of recoveries				0.8	1.0	0.7	1.3
(10) After-tax wedge net of charge-offs (row 8 − row 9)				7.9	8.2	8.8	9.1
(11) After-tax wedge net of charge-offs, credit cards				9.0	8.5	7.9	6.5

Sources: Rows (1) through (8) for 1972 to 1987 are reproduced from table 1 in Altig and Davis (1992). Data for later years as follows: Rows (1) and (4) are from various issues of the *Federal Reserve Bulletin* and the Federal Reserve's *Annual Statistical Digest.* Row (2) reflects the Tax Reform Act of 1986, which eliminated the tax deductibility of interest payments on nonmortgage loans. Row (5) is from table 1 in Poterba (2001), which is calculated from the NBER TAXSIM model. Poterba's 1999 value is used for the 2001 entry in row (5). Row (9) is from www.federalreserve.gov/releases/chargeoff/chg_all_sa.txt (visited April 3, 2002). Other rows are calculated by the authors as indicated. *Notes:* Borrowing costs, returns, and charge-offs are expressed as annual percentage rates. Row (9) reports the value of loans removed from the books and discharged against loan loss reserves net of recoveries as a percentage of loans outstanding. Rows (10) and (11) show the difference between the household cost of borrowing and the rate of return on risk-free investments after adjusting for tax considerations and the charge-off rate. Row (11) is calculated in the same manner as row (10), except that it makes use of interest-rate and charge-off data for credit cards instead of two-year personal loans.

and much closer to the data. Second, even a small wedge between borrowing rates and the risk-free return dramatically reduces the demand for equity. Third, greater income uncertainty raises equity demand in our model with realistic borrowing costs, contrary to its effect in the standard model with no wedge. Fourth, equity demand is a nonmonotonic function of relative risk aversion with realistic borrowing costs, again contrary to the standard model. Fifth, and not surprisingly in light of our previous remarks, equity demand is sensitive to the shape of the life-cycle income profile in our preferred model. Finally, we also consider a model with limited borrowing at the risk-free rate and show that it does a poor job of resolving the tension between borrowing and equity holdings. The limited-borrowing model implies that households borrow to finance equity holdings and always exhaust borrowing capacity. Both implications are sharply at odds with observed behavior.

We reiterate that our main goal is to construct a model that delivers realistic life-cycle behavior for both equity holdings and unsecured borrowing. We largely meet that goal, but gaps between theory and data remain. When fitted to the evidence on unsecured borrowing and the historical equity premium, equity holdings in our baseline specification are somewhat larger than in the data. And, like other life cycle models with no liquidity motive for bondholdings, our model does not generate realistic bond portfolio shares with moderately risk-averse investors.

The paper proceeds as follows. The rest of the introduction discusses related research and reviews some important facts about borrowing and equity holdings over the life cycle. Sections II and III describe the model and choice of parameters. Section IV considers life cycle behavior in our preferred model and alternatives, and section V compares model implications with empirical evidence. Where the models fail to fit the facts, we assess the significance of the failures. Section VI offers some concluding remarks, and an appendix describes our numerical solution method.

A. *Relationship to the Theoretical Literature*

The structure of our model departs modestly from the seminal work on life cycle portfolio behavior by Merton (1969) and Samuelson (1969). Indeed, our model differs from Samuelson's discrete-time setup in only three respects: the wedge between borrowing costs and risk-free returns, the presence of undiversifiable income shocks, and the use of realistic income profiles. The wedge and the undiversifiable shocks necessitate a computational approach to the analysis, which we pursue using the same methods as in Judd, Kubler, and Schmedders (2002). In our model, unlike Brennan (1971) or Heaton and Lucas (1997), higher borrowing costs raise the demand for equity in reasonable circumstances. The causal mechanism behind this result involves the impact of borrowing costs on precautionary savings and life cycle asset accumulation. More generally, life cycle factors play a central role in both equity market participation and equity accumulation behavior in our model.[1]

Bisin and Gottardi (1991) and Dubey, Geanakoplos, and Shubik (2003) consider models of adverse selection that endogenously generate differences in prices for buyers and sellers of financial assets. These models can deliver differential borrowing and lending rates, but they do not account for the wedge measured in the last two rows of table 1, which nets out uncollected loan obligations in order to highlight the cost of producing consumer credit. We take this cost as given and develop its implications for borrowing, equity demand, and participation behavior. Why the cost of producing consumer credit is so high is an interesting question that we leave for another occasion.

[1] Several recent studies analyze consumption and portfolio choice in life cycle and infinite-horizon models with hard borrowing limits. These studies are cited below or in the working paper version of this article. We recently became aware of a study by Cocco, Gomes, and Maenhout (forthcoming) that shares several elements of our analysis, including realistic borrowing costs.

TABLE 2.—UNSECURED DEBT, UNUSED CREDIT, STOCKS, AND HOUSING WEALTH BY AGE OF HOUSEHOLD HEAD, AS PERCENTAGE OF ANNUAL INCOME

	Unsecured Debt			Unused Credit			Equity Holdings (Stocks)			Stocks plus Home Equity		
Age Group	Median	90th %	Mean	Median	90th %	Mean	Median	90th %	Mean	Median	90th %	Mean
23–29	19	102	28	12	31	13	0	38	6	2	123	24
30–39	12	66	18	15	32	13	0	77	18	37	228	68
40–49	9	53	15	18	41	17	3	150	45	85	402	144
50–59	5	52	13	21	51	23	7	260	91	154	635	261
60–69	0	42	9	25	112	37	0	414	178	250	1,399	618
70–79	0	25	4	27	135	48	0	716	299	487	2,454	1,209

Notes:
1. Income is pretax household income from wages and salaries plus pretax retirement income. Retirement income includes annuities and benefits from social security, defined-benefit pensions, and disability programs. It does not include nonannuity income from assets in defined-contribution retirement plans.
2. Unsecured debt is the sum of credit card balances, installment loans, and other debt not secured by real estate, vehicles, or the like. Credit card balances are measured after the most recent payment.
3. Unused credit equals the difference between the household's credit limit on its existing credit cards and its actual credit card balance.
4. Equity is the sum of directly held stock and stock held through mutual funds, including investments held in defined-contribution retirement plans. Housing wealth is measured net of mortgage loans.
Source: Authors' calculations from the 1995 and 1998 Survey of Consumer Finances. After deleting households that report neither labor nor retirement income, the sample contains 7,830 observations. We compute all statistics using SCF sampling weights to correct for the oversampling of households with high net worth. We compute means using trimmed samples that exclude the top 5% of the ratio values.

In order to keep the focus on unsecured borrowing, our model omits ingredients that are probably important for a complete understanding of life cycle consumption and portfolio behavior. In particular, we omit housing consumption and borrowing secured by housing. Cocco forthcoming and Yao and Zhang (2005) argue that a realistic treatment of housing can bring life cycle models closer to the data. We also ignore the possibility that bonds provide important liquidity services, as argued by Bansal and Coleman (1996) and others.

B. *Facts about Borrowing and Equity over the Life Cycle*

Two well-documented sets of facts are relevant to an assessment of our model and alternatives. First, a large percentage of households hold little or no equity. Only 44% of households held stock in 1994, a big increase over the 28% figure for 1984 (Vissing-Jorgensen, 2002). Participation rates rise with age (Poterba & Samwick, 2001) and with education and income (Mankiw & Zeldes, 1991; Brav & Geczy, 1995), and self-employed persons are more likely to hold stock (Heaton and Lucas, 2000a). To a large degree, low equity market participation can be traced to the fact that many households have little or no financial wealth (Lusardi, Cossa, & Krupka, 2001). Among households that do own equity, most have modest holdings. Vissing-Jorgensen reports that the median level of equity holdings for stockholding households is approximately 21 thousand dollars, and the mean is 95 thousand dollars. Ameriks and Zeldes (2001) find that the level of stockholding rises with education, income, and age.

Second, unsecured consumer credit is widely available and widely used. Durkin (2000, table 1) reports that 74% of all American families had at least one credit card in 1995, and 44% of all families had a positive balance after the most recent payment. Despite the high borrowing costs documented in table 1, many households, especially younger ones, take on substantial unsecured debt. Table 2 provides evidence on this point, showing that many households adopt large debt positions (relative to annual income), and that debt-income ratios decline with age.

Table 2 also reports unused credit as a percentage of annual income. The reported measure is a lower bound, because it does not allow for the ability to acquire extra credit cards, raise the credit line on existing cards, or obtain other forms of personal credit. Most households have unused borrowing capacity, and middle-aged and older households in particular have considerable unused borrowing capacity. This pattern fits with much previous research that finds a declining incidence of binding borrowing constraints with age (for example, Jappelli, 1990, and Duca & Rosenthal, 1993). For a detailed description of life cycle and cross-sectional variation in household financial positions based on the 1998 SCF, see Kennickell Starr-McCluer, and Surette (2000).

II. The Model

We consider an optimizing model of household consumption and portfolio choice. The household life cycle consists of two phases, work and retirement, which differ with respect to the character of labor income. During the working years, log labor income ($\tilde{y}_t$) evolves as the sum of a deterministic component (d_t), a random-walk component ($\tilde{\eta}_t$), and an uncorrelated transitory shock ($\tilde{\varepsilon}_t$):

$$\tilde{y}_t = d_t + \tilde{\eta}_t + \tilde{\varepsilon}_t. \quad (1)$$

This type of income process is widely used in life cycle studies of consumption and asset accumulation.

During the retirement years, a household receives a fraction of its income in the last year of work. Ideally, we would specify retirement income as some fraction of, say, the highest n years of labor income—consistent with social security and most defined-benefit pension plans. However, such a structure is computationally burdensome, because it increases the dimensionality of the state space. As a computationally easier alternative, we first calculate the ratio of the average value of d_t in the highest n working years to the value of d in the last year of work. We then multiply this ratio by realized income in the last year of work to get the retirement basis. Finally, to get retirement income, we

TABLE 3.—PARAMETER SETTINGS

Parameter	Baseline	Alternative Values
Relative risk aversion	2	0.5 to 9
Annual discount factor	0.933	0.914 to 0.982
Age of labor force entry	21	
Age of retirement	65	
Age of death	80	
std($\Delta\tilde{\eta}$) (permanent shock)	12%	0, 15%
cov ($\Delta\tilde{\eta}$, $\tilde{r}_E$)	0	
std($\tilde{\varepsilon}$) (transitory shock)	15%	0, 21%
cov ($\tilde{\varepsilon}$, $\tilde{r}_E$)	0	
Replacement rate	80%	20%, 100%
n (for retirement basis)	30	
r_L (risk-free return)	2%	
r_B (borrowing rate)	8%	2%, 5%, 6%–20%
E($\tilde{r}_E$) (equity return)	8%	6%
std($\tilde{r}_E$)	15%	
Borrowing limit	None	0, 1 times annual income

multiply the retirement basis by a number between 0 and 1 called the replacement rate.

Households can trade three financial assets. They can buy equity with stochastic net return $\tilde{r}_E$, save at a net risk-free rate r_L, and borrow at the rate $r_B \geq r_L$. Households cannot take short positions in equity, nor can they borrow negative amounts. Households cannot die in debt, which implies that net indebtedness cannot exceed the present value of the household's lowest possible future income stream discounted at r_B. This debt limit is the only constraint on borrowing in our preferred model, but we also consider models that limit borrowing to a quantity BL times annual income.

A household chooses a contingency plan for consumption, borrowings, and asset holdings at date t to maximize

$$U(c_t) + \mathrm{E}_t \sum_{\alpha=t+1}^{T} \beta^{\alpha-t} U(\tilde{c}_\alpha) \tag{2}$$

subject to a sequence of budget constraints and possibly a borrowing limit BL, where c_α is consumption at age α, E_t is the expectations operator conditional on time-t information, β is a time discount factor, and U(·) is an isoelastic utility function.

III. Parameter Settings and Discretization

Tables 3 summarizes our parameter settings. We set the coefficient of relative risk aversion to 2 in our baseline specification and consider other values ranging from 0.5 to 9. Following Campbell (1999), we set the annual risk-free investment return to 2%, the expected return on equity to 8%, and the standard deviation of equity returns to 15%. We set the correlation of equity returns and labor income shocks to 0.[2] In line with table 1, we set the baseline borrowing rate to 8%, but we also consider a wide range of other values. According to table 2, more than 10% of households under 30 borrow in excess of their annual income, and many other households could borrow similarly large amounts. In this light, we set $BL = 1$ in the model with limited borrowing at the risk-free rate. For the model with no borrowing, $BL = 0$.

For the life cycle income process, we adopt parameter values estimated by Gourinchas and Parker (GP) (2002) from the Consumer Expenditure Survey (CEX) and the Panel Study of Income Dynamics (PSID).[3] The GP income measure is "after-tax family income less social security tax payments, pension contributions, after-tax asset and interest income" in 1987 dollars. GP also subtract "education, medical care and mortgage interest payments" from their measure of income, because "these categories of expenditure do not provide current utility but rather are either illiquid investments or negative income shocks." (Without these deductions, household income would be approximately 27% higher.) They restrict their sample to male-headed households and attribute the head's age to the entire household.

To estimate the deterministic component of income, GP fit a fifth-order polynomial in the head's age to CEX data on log family income. To estimate the standard deviation of transitory and permanent income shocks, they use the longitudinal aspect of the PSID. Because the income measures reported in household surveys contain much measurement error, the raw variance estimates substantially overstate income uncertainty. To adjust for this overstatement, we adopt GP's suggestion to reduce the estimated variance of the transitory shock by one-half and the variance of the permanent shock by one-third. The baseline specification in table 3 reports the standard deviations of the income shocks after adjusting for measurement error.

The resulting expected income profile reflects three elements of the GP income processes: (i) the profile of the deterministic component; (ii) the variance of the transitory shock to log income, which affects the level of expected income; and (iii) the variance of the permanent shock, which affects the level and slope of expected income. In the analysis below, we sometimes alter the variances of the income shocks in order to explore how income uncertainty affects equity demand and other outcomes. When we adjust the income process in this way, we also adjust the deterministic income path d_t to preserve the expected income profile.

We select the subjective time discount factor β so that the predicted life cycle borrowing profile matches the profile in table 2 as closely as possible. Specifically, given a

[2] Davis and Willen (2000) present evidence of nonzero correlations between labor income shocks and equity returns, and they consider the implications for life cycle portfolio choice. Haliassos and Michaelides (2003) also study the effect of a nonzero correlation on portfolio choice. Both studies find that correlation values in line with the evidence have modest effects on portfolio choice.

[3] Gourinchas and Parker estimate a life cycle income process for five education groups and for their full sample, which pools over education groups. To focus on essentials, we restrict attention to their pooled-sample income process. Earlier drafts of this paper report results by education group.

TABLE 4.—CALIBRATION OF SUBJECTIVE TIME DISCOUNT FACTOR TO THE DEBT-INCOME PROFILE

Row	β	std(Δη̃)	std(ε̃)		Means, Percent of Annual Income							Av. Abs. Dev. from Data
					23–29	30–39	40–49	50–59	60–69	70–79	23–79	
Data				Debt	28	18	15	13	9	4	15	
				Equity	6	18	45	91	178	299	68	
1	0.933	12	15	Debt	28	20	3	0	0	0	9	7.0
				Equity	3	14	68	187	330	234	128	53.5
2	0.914	15	21	Debt	30	25	7	1	0	2	11	6.8
				Equity	7	18	57	140	201	102	84	38.6
3	0.967	0	0	Debt	33	19	0	0	0	0	9	7.9
				Equity	0	2	83	254	479	404	184	99.0
4	0.912	15	0	Debt	25	19	0	0	0	0	8	7.7
				Equity	0	1	36	115	165	78	62	39.0
5	0.972	0	21	Debt	31	18	2	0	0	0	9	7.1
				Equity	10	41	148	344	607	505	253	160.1

Notes:
1. Debt-income and equity-income ratios in the data row are computed from the Survey of Consumer Finances as described in table 2. The average ratios for ages 23–79 are computed using SCF sample weights.
2. For model specifications 1 through 5, the reported time discount factor β minimizes the mean absolute deviation between the debt-income ratio in the model and the debt-income ratio in the data. The average is taken over the indicated age groups with weights proportional to the 1990 U.S. age distribution, as reported in table 1 of Bureau of the Census (1994).
3. std($\Delta\tilde{\eta}$) and std($\tilde{\varepsilon}$) denote standard deviations of the permanent and transitory income shocks, respectively. The remaining parameters are set to the baseline values reported in table 3.
4. The rightmost column reports the mean absolute deviation between the model and data for the debt-income and equity-income ratios.

specification of the income process for our preferred model, we choose β to minimize the average absolute deviation between the mean debt-income ratio in the model and the mean debt-income ratio in table 2. In computing the average deviation, we weight each age group in proportion to its 1990 U.S. population share. Row 1 of table 4 shows that a discount factor of 0.933 minimizes the average absolute deviation for our baseline income process. Row 2 carries out the same exercise for the GP income process with no adjustment for measurement error. The greater income uncertainty in row 2 raises precautionary saving and lowers borrowing, so that a lower discount factor of 0.914 is needed to match the borrowing profile. Rows 3–5 report the best-fitting discount factors when we turn off one or both income shocks. Overall, the model does a reasonable job of matching the data for each income process. The principal failure relates to borrowing later in the life cycle. We discuss the fit between the model and the data more extensively in section V.

Our model has three sources of randomness: a permanent labor income shock, a transitory income shock, and an asset return shock. We discretize the state space by the method of Tauchen and Hussey (1991), using two points for the permanent shock, two points for the transitory shock, and three points for the asset return shock.[4]

[4] There is no state of nature with zero income in our discretization. In reality, social safety nets effectively bound income above 0, which argues for a specification with no zero-income state. One might still ask, however, whether our results rely on an overly coarse income grid with a high income floor. To investigate this issue, we experimented with three rather than two grid points for each income shock. It turns out that a finer grid has little impact on model fit; an extra grid point, for the permanent shock actually improves the model's fit to the life cycle profile of equity holdings.

IV. The Demand for Equity over the Life Cycle

In this section, we explore how equity holdings and other outcomes are affected by four aspects of the household decision problem: (1) the borrowing regime, (2) the shape of the income profile, (3) risk aversion, and (4) undiversifiable income shocks. We also discuss the behavior of bond-holdings. Before proceeding, we define some useful terminology.

Borrowing capacity is the present value of future labor income (including retirement income), when discounted at the borrowing rate, along the lowest possible future income path.[5] The *equity premium* is the difference between the expected return on equity and the risk-free investment return. The *leverage premium* is the difference between the expected equity return and the borrowing rate. When the cost of borrowing exceeds the risk-free investment return, the equity premium exceeds the leverage premium. Hence, the net return on equity depends on the source of funds invested, as depicted in the following table:

Source of Funds	Opportunity Cost	Net Equity Return
Financial wealth	Risk-free return	Equity premium
Borrowing capacity	Borrowing rate	Leverage premium

A. *Effect of the Borrowing Rate and Borrowing Regime*

How does the borrowing rate affect the demand for equity over the life cycle? First, a higher borrowing cost lowers borrowing capacity by reducing the present value of labor income. Second, a higher borrowing rate lowers the

[5] Strictly speaking, the present value of future labor income is a lower bound on true borrowing capacity, which varies with equity holdings. Our numerical solution procedure uses the period-by-period budget constraints, but the concept of borrowing capacity is a useful aid to intuition.

leverage premium. And third, the borrowing rate affects the evolution of wealth over the life cycle. A low borrowing rate depresses financial wealth by encouraging greater borrowing for consumption smoothing purposes and by substituting for precautionary wealth holdings that households would otherwise accumulate to smooth transitory income shocks. But a low borrowing rate can also increase wealth: if the leverage premium is positive, borrowing to invest in equity enables the household to increase wealth over time.

As these remarks suggest, the relation between the cost of borrowing and the demand for equity is nonmonotonic. To illustrate this point, figure 1 shows life cycle equity holdings (averaged over many draws) in our baseline specification with alternative borrowing rates. When the borrowing rate equals the risk-free return of 2%, households invest enormous amounts in equity throughout the life cycle, a result that is insensitive to the shape of the income profile. Thus, the standard model with $r_B = r_L$ implies equity holdings that dwarf what we see in the data.

A borrowing rate of 5% yields much lower equity holdings throughout the life cycle. Why? An increase in the borrowing rate from 2% to 5% implies a reduction in the leverage premium from 6% to 3% and a decline in borrowing capacity. The effect on a very young household is easily understood: because it has no financial wealth, a smaller leverage premium and lower borrowing capacity mean lower equity demand. Less obviously, the disparity in equity holdings persists into retirement. Two forces are at work. First, households with a nonzero replacement rate still have borrowing capacity in retirement. Indeed, households with a positive leverage premium continue to borrow until the year before death. So even in retirement, the size of the leverage premium affects equity demand. Second, a higher leverage premium earlier in life leads, in expectation, to higher wealth accumulation by retirement. A household with a 2% borrowing rate has much greater wealth at retirement than a household with a 5% borrowing rate.

Equity demand behaves differently when the leverage premium is negative. Figure 2 shows that average equity demand *rises* with borrowing costs when the borrowing rate

Figure 1.—Mean Life Cycle Equity Holdings at Various Borrowing Rates: Baseline Parameter Settings

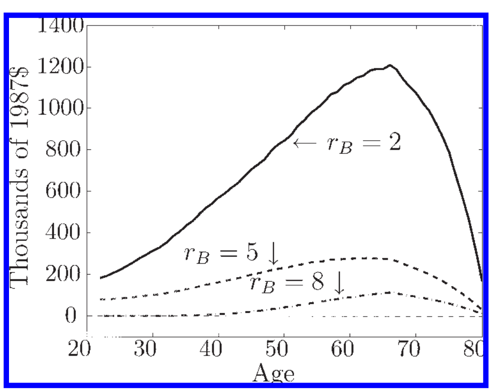
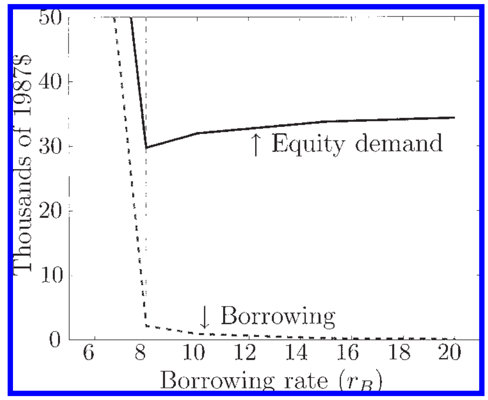


Figure 2.—Average Equity Demand and Borrowing as a Function of the Borrowing Rate: Baseline Parameter Settings



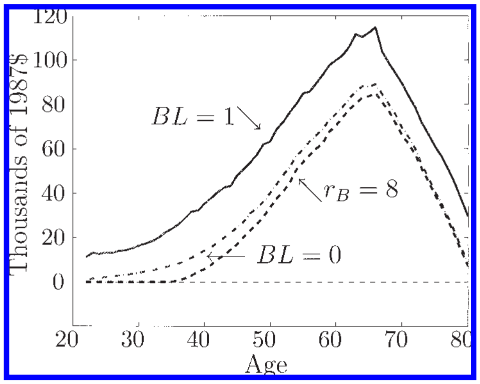
exceeds the return on equity.[6] This result can be understood as follows. When the leverage premium is negative, no household draws on borrowing capacity to buy equity, so that equity demand depends on the level of financial wealth and the share invested in equity. Higher borrowing rates then increase wealth accumulation in two ways. First, they discourage life cycle consumption smoothing through the loan market, so that households begin accumulating wealth at younger ages. Second, they inhibit reliance on borrowing to smooth transitory income shocks, leading to greater precautionary saving. The first effect involves the shape of the life cycle expected income profile, and it operates whether or not income is uncertain. The second effect arises from transitory income shocks.

Figure 3 compares the life-cycle pattern of median equity holding in our preferred model assuming $r_B = 8\%$ with alternative models assuming no borrowing ($BL = 0$) or limited borrowing at the risk-free rate ($BL = 1$). Both alternatives imply higher equity holdings throughout the life cycle. The no-borrowing model can be seen as a special case of our preferred model with r_B high enough to choke off all borrowing. Because a borrowing rate equal to the return on equity minimizes the demand for equity, shutting off all borrowing raises equity holdings. The model with limited borrowing at the risk-free rate yields even larger equity holdings, because households adopt a levered equity position and exhaust borrowing capacity throughout the life cycle. By exploiting the leverage premium households accumulate wealth more rapidly, and they invest part or all of this wealth in equity.

The model with realistic borrowing costs also implies much higher nonparticipation rates in equity markets than the alternative models, as seen in figure 4. In our preferred model with the baseline specification, participation rates are around 25% in the first decade of adulthood, and they rise steadily with age to reach 100% by age 50. It is worth

[6] In constructing average equity demand from simulated model outcomes, we use population weights for age groups from Bureau of the Census (1994, table 1).

FIGURE 3.—MEDIAN EQUITY HOLDINGS OVER THE LIFE CYCLE UNDER ALTERNATIVE BORROWING REGIMES: BASELINE PARAMETER SETTINGS

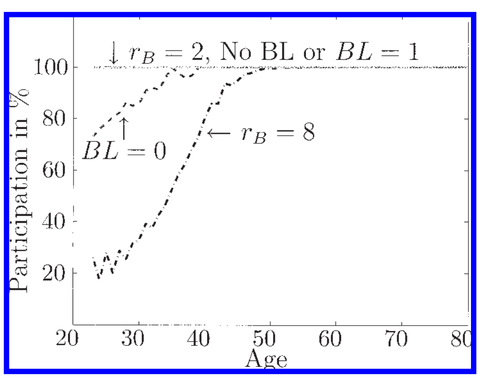


stressing that this life cycle participation pattern and the high rates of nonparticipation do not rest on any friction in the equity market itself. Participation costs, diversification costs, trading costs, and other frictions in the equity market would further reduce participation rates, a point we return to in section V.

At a borrowing rate of 8%, the median household does not participate in equity markets until age 36 (figure 3). Higher borrowing costs raise participation rates at all ages. When the interest rate is sufficiently high to eliminate borrowing, the median household holds equity at all ages (figure 3). When faced with a positive leverage premium—as in the model with limited borrowing at the risk-free rate—every household holds equity at all ages.

To sum up, we emphasize three points. First, even a modest wedge between borrowing and lending rates sharply reduces the demand for equity. Second, a borrowing rate equal to the return on equity minimizes the demand for equity. This result is particularly noteworthy in that the borrowing rates reported in table 1 lie near estimates of the expected return on equity. Third, households often hold no equity in the model with realistic borrowing costs—in contrast to models with lower borrowing rates, in which households always hold equity.

FIGURE 4.—EQUITY PARTICIPATION RATES OVER THE LIFE CYCLE UNDER ALTERNATIVE BORROWING REGIMES



B. Effect of the Expected Labor Income Profile

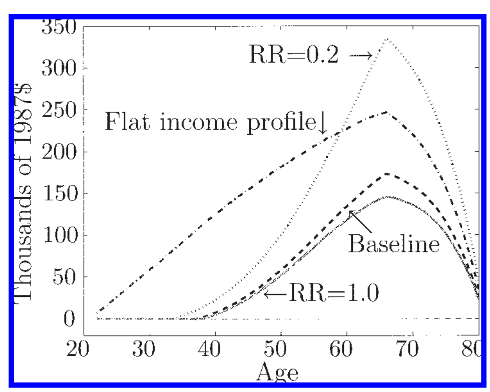
How does the shape of the expected income profile affect the demand for equity? The answer hinges on the cost of borrowing. When $r_B = r_L$, the shape of the income profile has little effect on equity demand with uncertain labor income and no effect with certain labor income. In contrast, when $r_B \geq E(\tilde{r}_E)$, the demand for equity is highly sensitive to the shape of the income profile. The explanation for this sensitivity is straightforward: households borrow only for consumption-smoothing purposes when $r_B \geq E(\tilde{r}_E)$, so they hold no equity until they attain positive financial wealth. The age at which this occurs depends on the shape of the income profile. The profile shape also affects equity demand in the intermediate case with $r_B \in (r_L, E(\tilde{r}_E))$, but the effect is stronger when $r_B \geq E(\tilde{r}_E)$.

To illustrate the effect of the profile shape, consider the case with $r_B = E(\tilde{r}_E)$ and no labor income risk. Figure 5 compares life cycle equity demand in our baseline case, assuming an 80% income replacement rate during retirement with three alternatives: a 20% replacement rate, a 100% replacement rate, and a flat profile with income set to the simple mean of labor income during the working years. The household with a flat profile invests in equity throughout life. Early investment, compounded by the high return on equity, means that the household with a flat profile accumulates large wealth and equity positions before the baseline household even begins to invest. A lower replacement rate leads to higher saving, earlier participation in equity markets, and greater equity holdings at each age.

C. Effect of Undiversifiable Labor Income Risk

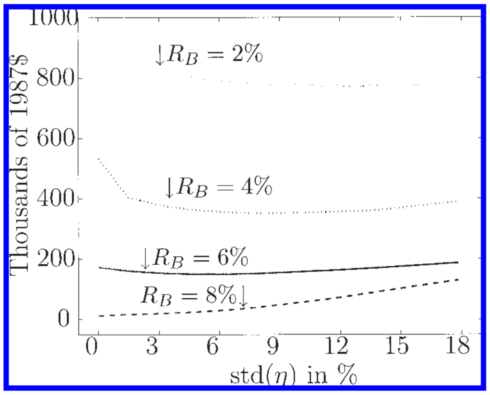
How does undiversifiable income risk affect the demand for equity over the life cycle? First, greater income risk makes households with proper preferences effectively more risk-averse, which reduces equity demand at given levels of financial wealth and borrowing capacity. Second, greater income risk intensifies the precautionary saving motive, which encourages wealth accumulation for consumption-

FIGURE 5.—LIFE CYCLE EQUITY HOLDINGS FOR ALTERNATIVE INCOME PROFILES



β = 0.972, and no labor income risk, as in specification 3 of table 4.

FIGURE 6.—AVERAGE EQUITY DEMAND AND THE VARIABILITY OF PERMANENT INCOME SHOCKS AT VARIOUS BORROWING COSTS



Baseline parameter settings except β = 0.95.

smoothing purposes. These two effects work in opposite directions.

The first effect dominates when $r_B = r_L$, so that greater income uncertainty lowers equity holdings. The second effect dominates when $r_B = \mathrm{E}(\tilde{r}_E)$. This case differs from the $r_B = r_L$ case for two reasons. First, when $r_B = \mathrm{E}(\tilde{r}_E)$, younger households hold (little or) no equity. Hence, they cannot offload (much) risk by reducing equity holdings, and the first effect vanishes. Second, it is more costly to rely on borrowing to smooth consumption at a high interest rate, so the precautionary motive for asset accumulation becomes stronger. As a result, income uncertainty increases equity demand when $r_B = \mathrm{E}(\tilde{r}_E)$. In the intermediate case with $r_B \in (r_L, \mathrm{E}(\tilde{r}_E))$, the relation between equity holdings and uncertainty is nonmonotonic, as seen in figure 6.[7] In unreported results, we verify that the relationships between income uncertainty and equity holdings shown in figure 6 also hold for lower (*RRA* = 0.5) and higher (*RRA* = 5) values of the relative risk aversion.

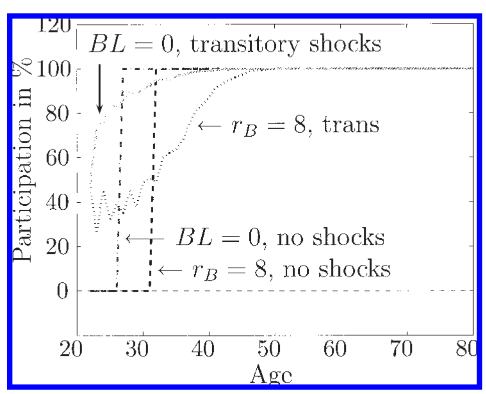
To better understand the effects of labor income risk, consider the distinct effects of permanent and transitory shocks on equity market participation rates in our preferred model (r_B = 8) and the no-borrowing model (*BL* = 0). Bigger permanent shocks raise precautionary saving and equity holdings in both models. In line with this observation, (unreported) simulations show that a bigger permanent-shock variance leads to higher participation rates in both models. In contrast, transitory income shocks push outcomes away from 0% and 100% participation. By encouraging precautionary savings, transitory shocks lead to greater equity holdings and higher participation rates. But a sufficiently bad transitory shock (or shock sequence) causes a household to draw down its financial assets and exit the equity market. Thus, transitory shocks create a motive to hold equity when the household would otherwise hold none, but they also give rise to circumstances in which some households exhaust asset holdings and turn to borrowing. Figure 7 illustrates these effects of transitory income shocks. Relative to a specification with no income risk, transitory shocks raise participation rates at younger ages and lower them at older ages in both models.

D. *Effect of Risk Aversion*

Greater risk aversion lowers a household's appetite for risk, and its demand for equity, at a given level of financial wealth. But risk aversion also has a powerful effect on wealth evolution over the life cycle. Higher risk aversion means higher precautionary savings, which raises wealth. Higher risk aversion also means a lower elasticity of substitution under our preference specification, which leads to more borrowing and less wealth accumulation with a rising income profile. As these remarks suggest, stronger risk aversion can mean higher or lower equity demand, and the effects vary significantly with age and income risk. When the borrowing rate equals the risk-free return, higher risk aversion leads to lower equity holdings throughout the life cycle. With realistic borrowing costs, the story is more complicated.

Figure 8 shows average equity demand as a function of risk aversion in the model with realistic borrowing costs. Absent income risk, higher risk aversion lowers equity demand as in the standard model with equal borrowing and lending rates. But consider specification 2 in table 4, which uses the unadjusted income variances from Gourinchas and Parker (2002) and a low discount factor. In this example, households are highly impatient and inclined to borrow, but higher risk aversion intensifies the precautionary demand for wealth accumulation. As a result, equity demand rises with risk aversion, until risk aversion is strong enough to

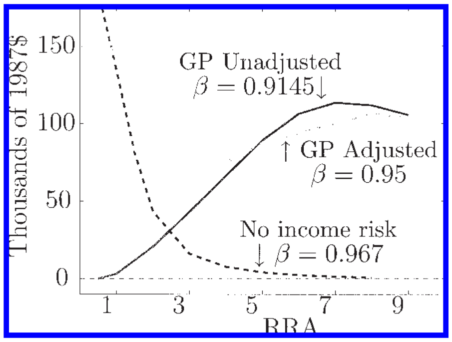
FIGURE 7.—PARTICIPATION WITH AND WITHOUT TRANSITORY INCOME RISK



Baseline setting with no permanent shocks and β = 0.972.

[7] Empirical evidence is mixed on the connection between income uncertainty and the demand for risky financial assets. Guiso, Jappelli, and Terlizessi (1996) find a small, positive relationship between income uncertainty and risky asset shares among Italian households, but Alan (2004) finds little support for a positive relationship in Canadian data. Hochguertel (2003) finds a small positive effect of income uncertainty on risky asset demand in Dutch data, but the effect diminishes or disappears when he allows for unobserved heterogeneity among households. In French data, Arrondel and Masson (2003) find that higher income risk leads to greater holdings of risky financial assets.

FIGURE 8.—AVERAGE EQUITY DEMAND AS A FUNCTION OF RELATIVE RISK AVERSION



Baseline parameter settings except where noted.

yield a portfolio dominated by bonds. Figure 8 also shows that equity demand is a nonmonotonic function of the risk aversion parameter for our baseline income process. For relative risk aversion below 2 and above 8, equity demand falls with risk aversion, as predicted by simpler models with $r_B = r_L$ or certain labor income. For relative risk aversion between 2 and 8, equity demand rises with risk aversion. Relative risk aversion near 2 or 3 imply values for equity demand near the (local) minimum.

The effects of risk aversion on participation are similarly ambiguous. Participation rates in our baseline specification are high for very low levels of risk aversion ($RRA < 1$) and for high levels ($RRA > 4$), but they are considerably lower for intermediate levels ($1 \leq RRA \leq 4$). The explanation for the nonmonotonic relationship between participation and risk aversion parallels the explanation given for the nonmonotonicity in the level of equity holdings. Gomes and Michaelides (2005) obtain a similar result about the effect of risk aversion on participation in a life cycle model with no borrowing, Epstein-Zin preferences, a one-time cost of entry into equity markets, and two risky assets.

E. *Bondholdings*

Given our baseline specification with low risk aversion, households rarely hold bonds in any of the models or borrowing regimes we consider. In this respect, our findings are consistent with previous work in the area by Heaton and Lucas (1997, 2000b), Viciera (2001), Gomes and Michaelides (2005), and Haliassos and Michaelides (2003).

Bodie, Merton, and Samuelson (1992) explain the intuition for low bond shares when labor income shocks are uncorrelated with equity returns. The standard Merton-Samuelson model tells us that a household should invest a fixed fraction of total wealth in risky assets. Total wealth is composed of human wealth and financial wealth. If human wealth is uncorrelated with the risky asset, then it counts toward the bond part of total wealth. The more human wealth a household has, the greater its effective bond position, and the larger the fraction of financial wealth allocated to the risky asset. In our baseline specification, the fraction of human wealth in total wealth almost always exceeds the target fraction of bonds in total wealth. Thus, when possible, households reduce their bond position by borrowing (provided that the borrowing rate is less than the equity return).

In table 5, panel A shows that households invest exclusively in equities in the baseline parameter specification. When households cannot borrow at the risk-free rate, they invest nothing in bonds, and equity holdings equal financial wealth. When they can borrow at the risk-free rate, they typically do so in order to adopt a levered equity position, so that equity holdings exceed net financial wealth.

TABLE 5.—EQUITY AND BOND HOLDINGS OVER THE LIFE CYCLE IN THE DATA AND FOUR MODELS

	Equity Holdings as a Percentage of Gross and Net Financial Wealth									
			Model							
							r_B = 2%			
	Data		r_B = 8%		No Borrowing		BL = 1		No BL	
Age Group	GFW	NFW	GFW	NFW	GFW	NFW	GFW	NFW	GFW	NFW
				A. Baseline—RRA = 2, RR = 80%						
23–39	35	75	100	−58	100	100	100	−1,262	100	636
40–59	45	50	100	101	100	100	100	166	100	232
60–79	31	31	100	100	100	100	100	128	100	168
23–79	28	29	100	107	100	100	100	166	100	227
				B. Alternative—RRA = 6, RR = 20%						
23–39	35	75	100	100	100	100	100	164	100	241
40–59	45	50	87	87	87	87	82	88	81	89
60–79	31	31	50	50	50	50	45	45	48	48
23–79	28	29	59	59	59	59	60	63	63	69

Notes:
1. Gross financial wealth (GFW) is equity plus bonds. Net financial wealth (NFW) is equity plus bonds minus debt. Entries report total equity of households in the group divided by total wealth of the same households. A negative entry under NFW means that net financial wealth is negative, and an entry that exceeds 100% means that the average household has a levered equity position.
2. Bondholdings as a percentage of GFW equal 100 minus the reported figure for equity holdings.
3. Parameters are set to the baseline values reported in table 3 unless otherwise noted. Averages over 23–79 computed using 1990 Census population weights as described in table 4.

TABLE 6.—DEBT, EQUITY, AND EQUITY MARKET PARTICIPATION OVER THE LIFE CYCLE

				Model											
										r_B = 2					
	Data			r_B = 8			No Borrowing			Borrowing Limit = 1			No Borr. Limit		
Age Group	Debt	Equity	Ptcp	Debt	Equity	Ptcp	Debt	Equity	Ptcp	Debt	Equity	Ptcp	Debt	Equity	Ptcp
23–29	28	6	41	28	3	25	0	15	80	100	77	100	1,212	1,254	100
30–39	18	18	51	20	14	51	0	36	95	100	110	100	1,394	1,694	100
40–49	15	45	56	3	68	93	0	93	100	100	182	100	1,561	2,204	100
50–59	13	91	57	0	187	100	0	205	100	100	299	100	1,723	2,820	100
60–69	9	178	41	0	330	100	0	345	100	100	451	100	1,888	3,679	100
70–79	4	299	34	0	234	100	0	243	100	100	352	100	1,196	2,867	100
23–79	15	68	49	9	128	77	0	146	96	100	234	100	1,506	2,364	100
Average absolute deviation from data:				7	54	34	15	67	48	85	141	52	1,491	2,271	52

Notes:
1. Debt-income and equity-income ratios are expressed as percentages of annual income. "Ptcp" is the percentage of households with positive equity holdings.
2. In the data columns, we compute averages using SCF sample weights. For the models, we compute averages using 1990 population weights as described in table 4. We also computed the average absolute deviations between the models and the data, using 1990 population weights.
3. All parameters are set to baseline values in table 3 unless otherwise noted.

We can generate positive bondholdings in any of the models by increasing the risk aversion parameter. Lower income replacement rates in retirement also increase the propensity to hold bonds. Panel B in table 5 provides an illustration by altering these two parameters in the baseline specification. First, we set risk aversion to 6 (compared with 2 in the baseline specification), increasing the desired fraction of total wealth invested in bonds. Second, we lower the replacement rate from 0.8 to 0.2, reducing the value of human wealth. The portfolio share invested in bonds rises with age to offset the life cycle decline in human wealth.

V. Comparing the Models with the Data

In this section, we assess four models in relation to evidence on borrowing, equity holdings, and equity participation rates over the life cycle. The four models are the standard one with unlimited borrowing at the risk-free rate, a model with limited borrowing at the risk-free rate ($BL = 1$), a model with no borrowing ($BL = 0$), and our preferred model with realistic borrowing costs ($r_B = 8\%$). Our preferred model outperforms the other models in two respects. First, it is the only one that can simultaneously deliver realistic life cycle profiles for borrowing and equity holdings. Second, the welfare costs of the gap between theoretical predictions and evidence are smallest for our preferred model. We conclude this section with a brief discussion of how margin loans would affect our analysis.

A. *Realistic Borrowing and Equity Demand*

Table 6 shows debt positions, equity holdings, and participation rates over the life cycle for the four models and in the SCF data. The model with unlimited borrowing at the risk-free rate ($r_B = 2\%$) produces equity holdings and borrowings that are an order of magnitude greater than in the data. This model cannot be made to fit the data by assuming greater patience or lower income risk, because households will continue to lever up in the equity market. Nor can reasonable levels of risk aversion fit the data. Even with relative risk aversion of 5, for example, the model predicts borrowing 20 times greater than in the data and equity holding 10 times greater.

The limited-borrowing model ($r_B = 2\%$, $BL = 1$) produces outcomes closer to the data, but it also fails in several respects. First, it implies much more borrowing than seen in the data. As before, greater patience does not help, because patient households still exploit the equity premium. In fact, willingness to postpone consumption frees up borrowing capacity for investment purposes and leads to even bigger equity holdings. Second, the limited-borrowing model cannot replicate the life cycle profile of the debt-income ratio unless we vary the exogenous borrowing limit in line with the age profile in the data. The model would still fail to match the evidence in section I B that unused credit rises with age. Third, the limited-borrowing model predicts 100% participation in equity markets at all ages, with equity financed in part by debt. In the data, however, a large fraction of households hold no equity, and few households hold both equity and unsecured debt.

The no-borrowing model and our preferred model with realistic borrowing costs produce similar levels of equity holdings that are much closer to the data. The model with realistic borrowing costs performs better in two key respects. First and foremost, the no-borrowing model is at odds with the prevalence of unsecured borrowing in the data and the widespread availability of unused credit (table 2). In contrast, our preferred model generates realistic borrowing behavior when calibrated to evidence on the cost of borrowing. Second, our preferred model delivers much higher nonparticipation rates in equity markets (figures 4 and 7) and a better fit to equity holdings (table 6). Our preferred model predicts that a majority of households under the age of 40 hold no equity, as in the data, but the no-borrowing model predicts that almost 90% of households under 40 hold equity. Our preferred model also predicts low equity holdings for younger households, in line with the data, and

TABLE 7.—WELFARE COSTS OF RESTRICTIONS ON EQUITY HOLDINGS: ALTERNATIVE BORROWING REGIMES

	$r_B = 8$	No Borrowing	$r_B = 2$	
			$BL = 1$	No BL
A. Baseline				
CE consumption ('000 $)	19.13	19.08	20.08	25.26
No Equity				
CE consumption ('000 $)	18.97	18.82	19.32	20.08
Δ ($)	−154	−265	−755	−5181
Δ (%)	−0.80	−1.39	−3.76	−20.51
No Equity until Age 50				
CE consumption ('000 $)	19.07	18.92	19.50	20.68
Δ ($)	−60	−158	−574	−4577
Δ (%)	−0.31	−0.83	−2.86	−18.12
50–50 Bond-Equity Mix				
CE consumption ('000 $)	19.01	18.91	19.64	*
Δ ($)	−114	−172	−436	*
Δ (%)	−0.60	−0.90	−2.17	*
B. $E(\tilde{r}_E) = 6\%$, $\beta = 0.937$				
CE consumption in ('000 $)	19.08	19.01	19.75	22.19
No Equity until Age 50				
CE consumption ('000 $)	19.06	18.93	19.44	18.60
Δ ($)	−20	−80	−315	−3589
Δ (%)	−0.10	−0.42	−1.60	−16.18
50–50 Bond-Equity Mix				
CE consumption ('000 $)	19.02	18.93	19.52	*
Δ ($)	−57	−85	−228	*
Δ (%)	−0.30	−0.45	−1.15	*

*In the model with $r_B = 2$ and no borrowing limit, the household can circumvent a minimum bond requirement by taking on more debt. If, instead, we require a long position in bonds equal to equity holdings, then the welfare cost of imposing a 50–50 bond-equity mix is very large in the model with $r_B = 2$ and no borrowing limit.

Notes:

1. See text for the calculation of certainty-equivalent (CE) consumption. Consumption is measured in 1987 dollars.
2. Baseline parameter settings except as noted.

less than half the levels predicted by the no-borrowing model. In short, a realistic treatment of borrowing also brings the theory closer to the evidence on life cycle patterns in equity holdings and participation rates.

With respect to explaining the life cycle behavior of consumption, borrowing, and asset accumulation, housing is the most important ingredient missing from our analysis. A full treatment of housing is beyond the scope of this article, but we can easily compare equity holdings in our models with risky asset holdings in the data, as measured by the sum of equity holdings and housing wealth. In this respect, a comparison of tables 2 and 7 shows that risky asset holdings (equities) in our preferred model ($r_B = 8\%$) and in the no-borrowing model are lower than equities plus housing in the data. The gap between theory and evidence for asset-to-income ratio widens with age. An important topic for future research is the integration of realistic borrowing costs into life cycle portfolio models that explicitly model housing wealth and consumption.

B. *Welfare Analysis of Model Failures*

Section IV D shows that our preferred model, like the alternatives, fails to match evidence on bondholdings. The model also predicts higher equity market participation rates than in the data. How serious are these failures? One useful way to address this question is to quantify the certainty-equivalent consumption cost of deviations between the data and the optimal behavior implied by the model.

To obtain certainty-equivalent consumption, we first calculate the lifetime expected utility U for a given consumption profile. We then find the constant level of consumption, $\bar{c}$, that yields the same level of lifetime expected utility. That is, we solve

$$\left(\sum_{t=0}^{T} \beta^t\right) \frac{\bar{c}^{1-\gamma}}{1-\gamma} = U \quad \text{for} \quad \bar{c} = \left(\frac{1-\gamma}{\sum_{t=0}^{T} \beta^t} U\right)^{\gamma-1}, \tag{3}$$

where β is the time discount factor, and γ is the relative risk aversion.

To measure the costs of suboptimal behavior, we consider three experiments: households do not hold equity, households hold no equity before age 50, and households allocate 50 cents out of every dollar of investment to bonds. We reach two sets of conclusions. First, in our preferred model, the costs of these deviations from optimal behavior are quite small, ranging from 0.1% to 0.8% of lifetime consumption.

Second, the costs are higher for the other models and, in the case of the model with unlimited borrowing at the risk-free rate, dramatically so.

Table 7 shows the results. Panel A considers the baseline specification, and panel B considers a lower equity return of 6%. Two observations motivate a lower equity return. First, many believe that an ex ante equity return of 8% is simply too high. Second, the cost of achieving a diversified equity portfolio lowers the net return, and for most investors mutual funds offer the only feasible means to obtain a broadly diversified portfolio. According to McGrattan and Prescott (2003), mutual fund costs range from 1.3% to 2.5% of assets per year in the period from 1980 to 2001.

For the baseline specification, our preferred model implies that the cost of never holding equity is 0.8% of lifetime consumption. The cost of a 50-50 bond-equity mix amounts to 0.6% of consumption. And if the household merely delays equity participation until age 50, the cost amounts to 0.3% of consumption. The costs are lower yet at a 6% equity return, as seen in panel B. For example, at a 6% return on equity, waiting till age 50 to participate in equity markets lowers certainty-equivalent consumption by 0.1%, which amounts to $20 per year in 1987 dollars.

The costs are bigger for the other models. The no-borrowing model implies that a no-equity restriction reduces certainty-equivalent consumption by 1.39%, nearly three-quarters bigger than in the preferred model. For the limited-borrowing model, the cost of the no-equity restriction is nearly 4% of consumption. Finally, the model with unlimited borrowing at the risk-free rate implies enormous welfare costs for suboptimal behavior: a household that refuses to hold equity accepts a 20% reduction in lifetime consumption according to this model. It is hard to imagine participation or transactions costs that would overcome a 20% or even a 4% loss of consumption.

It is useful to assess these results in light of Vissing-Jorgensen's (2002) study of stock market participation costs. She provides an informative discussion of these costs, and she estimates their effects on equity market participation rates and portfolio shares. Based on an after-tax equity premium of 5.6%, her estimates imply that a participation cost of $30 per year (in 1984 dollars) is sufficient to account for half of all nonparticipating households, and an annual cost of $175 is sufficient to account for 75%. Whereas Vissing-Jorgensen takes low asset holdings as given, our analysis explains low financial wealth as a natural consequence of life cycle factors and realistic borrowing costs.

Our model abstracts from many real-world features that generate demand for bonds, such as participation, diversification and rebalancing costs, a desire for liquidity, information costs, and so on. Because the gains to holding equity are modest in our preferred model, and very small for a large fraction of households, there is ample scope for these features to reduce equity market participation rates and increase bond portfolio shares.[8] Haliassos and Michaelides (2003) make an identical point in the context of an infinite-horizon model with no borrowing. Our analysis shows that this point carries even greater force in a life cycle model with realistic borrowing costs than in a model with no borrowing.

C. *Margin Loans*

Some commentators have suggested that our results on equity demand and equity market participation would not survive the introduction of margin loans. However, a few observations make clear why the introduction of margin loans would not greatly affect our results. First, initial margin requirements on equity are 50% or higher. Thus, for a household with $1,000 in financial wealth, a margin loan allows for an equity position of no more than $2,000. Second, the data show a large wedge between margin loan rates and risk-free returns. Kubler and Willen (2005) report that as of July 8, 2002, the rates on margin loans of less than $50,000 at five major brokerage houses (The Vanguard Group, Fidelity Investments, Charles Schwab, Salomon Smith Barney, and UBS Paine Webber) exceed the rate on 90-day U.S. Treasury bills by 357 to 570 basis points, depending on brokerage house and loan size. Even at these rates, brokerage houses require credit checks and reserve the right to deny margin credit or impose higher margin rates. Finally, the combination of unsecured borrowing and margin loans does not offer an attractive leverage premium. For example, at an 8% expected return on equity, a risk-free rate of 1.68% (the return on 90-day U.S Treasury bills as of July 8, 2002) and a 4.63% margin loan premium, the expected return on a margin-levered equity portfolio is $(1/0.5)8 - (1.68 + 4.63) = 9.69\%$. Combined with a wedge of 7.5 percentage points on unsecured borrowing, roughly the midpoint of the table 1 values, the fully levered portfolio offers a leverage premium of $9.69 - (1.68 + 7.5) = 0.51\%$. That is, the fully levered portfolio offers an expected return premium of 51 basis points with a standard deviation of $2 \times 15 = 30\%$. At a 6% expected return on equity, the margin-levered equity portfolio yields a negative return.

VI. Concluding Remarks

We showed that a model with a wedge between borrowing costs and the risk-free investment return can simultaneously deliver sensible life cycle profiles for debt and equity holdings and high rates of nonparticipation in equity markets. Realistic borrowing costs dramatically reduce equity holdings, and equity demand is at its minimum when

[8] Certain frictions (for example, a fixed cost of equity holding) lower equity market participation but do not raise bond shares conditional on participation. Other frictions (for example, proportional trading costs in equity markets) also raise bond shares conditional on participation. See Aiyagari and Gertler (1991) for an early analysis of trading frictions in equity markets.

the borrowing rate equals the expected return on equity. The model with realistic borrowing costs does a better job of fitting observed life-cycle patterns in borrowing, equity market participation and equity accumulation than alternative models with no borrowing or limited borrowing at the risk-free rate.

The opportunity to borrow at realistic rates in a life cycle setting has important consequences for wealth accumulation. Because households face an upward-sloping income profile, they borrow in the early part of the life cycle, which delays the age at which they participate in equity markets or accumulate significant holdings. This implication of our model helps explain the low equity holdings of most households in the face of an apparently high equity premium. Heaton and Lucas (2000b), Attanasio, Banks, and Tanner (2002), and others have emphasized this aspect of household behavior as an important puzzle.

Our analysis points to several directions for future research. We mention two here. First, our model implies that most households accumulate little or no financial wealth until middle age, consistent with much empirical evidence (for example, Kennickell et al., 2000, and Lusardi et al., 2001). Given its simplicity and its assumption of time-consistent, rational consumers, our model and analysis challenge claims that households save too little, or that they should be prompted to save more. A natural next step is to enrich the model to take account of housing consumption and real estate wealth and of the liquidity benefits of safe assets. We plan to evaluate richer versions of the model against a number of facts about consumption, homeownership, wealth accumulation, and portfolio behavior over the life cycle.

Second, our analysis highlights the role of borrowing costs and leverage as key factors in the demand for risky assets. Though margin loans provide limited scope for levered equity holdings (as we have shown), corporate bonds, government securities, real estate, and small-business wealth are often subject to much less stringent restrictions on leverage. Kubler and Willen (2005) consider a richer version of our model to address portfolio choice in a broader setting that encompasses a fuller menu of risky assets and leveraging methods. Leverage characteristics turn out to have important implications for portfolio shares, but the cost and availability of unsecured borrowing continue to play a central role in the demand for risky assets.

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APPENDIX

Computational Details

Our problem can be formulated as a standard finite-horizon dynamic program and solved by backward induction. It is well known (see Judd, 1998, chapter 12) that this type of problem can be solved by value-function or policy-function iteration. For reasons that will become clear, we use policy-function iteration. At age 80, the solution is trivial: consume everything. We then solve for optimal consumption and portfolio choice at age 79 conditional on financial wealth, income, the state of the world, and the (degenerate) policy rule at age 80. Next, we solve for consumption and portfolio choice at age 78—again conditional on financial wealth, income, the state of the world, and the calculated optimal policy rule at age 79. And so on.

The problem therefore reduces to solving two-period optimization problems and to approximating policy rules as functions of a minimal set of state variables (including current age). To model the wedge between borrowing and lending rates, we introduce two different bonds: a *lending bond* that cannot be sold short, and a *borrowing bond* that can only be sold short. Thus, we have three assets in the model and short-sale constraints on all three. The short-sale constraints frequently bind, and they create nondifferentiabilities in the policy function at points in the state space where they just become binding. The two-period optimization problem, even though relatively small, is therefore not completely trivial. For smooth, convex problems it is usually easy to solve the optimization problem by steepest descent methods (Judd, 1998, chapter 4). However, constraints on choice sets require the use of constrained optimization routines that are often numerically unstable and costly to set up. Because we need to solve the two-period problem at each iteration (age) at many points in the state space, it is essential to employ reliable methods with low setup costs. We found that standard constrained-optimization routines (such as NPSOL or MINOS) involved high setup costs or lacked sufficient reliability.

An alternative is to discretize both the state space and the space of available policies and use simple grid search methods to find the optimal policy at each iteration. The advantage of this method is numerical stability; the disadvantage is that it is very slow. In particular, because we effectively have three assets, a grid search approach is not feasible if we want to obtain sufficiently accurate solutions. Instead, we exploit the fact that the first-order conditions are necessary and sufficient and solve them, at each iteration, as a nonlinear system of equations. This is also why we use policy-function iteration. Because we work with the first-order conditions, only the derivative of the value function enters the two-period problem. Because we do not need the value function in our analysis, it is easier to work with the policy function directly.

We now describe in detail two aspects of the solution procedure: how to reduce the endogenous state space to one variable, and how to solve the two-period problem effectively. First, we use preference homotheticity to simplify the problem and reduce the number of continuous state variables to one. Second, we explain how to solve the two-period optimization problem.

A little notation will help. Let z_t be a Markov chain with finite support $z \in \{1, \ldots, S\}$ and transition π. The gross equity returns are $\tilde{R}_E(z_t)$, and the gross borrowing and lending rates are R_B and R_L, respectively. A date event z^t is a history of shocks $(z_1, \ldots, z_t)$. Let $y(z^t)$ denote income at time t.

Preference homotheticity allows us to simplify the problem by combining wealth and income into one variable (Deaton, 1991). Suppose we have solved for optimal policy rules from time $t + 1$ on. Suppose at date t, we are in state z with income y_t and wealth Ξ_t. The optimal policy rule for the next period specifies investment of $F^i_{t+1}(\Xi_{t+1}(z'), y_{t+1}(z'); z')$ in asset $i = B, L, E$ at time $t + 1$. Bellman's principle implies that the solution to the two-period problem below constitutes the optimal portfolio choice at t in state z with income y and financial wealth Ξ:

$$\max_{F^L,F^B,F^E} \frac{c_t^{1-\gamma}}{1-\gamma} + \beta E_t\left(\frac{c_{t+1}^{1-\gamma}}{1-\gamma}\right)$$

$$\begin{aligned}
\text{s.t.}\quad & c_t = y + \Xi - F^L + F^B - F^E, \\
& c_{t+1}(z') = y(z') + \Xi(z') - F^L(\Xi(z'),y(z');z') \\
&\qquad + F^B(\Xi(z'),y(z');z') - F^E(\Xi(z'),y(z');z') \\
&\qquad \forall\, z' \in \{1, \ldots, S\}, \Xi(z') = F^L R_L - F^B R_B + F^E R_E(z') \\
&\qquad \forall\, z' \in \{1, \ldots, S\}, \quad F^L \geq 0, \quad F^B \geq 0, \quad F^E \geq 0,
\end{aligned} \tag{A-1}$$

where we suppress time subscripts on variables other than consumption to reduce notational clutter.

Now divide through by y_t, define $x_t = c_t/y_t$, and consider the two-period optimization problem

$$\max_{f^L,f^B,f^E} \frac{x_t^{1-\gamma}}{1-\gamma} + \beta E_t\left(\frac{x_{t+1}^{1-\gamma}}{1-\gamma}\right)$$

$$\begin{aligned}
\text{s.t.}\quad & x_t = \xi - f^L + f^B - f^E, \\
& x_{t+1} = \frac{y_{t+1}(z')}{y_t}[\xi(z') - f^L(\xi(z');z') \\
&\qquad + f^B(\xi(z');z') - f^E(\xi(z');z')], \\
& \xi(z') = \frac{y_{t+1}(z') + f^L R_L - f^B R_B + f^E R_E(z')}{y_{t+1}(z')} \\
& f^L \geq 0, \qquad f^B \geq 0, \qquad f^E \geq 0.
\end{aligned} \tag{A-2}$$

Observe that the policy rules are now functions of a single endogenous state variable ξ, the ratio of financial wealth plus current income to current income. This reduction in the dimensionality of the state space greatly simplifies computation. We can recover the solution to the original problem (A-1) by multiplying the solution to the transformed problem (A-2) by current income:

$$\begin{aligned}
& c_t = y_t x_t, \\
& F^L = y_t f^L, \qquad F^B = y_t f^B, \qquad F^E = y_t f^E.
\end{aligned} \tag{A-3}$$

To solve the transformed two-period problem, we solve the associated Kuhn-Tucker conditions—a nonlinear system of equations and inequalities that is necessary and sufficient for optimality. Following Garcia and Zangwill (1981, pp. 65–68), we use a change of variables to eliminate inequalities in the Kuhn-Tucker conditions and state the optimality conditions as a system consisting solely of equations. The resulting system has three unknowns corresponding to the three asset holdings. In particular, let $\eta_j \in \mathcal{R}$ for $j = 1, 2, 3$, and define the Kuhn-Tucker multiplier for asset j, $\mu_j = (\max\{0, -\eta_j\})^3$. The consumer's holding of asset j is $\theta_j = (\max\{0,\eta_j\})^3$. Note that θ and μ are twice continuously differentiable, and that the complementary slackness conditions hold:

$$(\max\{0,\eta_j\})^3 \geq 0, \qquad (\max\{0, -\eta_j\})^3 \geq 0,$$

and

$$(\max\{0,\eta_j\})^3 \cdot (\max\{0,\eta_j\})^3 = 0.$$

We implement our solution algorithm using Fortran 90. A simple Newton method usually works well as a nonlinear equation solver when a good starting point is known. In some cases we need to use homotopy methods [as implemented in HOMPACK; see Watson, Billups, and Morgan (1987)] to solve the system.

Lastly, we draw attention to two practical aspects of our computational solution. First, the range of $f_t^j(\xi; z)$ will generally depend on t and z. In practice, we set arbitrary bounds on the range that vary only with t. We then verify that these bounds never bind in the simulations. Second, in generating $f_t^j(\xi; z)$, we don't solve equation (5) for every possible value of ξ. Instead, we solve it for a finite number of values of ξ and use cubic spline interpolation to fill in the rest. See Judd et al. (2002) for details on spline interpolation. Because the true policy functions have nondifferentiabilities, we use 50 knots for each spline interpolation to obtain sufficient accuracy.

Maximal relative errors in the Euler equations lie below 10^{-6}. Running times on a Pentium III computer with a 1.2-GHz processor and 1 Gbyte of RAM clustered around 4 or 5 min but range from 2 min for models with no labor income risk and borrowing rates above the expected return on equity to approximately 15 min for models with labor income risk and borrowing rates below the return on equity.

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