Optimal Life-Cycle Asset Allocation: Understanding the Empirical Evidence.*

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Abstract

We show that a life-cycle model with realistically calibrated uninsurable labor income risk and moderate risk aversion can simultaneously match stock market participation rates and asset allocation decisions conditional on participation. The key ingredients of the model are Epstein-Zin preferences, a fixed stock market entry cost, and moderate heterogeneity in risk aversion. Households with low risk aversion smooth earnings shocks with a small buffer stock of assets and consequently most of them (optimally) never invest in equities. Therefore, the marginal stockholders are (endogenously) more risk-averse and as a result they do not invest their portfolios fully in stocks.

JEL Classification: G11.

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1 Introduction

In this paper we present a life-cycle asset allocation model with intermediate consumption and stochastic uninsurable labor income, that provides an explanation for two very important empirical observations: low stock market participation rates in the population as a whole, and moderate equity holdings for stock market participants.

Our life-cycle model integrates three main motives that have been identified as quantitatively important in explaining individual and aggregate wealth accumulation. First, a precautionary savings motive in the presence of undiversifiable labor income risk generates asset accumulation to smooth unforeseen contingencies (Deaton (1991) and Carroll (1992, 1997)). Second, pension income is lower than mean working-life labor income implying that saving for retirement becomes important at some point in the life cycle. The combination of precautionary and retirement saving motives has recently been shown to generate realistic wealth accumulation profiles over the life cycle.[1] Third, we explicitly incorporate a bequest motive which has recently been shown to be important in matching the skewness of the wealth distribution (de Nardi (forthcoming) and Laitner (2002)).

More recently, life-cycle models incorporating some (or all) of these motives have been extended to include an asset allocation decision, both in an infinite-horizon[2] and in a finite-horizon, life-cycle setting.[3] However, several important predictions of these models are still at odds with empirical regularities. First, low stock market participation in the population (Mankiw and Zeldes (1991)) persists. The latest Survey of Consumer Finances (2001) reports that only 52 percent of US households hold stocks either directly or indirectly (through pension funds, for instance), while these models predict that, given the equity premium, all

[1] See, for instance, Hubbard, Skinner and Zeldes (1995), Carroll (1997), Attanasio, Banks, Meghir and Weber (1999), Gourinchas and Parker (2002), Dynan, Skinner and Zeldes (2002) and Cagetti (2003).

[2] See, for example, Telmer (1993), Lucas (1994), Koo (1998), Heaton and Lucas (1996, 1997, 2000), Polkovnichenko (2000), Viceira (2001) and Haliassos and Michaelides (2003).

[3] See, for instance, Cocco, Gomes and Maenhout (1999), Cocco (2000), Campbell, Cocco, Gomes and Maenhout (2001), Hu (2001), Storesletten, Telmer and Yaron (2001), Davis, Kubler and Willen (2002), Dammon, Spatt and Zhang (2001 and 2002), Polkovnichenko (2002), Yao and Zhang (2002) and Gomes and Michaelides (2003). Bertaut and Haliassos (1997) and Constantinides, Donaldson and Mehra (2002) analyze a three period model where each period amounts to 20 years.

households should participate in the stock market as soon as saving takes place. Second, households in the model invest almost all of their wealth in stocks, in contrast to both casual empirical observation, and to formal empirical evidence (see Poterba and Samwick (1999) or Ameriks and Zeldes (2001), for instance).

We develop a life-cycle asset allocation model that tries to address these two puzzles. We argue that it is possible to simultaneously match stock market participation rates and asset allocation conditional on participation, with moderate values of risk aversion (between 1 and 5), and without extreme assumptions about the level of background risk. Our model has three key features. First, we include a fixed entry cost for households that want to invest in risky assets for the first time. A large literature has concluded that some level of fixed costs seems to be necessary to improve the empirical performance of asset pricing models.[4] Since the excessive demand for equities predicted by asset allocation models is merely the portfolio-demand manifestation of the equity premium puzzle, introducing a fixed cost in the model seems to be a natural extension. Moreover, recent empirical work suggests that small entry costs can be consistent with the observed low stock market participation rates (see Paiella (2001), Degeorge, Jenter, Moel and Tufano (2002) and Vissing-Jørgensen (2002b)).

The other two key features are motivated by the (perhaps surprising) implication of the model that participation rates are an increasing function of risk aversion, at least over a wide range of parameter values. Specifically, changing risk aversion generates two opposing forces for determining the participation decision. On one hand, more risk averse households optimally prefer to invest a smaller fraction of their wealth in stocks. On the other hand, risk aversion determines prudence and more prudent consumers accumulate significantly more wealth over the life-cycle. We show that the higher wealth accumulation motive dominates for moderate coefficients of relative risk aversion (that is, not greater than 5). As a result, the less risk-averse investors have a weaker incentive to pay the fixed cost. This explains why previous attempts to match participation rates in the context of a life-cycle model were fairly unsuccessful. If we try to match asset allocation decisions by assuming high values of

[4] See, among others, Constantinides (1986), Aiyagari and Gertler (1991), He and Modest (1995), Saito (1995), Heaton and Lucas (1996), Luttmer (1996, 1999), Basak and Cuoco (1998) and Vayanos (1998).

risk aversion, the implied participation rates are counterfactually high.[5] Motivated by this result we allow for preference heterogeneity in the population, the second key feature of the model. As argued before, since the less risk-averse investors accumulate less wealth over the life-cycle, the majority optimally chooses not to pay the fixed cost. Therefore, *endogenously* stock market participants tend to be the more risk-averse investors and, consequently, even after paying the fixed cost they do not invest their portfolios fully in equities.

The final important feature of the model is the assumption of Epstein-Zin preferences, which allows us to separate risk aversion from the elasticity of intertemporal substitution (EIS). In the context of a life-cycle model with labor income, wealth accumulation is a crucial determinant of both the stock market participation and the asset allocation decision. Within the power utility framework, households with low risk aversion also have a high EIS. Given that the expected return from investing in the stock market is higher than the cost. Therefore, the marginal stockholders are (endogenously) more risk-averse and as a result they do not invest their portfolios fully in stocks.

It is important to mention that this form of heterogeneity is consistent with the existing empirical evidence. For instance, Vissing-Jørgensen (2002a) argues that "accounting for limited asset market participation is crucial for obtaining consistent estimates of the EIS" (p. 827). Vissing-Jørgensen then obtains estimates of the EIS greater than 0.3 for risky asset holders, while for the remaining households the EIS estimates are small and insignificantly different from zero. Vissing-Jørgensen and Attanasio (2003) further stress that loosening the link between risk aversion and intertemporal substitution can generate implications about the covariance of stock returns and individual consumption growth for stockholders that are not rejected in the data. For stockholders, Vissing-Jørgensen and Attanasio (2003) offer risk aversion estimates at around 5-10 and EIS estimates around one.

The rest of the paper is organized as follows. Section 2 summarizes results from the existing empirical literature on life-cycle asset allocation while section 3 outlines the model and calibration. In Section 4 (5) we discuss the results in the absence (presence) of the fixed entry cost, and section 6 concludes.

2 Empirical Evidence on Life-Cycle Asset Allocation and Stock Market Participation

In most industrialized countries, stock market participation rates have increased substantially during the last decade. Nevertheless, a large percentage of the population still does not own any stocks (either directly or indirectly through pension funds). Moreover, even those households which do own stocks, still invest a significant fraction of their portfolios in alternative assets.

Figures 1.1 and 1.2 summarize evidence reported in Ameriks and Zeldes (2001). Figure 1.1 plots the average life-cycle equity holdings for stock market participants (as a share of total financial wealth), based on the 1989, 1992, 1995 and 1998 waves of the Survey of Consumer Finances (SCF). Although the life-cycle profiles are very sensitive to the inclusion of time dummies versus the inclusion of cohort dummies, the average stock holdings are significantly below 100% in both cases. Figure 1.2 plots the corresponding stock market participation rate, obtained by running a Probit regression on the same data. These results are less sensitive to the choice of time versus cohort dummies. As expected, a very large fraction of the population does not own equities. In both cases the participation rate gradually increases until approximately age 50. When including cohort dummies, the profile is flat after age 50, while with time dummies it is decreasing. Ameriks and Zeldes (2001) obtain the same results after re-doing the analysis using TIAA-CREF data from 1987-1996, and so do Poterba and Samwick (1999), using SCF data.

The next two figures (1.3 and 1.4) report evidence from Guiso, Haliassos and Japelli (2002), using cross-sectional information for five different countries (U.S.A., U.K., Netherlands, Germany and Italy). Since this is a unique cross-section there are no time or cohort controls. Figure 1.3 plots equity holdings as a fraction of total financial wealth, conditional on stock market participation. We observe an increasing pattern for 4 countries (the U.K. is the exception), and again a very low level of stock holdings. Figure 1.4 plots the participation rates for the different countries. It shows an increasing participation rate until age 60: for all countries the participation rate is higher for the age bracket 50-60 than for the age bracket 20-30. After age 60, 4 out of 5 countries have a decreasing participation rate, which could be due to cohort effects.

We can summarize the existing evidence as follows.[7] First, the stock market participation rate in the U.S. population is close to 50%. Using the latest numbers from the SCF we compute it as 51.9% (details given in Appendix C). Second, participation rates increase during working life and there is some evidence suggesting that they might decrease during retirement although this might also be due to cohort effects. Third, conditional on stock market participation, households invest a large fraction of their financial wealth in alternative

[7] We must point out that several papers have contributed to this research. See for example, Guiso, Jappelli and Terlizzese (1996) (who focus mostly on the impact of background risk on asset allocation), King and Leape (1998), Heaton and Lucas (2000) and the papers in the volume edited by Guiso, Haliassos and Japelli (2002).

assets. According to the latest numbers from the SCF, the average equity holdings as a share of financial wealth for stock market participants, is 54.8%. Fourth, there is no clear pattern of equity holdings over the life-cycle.

3 The Model

3.1 Preferences

Time is discrete and t denotes adult age which, following the typical convention in this literature, corresponds to effective age minus 19. Each period corresponds to one year and agents live for a maximum of $T = 81$ periods (age 100). The probability that a consumer/investor is alive at time $(t+1)$ conditional on being alive at time t is denoted by p_t ($p_0 = 1$).

Households have Epstein-Zin utility functions (Epstein and Zin (1989)) defined over one single non-durable consumption good. Let C_t and X_t denote respectively consumption level and wealth (cash-on-hand) at time t then, the household's preferences are defined by

$$V_t = \{(1-\beta p_t)C_t^{1-1/\psi} + \beta E_t \left[p_t[V_{t+1}^{1-\gamma}] + (1-p_t) b \frac{(X_{t+1}/b)^{1-\gamma}}{1-\gamma} \right]^{\frac{1-1/\psi}{1-\gamma}} \}^{\frac{1}{1-1/\psi}} \tag{1}$$

where ρ is the coefficient of relative risk aversion, ψ is the elasticity of intertemporal substitution, β is the discount factor, and b determines the strength of the bequest motive.[8] Given the presence of a bequest motive, the terminal condition for the recursive equation (1) is:

$$V_{T+1} \equiv b \frac{(X_{T+1}/b)^{1-\rho}}{1-\rho} \tag{2}$$

3.2 Labor Income Process

Following the standard specification in the literature, the labor income process before retirement is given by

$$Y_{it} = P_{it} U_{it} \tag{3}$$

[8] For more motivation and details on the modelling of bequest motives in life-cycle models see Laitner (2002), or De Nardi (forthcoming).

$$P_{it} = \exp(f(t, Z_{it}))P_{it-1}N_{it} \tag{4}$$

where $f(t, Z_{it})$ is a deterministic function of age and household characteristics Z_{it}, P_{it} is a "permanent" component with innovation N_{it}, and U_{it} a transitory component. We assume that $\ln U_{it}$ and $\ln N_{it}$ are independent and identically distributed with mean $\{-.5 * \sigma_u^2, -.5 * \sigma_n^2\}$, and variances σ_u^2 and σ_n^2, respectively. The log of P_{it}, evolves as a random walk with a deterministic drift, $f(t, Z_{it})$.

For simplicity, retirement is assumed to be exogenous and deterministic, with all households retiring in time period K, corresponding to age 65 ($K = 46$). Earnings in retirement ($t > K$) are given by $Y_{it} = \lambda P_{iK}$, where λ is the replacement ratio (a scalar between zero and one). This specification, also standard in this literature, considerably facilitates the solution of the model, as it does not require the introduction of an additional state variable (see section 3.6).

Durable goods, and in particular housing, can provide an incentive for higher spending early in life. Modelling these decisions directly is beyond the scope of the paper, but nevertheless we will take into account these potential patterns in life-cycle expenditures. Using the P.S.I.D., for each age (t) we estimate the percentage of household income that is dedicated to housing expenditures (h_t) and subtract it from the measure of disposable income.[9] More details on this estimation are given below, when we discuss the calibration of the model.

3.3 Financial Assets

The investment opportunity set is constant and there are two financial assets, one riskless (treasury bills or cash) and one risky (stocks). The riskless asset yields a constant gross return, R^f, while the return on the risky asset (denoted by R_t^S) is given by

$$R_{t+1}^S - R^f = \mu + \varepsilon_{t+1} \tag{5}$$

where $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$.

We allow for positive correlation between stock returns and earnings shocks. More for-

[9] A similar approach is taken by Flavin and Yamashita (2002) in a model without labor income.

mally, the innovation to the permanent earnings shock follows the process:

$$\ln N_{it} = (\phi_N \frac{\varepsilon_t}{\sigma_\varepsilon} + (1 - \phi_N^2)^{1/2} \ln N_{it}^*)\sigma_n \tag{6}$$

where $\ln N_{it}^*$ follows a standard normal, and ϕ_N is the correlation coefficient between $\ln N_{it}$ and $\frac{\varepsilon_t}{\sigma_\varepsilon}$

Finally, as in Deaton (1991), we prevent households from borrowing against their future labor income. More specifically we impose the following restrictions:

$$B_{it} \geq 0 \tag{10}$$

$$S_{it} \geq 0 \tag{11}$$

3.5 The optimization problem and solution method

The complete optimization problem is then

$$MAX_{\{S_{it},B_{it}\}_{t=1}^{T}} E(V_0) \tag{12}$$

where V_0 is given by equations (1) and (2); subject to the constraints given by equations (5) to (11), and to the stochastic labor income process given by (3) and (4) if $t \leqslant K$, and $Y_{it} = \lambda P_{iK}$ if $t > K$.

Analytical solutions to this problem do not exist. We therefore use a numerical solution method based on the maximization of the value function to derive the optimal decision rules. The details are given in appendix A, and here we just present the main idea. We first simplify the solution by exploiting the scale-independence of the maximization problem and rewriting all variables as ratios to the permanent component of labor income (P_{it}). The laws of motion and the value function can then be rewritten in terms of the normalized variables, and we use lower case letters to denote them (for instance, $x_{it} \equiv \frac{X_{it}}{P_{it}}$). This allows us to reduce the number of state variables to three: age (t), normalized cash-on-hand (x_{it}) and participation status (whether the fixed cost has already been paid or not). In the last period the policy functions are determined by the bequest motive and the value function corresponds to the bequest function. We can now use this value function to compute the policy rules for the previous period and, given these, obtain the corresponding value function. This procedure is then iterated backwards.

3.6 Computing Transition Distributions

After solving for the optimal policy functions, we can simulate the model to replicate the behavior of a large number of households and compute, for example, the corresponding average allocations. Here we propose an alternative method of computing various statistics that is based on the explicit calculation of the transition distribution of cash on hand from one age to the next. The computational details are delegated to Appendix B, but the intuitive idea is straightforward. Once we have solved for the policy functions we can substitute those in the budget constraint to obtain the distribution of x_{t+1} as a function of x_t. Doing this for every possible x_t we are effectively computing the full transition matrix.[10]

Once we have these distributions, the unconditional mean consumption for age t can then be computed as[11]

$$\overline{c}_t = \theta_t \left\{ \sum_{j=1}^{J} \pi_{t,j}^{I} * c^{I}(x_j, t) \right\} + (1 - \theta_t) \left\{ \sum_{j=1}^{J} \pi_{t,j}^{O} * c^{O}(x_j, t) \right\} \tag{13}$$

where J is the number of grid points used in the discretization of normalized cash on hand, and $\pi_{t,j}^{I}$ and $\pi_{t,j}^{O}$ are the probability masses associated with each grid point at time t, for stockholders and non-stockholders, respectively. The participation rate at age t (θ_t) is given by

$$\theta_t = \theta_{t-1} + (1 - \theta_{t-1}) * \sum_{x_j > x^*} \pi_{t,j}^{O} \tag{14}$$

where x^* is the trigger point that causes participation, which is determined endogenously through the participation decision rule.

Finally, if we denote the share of liquid wealth invested in the stock market and in the riskless asset at age t by α_t^S, and α_t^B respectively, then the unconditional portfolio allocations are computed as:

$$\overline{\alpha}_t^S = \frac{\theta_t * \{\sum_{j=1}^{J} \pi_{t,j}^{I} * \alpha^S(x_j, t) * (x_j - c^I(x_j, t))\}}{\theta_t * \sum_{j=1}^{J} [\pi_{t,j}^{I} * (x_j - c^I(x_j, t))] + (1 - \theta_t) * \sum_{j=1}^{J} [\pi_{t,j}^{O} * (x_j - c^O(x_j, t))]} \tag{15}$$

and

$$\overline{\alpha}_t^B = 1 - \overline{\alpha}_t^S \tag{16}$$

[10] The results in the paper were computed both from the transition distributions and using Monte-Carlo simulations. The results were found to be identical, as long as the number of simulations is not too small (2000 or more).

[11] Superscript I denotes households participating in the stock market, while superscript O denotes households out of the stock market.

3.7 Parameter Calibration

3.7.1 Preference parameters

We will start by presenting results for a relatively standard choice, (risk aversion) $\rho = 5$, (EIS) $\psi = 0.2$ and (discount factor) $\beta = 0.96$. However, later on we will report results for several different values of both the coefficient of relative risk aversion (ρ) and the elasticity of intertemporal substitution (ψ), as these parameters will have very important implications for our results. We use the mortality tables of the National Center for Health Statistics to parameterize the conditional survival probabilities.

The importance of the bequest motive (b) is set at 2.5. As we discuss below, this parameter choice is motivated by the desire to match the wealth accumulation profiles observed in the data, but we will present some sensitivity analysis with respect to this parameter.

3.7.2 Labor income process

The deterministic labor income profile ($f(t, Z_{it})$ reflects the hump shape of earnings over the life-cycle, and the corresponding parameter values, just like the retirement transfers (λ), are taken from Cocco, Gomes and Maenhout (1999). With respect to standard deviations of the idiosyncratic shocks, the estimates range from 0.35 for σ_u and 0.12 for σ_n (Cocco et. al.(1999)) to 0.1 for σ_u and 0.08 for σ_n (Carroll (1992)). We use numbers similar to the ones in Gourinchas and Parker (2002), $\sigma_u = 0.15$ and $\sigma_n = 0.1$. It is common practice to estimate different labor income profiles for different education groups (college graduates, high-school graduates, households without a high-school degree). In our paper we only report the results obtained with the parameters estimated from the sub-sample of high-school graduates, as the results for the other two groups are very similar.

3.7.3 Asset returns, correlation and fixed cost

The constant net real interest rate ($R^f - 1$) is set at 2 percent, while for the stock return process we consider a mean equity premium (μ) equal to 4 percent and a standard deviation (σ_ε) of 18 percent. Considering an equity premium of 4% (as opposed to the historical 6%) is a fairly common choice in this literature (e.g. Yao and Zhang (2002), Cocco (2001) or

Campbell et. al. (2001)). Even after having paid the fixed entry cost, the average retail investor still faces non-trivial transaction costs, mostly in the form of mutual fund fees. This adjustment is a short-cut representation for those costs, since the dimensionality of the problem prevents us from modelling them explicitly (as in Heaton and Lucas (1996), for example).[12]

The evidence on the magnitude of the correlation between stock returns and permanent labor income shocks is mixed.[13] Davis and Willen (2001) and Heaton and Lucas (2000) do not distinguish between the two components of labor income (permanent and transitory) when computing the correlation coefficients. For the purposes of calibrating our model we need to know the magnitude of the correlation coefficient for these two shocks separately. Campbell, Cocco, Gomes and Maenhout (2001) estimate the correlation between the permanent component of labor income shocks and stock returns, and obtain a correlation coefficient of 0.15.[14] They do not estimate a correlation between transitory shocks and stock returns and just assume it to be equal to zero. We will use these numbers ($\phi_N = 0.15$ and $\phi_U = 0.0$) for our benchmark calibration, and perform sensitivity analysis around these values.

With respect to the fixed cost of participation we will consider two limit cases: one where the cost is zero, and one where it equals 0.025 (2.5% of the household's expected annual income). This parameter reflects both the monetary cost associated with the initial investment in the stock market, and the opportunity cost associated with obtaining the necessary information for making such investment.[15]

[12] Campbell et al. (2001) also argue that this is actually a better measure of a forward-looking equity premium.

[13] Moreover, it has been argued that these estimations suffer from a small sample bias since the time-series dimension is too short in micro-data, and estimations using macro data usually yield larger and more significant correlations (see, for example, Jermann (1999)).

[14] It is important to realize that, in their tables Campbell et al. (2001) actually report the correlation of the *aggregate* component of permanent labor income shocks with stock returns. This explains their high estimates: 45.6%. To obtain the correlation with the "total permanent shock", we need to adjust for the standard deviation of the aggregate component relative to the total, which gives the 15% number.

[15] Consider the average household which has an annual labor income of \$35000. If the time cost was zero, then this value of F would imply a monetary cost of \$875. If the monetary cost was zero, then this would

3.7.4 Housing expenditures

We measure housing expenditures using data from the Panel Study of Income Dynamics from 1976 until 1993.[16] For each household, in each year, we compute the ratio of annual mortgage payments and rent payments (housing related expenditures - H) relative to annual labor income (Y):

$$h_{it} \equiv \frac{H_{it}}{Y_{it}} \tag{17}$$

We combine mortgage payments and rent together since we are not modelling the housing decision explicitly. We identify the age effects by running the following regression on the full panel:

$$h_{it} = A + B_1 * age + B_2 * age^2 + B_3 * age^3 + time\ dummies + \zeta_{it} \tag{18}$$

where age is defined as the age of the head of the household. We eliminate all observations with age greater than 75.[17] The estimation results are reported in Table 1.

In the model we use

$$h_t = Max(A + B_1 * age + B_2 * age^2 + B_3 * age^3, 0) \tag{19}$$

which, given our parameter estimates, truncates h_t at zero for $age \geqslant 80$.

imply a time cost of 9.1 days (6.3 working days). More generally, any convex combination of these two is acceptable. For example, a time cost of one (two) day(s) and a monetary cost of \$779 (\$683). Paiella (2001) and Vissing-Jorgensen (2002b) have used Euler equation estimation methods to obtain implied participation costs from observed consumption choices. They find values in the \$75 to \$200 range, but these are per-period costs, so our number is quite reasonable when compared to their estimates.

[16]Before 1976 there is no information on mortgage expenditures, and 1993 is the last year available on final release from the PSID.

[17]There are several reasons for eliminating these households. First , there are very few observations within each age group beyond age 75. Second, for most of these households the values of h_{it} are equal to zero. Third, this is consistent with the estimation procedure used for the labor income process.

4 Results without the Fixed Participation Cost

4.1 Consumption and wealth accumulation

4.1.1 Power utility

Figures 2.1 and 2.2 plot distributions of normalized cash on hand (x_{it}) for different ages, during working life and during retirement, respectively. The preference parameters are $\rho = 5$ and $\psi = 0.2$. In figure 2.1, as households age and wealth accumulation increases, there is a shift of mean cash on hand to a higher level, while at the same time the distribution widens, reflecting the substantial heterogeneity associated with the realization of the undiversifiable and idiosyncratic labor income shocks. Figure 2.2 illustrates the wealth evolution during retirement, with both the mean and the variance of the distribution falling over time.

Mean normalized consumption ($\overline{c}_t$), mean normalized wealth ($\overline{w}_t$) and mean normalized income net of housing expenditures ($(1 - h_t) * \overline{y}_t$) are plotted in Figure 2.3. Early in life the household is liquidity constrained and saves only a small buffer stock of wealth. From approximately ages 30 to 35 onwards, she starts saving for retirement and bequests, and wealth accumulation increases significantly. During the retirement period consumption decreases as a result of the very high effective discount rate (high mortality risk). Wealth does not fall towards zero due to the presence of the bequest motive.[18]

4.1.2 Epstein-Zin utility

Tables 2.1 through 2.3 show the mean consumption to wealth ratio for different values of the preference parameters. We report results for values of risk aversion between 1 and 5 and for values of the elasticity of intertemporal substitution between 0.2 and 0.8, since this is the range that we will consider in the remaining part of the paper, and it is consistent with existing empirical evidence. Table 2.1 considers the first adult years ($20 - 35$) during which wealth accumulation is mostly driven by the precautionary savings motive. As a result, the optimal consumption to wealth ratio is significantly more affected by prudence than by

[18] Net income increases during the first years of retirement because the housing expenditures (h_t) are still positive and decreasing towards zero.

the elasticity of intertemporal substitution (EIS). Since the more risk averse investors are also the more prudent ones, the consumption to wealth ratio is a decreasing function of risk aversion. For very low values of risk aversion (close to 1) C/X converges to the 100% limit imposed by the borrowing constraint.

Table 2.2 summarizes the remaining pre-retirement period ($36-65$), during which savings are now determined by the preferences for low-frequency consumption smoothing, while table 2.3 reports the results for the retirement period ($66-100$). Campbell and Viceira (1999) show that, in an infinite-horizon portfolio choice model without labor income, the consumption-wealth ratio is a decreasing (increasing) function of the EIS for low (high) values of risk aversion. This is driven by the trade-off between the expected return on invested wealth and the discount rate. The less risk-averse households invest a larger fraction of their portfolio in stocks, and therefore the expected return on their invested wealth is higher. As risk aversion increases sufficiently, the discount rate exceeds the return on the portfolio and the effect reverses.[19]

The results in tables 2.2 and 2.3 are qualitatively similar to the ones in Campbell and Viceira (1999), and can be summarized as follows. First, in our model, for all values of ρ that we consider, the consumption to wealth ratio is always a decreasing function of the EIS. Second, just like in table 2.1, as ρ falls, C/X converges to the 100% limit given by the borrowing constraint (absent in Campbell and Viceira (1999)). This explains why the consumption to wealth ratio is almost independent of ψ for very low values of risk aversion. Third, as ψ approaches 1 the consumption wealth ratio converges to the same value regardless of ρ. This pattern is not clearly visible for low values of ρ due to the presence of the borrowing constraints. In their absence C/X would be a very steep function of ψ, but in our model this only occurs as the EIS is very close to 1.[20] Finally, combining the first and the third results, we can conclude that, for a given EIS (less than 1), the consumption to wealth ratio is again a decreasing function of ρ, just like in the buffer stock period (reported in table 2.1).

[19] As pointed below, in our model this would only occur for value of ρ higher than the ones considered in this paper.

[20] For $\rho = 1.2$ and for the age group $36 - 65$, the consumption wealth ratio falls from 88% with $\psi = 0.5$, to 43% when $\psi = 0.8$, and (not reported) 15% when $\psi = 0.95$.

4.2 Asset Allocation

Figure 2.4 graphs the unconditional mean asset allocation in equities ($\overline{\alpha}_t$) for the same preference parameters as in figure 2.3 ($\rho = 5$ and $\psi = 0.2$). Since the qualitative results for Epstein-Zin cases are identical, we will only discuss them in the next section when we conduct the quantitative evaluation of the model. Even though earnings risk is uninsurable, cash is a closer substitute for future labor income than stocks (see Heaton and Lucas (1997)). Young households are "overinvested in their human capital" and view this non-tradeable asset as an implicit riskless asset in their portfolio. Given that the holdings of this relatively riskless asset are larger in the early part of the life-cycle, young households allocate most of their financial wealth to stocks.[21] As retirement approaches, and financial wealth increases relative to the present value of future labor income, agents start investing in cash. When retirement savings is at its peak, more than 50% of total wealth is now being invested in the riskless asset.

During retirement both future labor income (the present value of the pension transfers) and financial wealth are falling, so that the optimal asset allocation is determined by the relative speed at which these two decrease. Naturally this depends both on the discount rate (adjusted for the survival probabilities) and the strength of the bequest motive. Given our parameter values, during most of the retirement period, future labor income and wealth decay at similar rates, and as a result the share of wealth invested in stocks remains approximately constant.[22]

[21] During the very first years of adult life households hold a small fraction of their wealth in cash since the present value of future labor income is actually still increasing.

[22] Except during the last years, when most households have very little financial wealth left.

5 Results with the Fixed Participation Cost

5.1 Baseline case with power utility

5.1.1 Participation decision

Figure 3.1 shows the participation rate during working life. The participation decision is determined by four factors. First, it is an increasing function of wealth accumulation. Intuitively, households that accumulate more wealth over the life-cycle have a stronger incentive to enter the stock market. Second, for the same level of wealth accumulation, participation is a positive function of the optimal share of wealth invested in stocks. Third, since F is an one-time cost, participation is also a positive function of the investment horizon. Fourth, since the cost must be paid at the time of entry, the likelihood of participating in the stock market is a negative function of current marginal utility.

Since young households are liquidity constrained, their marginal utility is extremely high and as a result they do not participate in the stock market until sufficient wealth has been accumulated. As we can see from Figure 3.1, given these preference parameters, this happens very fast and by age 25 the participation rate is almost 100%. As a result, the average life-cycle profiles of wealth accumulation, consumption and equity shares are almost identical to the ones obtained without the fixed cost (reported in figures 2.3 and 2.4), and are therefore omitted here.

5.1.2 Wealth distributions

Figure 3.2 plots the evolution of the distributions of cash on hand for the two types of agents: stock market participants and non-participants at age 30, still with $\rho = 5$ and $\psi = 0.2$. There is a pronounced spike around the normalized cash on hand level of 0.75; beyond that level, stock market participation becomes optimal and the two distributions overlap for a small interval, mostly representing the incurrence of the fixed entry cost. Figure 3.3 plots the distributions of cash on hand for ages 50 for both types of agents. Conditional on age, the distribution of cash on hand for stock holders has a much higher variance than the wealth distribution for the households that have not participated in the stock market.

5.1.3 Sensitivity analysis

Housing expenditures

In our baseline calibration we assumed that housing expenditures constitute a fixed proportion of labor income. We will now allow for a stochastic component in this ratio. More precisely, disposable income is now given by $(1-\widetilde{h}_t)Y_{i,t+1}$ where

$$\widetilde{h}_t = h_t * \exp(\varepsilon_t^h) \tag{20}$$

and ε_t^h follows a normal distribution with zero mean and variance $\sigma^2_{\varepsilon^h}$.

In Figure 3.4 we plot the average share of wealth invested in stocks for our baseline case and for $\sigma_{\varepsilon^h} = 0.25$. This effectively corresponds to an increase in the level of background risk, and it is equivalent to an increase in the variance of the transitory labor income shocks. We find that the results are quite similar under both specifications. The increase in background risk reduces the willingness to invest in stocks, but since these are transitory shocks the effect is not very large. For the same reason, the wealth accumulation and the participation rate for the two cases are also very similar, and therefore we do not report them.

Bequest motive

Next we perform some sensitivity analysis with respect to the importance of the bequest motive. Figure 3.5 plots wealth accumulation for different values of the parameter b, while figure 3.6 plots the corresponding conditional asset allocations. A stronger bequest motive increases wealth accumulation at every stage of the life-cycle, and the effect is strongest during retirement, as expected. The increase in wealth accumulation leads to a modest reduction in the share of equity investment during working life. Since both of these effects have a fairly modest impact until retirement, the implied participation rates are not significantly affected and therefore we do not report them. During retirement, an increase in the bequest motive decreases the speed at which wealth is being drawn down, and leads to a higher ratio of financial wealth to labor income. As a result, for a given age, a stronger (weaker) bequest motive decreases (increases) the optimal equity share.

Correlation between stock returns and labor income shocks

As mentioned before, the empirical evidence on the magnitude of the correlation coefficients between stock returns and the different labor income shocks (transitory and permanent) is mixed. In our baseline calibration we have assumed $\phi_N = 0.15$ and $\phi_U = 0.0$, following the estimation of Campbell et al. (2001). In figure 3.7 we now check if the results are sensitive to these values. We only report the asset allocation decisions, since the participation decision is almost identical in all cases.

Campbell et al. (2001) do not actually estimate $\phi_U = 0.0$, they just assume it. So in our first experiment we allow for a positive correlation between stock returns and the transitory labor income shocks, in particular we consider $\phi_N = 0.15$ and $\phi_U = 0.1$. The results are very similar to the ones obtained for the baseline case. In the second experiment we now set $\phi_N = 0.0$ and assume that the correlation is instead driven exclusively by the transitory shocks, so $\phi_U = 0.15$. We again obtain results that are extremely close to our baseline case. The share invested in equities is higher but only marginally so. Finally, we consider the case in which there is no correlation between stock returns and labor income shocks. Only in this case do we find a visible difference relative to the benchmark calibration, as investors now allocate a higher fraction of their wealth to equities.

Initial wealth distribution

So far we have assumed that all households start at age 20 with zero initial wealth. Table 3 reports summary statistics for the wealth distribution for households of age 20 (or lower) from the Survey of Consumer Finances (details given in Appendix C). In figure 3.8 we report the mean wealth accumulation profile obtained when we use this distribution as the initial condition in our model.[23] With the exception of the first few years, the wealth profiles are virtually indistinguishable. This occurs because young households are liquidity constrained and they therefore prefer to consume all of this additional wealth now rather than save it.

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5.2 Changing risk aversion and the impact of background risk

The stock market participation rate implied by the baseline parameters is counterfactually high. In this section we explore the model's ability to produce more realistic results by considering different preference parameter values. As mentioned before, the participation decision is an increasing function of both wealth (X) and the optimal share of wealth invested in risky assets (α). For a fixed EIS, decreasing risk aversion increases the optimal share invested in stocks, but as shown in section 4.1, it also decreases wealth accumulation at every stage of the life-cycle. A lower coefficient of risk aversion decreases the precautionary savings motive leading to less wealth accumulation early in life (table 2.1). Later in life, we have again less wealth accumulation (see table 2.2) since the expected return on invested wealth is higher and $\psi < 1$. Therefore, the impact on the participation decision resulting from changes in risk aversion, will depend on which effect dominates: the impact on X, or the impact on α.

5.2.1 Wealth accumulation

We start by decreasing ρ from 5 to 2, while maintaining the power utility assumption, thus increasing the elasticity of intertemporal substitution (ψ) to 0.5. In figure 4.1 we plot the wealth accumulation for this case and for the baseline parameter values ($\rho = 5$ and $\psi = 0.2$). As expected, wealth accumulation is significantly reduced at every stage of the life-cycle. As previously shown in section 4.1, the average consumption to wealth ratio is now 86% for the age group $20 - 35$, and 35% for the the age group $36 - 65$, as opposed to 66% and 19% respectively. However, from the results in section 4.1, we know that if we depart from power utility and decrease both risk aversion (ρ) and the EIS (ψ) simultaneously, this will significantly reduce wealth accumulation. Consider then decreasing ρ to 2, but now keeping ψ at 0.2. The consumption wealth ratio for the first age group is not significantly affected (90% instead of 86%) since, at this stage of the life-cycle, savings are essentially driven by prudence (which remains constant). However, for the second age group, wealth accumulation is determined mostly by the elasticity of intertemporal substitution. As a result, the average consumption to wealth ratio is now almost doubled, increasing from 35% to 67%. As shown in figure 4.1, this leads to a very significant reduction in life-cycle wealth accumulation.

5.2.2 Stock Market Participation Rates and Asset Allocation

Figure 4.2 plots the participation rates for the two values of risk aversion, 5 and 2, with the elasticity of intertemporal substitution equal to 0.2. Given the large differences in wealth accumulation, it is not surprising that the wealth effect dominates with respect to the participation decision. The less prudent households ($\rho = 2$) save less and as a result their participation rate is smaller. While almost all high-prudence households have already paid the fixed cost by age 25, only 75% of the households with $\rho = 2$ have done so. Nevertheless, by age 35, all the less risk-averse investors have also paid the fixed cost. Moreover, as shown in figure 4.3, the reduction in risk aversion generates counterfactually high equity holdings for those investors that have paid the fixed cost.

5.2.3 The impact of background risk

The previous results illustrate one important trade-off generated by the level of background risk. When faced with more background risk (for example, due to more labor income risk, consumption risk, or housing/mortgage risk) agents will invest a smaller fraction of their financial wealth in risky assets. However, they will also accumulate a larger buffer stock of wealth, thus having a stronger incentive to enter the stock market. We have considered three different experiments in which we have increased the investor's background risk. In the first two we have assumed a higher variance of respectively transitory and permanent labor income shocks, and in the third we have included a positive probability of a disastrous labor income shock. Figure 4.4 shows the results for the case of the first experiment.[24,25] As expected, background risk crowds-out stock holdings and households invest a smaller fraction of their portfolio in equities. However, they also increase their buffer stock of wealth, and as a result the stock market participation rate is higher than before.

[24] The variance of the transitory labor income shocks was increased by a factor of three.

[25] The results for the other two cases are qualitatively identical, and they are available upon request.

5.3 Asset allocation and participation rates with preference heterogeneity

5.3.1 Matching participation rates and conditional asset allocations

Given our previous results, we can simultaneously match stock market participation rates and asset allocation conditional on participation, with moderate degrees of risk aversion, if we allow for preference heterogeneity. Households with very low risk aversion and low EIS smooth idiosyncratic earnings shocks with a small buffer stock of assets, and most of them never invest in equities (thus behaving as in the Deaton (1991) infinite horizon model). This seems to describe adequately the behavior of a large fraction of the U.S. population that retires without significant financial assets (and does not participate in the stock market). Within the low EIS and low risk aversion group, only a small fraction owns stocks, and they do so only as they get close to retirement. On the other hand, investors with high prudence and high EIS are the ones that participate in the stock market from early on, since they accumulate more wealth and therefore have a stronger incentive to pay the fixed cost. Therefore, the marginal stockholders are (endogenously) more risk-averse and as a result they do not invest their portfolios fully in stocks.

In this final section we try to evaluate how much heterogeneity we need to match the data. In other words, can the model consistently explain the two facts for a plausible distribution of preference parameters across the population? Table 4 reports participation rates and average equity shares for stock market participants, for different distributions, and compares them with the empirical evidence from the SCF (panel 1). We first consider a 50% split between investors with both low risk aversion and low EIS ($\rho = 1.2$ and $\psi = 0.2$), and investors with moderate risk aversion and moderate EIS ($\rho = 5$ and $\psi = 0.5$). The model delivers a participation rate of 52.1% and an equity share of 54.5% for stock market participants, which matches fairly well with the empirical evidence reported in section 2 (and summarized in the first panel of table 4).

It is important to mention that this form of heterogeneity is consistent with the existing empirical evidence. Attanasio, Banks and Tanner (2002) show that the CRRA coefficient is much higher (thus much lower EIS) for non-stockholders than for stockholders. Vissing-

Jørgensen (2002a) focusses on this distinction and argues that "accounting for limited asset market participation is crucial for obtaining consistent estimates of the EIS" (p. 827). Vissing-Jørgensen then obtains estimates of the EIS greater than 0.3 for risky asset holders, while for the remaing households the EIS estimates are small and insignificantly different from zero. Vissing-Jørgensen and Attanasio (2003) further stress that loosening the link between risk aversion and intertemporal substitution can generate implications about the covariance of stock returns and individual consumption growth for stockholders that are not rejected in the data. They offer risk aversion estimates for stockholders at around 5-10 and EIS estimates around one. Overall, the existing estimates of EIS and risk aversion are consistent with the values that we use in this paper.

5.3.2 Life-cycle profiles

We now report the life-cycle profiles of stock market participation and asset allocation implied by the model. As argued in section 2, in the data these profiles are not very robust to specific assumptions about cohort or time effects. As a result, in this paper we have mostly focused on life-cycle averages.

Figure 5.1 plots the stock market participation rate implied by the model for different age groups, together with the corresponding numbers from the SCF (see appendix C for details), while figure 5.2 does the same but now for the average asset allocation of stock market participants. The participation rates are extremely similar, with the largest difference occurring at retirement when the participation rate in the data declines while it remains constant in the model. However, as shown in figure 1.2, this is exactly one of the results that is not robust to the assumption of cohort dummies versus time dummies. With respect to the asset allocation decisions, we do observe a more significant difference, in this case for young households. In the model these agents invest a significant fraction of their portfolio in equities while in the data, regardless of the controls, this does not happen.

5.3.3 Sensitivity analysis and robustness

So far we have assumed that households start at age 20 with zero initial wealth since we have seen in section 5.1.3 that, if we use an initial wealth distribution calibrated from the SCF, the results remain virtually unchanged for $\rho = 5$. However, this is unlikely to be case for investors with low risk aversion and low EIS since they save very little. By giving these households some positive initial wealth, we are likely to see an increase in stock market participation rates. In the third panel of table 4 we show that this effect is not too large, and we can replicate the previous results by considering a slightly lower value of risk aversion: $\rho = 1.1$.[26]

It is important to point out that we do not need to assume a very low value of the EIS to generate large non-participation, since we can compensate for a higher ψ by decreasing risk aversion even further. This is shown in the fourth panel of table 4, where we fix the EIS coefficient equal to 0.5 for both types of investors. To reproduce the results in the first panel, we find that we need to decrease ρ to 1.07 for the less risk-averse group.

Given our previous discussion, we know that households with risk aversion between 1.5 and 4 will tend to participate in the stock market from early on, and invest almost all of their wealth in stocks. Naturally, it is not reasonable to assume that the distribution of coefficients of risk aversion mysteriously collapses to the two extremes that we have previously considered (1.2 and 5). In the fifth panel of table 4 we now consider a smoother distribution, with ρ ranging from 1 to 5. It is important to point out that this is not a uniform distribution, as there is a slightly higher fraction of less risk-averse households. If we want to match both facts simultaneously, with a (relatively) smooth distribution, we need it to exhibit some negative skewness. As predicted, both the participation rate and the equity share are now higher than before but not significantly so. The equity share is now 57%, while the participation rate is equal to 57%, numbers that are still extremely close to the empirical evidence (panel 1).

[26] Alternatively we could consider a lower value of the EIS. With $\psi = 0.1$ we would again obtain very similar results.

5.4 Wealth Distribution

In this section we compare the wealth accumulation predicted by the model, with the empirical evidence in the SCF. Given the (exogenous) differences in the preference parameters and the (endogenous) differences in the participation decision, our model generates a large degree of heterogeneity in wealth accumulation. To illustrate, we compare both median wealth accumulation and the extremes of the distribution ($10th$ and $90th$ percentiles) to see if the model generates the degree of heterogeneity observed in the SCF. We divide households in the three usual age groups: buffer stock savers ($20-35$), retirement savers ($36-65$) and retirees (over 66).

The results are shown in table 5. The model can replicate the low wealth accumulation patterns of the poorer households in the data. Households with the lowest income realizations tend not to participate in the stock market and accumulate very little wealth over the life-cycle. This is consistent with the results in Hubbard, Skinner and Zeldes (1995) who illustrate in a similar model how the presence of social insurance (pensions) can crowd out private saving over the life cycle for the poorest quintile of the wealth distribution. Nevertheless, in the SCF these households still accumulate some non-negligible wealth during retirement, something that does not happen in the model. For the median household, the model does quite well early in life, it overshoots for the second age group, and undershoots at retirement. Finally, at the high-end of the distribution we can generate extremely large wealth accumulation, although not quite as high as in the data. This difference is most significant during the retirement period and early in life. Overall the degree of heterogeneity in the wealth distribution is comparable to the one observed in the data. The model consistently generates low wealth accumulation at retirement, which would suggest the presence of a stronger bequest motive but, as shown in section 5.1.3, a stronger bequest motive also increases wealth accumulation at mid-life.

In the final panel of table 5 we simulate the model with the initial distribution of wealth calibrated from the SCF. The results are almost identical to the previous ones: we only observe a minor increase in wealth accumulation at the 90^{th} percentile.

6 Conclusion

In this paper we present a life-cycle asset allocation model with realistically calibrated uninsurable labor income risk, that provides an explanation for two very important empirical observations: low stock market participation rates in the population as a whole, and moderate equity holdings for stock market participants. We do not rely on high values of risk aversion, or on extreme assumptions about background risk.

In our model households with very low risk aversion and low EIS, accumulate very little wealth and as a result (most of them) never invest in equities. On the other hand, the more prudent investors are the ones that participate in the stock market from early on, as they accumulate more wealth and therefore have a stronger incentive to pay the fixed entry cost. Therefore, the marginal stockholders are (endogenously) more risk-averse and as a result they do not invest their portfolios fully in stocks. On the negative side the model still counterfactually predicts that, young households that have already paid the participation cost, will invest most of their portfolio in equities.

Appendix A: Numerical Solution Method

We first simplify the solution by exploiting the scale-independence of the maximization problem and rewriting all variables as ratios to the permanent component of labor income (P_{it}). The laws of motion and the value function can then be rewritten in terms of these normalized variables, and we use lower case letters to denote them (for instance, $x_{it} \equiv \frac{X_{it}}{P_{it}}$). This allows us to reduce the number of state variables to three; one continuous state variable (cash on hand, x_{it}) and two discrete state variables (age, t, and participation status, whether the fixed cost has been paid or not). We discretize the state-space along the cash-on-hand dimension (the only continuous state variable), so that the relevant policy functions can now be represented on a numerical grid.

We solve the model using backward induction. For every age t prior to T, and for each point in the state space, we optimize using grid search. So we need to compute the value associated with each level of consumption, the decision to pay the fixed cost, and the share of liquid wealth invested in stocks. From the Bellman equation, these values are given as current utility plus the discounted expected continuation value ($E_t V_{t+1}(.,.)$), which we can compute once we have obtained V_{t+1}. In the last period the policy functions are determined by the bequest motive and the value function corresponds to the bequest function, regardless of whether the fixed cost has been paid before or not. This gives us the terminal condition for our backward induction procedure. We perform all numerical integrations using Gaussian quadrature to approximate the distributions of the innovations to the labor income process and the risky asset returns. We evaluate the value function, for points which do not lie on state space grid, using a cubic spline interpolation.

Once we have computed the value of all the alternatives we just pick the maximum, thus obtaining the policy rules for the current period (S_t and B_t). At each point of the state space, the participation decision is computed by comparing the value function conditional on having paid the fixed cost (adjusting for the payment of the cost itself) with the value function conditional on non-payment. Substituting these decision rules in the Bellman equation we obtain this period's value function ($V_t(.,.)$), which is then used to solve the previous period's maximization problem. This process is iterated until $t = 1$.

Appendix B: Computing the Transition Distributions

To find the distribution of cash on hand, we first compute the relevant optimal policy rules; bond and stock policy functions for stock market participants and non-participants and the $\{0,1\}$ participation rule as a function of cash on hand. Let $b^I(x)$ and $s^I(x)$ denote respectively the bonds and stock policy rules for individuals participating in the stock market, and let $b^O(x)$ be the savings decision for the individual out of the stock market. We assume that households start their working life with zero liquid assets. During working life, for the households that have not paid the fixed cost, the evolution of normalized cash on hand is given by[27]

$$\begin{aligned} x_{t+1} &= [b^O(x_t)R_f]\left\{\frac{P_t}{P_{t+1}}\frac{\exp(f(t,Z_t))}{\exp(f(t+1,Z_{t+1}))}\right\} + (1-h_{t+1})U_{t+1} \\ &= w\left(x_t|\frac{P_t}{P_{t+1}},\frac{\exp(f(t,Z_t))}{\exp(f(t+1,Z_{t+1}))}\right) + (1-h_{t+1})U_{t+1} \end{aligned} \tag{21}$$

where $w(x)$ is defined by the last equality and is conditional on $\{\frac{P_t}{P_{t+1}}\}$ and the deterministically evolving $\frac{\exp(f(t,Z_t))}{\exp(f(t+1,Z_{t+1}))}$. Denote the transition matrix of moving from x_j to x_k,[28] conditional on not having paid the fixed cost as T^O_{kj}. Let Δ denote the distance between the equally spaced discrete points of cash on hand. The random permanent shock $\frac{P_t}{P_{t+1}}$ is discretized using Gaussian quadrature with H points: $\frac{P_t}{P_{t+1}} = \{N_m\}_{m=1}^{m=H}$. $T^O_{kj} = \Pr(x_{t+1=k}|x_{t=j})$ is found using[29]

$$\sum_{m=1}^{m=H} \Pr\left(x_{t+1}|x_t,\frac{P_t}{P_{t+1}} = N_m\right) * \Pr\left(\frac{P_t}{P_{t+1}} = N_m\right) \tag{22}$$

Numerically, this probability is calculated using

$$T^O_{kjm} = \Pr\left(x_k + \frac{\Delta}{2} \geqslant x_{t+1} \geqslant x_k - \frac{\Delta}{2}|x_t = x_j, \frac{P_t}{P_{t+1}} = N_m\right) \tag{23}$$

Making use the approximation that for small values of σ_u^2, $U \sim N(\exp(\mu_u + .5*\sigma_u^2), (\exp(2*\mu_u + (\sigma_u^2))*(\exp(\sigma_u^2)-1)))$, and denoting the mean of $(1-h_t)U$ by $\overline{U}$ and its standard

[27] To avoid cumbersome notation, the subscript i that denotes a particular individual is omitted in what follows.

[28] The normalized grid is discretized between $(x\min, x\max)$ where $x\min$ denotes the minimum point on the equally spaced grid and $x\max$ the maximum point.

[29] The dependence on the determinastically evolving $\frac{\exp(f(t,Z_t))}{\exp(f(t+1,Z_{t+1}))}$ is implied and is omitted from what follows for expositional clarity.

deviation by σ, the transition probability conditional on N_m equals

$$T^O_{kjm} = \Phi\left(\frac{x_k + \frac{\Delta}{2} - w(x_t|N_m) - \overline{U}}{\sigma}\right) - \Phi\left(\frac{x_k - \frac{\Delta}{2} - w(x_t|N_m) - \overline{U}}{\sigma}\right) \tag{24}$$

where Φ is the cumulative distribution function for the standard normal. The unconditional probability from x_j to x_k is then given by

$$T^O_{kj} = \sum_{m=1}^{m=H} T^O_{kjm} \Pr(N_m) \tag{25}$$

Given the transition matrix $\mathbf{T}^O$ (letting the number of cash on hand grid points equal to J, this is a J by J matrix; T^O_{kj} represents the {kth,jth} element), the next period probabilities of each of the cash on hand states can be found using

$$\pi^O_{kt} = \sum_j T^O_{kj} * \pi^O_{jt-1} \tag{26}$$

We next use the vector $\mathbf{\Pi}^O_t$ (this is a J by 1 vector representing the mass of the population out of the stock market at each grid point; π^O_{kt} represents the {kth} element at time t) and the participation policy rule to determine the percentage of households that optimally choose to incur the fixed cost and invest in risky assets. This is found by computing the sum of the probabilities in $\mathbf{\Pi}^O_t$ for which $x > x^*$, x^* being the trigger point that causes participation (x^* is determined endogenously through the participation decision rule). These probabilities are then deleted from $\mathbf{\Pi}^O_t$ and are added to $\mathbf{\Pi}^I_t$, appropriately renormalizing both $\{\mathbf{\Pi}^O_t, \mathbf{\Pi}^I_t\}$ to sum to one. The participation rate (θ_t) can be computed at this stage as

$$\theta_t = \theta_{t-1} + (1 - \theta_{t-1}) * \sum_{x_j > x^*} \pi^O_{t,j} \tag{27}$$

The same methodology (but with more algebra and computations) can then be used to derive the transition distribution for cash on hand conditional on having paid the fixed cost, $\mathbf{T}^I_t$. The corresponding normalized cash on hand evolution equation is

$$\begin{aligned} x_{t+1} &= [b(x_t)R^f + s(x_t)R^S_{t+1}]\left\{\frac{P_t}{P_{t+1}}\frac{\exp(f(t, Z_t))}{\exp(f(t+1, Z_{t+1}))}\right\} + (1 - h_{t+1})U_{t+1} \\ &= w\left(x_t|R^S_{t+1}, \frac{P_t}{P_{t+1}}\right) + (1 - h_{t+1})U_{t+1} \end{aligned} \tag{28}$$

where $w(x)$ is now conditional on $\{R^S_{t+1}, \frac{P_t}{P_{t+1}}\}$[30]. The random processes $R^S_{t+1}$and $\frac{P_t}{P_{t+1}}$ are discretized using Gaussian quadrature with H points: $R^S_{t+1} = \{R^S_l\}_{l=1}^{l=H}$ and $\frac{P_t}{P_{t+1}} = \{N_n\}_{n=1}^{n=H}$. $T^I_{kj} = \Pr(x_{t+1=k}|x_{t=j})$ is obtained from

$$\sum_{l=1}^{l=H}\sum_{n=1}^{n=H} \Pr\left(x_{t+1}|x_t, R^S_{t+1} = R^S_l, \frac{P_t}{P_{t+1}} = N_n\right) * \Pr(R^S_l) * \Pr(N_n) \tag{29}$$

where $\Pr(R^S_l)$ and $\Pr(N_n)$ stand respectively for $\Pr(R^S_{t+1} = R^S_l)$ and $\Pr\left(\frac{P_t}{P_{t+1}} = N_n\right)$, and where the independence between $\frac{P_t}{P_{t+1}}$ and R^S_{t+1} was used.[31] Numerically, this probability is calculated using

$$T^I_{kjln} = \Pr\left(x_k + \frac{\Delta}{2} \geqslant x_{t+1} \geqslant x_k - \frac{\Delta}{2}|x_t = x_j, \frac{P_{it}}{P_{it+1}} = N_n, R^S_{t+1} = R^S_l\right) \tag{30}$$

The transition probability conditional on N_n, R^S_l and R^B_m equals

$$T^I_{kjln} = \Phi\left(\frac{x_k + \frac{\Delta}{2} - w(x_t|N_n, R^S_l) - \overline{U}}{\sigma}\right) - \Phi\left(\frac{x_k - \frac{\Delta}{2} - w(x_t|N_n, R^S_l) - \overline{U}}{\sigma}\right) \tag{31}$$

The unconditional probability from x_j to x_k is then given by

$$T^I_{kj} = \sum_{l=1}^{l=H}\sum_{n=1}^{n=H} T^I_{kjln} \Pr(R^S_l) \Pr(N_n) \tag{32}$$

Given the matrix $\mathbf{T}^I$, the probabilities of each of the states are updated by

$$\pi^I_{kt+1} = \sum_j T^I_{kj} * \pi^I_{jt} \tag{33}$$

[30]The dependence on the non-random earnings component is omitted to simplify notation.

[31]The methodology can be applied for an arbitrary correlation structure between the stock market and permanent shock innovation using the Choleski decomposition of the variance-covariance matrix of the innovations.

Appendix C: Survey of Consumer Finances Data

The SCF is probably the most comprehensive source of data on U.S. household assets. The SCF uses a two-part sampling strategy to obtain a sufficiently large and unbiased sample of wealthier households (the rich sample is chosen randomly using tax reports). To enhance the reliability of the data, the SCF makes weighting adjustments for survey non-respondents; these weights were used in computing the values reported in the tables. The specific names in the codebook for the variables used are given below.

We construct a measure of labor income that matches as closely as possible the process for Y_{it} (earnings) in the text. Labor income is therefore defined as the sum of wages and salaries (X5702), unemployment or worker's compensation (X5716) and Social Security or other pensions, annuities, or other disability or retirement programs (X5722). Liquid wealth is variable FIN in the publicly available SCF data set, to which home equity was added. Variable FIN is made up of LIQ (all types of transaction accounts (checking, saving, money market and call accounts)), CDS (certificates of deposit), total directly-held mutual funds, stocks, bonds, total quasi-liquid financial assets (the sum of IRAs, thrift accounts, and future pensions), savings bonds, the cash value of whole life insurance, other managed assets (trusts, annuities and managed investment accounts in which the household has equity interest) and other financial assets: includes loans from the household to someone else, future proceeds, royalties, futures, non-public stock, and deferred compensation. Home equity is defined as the value of the home less the amount still owed on the first and 2nd/3rd mortgages and the amount owed on home equity lines of credit. This definition of wealth is consistent with both the definition in Hubbard, Skinner and Zeldes (1995) and Heaton and Lucas (2000).

Financial assets invested in the risky asset can either be directly-held stock or stock mutual funds or amounts of stock in retirement accounts. We follow the procedures the SCF uses to construct this number for each household (variable EQUITY). Specifically, this is done by computing the full value of stocks, adding the full value if an asset is described as a stock mutual fund, and half the value if the asset refers to a combination of mutual funds. To this, IRAs/Keoghs invested in stock are computed by adding the full value if mostly invested in stock, half the value if split between stocks/bonds or stocks/money market, and one third of the value if split between stocks/bonds/money market. We also add other managed assets with equity interest (annuities, trusts, MIAs) by adding the full value if mostly invested in stock, half the value if split between stocks/MFs & bonds/CDs, or "mixed/diversified" and one third of the value if "other". We also add thrift-type retirement accounts invested in stock: the full value if mostly invested in stock and half the value if split between stocks and interest earning assets. Stock market participation is then determined by checking whether the full value of stocks (EQUITY) is greater than zero (variable HEQUITY).

The share of wealth in stocks conditional on HEQUITY being positive is constructed using (EQUITY)/(FIN) where all the variables have been defined above.

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Table 1: Regression of the ratio of housing expenditures to labor income (he_{it}), on age polynomials and time dummies

	coefficient	t-stat
Constant	0.703998	5.47
Age	-0.0352276	-3.70
Age^2	0.0007205	3.17
Age^3	-0.0000049	-2.84
adj. R^2	0.025	

Notes: Data from the Panel Study of Income Dynamics from 1976 until 1993. For each household, in each year, we compute the ratio of annual mortgage payments plus rent payments relative to annual labor income, and regress this ratio against a constant a cubic polynomial of age (where age is defined as the age of the head of the household) and time dummies. We eliminate all observations with age greater than 75.

Table 2.1: Average Consumption-Wealth Ratio (C/X) for different values of both the coefficient of risk aversion (ρ) and the elasticity of intertemporal substitution (ψ), from age 20 until age 35.

ρ	$\psi = 0.8$	$\psi = 0.5$	$\psi = 0.2$
1	98%	99%	99%
1.2	87%	92%	93%
2	76%	86%	90%
4	61%	67%	75%
5	55%	60%	66%

Table 2.2: Average Consumption-Wealth Ratio (C/X) for different values of both the coefficient of risk aversion (ρ) and the elasticity of intertemporal substitution (ψ), from age 36 until age 65.

ρ	$\psi = 0.8$	$\psi = 0.5$	$\psi = 0.2$
1	98%	99%	99%
1.2	43%	88%	94%
2	18%	35%	67%
4	14%	18%	27%
5	13%	16%	19%

Table 2.3: Average Consumption-Wealth Ratio (C/X) for different values of both the coefficient of risk aversion (ρ) and the elasticity of intertemporal substitution (ψ), from age 66 until age 100.

ρ	$\psi = 0.8$	$\psi = 0.5$	$\psi = 0.2$
1	100%	100%	100%
1.2	88%	100%	100%
2	25%	71%	97%
4	23%	29%	59%
5	25%	26%	47%

Table 3: Wealth distribution (wealth to income ratios) for households with head aged 20 or less. The data are taken from the 2001 Survey of Consumer Finances (details in Appendix C). X defines liquid wealth and Y labor or pension income.

decile	10%	20%	30%	40%	50%	60%	70%	80%	90%
X/Y	0.000	0.015	0.043	0.113	0.167	0.236	0.267	0.406	0.863

Table 4: Average stock market participation rate ($\overline{P}$) and average stock holdings for stock market participants ($\overline{\alpha}_P^S$).

Panel 1- Data from the 2001 Survey of Consumer Finances (details in Appendix C).

$\overline{P}$	$\overline{\alpha}_P^S$
51.94%	54.76%

Panel 2- Distribution: 2 groups of agents, ($\rho = 1.2$ and $\psi = 0.2$) and ($\rho = 5$ and $\psi = 0.5$), with 50% weight each.

$\overline{P}$	$\overline{\alpha}_P^S$
52.14%	54.48%

Panel 3- Distribution: 2 groups of agents, ($\rho = 1.1$ and $\psi = 0.2$) and ($\rho = 5$ and $\psi = 0.5$), with 50% weight each. Initial wealth distribution calibrated from the SCF.

$\overline{P}$	$\overline{\alpha}_P^S$
50.36%	53.32%

Panel 4- Distribution: 2 groups of agents, ($\rho = 1.07$ and $\psi = 0.5$) and ($\rho = 5$ and $\psi = 0.5$), with 50% weight each.

$\overline{P}$	$\overline{\alpha}_P^S$
54.42%	56.24%

Panel 5- Distribution: 3 groups of agents, ($\rho = 1$ and $\psi = 0.2$) and ($\rho = 3$ and $\psi = 0.5$) and ($\rho = 5$ and $\psi = 0.5$), with weights 40%, 30% and 30% respectively.

$\overline{P}$	$\overline{\alpha}_P^S$
56.98%	56.56%

Table 5: Distribution of wealth to labor income ratios (X/Y) from the 2001 Survey of Consumer Finances, for different age groups (appendix C provides more details). X defines liquid wealth and Y labor or pension income.

	20−35	36−65	⩾65
10^{th} percentile	0.002	0.071	0.371
median	0.287	2.170	7.931
90^{th} percentile	2.702	10.648	33.363

Distribution of wealth to income ratios (X/Y) implied by the model, for different age groups.

	20−35	36−65	⩾65
10^{th} percentile	0.006	0.005	0.006
median	0.261	3.115	4.838
90^{th} percentile	0.748	8.184	17.539

Distribution of wealth to income ratios (X/Y) implied by the model, for different age groups (initial wealth calibrated from the SCF).

	20−35	36−65	⩾65
10^{th} percentile	0.006	0.005	0.006
median	0.263	3.116	4.839
90^{th} percentile	0.886	8.371	17.865

Figure 1.1 - Equity Holdings as a Fraction of Total Financial Wealth for Stock Market Participants (Ameriks and Zeldes, 2001 - OLS Regressions)

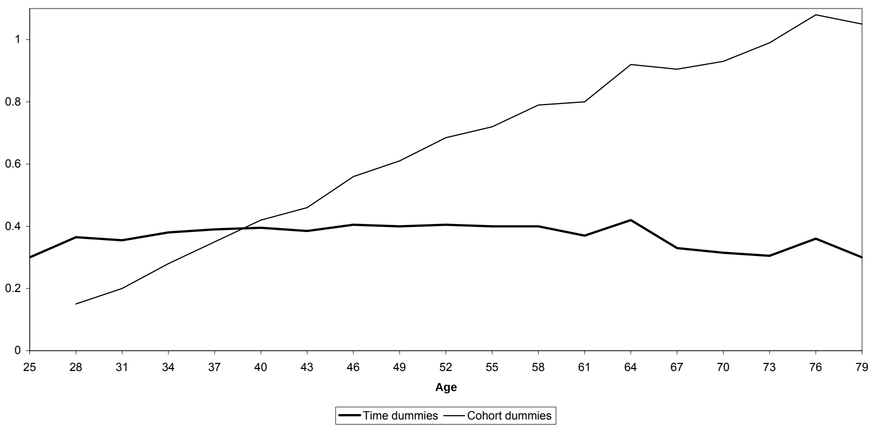


Figure 1.2 - Stock Market Participation (Ameriks and Zeldes, 2001 - Probit Regressions)

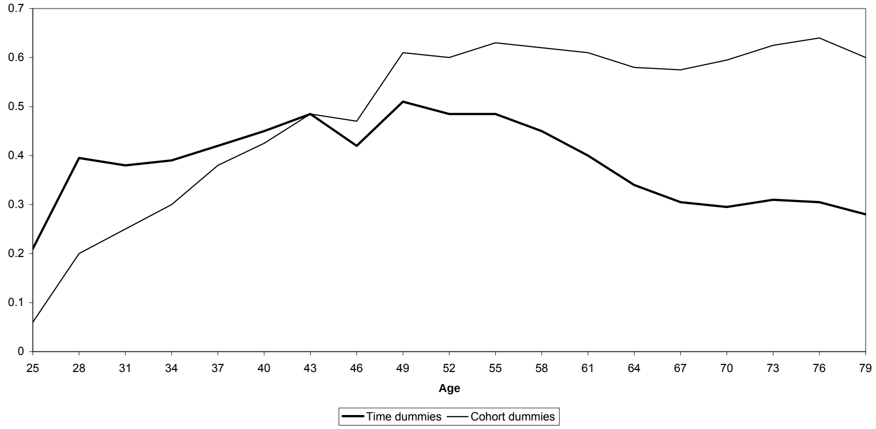


Figure 1.3 - Equity Holdings as a Fraction of Total Financial Wealth, Conditional on Participation (Guiso, Haliassos and Japelli, 2001)

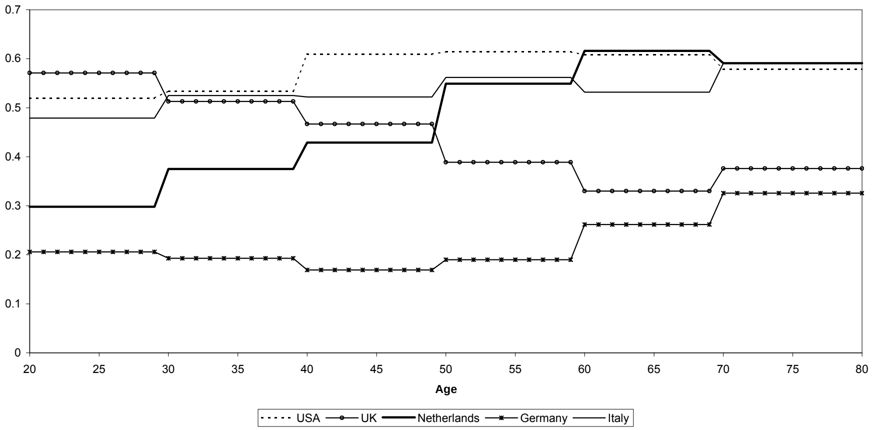


Figure 1.4 - Stock Market Participation (Guiso, Haliassos and Japelli, 2001)

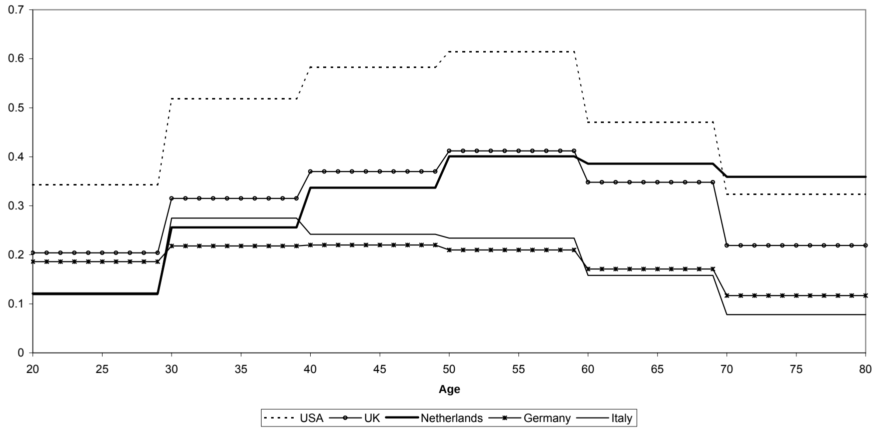


Figure 2.1: Distributions for Normalized Cash on Hand
Model without fixed cost

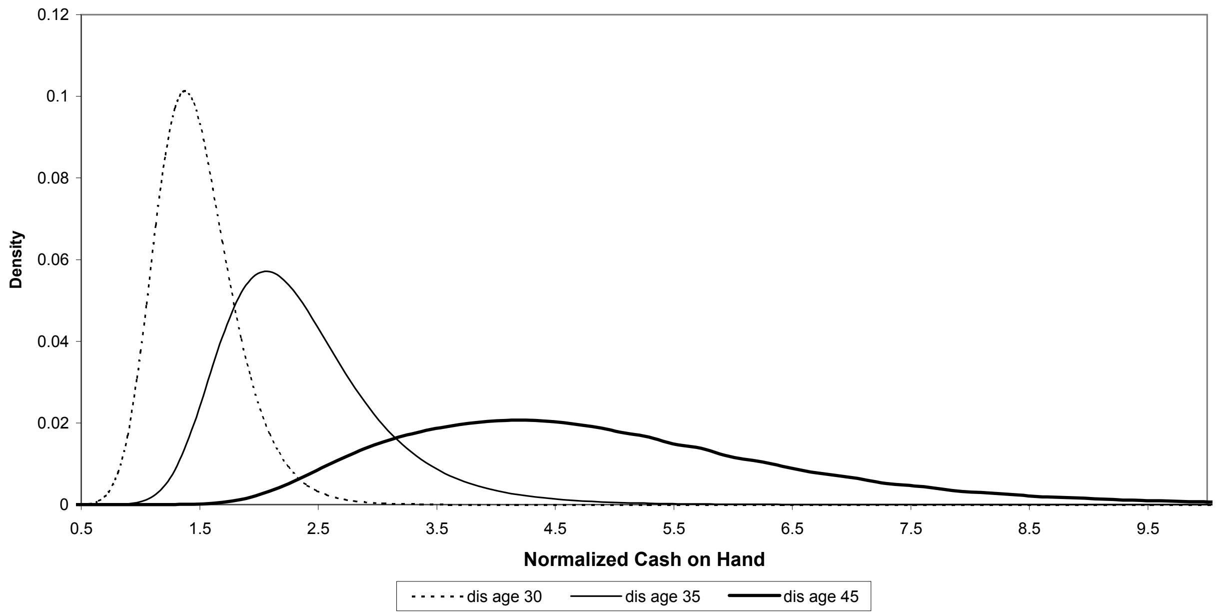


Figure 2.2: Distributions for Normalized Cash on Hand (Retirement stage)
Model without the fixed cost

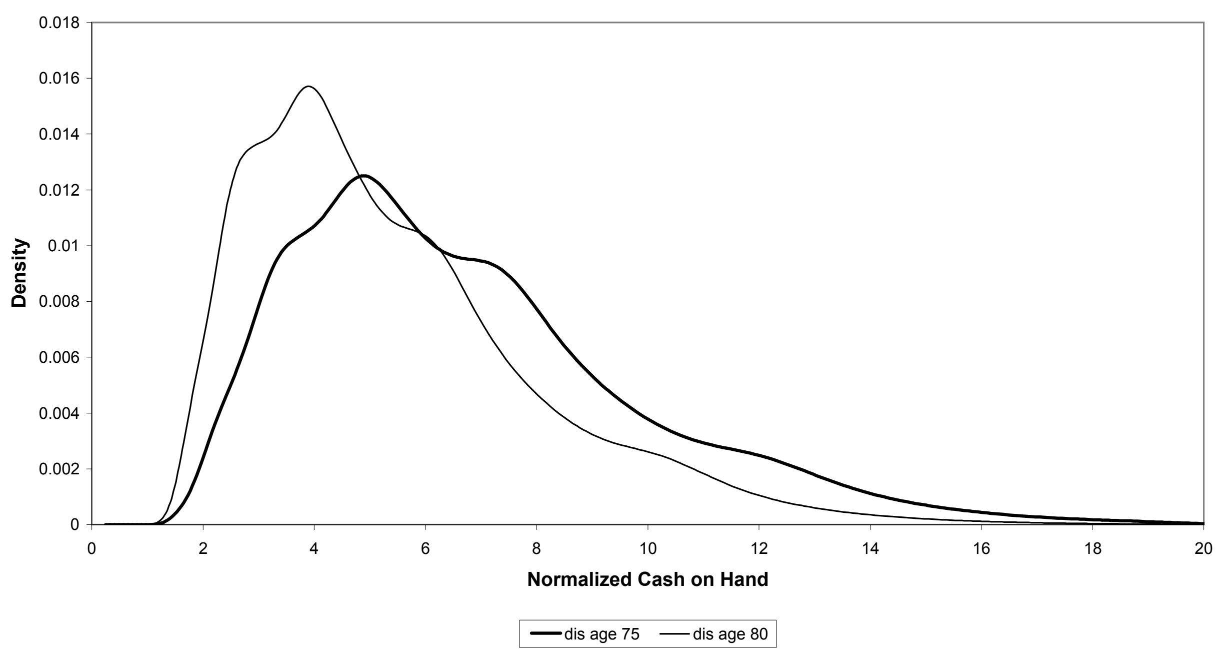


Figure 2.3 - Consumption, Income and Wealth

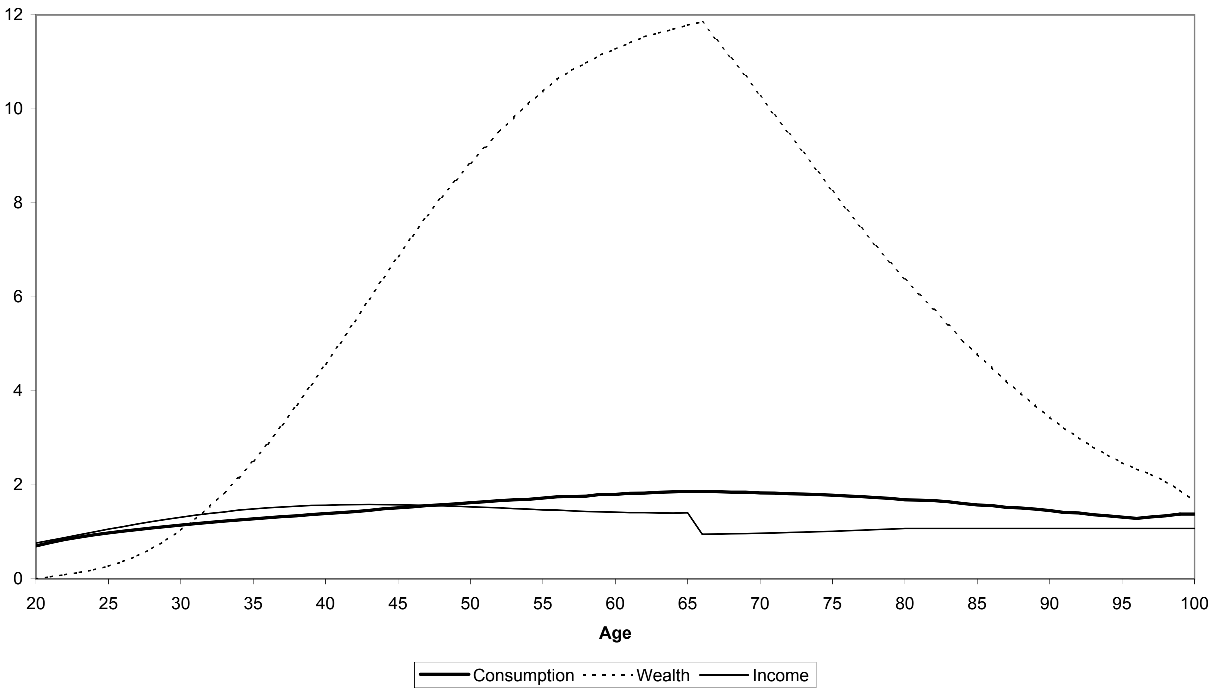


Figure 2.4 - Asset Allocation

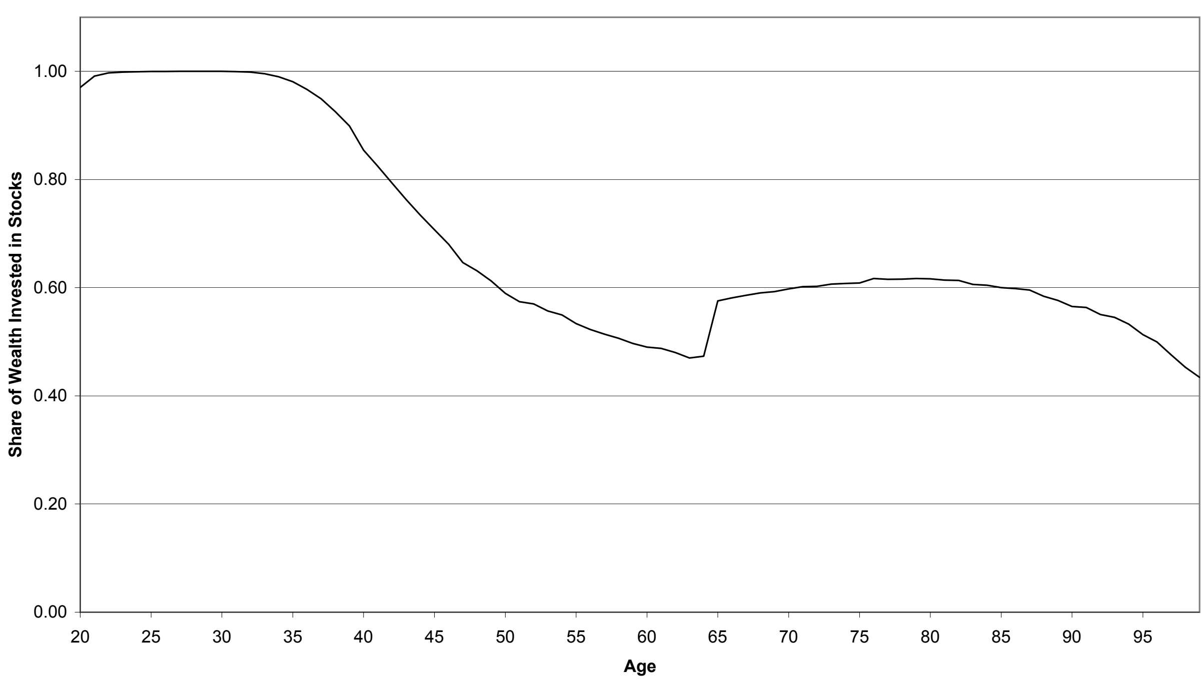


Figure 3.1- Stock Market Participation

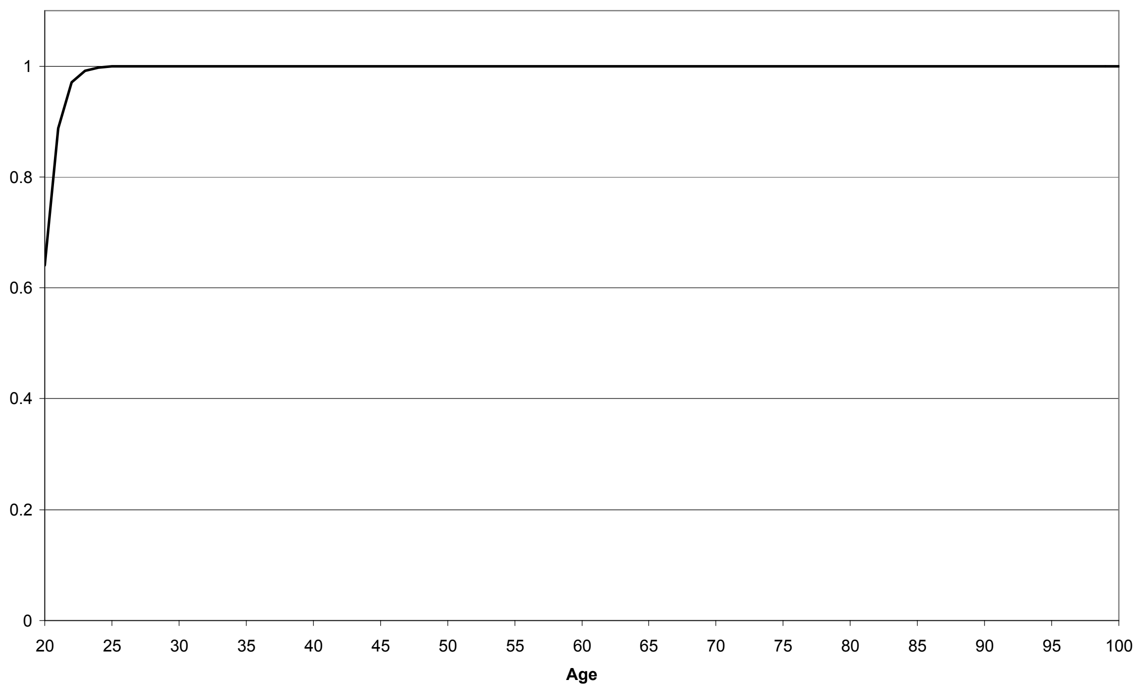
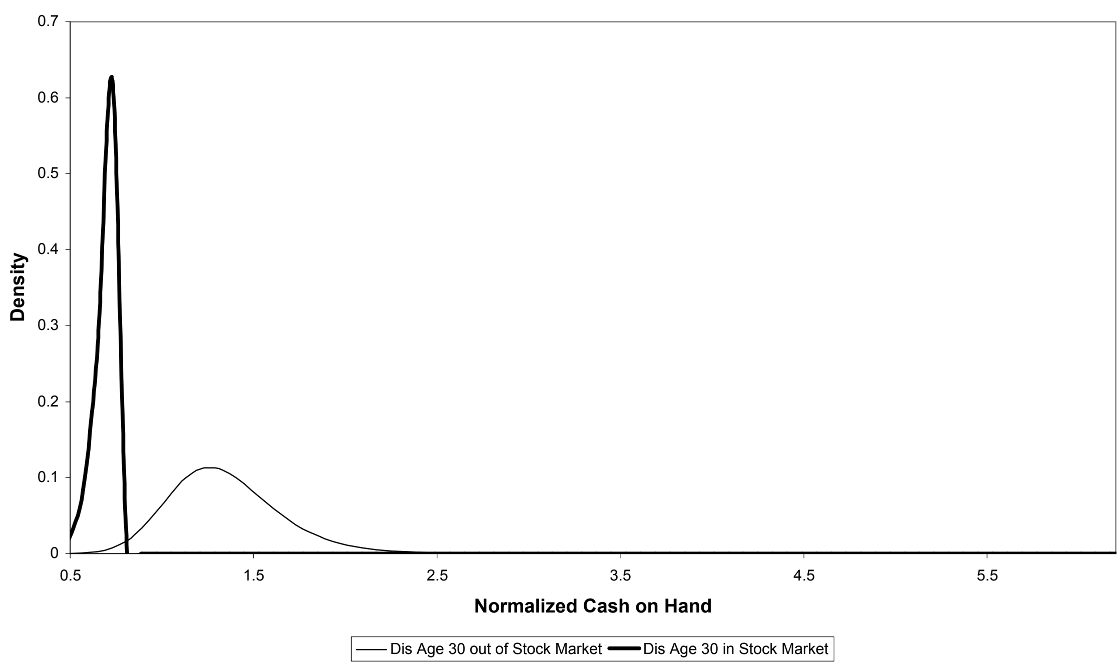


Figure 3.2 : Distributions for Normalized Cash on Hand
Model with the Fixed Cost



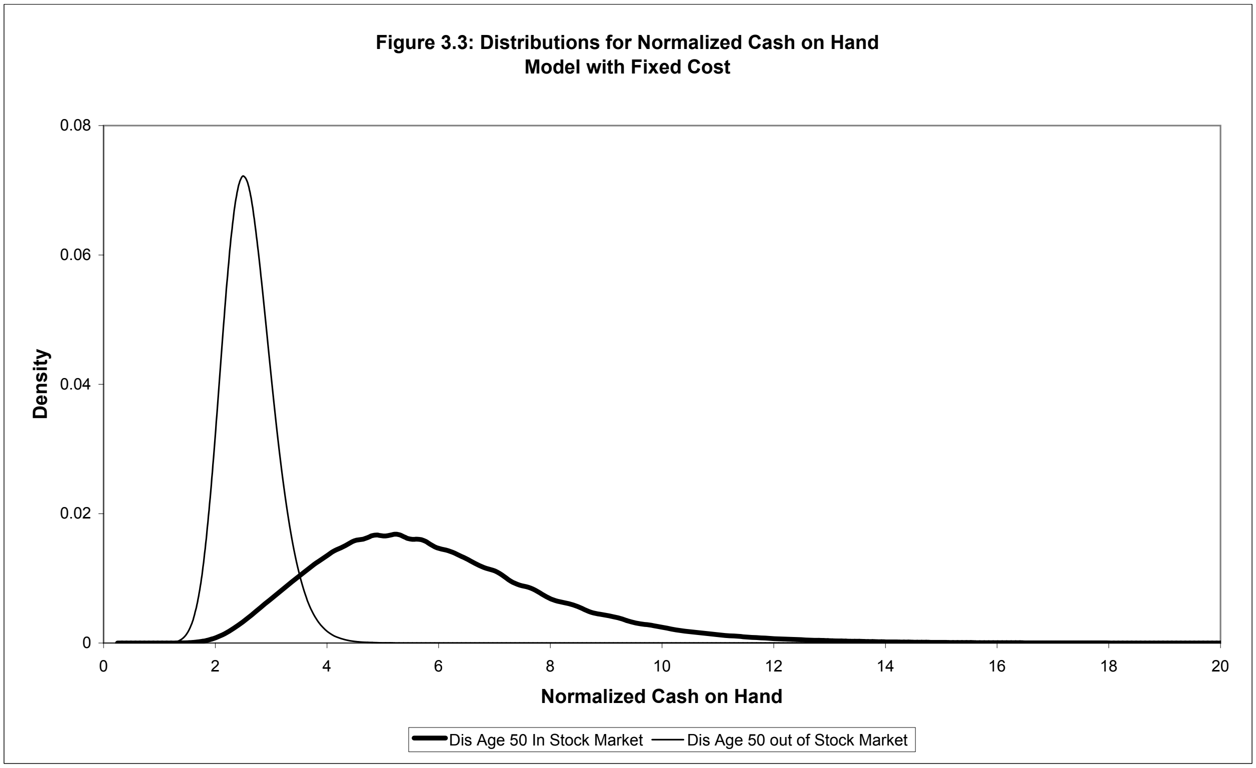


Figure 3.3: Distributions for Normalized Cash on Hand
Model with Fixed Cost
Density
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
18
20
Normalized Cash on Hand
Dis Age 50 In Stock Market
Dis Age 50 out of Stock Market

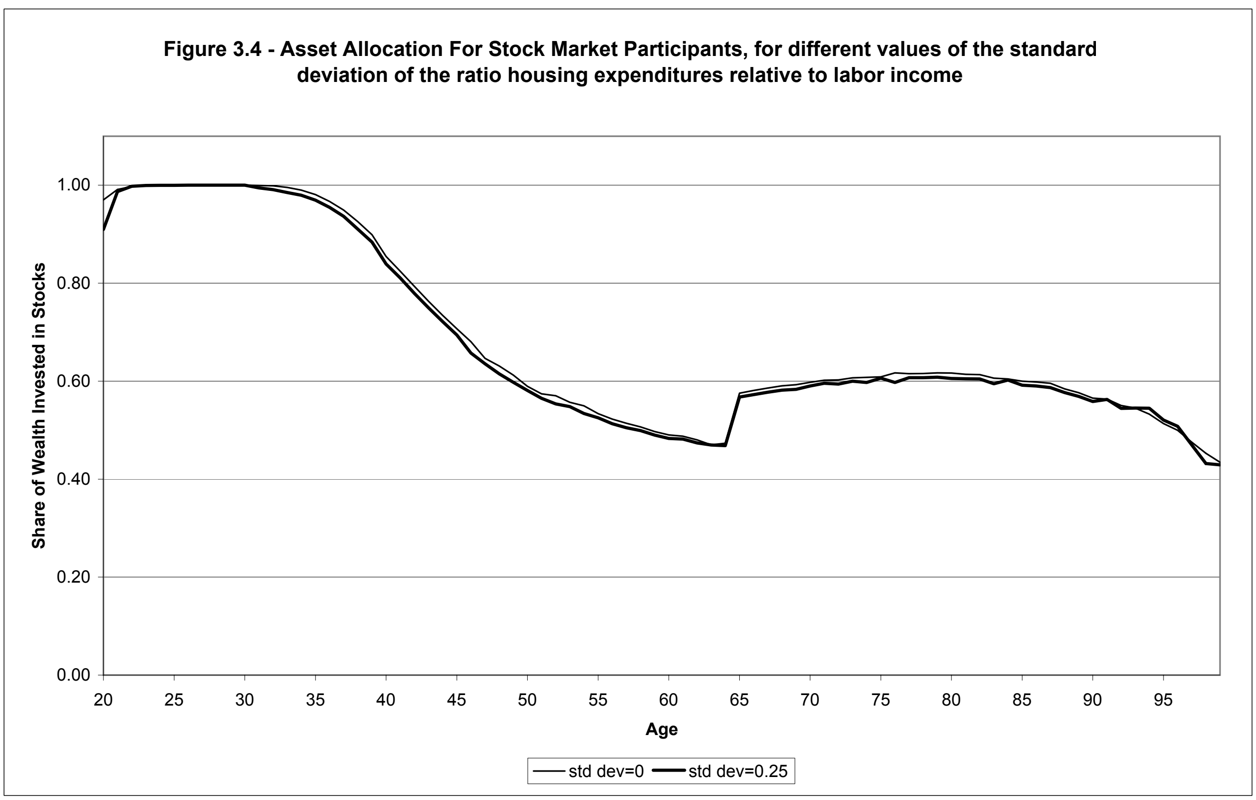


Figure 3.4 - Asset Allocation For Stock Market Participants, for different values of the standard deviation of the ratio housing expenditures relative to labor income
Share of Wealth Invested in Stocks
1.00
0.80
0.60
0.40
0.20
0.00
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Age
std dev=0
std dev=0.25

Figure 3.5 - Wealth accumulation for different values of the bequest parameter

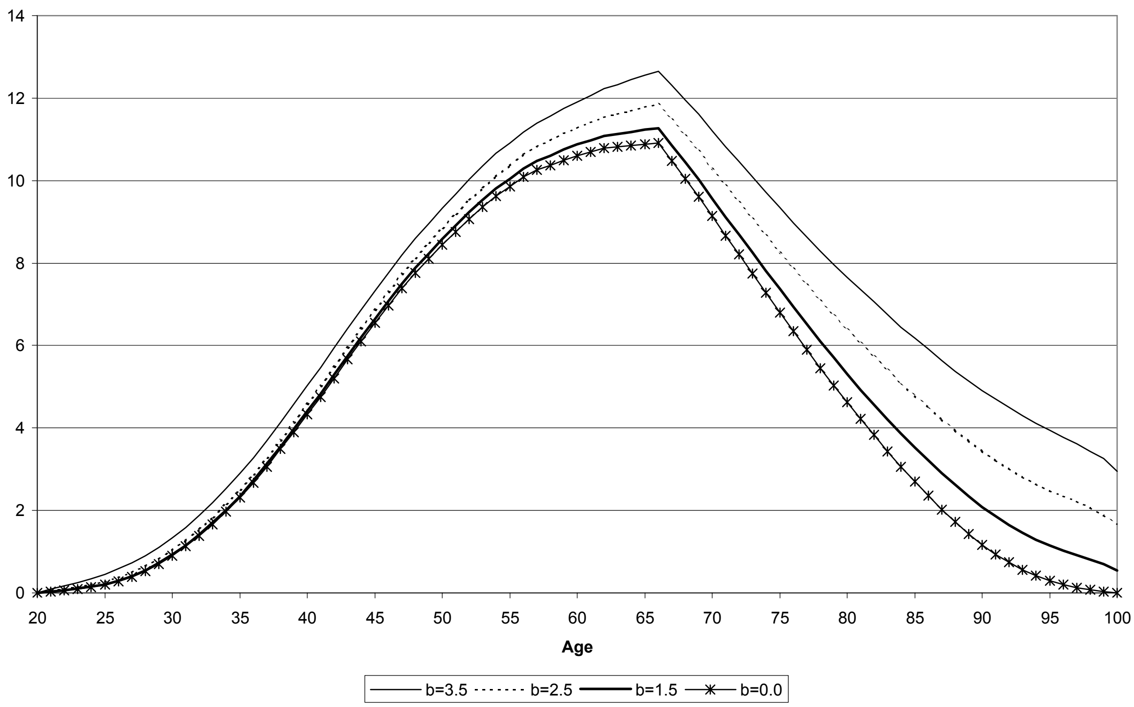
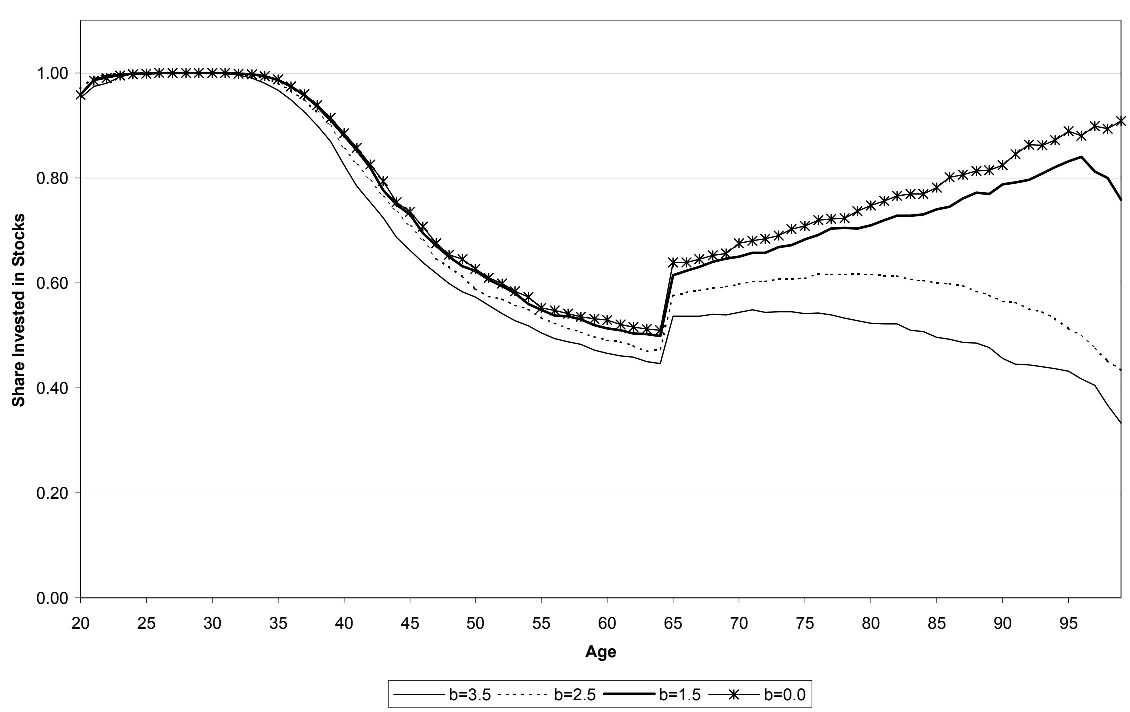


Figure 3.6 - Conditional Asset Allocation for different values of the bequest parameter



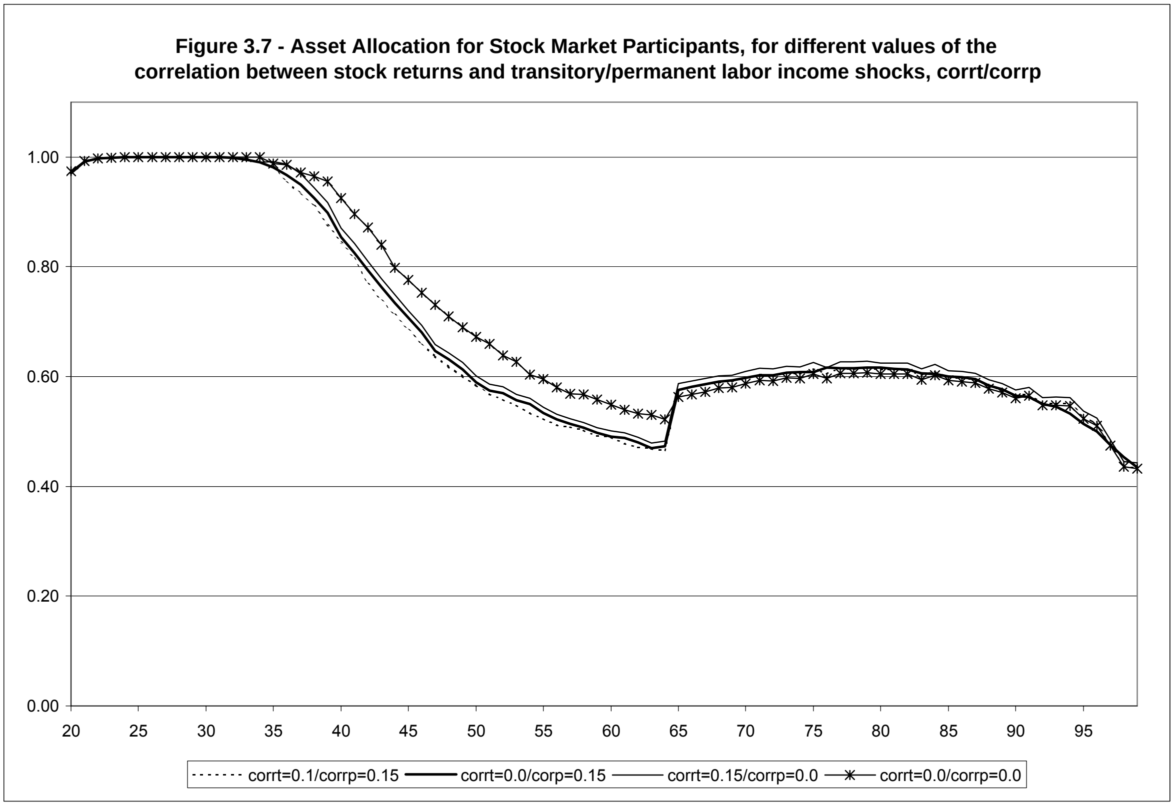


Figure 3.7 - Asset Allocation for Stock Market Participants, for different values of the correlation between stock returns and transitory/permanent labor income shocks, corrt/corrp
1.00
0.80
0.60
0.40
0.20
0.00
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
corrt=0.1/corrp=0.15
corrt=0.0/corrp=0.15
corrt=0.15/corrp=0.0
corrt=0.0/corrp=0.0

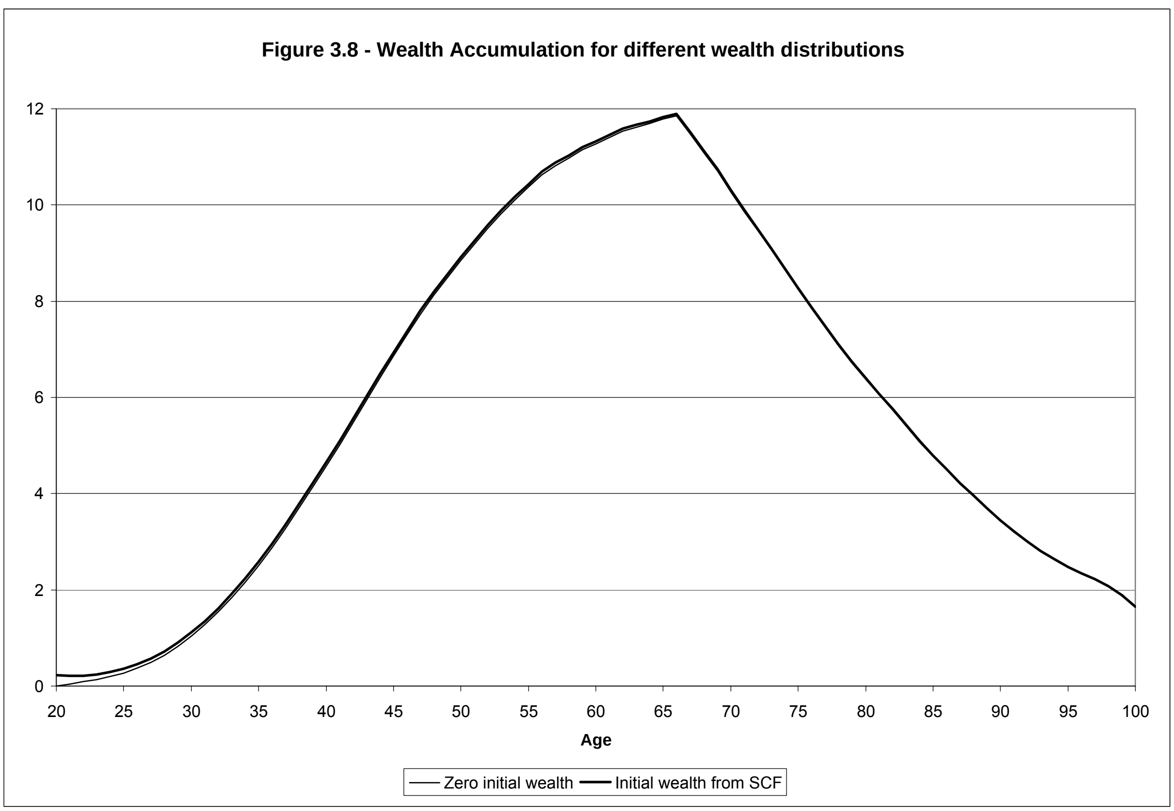


Figure 3.8 - Wealth Accumulation for different wealth distributions
12
10
8
6
4
2
0
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Age
Zero initial wealth
Initial wealth from SCF

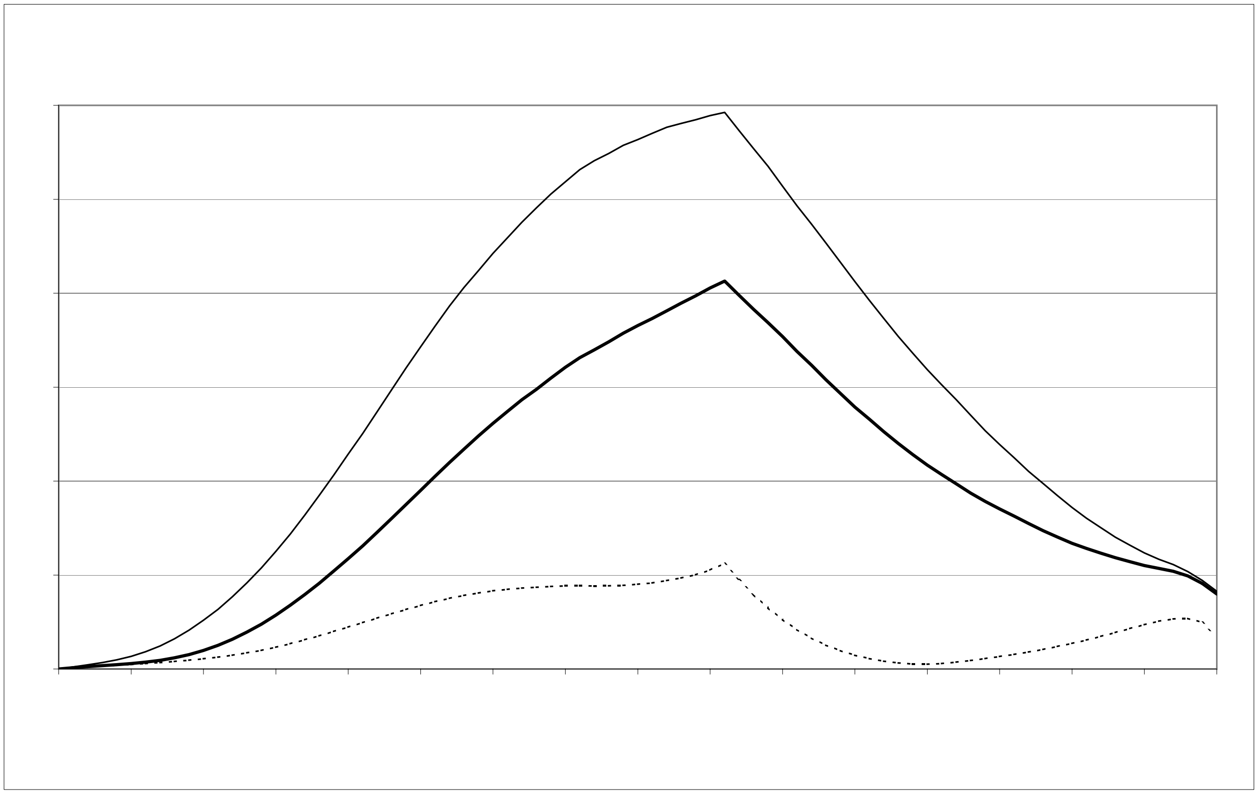


Figure 4.2 - Stock Market Participation for different values of risk aversion

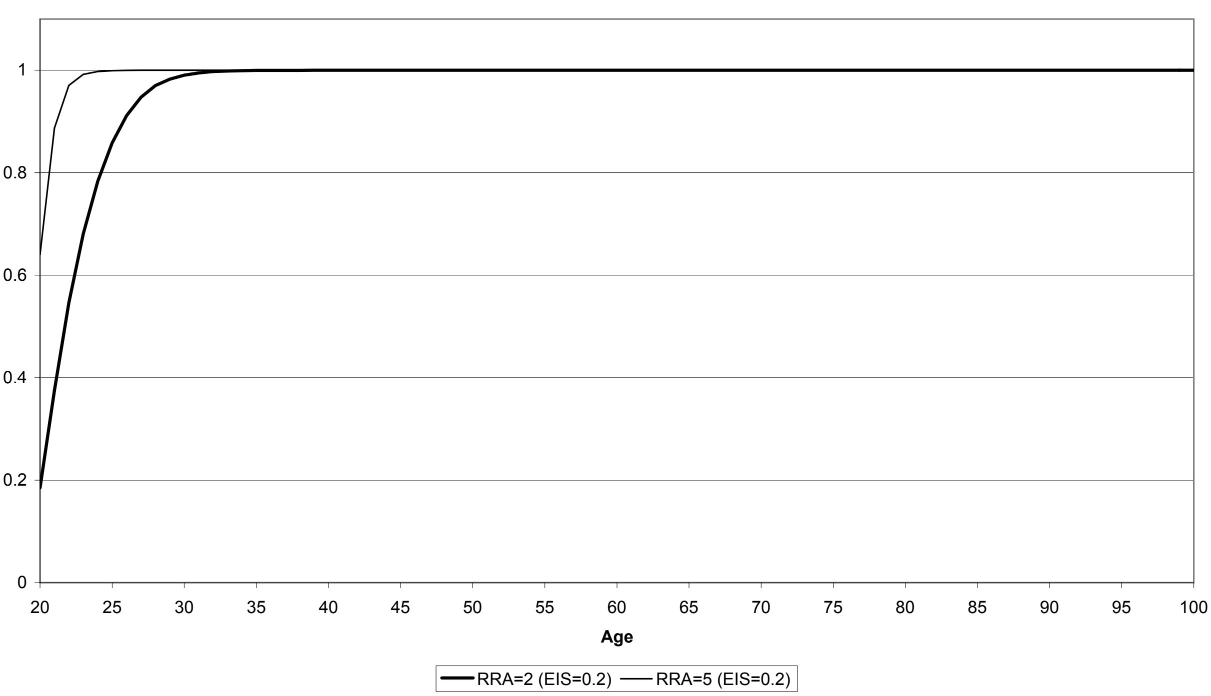


Figure 4.3 - Asset Allocation for Stock Market Participants, for different values of risk aversion

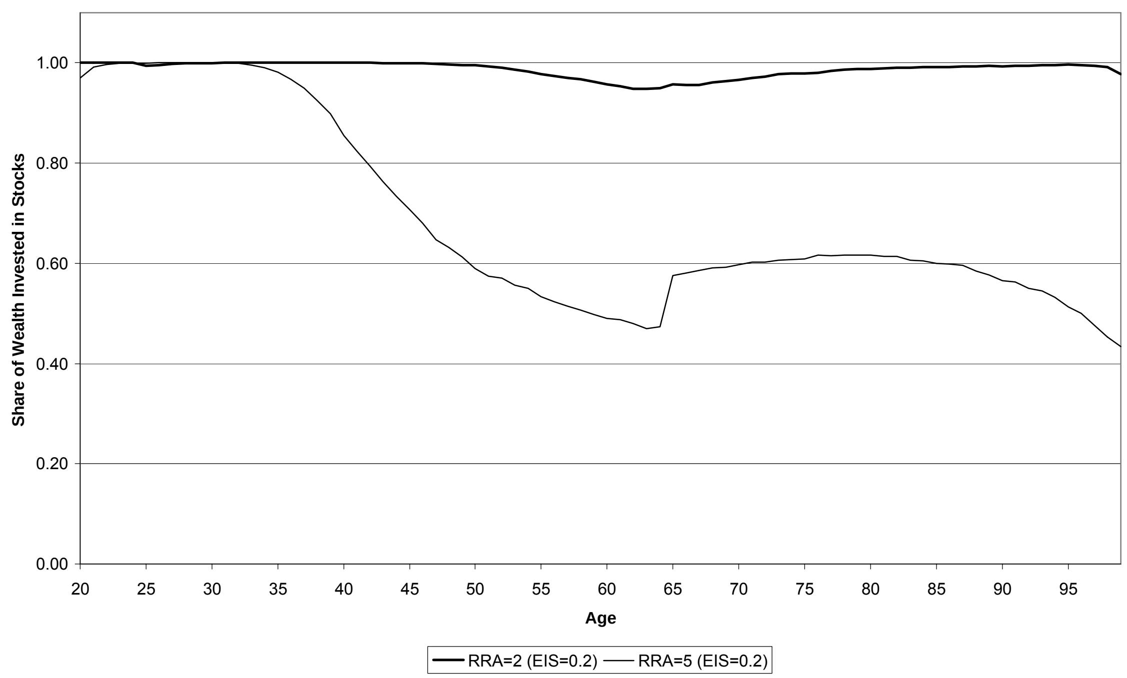
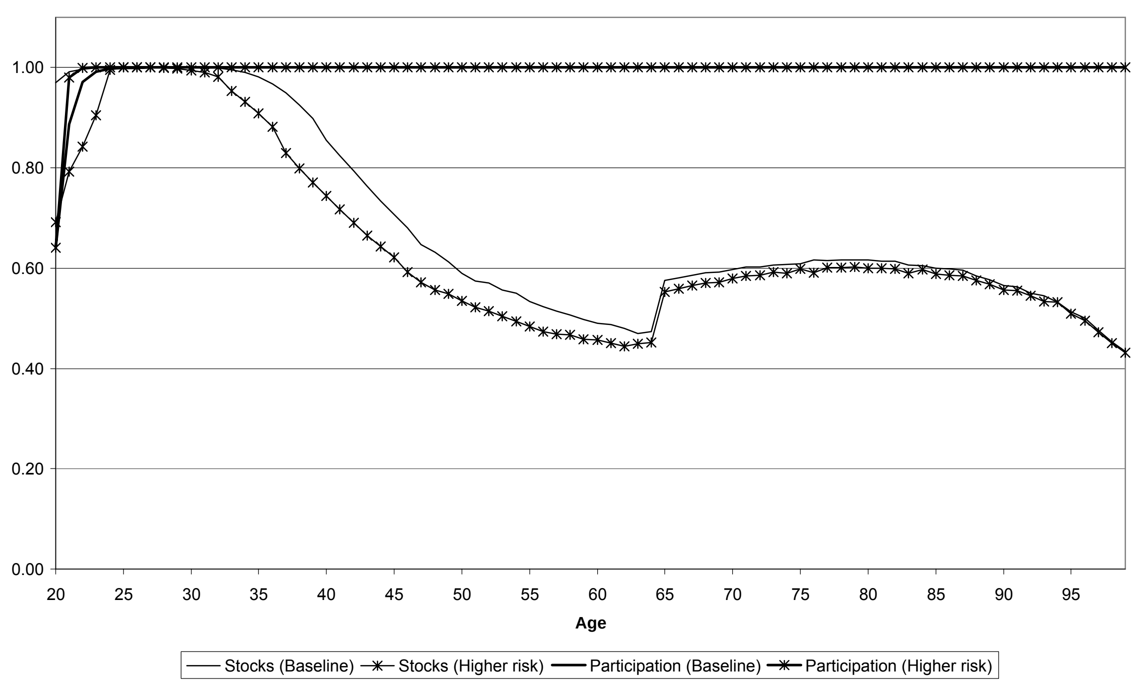


Figure 4.4 - Stock Market Participation Rate and Share of Wealth Invested in Stocks for different levels of background risk



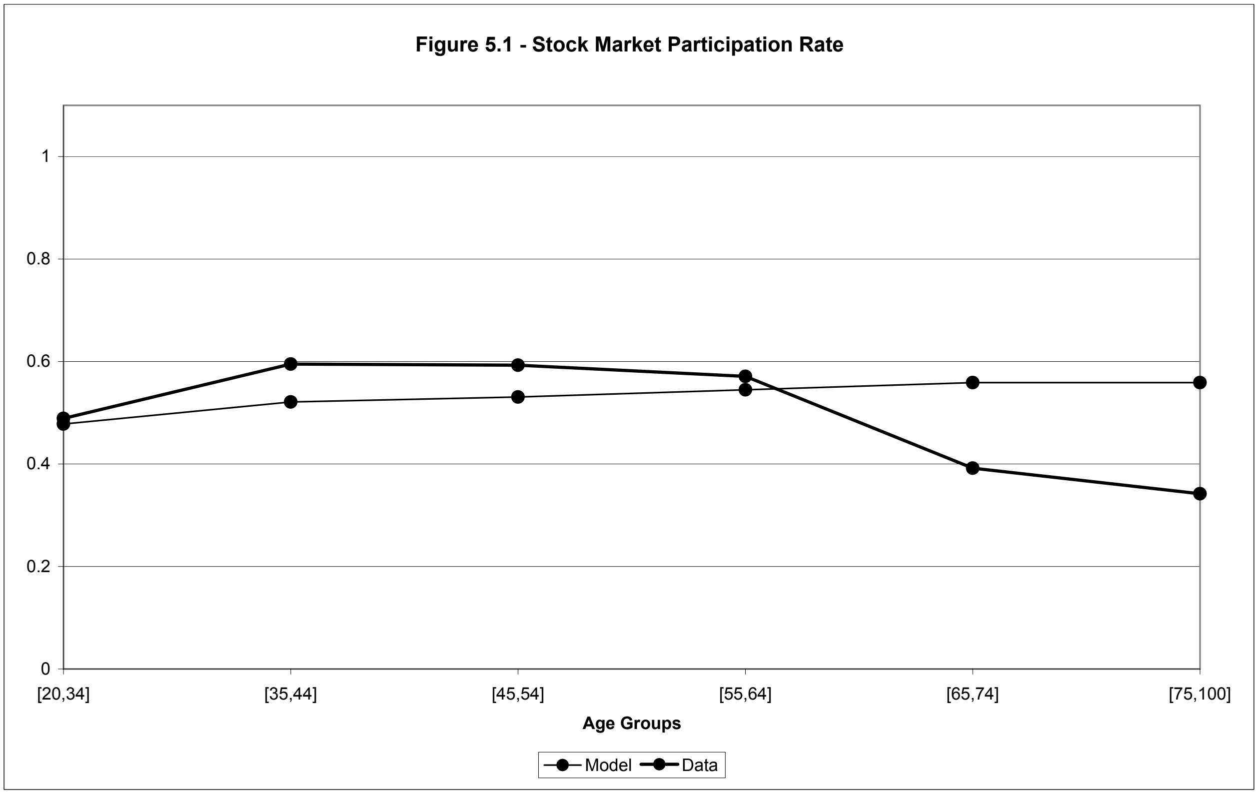


Figure 5.1 - Stock Market Participation Rate
1
0.8
0.6
0.4
0.2
0
[20,34]
[35,44]
[45,54]
[55,64]
[65,74]
[75,100]
Age Groups
Model
Data

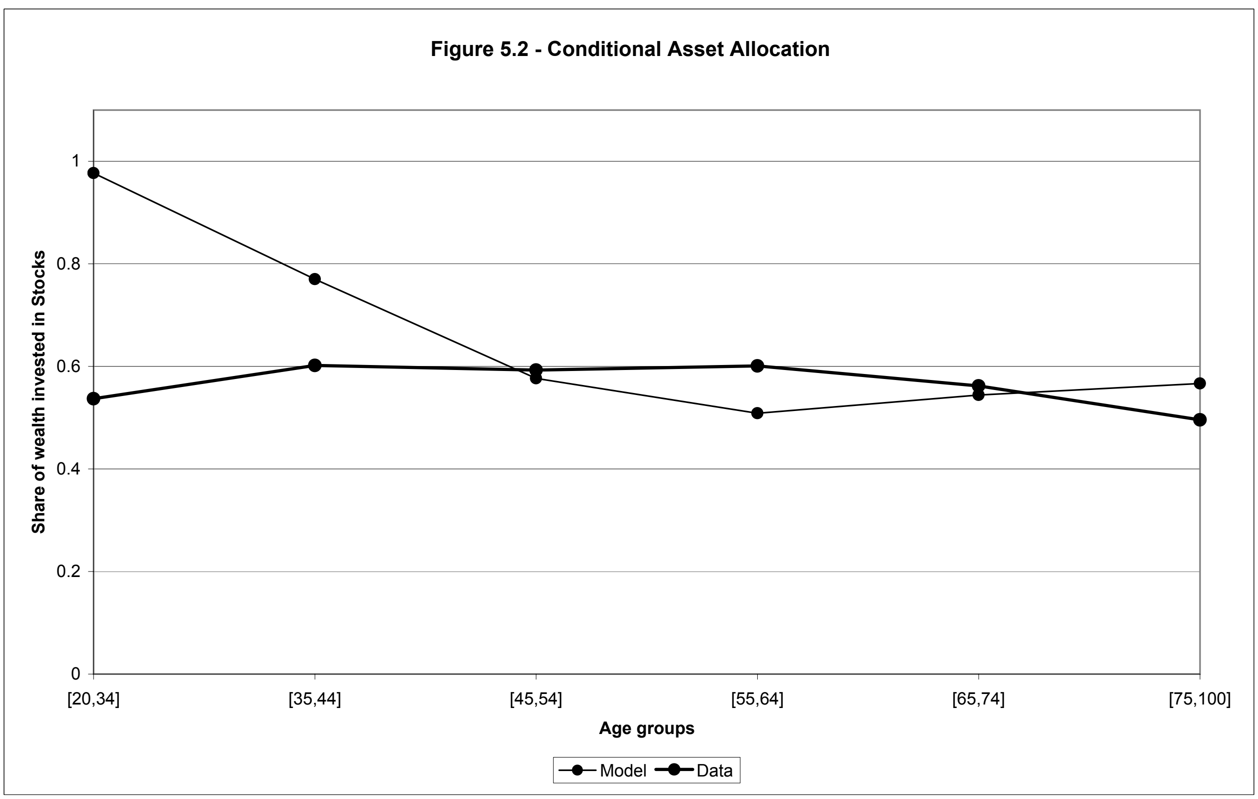


Figure 5.2 - Conditional Asset Allocation
Share of wealth invested in Stocks
1
0.8
0.6
0.4
0.2
0
[20,34]
[35,44]
[45,54]
[55,64]
[65,74]
[75,100]
Age groups
Model
Data