

# On the Asset Allocation of a Default Pension Fund

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## Abstract

We characterize the optimal default fund in a defined contribution (DC) pension plan. Using detailed data on individuals' holdings inside and outside the pension system, we find substantial heterogeneity within and between passive and active investors in terms of labor income, financial wealth, and stock market participation. We build a life-cycle consumption-savings model, with a DC pension account and an opt-out/default choice, that produces realistic investor heterogeneity. Relative to a common age-based allocation, implementing the optimal default asset allocation implies a welfare gain of 1.5% during retirement. Much of the gain is attainable with a simple rule of thumb.

**JEL classification:** D91, E21, G11, H55.

**Keywords:** Age-based investing, default fund, life-cycle model, pension-plan design.

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# 1 Introduction

The worldwide shift from defined benefit (DB) to defined contribution (DC) pension plans challenges pension investors, who have been given greater responsibility to choose their contribution rates and manage their asset allocations. Many investors seem uninterested, display inertia (Madrian and Shea, 2001), or lack financial literacy (Lusardi and Mitchell, 2014), ending up in the default option. Consequently, the design of the default option in a pension plan may be a powerful tool for improving investment outcomes.<sup>1</sup>

This paper studies one important aspect of the design of the default pension fund: the optimal asset allocation. The asset allocation aspect is particularly suitable for designing prudent default funds, as the optimal allocation decision requires knowledge of asset classes and financial literacy, while knowledge of the optimal contribution rate may be intrinsic to the individual (Carrol et al., 2009; Choi et al., 2010). We make both an empirical and a theoretical contribution to this literature. We begin by constructing a dataset of Swedish investors' detailed asset holdings inside and outside the pension system.<sup>2</sup> We find that remaining in the default fund or not changing funds for a long time after an initial opt-out decision is a strong indicator of not having any equity exposure outside the pension system. These passive investors have a 16-percentage-point lower stock market participation rate outside the pension system than do active investors, one third of the difference being unexplained by observable characteristics such as labor income, financial wealth, and education. Overall, passive investors can be characterized as less sophisticated. Moreover, there is considerable heterogeneity among passive investors. Passive investors participating

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<sup>1</sup>Studies have examined the design of the enrollment features (Carrol et al., 2009), contribution rates (Madrian and Shea, 2001; Choi et al., 2003), choice menus (Cronqvist and Thaler, 2004), and equity exposures within pension plans (Benartzi and Thaler, 2001; Huberman and Jiang, 2006). Benartzi and Thaler (2007) reviewed heuristics and biases in retirement savings behavior. More recently, Chetty et al. (2014) documented inertia among pension investors with respect to their contribution rates, Poterba (2014) discussed the savings rates required to obtain warranted replacement rates, and Sialm et al. (2015) argued that sponsors of DC plans should adjust plan options to overcome investor inertia.

<sup>2</sup>Calvet et al. (2007, 2009) used data on asset holdings outside the pension system. To the best of our knowledge, we are the first to combine these register-based data with information about savings inside the pension system. Bergstresser and Poterba (2004) and Christelis et al. (2011) used survey data when studying equity exposure and the location choice between taxable and tax-deferred accounts.

in the stock market have financial wealth equaling 1.4 years of labor income, while passive investors not participating have financial wealth equaling only five months of labor income. Similarly, participating passive investors have 4.3 times as much financial wealth as do non-participating passive investors. These basic facts make it reasonable to question the ability of a one-size-fits-all design of the default fund to meet all passive investors' needs.

Motivated by these findings, we set up a model to study the optimal asset allocation of the default fund for passive investors. Our model belongs to the class of life-cycle portfolio-choice models with risky labor income (see, e.g., Viceira, 2001; Cocco et al., 2005; Gomes and Michaelides, 2005), meaning that it generates cross-sectional heterogeneity in income and wealth. We extend the model to include a pension system with a DC pension account, so that illiquid savings inside the pension system coexist with liquid savings outside it. The decision to be active or passive in the DC pension account and the decision whether to participate in the stock market outside the pension system are endogenous but subject to costs. We justify a dispersion in costs with heterogeneity in financial literacy and financial sophistication (e.g., experience of making investment decisions and various costs associated with investing). While an endogenous decision regarding stock market participation is standard, our model is the first to endogenously determine the passive pension investors who remain in the default fund.

The model provides a normative suggestion regarding the asset allocation in the default fund. We find substantial cross-sectional heterogeneity in the optimal DC equity share. The year before retirement, ten percent of default investors have an optimal DC equity share of 39% or more, while ten percent of default investors have an optimal DC equity share of 9% or less. We also find that the optimal DC equity share varies substantially with past stock market performance. From the perspective of a 25-year-old, there is a 10% probability that the optimal DC equity share will be 34% or more in the year before retirement, and a 10% probability it will be 20% or less. This implies that different birth cohorts have different optimal DC equity shares, depending on realized returns during their working phase. Conceptually, the optimal equity exposure in the individual's DC account depends on the account balance relative to the financial wealth outside the pension system

and on the present value of future labor income (Merton, 1971). This means that the DC account balance is a useful guide for active rebalancing. For example, if the account balance is low (high) due to poor (good) past equity returns, more (less) equity risk can be assumed. The same reasoning applies to idiosyncratic labor income shocks.

That passive and active investors are endogenously determined in the model is important. As in Carroll et al. (2009), passive investors endogenously adapt to changes in the default design. In this paper, the design concerns the asset allocation. We examine how the share of passive investors changes as the degree of customization of the default to individual circumstances increases. Starting from a common age-based investing rule (i.e., 100 minus one's age being the percentage allocated to equity), we find that a simple rule of thumb conditioned on the age, DC account balance, and stock market participation status of the investor reduces the share of active investors (who opt out) by 16.6 percentage points. Moreover, we find that the rule can be robustly estimated across different samples of default investors. This suggests that the rule is flexible enough to accommodate default investors who have arisen from varying institutional settings and initial designs.

In terms of welfare gains, moving from age-based investing to full customization of the default fund implies individual gains in certainty-equivalent consumption in the range of 0.9% to 2.9% during the retirement phase, with an average gain of 1.5%. Much of the average gain, 0.9%, is attainable if the proposed rule of thumb is implemented. To put the gain from the rule of thumb in perspective, we find that starting from the best age-based asset allocation rule and then shifting to the rule of thumb implies a gain of 0.6%. In contrast, starting from the best constant asset allocation and then shifting to the best age-based asset allocation implies a gain of 0.4%. Consequently, implementing the rule of thumb can add as much value as implementing age-based glide paths for the equity share or introducing target dates. Another noteworthy aspect is that such a change to the default fund's asset allocation is Pareto improving: from an ex ante perspective, there are only winners and no losers, unlike, for instance, in a redistributive tax reform.

Importantly, our main results are robust to several modifications of the model. They hold if investors' portfolio choices outside the pension system are subject to frictions or investment

mistakes (Choi et al., 2009; Card and Randsom, 2011; Chetty et al. 2014; Campbell, 2016), if the equity risk premium is low, if equity returns are left skewed, if the correlation between labor income growth and equity returns is high, or if investors can withdraw wealth tied up in real estate during retirement. In particular, the welfare gain, the fraction of it attained using the rule of thumb, and the changes in the fraction of investors who opt out, are all similar to those in the main analysis.

Our work relates to that of Gomes et al. (2009), Campanale et al. (2014), and Dammon et al. (2004). Gomes et al. (2009) studied the effects of tax-deferred retirement accounts and found the largest effects on savings rates relative to a non-tax environment for investors with high savings rates. Campanale et al. (2014) investigated how stock market illiquidity affects a portfolio-choice model's ability to replicate the distribution of stock holdings over the life cycle and the wealth distribution. Dammon et al. (2004) studied the location decision for stocks and bonds in liquid taxable and illiquid tax-deferrable accounts.

Our work also relates to that of Lucas and Zeldes (2009), who examined the investment decisions of pension plans in the aggregate, and Abel (2001), who considered the aggregate implications of an asset allocation change to a fully funded DC social security system when some workers do not participate in the stock market. However, our model considers individual outcomes beyond aggregate ones at the pension plan level. In this sense, Shiller's (2006) evaluation of life-cycle personal accounts for social security is closer to our study. Our focus on investor heterogeneity is complementary to the work of Poterba et al. (2007), who simulated individuals' pension benefits in DB and DC plans and reported distributions across individuals.

The paper proceeds as follows. Section 2 provides an overview of the Swedish pension system. Section 3 describes our data. Section 4 empirically analyzes individuals' portfolio choices inside and outside the pension system and how they are related. Section 5 presents our life-cycle model and its calibration. Section 6 analyzes the optimal design of the default pension fund. It also analyzes gradual customization and considers several robustness tests. Finally, Section 7 concludes.

## 2 The Swedish pension system

The Swedish pension system rests on three pillars: public pensions, occupational pensions, and private savings. Below, we describe the public and occupational pensions.

The public pension system was reformed in 2000.<sup>3</sup> It has two major components referred to as the income-based and premium pensions. A means-tested benefit provides a minimum guaranteed pension.

The contribution to the income-based pension is 16% of an individual's capped income (in 2016 the cap is SEK 444,750, or approximately USD 53,300).<sup>4</sup> The return on the contribution equals the growth rate of aggregate labor income measured by an official "income index." Effectively, the return on the income-based pension is similar to that of a real bond. The income-based pension is notional in that it is not reserved for the individual but is instead used to fund current pension payments as in a traditional pay-as-you-go system. The notional income-based pension is also DC, but to avoid confusion we simply refer to it as the notional pension.

The contribution to the premium pension is 2.5% of an individual's income (capped as above). Unlike the income-based pension, the premium pension is a fully funded DC account used to finance the individual's future pension. Individuals can choose to actively allocate their contributions to up to five mutual funds from a menu of several hundred. The premium pension makes it possible for individuals to gain equity exposure. Indeed, most of the investments in the system have been in equity funds (see, e.g., Dahlquist et al., 2017). A government agency manages a default fund for individuals who are passive and do not make an investment choice. Up to 2010, the default fund invested mainly in stocks but also in bonds and alternatives. In 2010, the default fund became a life-cycle fund. At retirement, the savings in the income-based pension and the premium pension are transformed into actuarially fair lifelong annuities.

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<sup>3</sup>Individuals born between 1938 and 1954 are enrolled in a mix of the old and new pension systems, while individuals born after 1954 are enrolled entirely in the new system.

<sup>4</sup>At the beginning of 2016, the SEK/USD exchange rate was 8.35. During our sample period, the exchange rate fluctuated between six and ten SEK per USD. We often report numbers from 2007 when the exchange rate at the end of the year was 6.47. We henceforth report numbers in SEK.

In addition to public pensions, approximately 90% of the Swedish workforce is entitled to occupational pensions. Agreements between labor unions and employer organizations are broad and inclusive and have gradually been harmonized across educational and occupational groups. For individuals born after 1980, the rules are fairly homogenous, regardless of education and occupation. The contribution is 4.5% of an individual's income up to the cap in the public pension system and greater for the part of the income that exceeds that cap, to compensate for the cap in the public pension and to achieve a similar replacement rate even for high-income individuals. These contributions go into a designated individual DC account. While the occupational pension is somewhat more complex and tailored to specific needs, it shares many features with the premium pension. Specifically, it is an individual DC account and there is a menu of mutual funds to choose from. The plan sponsor chooses the default fund.

Next we discuss our data on individuals' savings inside and outside the pension system.

### **3 Data**

We tailor a registry-based dataset to our needs. This dataset's foundation is a representative panel dataset for Sweden, i.e., Longitudinal Individual Data (LINDA). LINDA covers more than 300,000 households and is compiled by Statistics Sweden. We use eight waves between 2000 and 2007 and consider socioeconomic information such as age, education, and labor income. Our sample period is determined by the launch of the new pension system in 2000 and by the availability of detailed financial wealth data (described below) up to 2007. Online Appendix A.1 contains further information on LINDA. We match LINDA with data from two additional sources.

We first add data from the Swedish Tax Agency (through Statistics Sweden) covering individual non-pension financial wealth. This is a registry-based source of financial holdings outside the public pension system. Specifically, the tax reporting allows us to compute the value of the holdings of all bonds, stocks, and mutual funds that an individual holds at each year-end. There are three exceptions to these detailed tax reports. The first is the holdings

of financial assets within private pension accounts, for which we observe only additions and withdrawals since 1991. The second exception is that bank accounts with small balances are missing. To match the aggregate, these missing values are imputed. The third exception is the so-called capital insurance accounts, for which we observe the account balances but not the detailed holdings.<sup>5</sup> There is also a tax on real estate, allowing us to accurately measure the value of owner-occupied single-family houses and second homes. Apartment values are also available, though they are less accurately measured. Finally, we observe total debt (e.g., mortgages and student loans).

We also add Swedish Pensions Agency data covering pension savings. We have information on individuals' entry into the pension system and on their mutual fund holdings in their premium pension accounts at each year-end. Unfortunately, it is impossible to match these data with occupational pension accounts because these accounts are administered by private entities. Moreover, individuals' holdings in occupational pension plans are not covered by the tax-based dataset described above. However, we know the typical contribution rates in occupational pension plans and the typical allocations of these plans to equities and bonds. In our model, we assume that the typical contribution rates and allocations in occupational pension plans apply to all enrolled individuals.

In previous studies, the tax-based holdings information and records from the Swedish Pensions Agency have been used separately. Calvet et al. (2007, 2009), Vestman (2017), and Koijen et al. (2015) used non-pension financial wealth to answer questions related to investors' diversification, portfolio rebalancing, housing and stock market participation, and consumption expenses. Dahlquist et al. (2017) used information from the Swedish Pensions Agency to analyze the activity and performance of pension investors. To the best of our knowledge, we are the first to combine comprehensive, high-quality panel data on individuals' investments inside and outside the pension system.

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<sup>5</sup>Capital insurance accounts are savings vehicles exempt from regular capital gains and dividend income taxes, but instead taxed at a flat rate on the account balance. According to Calvet et al. (2007), these accounts accounted for 16% of aggregate financial wealth in 2002.



## 4 Empirical analysis

### 4.1 Sample restrictions

We begin with all individuals in the 2007 wave of LINDA, matching them with Swedish Pensions Agency records of DC account holdings at every year-end between 2000 and 2007. There are 430,216 individuals covered in both datasets. We then impose four sample restrictions. We exclude individuals for whom we lack portfolio information at the end of each year since they entered the premium pension system. To better match the model to data, we also exclude the richest percentile in terms of net worth. We also exclude individuals below age 25 years as they do not fully qualify for occupational pension plans. Finally, we exclude individuals for whom we lack educational information; this applies mainly to recent immigrants and the very old. Our final sample comprises 301,632 individuals.

### 4.2 Passive and active pension investors

We classify all individual investors as passive or active, based on the DC account activity between 2000 and 2007. Passive investors are either investors who have had their premium pension in the default fund since entering the pension system or investors who opted out of the default fund when entering the pension system but since then have never changed their allocations.

The default investors have clearly been passive. Our classification of initially active investors as passive is based on three arguments. First, at the time of the new system launch there was strong encouragement to actively choose a portfolio of one's own. This was done via massive advertising campaigns from the government and money management firms (see Cronqvist and Thaler, 2004, who characterized the launch of the plan as “pro choice”). However, that many individuals who opted out never made any subsequent allocation changes suggests that they would have been in the default fund if not so strongly encouraged to opt out. Second, Dahlquist et al. (2017) documented that initially active investors on average have had worse returns than active and default investors, refuting the idea that their passivity

is due to complacency. Finally, our classification is consistent with the substantial increase in default investors in the years after the launch. For example, among 25-year-old individuals, the fraction of new investors who stayed in the default increased from 27% in 2000 to 66% in 2001, and thereafter increased steadily to 92% in 2007.

Active investors have, after entering the pension system, opted out and made at least one change to their allocations. Note that our classification based on activity relies on the panel dimension of the data. Previous analyses of the choice between taxable and tax-deferred accounts have relied on cross-sectional data (see, e.g., Christelis et al., 2011).

### 4.3 Summary statistics

Table 1 reports the averages of key variables in 2007. The first column reports the values for all investors and the remaining two columns report the values for passive and active investors. Passive investors account for 60.5% of all investors while active investors account for 39.5%. Of the passive investors, 51.8% are default investors and the remaining 48.2% opted out of the default fund when entering the pension system but since then have never changed their allocations.

The average investor is 47 years old, with no substantial difference in age between passive and active investors. The average labor income of a passive investor is SEK 224,526, or only 79% of the average labor income of active investors. In untabulated results, we find that this ratio remains fairly stable over the life cycle. Hence, the difference in labor income between passive and active investors is not attributable to age differences, but is likely an artifact of other differences (e.g., educational and industry differences, as discussed below). Similarly, there is also a substantial difference in financial wealth (i.e., liquid savings not tied to pension accounts). The financial wealth of the average passive investor is only 74% of that of the average active investor. This means that the pension savings, which are proportional to labor income absent differences in returns, are relatively more important to passive investors.

The table also reports the stock market exposure outside the pension system. We define stock market participation as direct investments in stocks or investments in equity mutual

funds. The stock market participation is 45.5% for passive investors and 61.9% for active investors. That is, passive investors have a 16.4 percentage-point-lower stock market participation rate than do active investors. The lower participation of passive investors also shows up in equity shares. The average equity share is 19.6% for passive investors and 29.0% for active investors. However, conditioning on stock market participation, the passive and active investors have similar equity shares (43.2% and 46.9%, respectively).

There are also large differences in real estate ownership. The ownership rate is 65.2% among passive investors, much lower than the 79.3% among active investors. The differences in financial and real estate wealth are captured in net worth, which is real estate wealth plus financial wealth minus total liabilities. Average net worth among passive investors equals 79% of average net worth among active investors, implying that the net worth-to-labor income ratio is similar for the two groups. Notably, net worth is almost three times as large as financial wealth in both groups, a factor on which we later elaborate.

Finally, passive and active investors also differ in education. Though the fraction of high school graduates is about the same (53.9% for passive investors and 55.1% for active investors), the fraction of investors with a college degree is five percentage points lower among passive investors than among active investors (26.7% versus 32.0%). Instead, passive investors are much more likely than active investors to have finished only elementary school (18.4% versus 11.6%).

#### 4.4 Activity and stock market participation

We next turn to a more formal comparison of investment behavior inside and outside the pension system. Specifically, we study how activity inside the pension system relates to stock market participation outside the pension system. We begin by running two main regressions:

$$D(\text{Activity}_i = 1) = \alpha' X_i + \varepsilon_i^A, \quad (1)$$

$$D(\text{Participation}_i = 1) = \beta' X_i + \varepsilon_i^P, \quad (2)$$

where  $D(\text{Activity}_i = 1)$  is a dummy variable taking a value of one if the individual is active inside the pension system,  $D(\text{Participation}_i = 1)$  is a dummy variable taking a value of one if the individual holds stocks directly or equity funds outside the pension system,  $X_i$  is a vector of individual characteristics, and  $\varepsilon_i^A$  and  $\varepsilon_i^P$  are error terms. As the classification of activity refers to the 2000–2007 period, we restrict ourselves to considering activity and participation at the end of 2007. We let the individual continuous characteristics enter linearly, and as an alternative we consider piecewise linear splines for them, for example, as in Chetty et al. (2017). The characteristics are chosen to be largely consistent with a structural life-cycle model of portfolio choice, similar to the model we set up in the next section. Hence, we include age, labor income, and financial wealth as individual characteristics; we also consider a real estate dummy, educational dummies, geographical dummies, and industry dummies. All characteristics are measured at the end of 2007.

We then run a complementary regression:

$$\hat{\varepsilon}_i^P = \gamma \hat{\varepsilon}_i^A + \varepsilon_i, \quad (3)$$

where  $\hat{\varepsilon}_i^A$  and  $\hat{\varepsilon}_i^P$  are the residuals from regressions (1) and (2), and  $\varepsilon_i$  is an error term. This residual regression helps us understand the commonality of endogenous activity inside the pension system and endogenous stock market participation outside the pension system, after controlling for individual characteristics in  $X_i$ . We emphasize that we make no causal interpretation (i.e., that activity would cause participation). The regression simply captures the correlation between activity and participation after controlling for age, labor income, financial wealth, etc.

Panel A in Table 2 reports the results of the main regressions (1) and (2). (Note that in the regressions, age is scaled down by 100 and labor income and financial wealth are scaled down by 1,000,000.) Specifications I and III serve as benchmarks and refer to the linear specifications. Activity and participation are both positively related to age, labor income, and financial wealth. The estimated effects of being ten years older are a 1.0 percentage-point-higher activity rate and a 2.8 percentage-point-higher participation rate. The effects

of SEK 100,000 more in labor income are similar for activity and participation (1.5 and 1.1 percentage points higher, respectively), while the effects of SEK 100,000 more in financial wealth are lower for activity than for participation (0.5 and 2.8 percentage points higher, respectively).

The above estimates can be compared with the estimate in the residual regression (3), reported in Panel B. The results indicate that after controlling for individual characteristics, there is a strong positive relationship between activity in the pension system and stock market participation. Being an active investor in the pension system increases the likelihood of having equity exposure outside the pension system by 9.7 percentage points. This effect can in turn be compared with the 16.4 percentage-point difference in the unconditional participation rate between passive and active investors. That is, including a rich set of controls reduces the participation rate gap by 6.7 percentage points, but it remains substantial.

Specifications II and IV let age, labor income, and financial wealth enter as piecewise linear splines. Even with these richer specifications, there is still a strong positive relationship between activity and stock market participation. An active investor in the pension system is 6.0 percentage points more likely to participate in the stock market outside the pension system. Hence, our results suggest that approximately 1/3 of the gap is driven by differences in unobservable characteristics. One such unobservable characteristic could be experience of making investment decisions.

The bottom-line finding of our regressions is that activity in the pension system is strongly associated with equity exposure outside the pension system. Even when controlling for individual characteristics that correspond to the state variables of a standard life-cycle portfolio-choice model, the gap in stock market participation between passive and active investors is substantial. These findings have implications for the design of an optimal default fund. In addition, the findings underscore the importance of modeling limited stock market participation outside the pension system. We will design and calibrate our model to capture both the choice of being active in the pension system and the choice of participating in the stock market outside the pension system.

## Industry

We include fixed effects for education, geography, and industry in the regressions. The strongest source of heterogeneity appears along the industry dimension. This is also evident from the unconditional statistics: employees of the financial sector have the highest rate of stock market participation and activity, which we interpret as a sign of familiarity with investing. In contrast, employees in the hotel and restaurant sector have the lowest rate of participation and activity. Unconditionally, the two groups differ by over 30 percentage points in activity and participation. In Online Appendix A.2, we report, for each industry, participation and activity rates (unconditional and conditional ones from the regressions) as well as the conditional correlation given by industry-specific estimates of equation (3). Despite the large cross-sectional differences, our finding is robust across industries.

## Real estate wealth

As real estate wealth constitutes a large share of investors' net worth, real estate owners may draw upon it during retirement. In Online Appendix A.2, we report the equivalent of Tables 1 and 2 for renters and real estate owners separately. Importantly, renters have a lower rate of activity in the DC account (28%) than do real estate owners (44%) and a lower participation rate (48%) than do real estate owners (66%). Renters also have less financial wealth relative to labor income. A design of a default pension fund that can condition on these differences in wealth composition (e.g., expose renters to the stock market) would appear to be an attractive policy tool. We later explore the robustness of our model results to heterogeneity in net worth.

## 4.5 Heterogeneity among passive investors

In this section we demonstrate that there is considerable heterogeneity among passive investors. Understanding how these investors differ from one another is important for the design of a default fund. Table 3 presents the distributions of variables for passive investors. Panel A shows that passive investors exist in all age categories and differ greatly in labor

income, financial wealth, equity exposure, and net worth. Regarding the inequality in labor income, 25% of passive investors earn under SEK 99,911 whereas 25% earn over SEK 303,797. The inequality in financial wealth is also great: 25% have under SEK 17,116 in financial wealth whereas 25% have SEK 218,505 or more. This inequality applies to equity exposure as well, most passive investors having no equity exposure outside the pension system, whereas 10% have at least 63.4% of their financial wealth allocated to equities. Net worth is approximately three times as great as financial wealth in the middle and the right tail of the distribution and negative in the left tail.

In Panels B and C, passive investors are split into stock market participants and non-participants. While participants and non-participants differ little in age, they differ somewhat in labor income and considerably in financial wealth. The median non-participant earns 82% of what the median participant does. Furthermore, the median non-participant has just 15% of the financial wealth of the median participant. Only 10% of participants have less financial wealth than does the median non-participant. Finally, financial wealth can be contrasted to labor income. Stock market participants have financial wealth worth 1.4 years of labor income, while non-participants have financial wealth worth just five months of labor income. As participants have higher labor income, the average participating passive investor has 4.3 times as much financial wealth as does the average non-participating passive investor. Their difference in net worth is not quite as great: the average participating passive investor has 3.2 times as much net worth as does the average non-participating passive investor.

The takeaway is that there is considerable heterogeneity even among passive fund investors. Specifically, stock market participation serves as an indicator variable, most participants being richer in terms of labor income, financial wealth, and net worth. These basic facts make it reasonable to question the ability of a one-size-fits-all design of the default fund to meet all investors' needs. This suggests that it may be beneficial to carefully design the default fund to suit each investor's specific situation rather than imposing one allocation on all.

## 5 Model

Following the empirical analysis, we set up a life-cycle model of an investor in order to study the decision of whether or not to be active and to examine the optimal asset allocation of the default fund for passive investors. The model builds on the work of Viceira (2001), Cocco et al. (2005), and Gomes and Michaelides (2005) and includes risky labor income, a consumption–savings choice, and a portfolio choice. We extend the standard model with a pension system in which individuals save in illiquid pension accounts, from which their pension is received as annuities. Importantly, we also extend the model with an endogenous decision whether to remain in the default pension fund or opt out. Next we describe the model’s building blocks.

### 5.1 Demographics

We follow individuals from age 25 years until the end of their lives. End of life occurs at the latest at age 100, but could occur before as individuals face an age-specific survival rate,  $\phi_t$ . The life cycle is split into a working phase and a retirement phase. From the ages of 25 to 64 years, individuals work and receive labor income exogenously; they retire at age 65.

### 5.2 Preferences

Individuals have Epstein and Zin (1989) preferences over a single consumption good. At age  $t$ , each individual maximizes the following:

$$U_t = \left( c_t^{1-\rho} + \beta \phi_t E_t [U_{t+1}^{1-\gamma}]^{\frac{1-\rho}{1-\gamma}} \right)^{\frac{1}{1-\rho}}, \quad (4)$$

$$U_T = c_T, \quad (5)$$

where  $\beta$  is the discount factor,  $\psi = 1/\rho$  is the elasticity of intertemporal substitution,  $\gamma$  is the coefficient of relative risk aversion, and  $t = 25, 26, \dots, T$  with  $T = 100$ . For notational convenience, we define the operator  $\mathcal{R}_t(U_{t+1}) \equiv E_t [U_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}$ .



### 5.3 Labor income

Let  $Y_{it}$  denote the labor income of employed individual  $i$  at age  $t$ . During the working phase (up to age 64 years), the individual faces a labor income process with a life-cycle trend and permanent income shocks:

$$y_{it} = g_t + z_{it}, \quad (6)$$

$$z_{it} = z_{it-1} + \eta_{it} + \theta\varepsilon_t, \quad (7)$$

where  $y_{it} = \ln(Y_{it})$ . The first component,  $g_t$ , is a hump-shaped life-cycle trend. The second component,  $z_{it}$ , is the permanent labor income component. It has an idiosyncratic shock,  $\eta_{it}$ , which is distributed  $N(-\sigma_\eta^2/2, \sigma_\eta^2)$ , and an aggregate shock,  $\varepsilon_t$ , which is distributed  $N(-\sigma_\varepsilon^2/2, \sigma_\varepsilon^2)$ . The aggregate shock also affects the stock return, and  $\theta$  determines the contemporaneous correlation between labor income and stock return. We allow for heterogeneity in income at age 25 years by letting the initial persistent shock,  $z_{i25}$ , be distributed  $N(-\sigma_z^2/2, \sigma_z^2)$ .

During retirement (from age 65 years and onwards), the individual has no labor income.<sup>6</sup> Pension income is often modeled as a deterministic replacement rate relative to the labor income just before retirement.<sup>7</sup> However, in our model, the replacement rate is endogenously determined. Apart from her own savings in (liquid) financial saving, the individual relies entirely on annuity payments from pension accounts. Later we discuss these accounts in detail.

### 5.4 Investor heterogeneity

The decisions to opt out of the default pension fund and to participate in the stock market outside the pension system are endogenous. Both these decisions are surrounded by frictions.

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<sup>6</sup>Hence, the retirement decision is not endogenous as in French and Jones (2011). More generally, we do not consider endogenous labor supply decisions as in Bodie et al. (1992) and Gomes et al. (2008).

<sup>7</sup>One exception is that of Cocco and Lopes (2011), who modeled the preferred DB or DC pension plan for different investors.

To opt out, a one-time cost,  $\kappa_i^{\text{DC}}$ , must be paid; to enter the stock market, a one-time cost,  $\kappa_i$ , must be paid. A new feature of our model is that we allow for different magnitudes of these costs for different investors. The support of each cost's cross-sectional distribution as well as the correlation between them are set to match the shares of active and passive non-participants, and the shares of active and passive participants in the data. The joint distribution of  $\kappa_i^{\text{DC}}$  and  $\kappa_i$  is non-parametric. The calibration section describes the process of determining the joint distribution. While the costs are known to each investor, in some analyses we will treat the costs as unobserved by the designer of a default pension fund.

One-time costs of our kind are common in portfolio-choice models (see, e.g., Alan, 2006; Gomes and Michaelides, 2005, 2008). We allow for a full cross-sectional joint distribution of costs over the two endogenous decisions. We justify the dispersion in costs with reference to the documented heterogeneity in financial literacy and financial sophistication (see Lusardi and Mitchell, 2014, for an overview). Moreover, by introducing a dispersion in the cost of participating in the stock market, we can better capture the life-cycle participation profile in the data.<sup>8</sup>

## 5.5 Opting out and participating in the stock market

The decision to opt out of the default pension fund is made at age 25 years and is associated with a binary state variable,  $I_i^{\text{DC}}$ . This is consistent with the high degree of persistent inactivity among pension investors ever since the launch of the new system in 2000. Since the opt-out choice is made at age 25, there is a trivial law of motion for  $I_i^{\text{DC}}$  and it is denoted without a time subscript.

The decision to enter the stock market can be made at any life-cycle stage. Stock market participation is associated with a persistent binary state variable,  $I_{it}$ , that tracks the current

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<sup>8</sup>Fagereng et al. (2017) presented an alternative setup to account for the empirical life-cycle profiles of portfolio choice. Their model involves a per-period cost and a probability of a large loss on equity investments. We consider a probability of a large return loss in the robustness analysis.

status at age  $t$ . The law of motion for  $I_{it}$  is:

$$I_{it} = \begin{cases} 1 & \text{if } I_{it-1} = 1 \text{ or } \alpha_{it} > 0 \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

where  $\alpha_{it}$  is the fraction of financial wealth invested in the stock market. The cost associated with stock market entry then becomes  $\kappa_i(I_{it} - I_{it-1})$ .

## 5.6 Asset returns

The gross return on the stock market,  $R_{t+1}$ , follows a log-normal process:

$$\ln(R_{t+1}) = \ln(R_f) + \mu + \varepsilon_{t+1}, \quad (9)$$

where  $R_f$  is the gross return on a risk-free bond and  $\mu$  is the equity premium. Recall that the shock,  $\varepsilon_t$ , is distributed  $N(-\sigma_\varepsilon^2/2, \sigma_\varepsilon^2)$ , so  $E_t(R_{t+1} - R_f) = \mu$ . Also recall that  $\varepsilon_t$  affects labor income in (7), and that the correlation between stock returns and labor income is governed by the parameter  $\theta$ .

## 5.7 Three savings accounts

Each individual has three financial savings accounts: (i) a liquid account outside the pension system (referred to as financial wealth), (ii) a fully-funded DC account in the pension system, and (iii) a notional account belonging to the pension system. The notional account, which constitutes the basis of the pension, is income based and evolves at the rate of the risk-free bond. The DC account is also income based but the investor can choose how to allocate between bonds and stocks; it corresponds to the default fund we wish to design.

The account outside the pension system is accessible at any time. Each individual chooses freely how much to save and withdraw from it. In contrast, the contributions to the pension accounts during the working phase are determined by the pension policy (rather than by the individual) and are accessible only in the form of annuities during retirement. Importantly,

the two pension accounts include insurance against longevity risk.

### Financial wealth

The individual starts the first year of the working phase with financial wealth,  $A_{i25}$ , outside the pension system. The log of initial financial wealth is distributed  $N(\mu_A - \sigma_A^2/2, \sigma_A^2)$ . In each subsequent year, the individual can freely access the financial wealth, make deposits, and choose the fraction to be invested in risk-free bonds and in the stock market. However, the individual cannot borrow:

$$A_{it} \geq 0, \tag{10}$$

and the equity share is restricted to be between zero and one:

$$\alpha_{it} \in [0, 1]. \tag{11}$$

Taken together, (10) and (11) imply that individuals cannot borrow at the risk-free rate and that they cannot short the stock market or take leveraged positions in it.

The individual's cash on hand (i.e., the sum of financial wealth and labor income) develops according to:

$$X_{it+1} = A_{it} (R_f + \alpha_{it}(R_{t+1} - R_f)) + Y_{it+1}. \tag{12}$$

Supported by the analysis in Fischer et al. (2013), we do not model taxes on capital gains.

### DC account

Inside the pension system, each individual has a DC account with a balance of  $A_{it}^{\text{DC}}$ . During the working phase, the contribution rate equals  $\lambda^{\text{DC}}$ .<sup>9</sup>

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<sup>9</sup>In line with the Swedish pension system, we implement the contribution as an employer tax. This means that the contributions do not show up as withdrawals from gross labor income in the individual's budget constraint. This is consistent with our calibration of the labor income process to micro data (i.e., our measure of gross labor income is net of the employer tax).

The investor cannot short the stock market or take leveraged positions in it:

$$\alpha_{it}^{\text{DC}} \in [0, 1]. \quad (13)$$

Before retirement, the law of motion for the DC account balance is:

$$A_{it+1}^{\text{DC}} = A_{it}^{\text{DC}}(R_f + \alpha_{it}^{\text{DC}}(R_{t+1} - R_f)) + \lambda^{\text{DC}}Y_{it}, \quad (14)$$

Upon retirement at age 65, withdrawal starts. We assume that the investor is allowed to make a one-time decision on the equity exposure for the remainder of her life (i.e.,  $\alpha_{i65}^{\text{DC}} = \alpha_{i66}^{\text{DC}} = \dots = \alpha_{i100}^{\text{DC}}$ ). Note that this variable becomes a state variable.

### Asset allocation in the DC account during working life

We consider different rules for  $\alpha_{it}^{\text{DC}}$  prior to retirement. Active investors who opt out are assumed to choose the equity share in the DC account fully rationally. Later we outline this dynamic programming problem in detail.

It is common to formulate investment rules that depend on age. One such rule is to invest 100 percent minus one’s age in equity and the remainder in bonds. According to this rule, a 30-year-old would invest 70% in equities and a 70-year-old would invest 30% in equities. We refer to this as the “100-minus-age” rule. This rule can be modified to have different equity exposures at the beginning of the working phase and in retirement. We assume that default investors are exposed to an age-based equity share of “100-minus-age” during the working phase and 35% in retirement. We then contrast the consequences of this design to three alternatives:

1. the optimal equity share conditioned on all state variables in the model (i.e., apart from the cost associated with opting out, it is equivalent to the allocation of an active investor who opts out);
2. a rule of thumb conditioned on a sub-set of observable characteristics that appear as state variables; and

3. the average optimal age-based equity share (i.e., a glide path conditioned only on age and equaling the average optimal equity share).

### **Notional account**

The law of motion for the notional account balance during the working phase is:

$$A_{it+1}^N = A_{it}^N R_f + \lambda^N Y_{it}, \quad (15)$$

where  $\lambda^N$  is the contribution rate for the notional account.

To economize on state variables, we use  $z_{i64}$  to approximate the notional account balance at retirement. This approximation is based on simulations of equations (6), (7), (9), and (15) to obtain the best fit between  $z_{i64}$  and  $A_{i64}^N$  using regression analysis. This approximation works well. We provide further details in Online Appendix A.3.

### **Annuitization of the pension accounts**

Upon retirement at age 65 years, the DC account and the notional account are converted into two actuarially fair lifelong annuities. These insure against longevity risk through within-cohort transfers from individuals who die to surviving individuals. The notional account provides a fixed annuity with a guaranteed minimum. If the account balance is lower than is required to meet the guaranteed level at age 65, the individual receives the remainder at age 65 in the form of a one-time transfer from the government. The annuity from the DC account is variable and depends on the choice of equity exposure as well as realized returns. In expectation, the individual will receive a constant payment each year. We abstract from different tax rates between realized capital gains outside the pension system and the annuity payments inside the pension system.

## 5.8 Individual's problem

Next we describe the individual's problem. To simplify the notation, we suppress the subscript  $i$ . In Online Appendix A.4, we describe the method for solving the investor's problem.

### Be active or stay in the default fund

Let  $V_t(X_t, A_t^{\text{DC}}, z_t, \kappa, \kappa^{\text{DC}}, I_{t-1}, I^{\text{DC}})$  be the value of an individual of age  $t$  with cash on hand  $X_t$ , DC account balance  $A_t^{\text{DC}}$ , a persistent income component  $z_t$ , cost of stock market entry  $\kappa$ , cost of opting out  $\kappa^{\text{DC}}$ , stock market participation experience  $I_{t-1}$ , and whose activity in the DC account is  $I^{\text{DC}}$ .

The individual chooses whether to remain in the default fund ( $I^{\text{DC}} = 0$ ) or to opt out ( $I^{\text{DC}} = 1$ ):

$$\max_{I^{\text{DC}} \in \{0,1\}} \{V_{25}(X_t, 0, z_{25}, \kappa, \kappa^{\text{DC}}, 0, 0), V_{25}(X_t - \kappa^{\text{DC}}, 0, z_{25}, \kappa, \kappa^{\text{DC}}, 0, 1)\}$$

The decision to be active thus comes at a cost. The tradeoff for investors arises because staying in the default fund is costless but implies a suboptimal asset allocation. Unlike the model of Carroll et al. (2009), the one-time opportunity to opt out implies that there is no option value associated with waiting to take action.<sup>10</sup>

### Active investor's problem

The following describes the individual's problem when the equity share in the DC account is chosen optimally (i.e., conditional on all state variables) subject to paying the cost  $\kappa^{\text{DC}}$  (i.e.,  $I^{\text{DC}} = 1$ ). We refer to this as the active investors' dynamic programming problem. For brevity, we introduce the notation  $\Psi_t = (X_t, A_t^{\text{DC}}, z_t)$ .<sup>11</sup>

<sup>10</sup>Apart from simplicity, this model choice can be broadly justified by the finding of Dahlquist et al. (2017) that 69% of premium pension investors made no fund changes to their portfolio of funds between 2000 and 2010.

<sup>11</sup>Note that compared with working life, an additional state variable at age 65 years or older is  $\alpha_{65}^{\text{DC}}$ . For simplicity, we omit this variable from the value function.

### Participant's problem

An active investor who has already entered the stock market solves the following problem:

$$V_t(\Psi_t, \kappa, \kappa^{\text{DC}}, 1, 1) = \max_{A_t, \alpha_t, \alpha_t^{\text{DC}}} \left\{ \left( (X_t - A_t)^{1-\rho} + \beta \phi_t \mathcal{R}_t (V_{t+1}(\Psi_{t+1}, \kappa, \kappa^{\text{DC}}, 1, 1))^{1-\rho} \right)^{\frac{1}{1-\rho}} \right\}$$

subject to equations (6)–(14).

### Stock market entrant's problem

Let  $V_t^+(\Psi_t, \kappa, \kappa^{\text{DC}}, 0, 1)$  be the value for an active investor with no previous stock market participation experience who decides to participate at age  $t$ . This value is formulated as:

$$V_t^+(\Psi_t, \kappa, \kappa^{\text{DC}}, 0, 1) = \max_{A_t, \alpha_t, \alpha_t^{\text{DC}}} \left\{ \left( (X_t - A_t - \kappa)^{1-\rho} + \beta \phi_t \mathcal{R}_t (V_{t+1}(\Psi_{t+1}, \kappa, \kappa^{\text{DC}}, 1, 1))^{1-\rho} \right)^{\frac{1}{1-\rho}} \right\}$$

subject to equations (6)–(14).

### Non-participant's problem

Let  $V_t^-(\Psi_t, \kappa, \kappa^{\text{DC}}, 0, 1)$  be the value for an active investor with no previous stock market participation experience who decides not to participate at age  $t$ . This value is formulated as:

$$V_t^-(\Psi_t, \kappa, \kappa^{\text{DC}}, 0, 1) = \max_{A_t, \alpha_t^{\text{DC}}} \left\{ \left( (X_t - A_t)^{1-\rho} + \beta \phi_t \mathcal{R}_t (V_{t+1}(\Psi_{t+1}, \kappa, \kappa^{\text{DC}}, 0, 1))^{1-\rho} \right)^{\frac{1}{1-\rho}} \right\}$$

subject to equations (6)–(14).

Note that as  $\alpha_t = 0$ , the return on financial wealth is simply  $R_f$ .

### Optimal stock market entry

Given the entrant's and non-participant's problems, the stock market entry is given by:

$$V_t(X_t, A_t^{\text{DC}}, z_t, \kappa, \kappa^{\text{DC}}, 0, 1) = \max_{I_t \in \{0,1\}} \left\{ V_t^-(X_t, A_t^{\text{DC}}, z_t, \kappa, \kappa^{\text{DC}}, 0, 1), V_t^+(X_t - \kappa, A_t^{\text{DC}}, z_t, \kappa, \kappa^{\text{DC}}, 0, 1) \right\}.$$



## Default investor’s problem

The default investor’s problem is almost identical to the active investor’s problem, but with two differences. First, common to all default fund schemes is that default investors do not incur the cost  $\kappa^{\text{DC}}$ . Second,  $\alpha_t^{\text{DC}}$  is sometimes determined differently. If the equity share of the default fund is only a function of age (the unconditional optimal glide path or “100-minus-age”) or a function of a subset of state variables (a rule of thumb), then the asset allocation is suboptimal relative to that implied by the active investor’s dynamic programming problem. Only if the equity share of the default fund is fully customized and conditioned on all state variables, is the default investor’s asset allocation identical to the active investors.

## Portfolio choice outside the pension system

In the main analysis, we assume full rationality. In the robustness analysis, we consider the consequences of investment mistakes outside the pension system.

### 5.9 Calibration

In this section we describe our calibration strategy. Table 4 reports the values of key parameters. Most parameters are set either according to the existing literature or to match Swedish institutional details; those parameters can be said to be set exogenously. Three sets of parameters are used to match the data as well as possible; those parameters can be said to be determined endogenously.

#### Exogenous parameters

There are six sets of exogenous parameters. We briefly describe the calibration strategy for them and include a more detailed discussion in Online Appendix A.5.

First, we set the equity premium to 4% per year and the standard deviation of the stock market return to 18% per year. We set the simple risk-free rate to zero.

Second, we set labor income according to Swedish data. We find that the standard

deviation of permanent labor income equals 0.072. We set the one-year correlation between permanent income growth and stock market returns to 10%. This corresponds to a  $\theta$  of 0.040. The mean financial wealth for 25-year-old default investors is set to SEK 76,800. The cross-sectional standard deviations are set to 0.366 ( $\sigma_z$ ) and 1.392 ( $\sigma_A$ ) to match the data for 25-year-old individuals.

Third, we consider the contribution rates. We set the contribution rate for the notional account to 16% and for the DC account to 7%. This mirrors the premium pension account with a contribution rate of 2.5% and the occupational pension account with a typical contribution rate of 4.5%.

Fourth, we determine an annuity factor of 5.6% of the notional account balance at age 65 years. The annuity factor of the DC account depends on risk taking at age 65. Both factors are based on  $\phi_t$ , which in turn is based on the unisex mortality table of Statistics Sweden.

Fifth, we set the elasticity of intertemporal substitution to 0.5.

Finally, we determine the DC equity share profile of the calibration. To obtain a single life-cycle profile usable in the calibration, we mix the cohorts' time series profiles as of 2007. For practical purposes, a good fit turns out to be a linear profile such that the equity share equals "100-minus-age" during working life and 35% through retirement. We further justify this in Online Appendix A.5.

## Endogenous parameters

Three sets of parameters are treated as endogenous in the calibration, marked by an asterisk "\*" in Table 4. Table 5 reports matched moments in the data (from the working phase) and model.<sup>12</sup>

First, the discount factor,  $\beta$ , is calibrated to match the 0.922 ratio of financial wealth to labor income. A discount factor of 0.933 fits the ratio well. The top-left panel of Figure 1 shows the full life-cycle profile of financial wealth. The model fits the financial wealth

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<sup>12</sup>Note that we match the model to data from 2007. This does not allow us to control for cohort or time effects when we report the age profiles unlike, e.g., Ameriks and Zeldes (2004). However, Vestman (2017) found that controlling for either cohort or time effects (one at a time) when estimating age profiles for labor income and financial wealth matters little.

reasonably well, undershooting somewhat up to age 42 and overshooting after that.

Second, the relative risk aversion coefficient,  $\gamma$ , determines the conditional equity share. We weight the equity share of each age group by its financial wealth. A relative risk aversion of 14 provides a reasonable fit. We consider an equity premium of 2%, which allows for a lower relative risk aversion coefficient, in the robustness analysis. The value-weighted conditional equity share is 0.454 in the data and 0.519 in the model. The lower-left panel of Figure 1 depicts the life-cycle profile. The model overshoots early in the life cycle and undershoots in the ten years before retirement. This is a common feature of life-cycle portfolio-choice models. We consider alternative specifications in the robustness analysis in which the investor makes random allocation mistakes or has the equity share found in the data. We are reluctant to increase the relative risk aversion further, as this would lead to a worse discrepancy close to retirement age. In the model there is a noticeable increase in the equity share after age 70 years. However, if value weighted, this increase is negligible as the financial wealth is then small.

Third, we calibrate the joint distribution of the two costs,  $\kappa$  and  $\kappa^{\text{DC}}$ , to the joint distribution of active/passive and participating/non-participating investors, which is a total of four moments (they sum to one). For computational ease, we approximate each distribution with five equally spaced values, in turn enabling us to include up to 25 combinations, forming a  $5 \times 5$  matrix. We give each included type the same weight. For each cost, we let the lower support be given by zero. The upper support of  $\kappa$  is determined by the share of non-participation in the data (48.1%) and the upper support of  $\kappa^{\text{DC}}$  is determined by the share of passive investors (60.5%). These shares imply an upper support of  $\kappa$  equaling SEK 15,600 and an upper support of  $\kappa^{\text{DC}}$  equaling SEK 3,600. The cost associated with opting out is smaller because the benefits of doing so mainly accrue in forty years time. The shares of investors who are active and participate (24.4%) and who do not participate and are passive (33.0%) determine the correlation between the two costs. If we included all 25 combinations, the correlation between  $\kappa$  and  $\kappa^{\text{DC}}$  would be zero and the correlation between non-participation and default investing would be determined entirely by observable characteristics, such as financial wealth and labor income. If we included only the diagonal

elements of the  $5 \times 5$  matrix, the correlation between the costs would be one. To systematically determine which of the 25 types of combinations of  $\kappa$  and  $\kappa^{\text{DC}}$  to include, we start from the case of a perfect correlation along the diagonal of the square matrix and then add types in layers progressively further from the diagonal to achieve the best fit of the shares of active participants and passive non-participants. The best fit is obtained when including three layers on each side of the diagonal (i.e., including 23 types). The matrix below illustrates this process:

$$\begin{array}{c|ccccc} \bar{\kappa}^{\text{DC}} & 4 & \mathbf{3} & \mathbf{2} & \mathbf{1} & \mathbf{0} \\ & \mathbf{3} & \mathbf{2} & \mathbf{1} & \mathbf{0} & \mathbf{1} \\ & \mathbf{2} & \mathbf{1} & \mathbf{0} & \mathbf{1} & \mathbf{2} \\ & \mathbf{1} & \mathbf{0} & \mathbf{1} & \mathbf{2} & \mathbf{3} \\ 0 & \mathbf{0} & \mathbf{1} & \mathbf{2} & \mathbf{3} & \mathbf{4} \\ \hline & 0 & & & & \bar{\kappa} \end{array},$$

where the elements on the diagonal and the three layers on each side of the diagonal are in bold. Equally weighting these 23 types implies a correlation between  $\kappa$  and  $\kappa^{\text{DC}}$  of 0.2. Moreover, as we use a square matrix, the two marginal distributions have the same shape and are symmetric around their means and modes (equaling SEK 7,800 for the participation cost and SEK 1,800 for the opt-out cost). We find our modeling approach appealing as it lets us minimize the costs for the average investor (see Vissing-Jørgensen, 2002).

## Simulation method

There are two main sources of risk in our model: (i) aggregate equity returns and (ii) idiosyncratic labor income shocks. Our simulation method lets us separately study the two risk sources. For each of the 23 types, we consider 500 individuals with different idiosyncratic labor income shocks, for a total of 11,500 individuals in an economy. The 23 individual types share the same income realization but have different costs. Strictly speaking, an economy is a single birth cohort, which we follow over its life. The economy faces one equity return realization of 75 annual returns, common to all individuals in the economy. We simulate a

total of 50 economies.

When we take the average for each individual over the 50 economies, we obtain ex ante life-cycle profiles of 11,500 individuals; this distribution represents the inequality across individuals. When we instead take the average for each economy over the 11,500 individuals, we can analyze the role of aggregate equity risk. When we compute averages over both sources of risk, we obtain unconditional averages. We simply refer to them as averages.<sup>13</sup>

## Model fit

Figure 2 demonstrates the model’s ability to endogenously sort individuals in terms of average labor income and financial wealth. The top-left panel shows the model’s ability to produce a gap in labor income between opt-out and default investors that is very similar to the data. The top-right panel shows a similar gap in financial wealth between opt-out and default investors. The opt-out and default investors result from endogenous choice when investors are exposed to “100-minus-age” (as in the calibration). The bottom-left panel shows labor income for participants and non-participants. The gap in the model is qualitatively very similar to the gap in the data (but widens a little too much late in the working phase). The bottom-right panel shows that the model also generates a substantial gap in financial wealth, starting from age 40 years. We find the fit remarkable considering that neither the labor income nor financial wealth of any sub-group of investors is targeted in the calibration.

## 6 Optimal design

In this section we first report who the default investors are and discuss the optimal design for these investors. We then consider how the optimal asset allocation responds to realized equity returns and to labor income shocks. Initially, the default investors arise from the

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<sup>13</sup>For every economy, the same idiosyncratic income shocks are used. The cross-sectional average of these shocks is zero for each year. Furthermore, we reuse the idiosyncratic income shocks and stock market returns for all cost types and all designs of the default fund. We also reuse initial draws of  $z_{i25}$  and  $A_{i25}$ . This simulation method is similar to that of Campbell and Cocco (2015), who also distinguished between aggregate and idiosyncratic shocks.

“100-minus-age” allocation. Later, we illustrate the optimal allocation for different groups of default investors that have endogenously arisen under other default designs. For each of these designs, and groups of default investors, we report the welfare implications of implementing an even more customized default. The optimal design is a counterfactual outcome: it answers the question of which asset allocation a given group of default investors prefers.

## 6.1 Who are the default investors?

Our model allows the opt-out/default choice to be shaped by both observable and unobservable characteristics, as in the data. We begin by reporting the effect of these characteristics on the choice.

Taking opt-out and default investors together, the average cost of opting out is SEK 1,800; however, for default investors the average is SEK 2,500 and for opt-out investors it is SEK 800. In addition, there is substantial variation within the investor groups. We also find a substitution effect between the two costs, such that the share of opt-out investors at a given opt-out cost increases with the participation cost, suggesting that financial wealth and the DC account are imperfect substitutes. Online Appendix A.6 reports the share of opt-out investors for each of the 23 cost types.

## 6.2 Optimal asset allocation for default and opt-out investors

Figure 3 shows averages of all model outcomes for default and opt-out investors under the optimal asset allocation. The groups of default and opt-out investors are a result of endogenous choice when exposed to the “100-minus-age” default design. For the default group, we report the paths associated with their (counterfactual) optimal asset allocation.

The top-left panel reports labor income during the working phase and pension (i.e., annuities from the DC and notional accounts) during retirement. Labor income is substantially higher for opt-out investors, indicating that labor income matters for the opt-out decision. The top-right panel shows consumption, which is hump shaped as individuals do not fully smooth their consumption.

The three following panels show the notional account, DC account, and financial wealth, all of which are distinctly built up during the working phase and then depleted. The high contribution rates for the two pension accounts make their balances large relative to financial wealth even at a young age. Already before age 30 years, the DC account is as large as the financial wealth. The importance of the DC account then increases and at age 65 it is 2.9 times as large as the financial wealth for default investors. Note that the annuity floor, which is more important for default investors, is manifested as a jump in the profile for the notional account between ages 64 and 65.

The magnitude of the DC account relative to financial wealth and to the notional account illustrates the potency of the optimal asset allocation of the default fund: total equity exposure is essentially determined by the equity share in the DC account. Financial wealth serves mainly as a buffer for precautionary savings motives, peaking just before retirement and then quickly depleting.

The third panel on the right illustrates the stock-market participation rate for default and opt-out investors. Default investors display a gap relative to opt-out investors of at most 20 percentage points during working life.

The bottom-left panel shows the equity share in financial wealth (outside the pension system) conditional on participation. It first increases slightly and then decreases until retirement, when it jumps. The increase up to age 35 years is driven by selection. As wealth-poorer households enter, they can tolerate a higher conditional equity share. Around age 40, the sample of participants stabilizes and the conditional equity share gradually falls. As the present value of labor income diminishes and financial wealth increases, a high equity share cannot be tolerated (Merton, 1971; Cocco et al., 2005). After retirement, individuals tolerate a somewhat higher equity exposure. Note that the increase in the conditional equity share after retirement is economically not as important, as the financial wealth is then low.

Finally, the bottom-right panel shows the DC equity share for default and opt-out investors. At age 25 years it is 100%. It remains high until age 35 when it starts to decrease almost linearly. Notably, the change is greater for opt-out than default investors. By age 45 there is a gap of 15 percentage points between default and opt-out investors, with default

investors being on a more aggressive path than opt-out investors. The main takeaway is that the endogenous selection into the default fund has implications for the optimal DC equity share. Starting at age 35, default investors prefer a more aggressive allocation than do opt-out investors. The average DC equity share fits well with target-date (or life-cycle) funds offered by mutual fund families such as Fidelity and Vanguard. The equity share in their funds is typically around 80–90% until 30 years before retirement (at age 35 in our model), when the equity share declines by 1.5–2 percentage points per year until retirement (at age 65 in our model). Even though the average equity share of the model fits well with the allocation of target-date funds, the model average masks considerable variation, which we explore in the remainder of the paper.

### 6.3 Equity risk and inequality

Figure 4 shows the aggregate equity risk and inequality implied by the optimal asset allocation for default investors. The panels to the left refer to averages over individuals, highlighting the equity risk; the panels to the right refer to averages over economies, highlighting the inequality across individuals arising from idiosyncratic labor income shocks. We sort the variables by the DC equity share in each of the top panels, maintaining that sorting for the remaining panels. As before, the default investor outcomes are the counterfactual ones associated with the optimal DC equity share when investors are exposed to a default design equaling “100-minus-age.”

The top-left panel shows how the DC equity share varies over the economies, i.e., how much it varies with the realized equity returns. The second decile indicates that, with a probability of at least 10%, the DC equity share exceeds 34% throughout the working phase (jumping to approximately 44% at retirement). The ninth decile indicates the opposite pattern: with a probability of at least 10%, the DC equity share decreases to under 20% before retirement. The panel below shows the corresponding values for the DC account. It indicates a strong negative correlation between the DC equity share and the DC account balance, a high equity share corresponding to a low account balance and vice versa. The remaining



three panels to the left show the corresponding values for labor income and pension, financial wealth, and stock market participation. None of these variables covaries as strongly with the DC equity share as does the DC account balance.

As the DC equity share correlates negatively with the DC account balance, while labor income (and hence contributions to the DC account) does not, the analysis suggests that realized equity returns affect the optimal asset allocation, by means of active rebalancing. As returns exceed expectations, it is optimal to invest less in equity and vice versa. The mechanism behind this property of the optimal allocation is that previously mentioned (relating the ratio of the DC account balance to the other accounts and to the present value of labor income).

The top-right panel shows the inequality in the DC equity share. The first decile has the highest DC equity share and the tenth the lowest. We report the second and ninth deciles. The second decile has an average DC equity share that stays above 60% until age 53 years and then declines to 39% just before retirement. The ninth decile has an average DC equity share of 18% at age 50 and declines below 9% just before retirement. The gap between the second and ninth deciles starts to widen at age 40, when it exceeds 30 percentage points; it is 60 percentage points among 50-year-old investors.

The four panels below show how the inequality in DC equity shares relates to other characteristics. Individuals with a high optimal DC equity share have low DC account balances, are somewhat income poor, and are unlikely to participate in the stock market; individuals with a low optimal DC equity share have high DC account balances, are somewhat income rich, and are likely to participate in the stock market.<sup>14</sup>

To sum up, variation across economies implies that equity return realizations matter for the DC equity share. This means that different birth cohorts have different optimal allocations at the same age. Moreover, the large cross-sectional dispersion in optimal eq-

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<sup>14</sup>In an unreported graph we also plot the ratio of the DC account balance to labor income. For default investors under 50 years old, there is little difference in this ratio between the second and ninth deciles, suggesting a selection effect in terms of participation. Later in life, starting from age 50, the second decile has a low ratio and the ninth decile a high ratio, consistent with the standard mechanism already alluded to.

uity shares emphasizes the potential of an asset allocation conditional on investor-specific characteristics. In other words, different default investors have different needs.

## 6.4 Mass customization: A rule of thumb beyond age

In this section we approximate the optimal design with regressions on observable characteristics. Such regressions are a means to create a rule of thumb that effectively allows rule-based mass customization.

To complement our previous illustration of equity risk and inequality, we regress the optimal equity share of default investors on their characteristics. More specifically, we run the following regression on model-generated data:

$$\alpha_{it}^{\text{DC}} = \beta_0 + \beta_1 t + \beta_2 A_{it} + \beta_3 A_{it}^{\text{DC}} + \beta_4 Y_{it} + \beta_5 I_{it} + \varepsilon_{it}, \quad (16)$$

where the dependent variable is the optimal DC equity share of individual  $i$  of age  $t$ , and all covariates are state variables of the model. Note that  $A_{it}$  and  $A_{it}^{\text{DC}}$  are functions of both idiosyncratic income shocks and aggregate equity returns. We do not include the costs,  $\kappa_i$  and  $\kappa_i^{\text{DC}}$ , as they would be unobservable in actual data.

We run the regression on individuals during their working phase. Note that the  $R$ -squared in the regression captures the efficiency of the investment rule relative to the optimal equity share conditioned on all state variables in the model.<sup>15</sup>

This analysis relates to Merton (1971), who derived the intertemporal hedging motive arising from the present discounted value of labor income. Cocco et al. (2005) discussed the role of financial wealth relative to total wealth (including the present value of labor income) when labor income is uninsurable. In our model the value of the three accounts ( $A_{it}$ ,  $A_{it}^{\text{DC}}$ , and  $A_{it}^{\text{N}}$ ) and the present value of labor income guide optimal equity shares inside and outside the pension system. The purpose of our analysis is to obtain an asset allocation rule that

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<sup>15</sup>We have considered regression specifications in which income and asset values are in logs rather than levels. They consistently perform worse, in terms of both  $R$ -squared and welfare gain, when implemented as a rule of thumb in the model.

is implementable for the designer of a default pension fund. We therefore focus on different subsets of the state variables and do not include wealth ratios in the analysis. Related to this, Dammon et al. (2004) focused on the optimal equity share in a tax-deferrable (retirement) account as a function of age and account balance.

Table 6 reports the regression results using different specifications. Specification I mimics the simple age-based investment rule. The estimate suggests that individuals should decrease their DC equity exposure by 2.4 percentage points every year. This linear specification is admittedly a crude regression specification, because it results in many young individuals being forced into a DC equity share of 100%. The estimated intercept indeed implies that the predicted DC equity share for a 25-year-old is 114.6%. Nevertheless, the interpretation is that a better rule for the DC equity share would be to have it at 100% until about age 30 and thereafter let it fall by 2.4 percentage points per year. Note that this is a steeper reduction in equity exposure over time than that of the “100-minus-age” rule. Interestingly, the  $R$ -squared for our rule is as high as 63.0%. In untabulated results, we find that specifications with a polynomial in age improve the  $R$ -squared only marginally.

To better understand the role of incremental information in the form of additional state variables, Specifications II–V add one additional state variable at a time to the age variable. All additions significantly improve the regression fit. In Specifications II and III, labor income and financial wealth add 6 and 11 percentage points to the  $R$ -squared. The stock market participation status in Specification IV adds 10 percentage points, and the estimates suggest that stock market participants should have 23.3 percentage points less exposure to equity than do non-participants, a substantial difference. However, the single most influential state variable is the DC account balance. Specification V shows that the DC equity share should be reduced by 0.9 percentage points per year as a direct effect of age. The remaining reduction is contingent on the development of the DC account balance. In addition to the direct effect, the DC equity share should be reduced by 6.7 percentage points for every increase of SEK 100,000 in the account balance. This increase is in turn a function of the contribution to the account (i.e., labor income) and the realized equity return. The  $R$ -squared associated with this simple asset allocation rule increases by 16 percentage points relative to Specification I,

implying that the rule can account for an impressive 78.6% of the variation in the optimal allocation. It is particularly encouraging that the DC account balance is the single best piece of incremental information, as it is directly observable.

Specification VI shows the effects of the rule based on both the DC account balance and stock market participation. The optimal rule can be stated as follows: Reduce the DC equity share by 0.8 percentage points every year. In addition, reduce the DC equity share by 6.0 percentage points for every SEK 100,000 invested in the account. Finally, reduce the life-cycle path by 19.6 percentage points if the individual is a stock market participant. This rule summarizes the model implications well and accounts for 85.5% of the model's optimal asset allocation rule. The  $R$ -squared for Specification VII reveals that labor income and financial wealth add little on the margin.

## 6.5 Welfare effects

We next analyze the welfare effects of implementing an increasingly customized default design. Along with the welfare effects, we also analyze the endogenous change in the shares of default and opt-out investors.

### Three default designs and three groups of default investors

We gradually increase the customization, starting from the baseline calibration “100-minus-age.” This is our first allocation rule and default investor sample (58.7% of all individuals). Based on the optimal design for them, we obtain the average optimal age-based rule, representing the best purely age-based rule for default investors. The bottom-right panel of Figure 3 reports its glide path. Based on this design, we obtain a second sample of default investors. From this sample we estimate a rule-of-thumb allocation using specification VI in Table 6. We implement this rule of thumb and obtain a third sample of default investors. Finally, we report results for the optimal design. For each incremental shift in customization we report the welfare gain relative to the previous design and the share of default investors. We report effects for the sample of investors who stay in the default under the “100-minus-age”

allocation unless otherwise noted.<sup>16</sup>

## Responses to the customization

The first row of Table 7 reports how the share of default investors increases as the degree of customization of the design increases, starting from “100-minus-age. Shifting the glide path to the average within the model increases the share by 9.2 percentage points to 67.9%. Shifting the design from the average to the rule of thumb further increases the share of default investors by 7.4 percentage points to 75.3%. Put differently, implementing the rule of thumb induces an endogenous response so that the share of opt-out investors is reduced by 16.6 percentage points.

A central insight is that the groups of opt-out and default investors are endogenously generated, arising in response to a particular default design and institutional setting. Carroll et al. (2009) studied how the optimal design depends on the underlying characteristics of the default group (e.g., whether they are procrastinators or whether they lack financial literacy). We have a limited ability to explore such differences. However, we explore how the optimal default design changes across our samples of default investors arising from different default designs. The default investors are less negatively selected the more customized the default fund is. Considering the life-cycle paths for the suboptimal default designs, labor income peaks at SEK 261,400 under the “100-minus-age” design and at SEK 282,200 under the rule of thumb. Despite these fairly large differences, the discrepancy of the average DC equity share is small – at most three percentage points in mid working life. We view this as quite encouraging, as it suggests that the optimal DC equity share is robust to particular historical (suboptimal) default designs.

## Welfare

We report welfare effects based on ex ante increases in certainty-equivalent consumption (i.e., based on unconditional expectations at age 25). The advantage of this measure is that

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<sup>16</sup>Finding the optimal design for any degree of customization is a fixed-point problem. We present the results of one iteration, as a second iteration yields very similar DC equity shares and rule of thumb.

it trades off increases in returns (i.e., pension income) against increases in risk (in returns and pension income) in a consistent manner. (In contrast, if we maximized the average expected replacement rate, it would suffice to maximize the allocation to equity.) We report the gain in certainty-equivalent consumption during retirement. In other words, the welfare gain is measured as the percent increase in certainty-equivalent consumption during retirement, viewed from the perspective of a 25-year-old investor whose consumption remains the same during the working phase. Alternatively, the gain could be measured as an increase during the working and retirement phases. The gain is then smaller by a factor of approximately 29 because of discounting. In Online Appendix A.7, we describe how to derive this measure from the investors' value function.

The second row of Table 7 reports the incremental increases in welfare as the design becomes more customized. Moving from the “100-minus-age” to average optimal glide path increases investors' welfare by 0.3% on average. This effect is small relative to the effect of moving from the average optimal to the rule of thumb glide path, implying a gain of 0.6%. To put this in perspective, we investigated the gain from a shift from the optimal constant equity share (i.e., 50% equity and 50% risk-free in our baseline calibration) to the “100-minus-age” allocation. We do so because life-cycle investing or target date investing is commonly believed to add value to pension investors. Surprisingly, we find that the gain is a mere 0.1%. Thus, modifying the glide path further toward that of the average optimal is more valuable to investors than is switching from the optimal constant to “100-minus-age” allocation. Moreover, moving from the average optimal to the rule of thumb is associated with a 1.5-times-greater gain than is moving from the optimal constant equity share to the average optimal glide path. This suggests that customization, beyond that of age, provides value to pension investors. Finally, moving from the rule of thumb to the true optimal allocation adds an incremental effect of 0.6%. The total effect of moving from “100-minus-age” to the optimal allocation is thus 1.5%. This is a sizeable gain for this class of incomplete market models. In comparison, Campbell and Cocco (2015) reported a 1.1% welfare gain from offering fixed-rate mortgages in high-yield states for one-year bonds. Furthermore, unlike many other reforms (e.g., tax or unemployment insurance reforms), customization

is Pareto improving: ex ante there are no losers from a better design. We find that the range of the total welfare gain by moving from the “100-minus-age” to optimal allocation is 0.9–2.9%. In an unreported analysis, we investigated how much individuals who switch from opting out to being default investors gain relative to those who already were default investors. Switchers gain only 0.1 percentage points more, reassuring us that the results are not driven by reductions in the cost of opting out (i.e., that fewer individuals pay the cost,  $\kappa_i^{\text{DC}}$ ). Moreover, we checked that no default investors abandon the default fund and opt out as customization increases.

We emphasize that moving from a suboptimal age-based investment rule (e.g., “100-minus-age”) to the rule of thumb achieves much (60%) of the potential welfare gain from implementing the optimal design. Furthermore, it turns out to be of little importance to tailor the rule precisely to a particular endogenous sample of default investors. The bottom panel of Table 7 reports regression results. For any of our samples of default investors the rule is quite similar. This is compelling, as the similarity further supports our previous argument that the optimal default design seems robust to particular initial suboptimal default offerings.

## 6.6 Effects on pension income

The optimal design trades off risk against return perfectly. To understand how this affects pension income, the bottom panel of Table 7 reports the average pension, equity risk, and inequality for the four designs. The first measure is an (unconditional) average over individuals and economies; the last two measures are standard deviations of log pension income, computed across economies or individuals. Notably, the average pension is little affected by customization, being highest for the rule of thumb and lowest for the optimal design. However, this variation is small compared with the variation in equity risk and inequality. Inequality decreases by 16% and equity risk by 28% in the optimal design. The bottom line is that the optimal default mainly reduces excess equity risk, providing a means to reduce inequality while maintaining the same average pension income.<sup>17</sup>

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<sup>17</sup>Our proposed linear rule of thumb is a little coarse in terms of managing equity risk. It offers the most equity risk, so the average pension is high under its implementation. This is because linearity implies that

## 6.7 Robustness

We investigate how our main results depend on alternative assumptions in our model. Importantly, we recalibrate our model to these assumptions to maintain the best possible fit for the targeted moments in the data. Below, we briefly describe the main findings. We report the details of the alternative calibrations, targeted moments, and main results in Online Appendices A.8 and A9.

We find that our main results hold both qualitatively and quantitatively throughout the exercises. In particular, the welfare gain, the fraction of it that can be achieved using either the optimal average allocation or rule of thumb, and the changes in the fraction of investors who opt out, are all similar to those in the benchmark case.

### **Alternative processes for equity returns and model misspecification**

A common choice for the equity risk premium in portfolio-choice models is 4%, as in our baseline calibration; we investigate how our results depend on its magnitude by decreasing it to 2%. Note that a lower equity premium tends to come with a lower risk aversion, so this case is also a robustness check of the importance of a high risk aversion. That the results are robust to this change is not obvious. On the one hand, equity and bonds become more similar in terms of expected return, so the asset allocation decision becomes less potent. On the other hand, it may be valuable to extract even a small equity premium in states in which risk-averse individuals can tolerate it. Our main welfare results are insensitive to this change. The welfare gain associated with a shift from “100-minus-age” to optimal is 1.6%, 63% of which can be attained by the rule of thumb. The opt-out rates are unaffected.

It is well documented that equity returns are left skewed. In life-cycle portfolio-choice models, this feature has been implemented as a small probability of a disastrous equity return (see, e.g., Alan, 2012; Fagereng et al., 2017). We follow the approach of Judd et al. (2011) and modify the equity return distribution so that an annual return of  $-41\%$  (the

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the equity exposure late in life exceeds that of the optimal design. It is easy to formulate an extended rule that corrects this and provides an average pension, equity risk, and inequality that lie between the average optimal and optimal designs. Designers will need to trade off simplicity against accuracy.



expected return minus two and a half standard deviations) is drawn with a 2% probability. Importantly, this disaster shock feeds into labor income through (7) and (9). From this exercise, we conclude that our main results are robust. The total welfare effect is still 1.5% and the rule of thumb accounts for 60% of the total welfare gain.

We also consider the effects of model misspecification along these dimensions, analogous to Michaelides and Zhang (2015). We implement the benchmark estimates for the rule of thumb in a model using either of the above alternative stochastic processes. Even when feeding in such a misspecified rule of thumb, there are no meaningful differences.

### **Suboptimal portfolio choice outside the pension system**

In our main analysis, stock market participants allocate their portfolio optimally outside the pension system. We view this as a natural baseline, as the implementation of any systematic suboptimal behavior outside the pension system would increase the value of a well-designed default allocation inside the pension system. However, empirical evidence suggests that investors lack knowledge of different asset classes' risk-return properties and consequently of how to form their portfolios (see, e.g., Carrol et al., 2009). Empirical evidence also suggests that individuals make savings and allocation choices in one account independently of what is happening in other accounts (Choi et al., 2009; Card and Ransom, 2011; Chetty et al., 2014). We therefore analyze whether our results are affected by individuals making mistakes outside the pension system. More specifically, we consider two kinds of mistakes.

First, we assume that individuals participating in the stock market hold a constant fraction of their financial wealth in equity. We let this fraction equal the mean in the data (43.2%). Under this behavior, the value of a customized default in the DC account increases. Moving from “100-minus-age” to the optimal design implies a welfare gain of 2.1%, and implementing the rule of thumb captures half of this gain.

Second, we assume that individuals participating in the stock market make random allocation mistakes. That is, unlike in the first analysis, there is variation in the cross-section. We implement this as an exogenous time-invariant state variable. Individuals are predestined

to hold one of five equity shares if they choose to become stock market participants. The five values correspond to the mean of each quintile of the cross-sectional distribution. That individuals are aware of their tendency to make mistakes is consistent with the argumentation of Calvet, Campbell, and Sodini (2007). We assume that the designer of the default pension fund cannot observe these five types when implementing the rule of thumb. In this exercise, the value of the optimal default compared to “100-minus-age” is 2.3%. Implementing the rule of thumb again captures half of this gain. Hence, even with unobserved cross-sectional variation in suboptimal equity shares, the rule of thumb adds value.

The results illustrate how a prudent default can compensate for systematic portfolio-choice mistakes outside the pension system.

### **Moderating the attractiveness of equities among the young**

Figure 1 shows a difference in the life-cycle profile of the conditional equity share between the data and the model. In the data, the profile is flat; in the model, it slopes downwards and the difference between the maximum and minimum points during the working phase is 76 percentage points. This follows from the bond-like property of labor income, and there does not seem to be a commonly agreed solution to this in the literature.

Benzoni et al. (2007) let labor income and dividends be cointegrated, making equity more risky for young investors and even generating an upward slope in the equity share. Relatedly, Storesletten et al. (2007) introduced cyclical income risk and Huggett and Kaplan (2016) introduced left skewness in labor income together with cyclical income risk. All these models introduce features that make labor income more risky.

As a complement to assuming outright suboptimal behavior, we also make the stream of labor income more equity like. We can preserve a substantial stock market participation rate outside the DC account if the correlation between labor income growth and equity returns is smaller than 0.30. With a correlation of 0.22, the difference between the maximum and minimum points of the conditional equity share during the working phase declines from 76 to 44 percentage points. The main results regarding welfare and the share of default investors

under the rule of thumb remain intact.

To stress the model further, we combine the high correlation with the left skewness in stock market returns (we increase the probability to 5%). We can then further reduce the slope of the conditional equity share from 44 to 29 percentage points. Again, the welfare gains from introducing the optimal design or the rule of thumb are similar.

## **Real estate wealth**

We highlighted the importance of real estate in our empirical analysis. Renters are less likely to be active investors than are real estate owners. They are also less likely to be stock market participants. Furthermore, real estate wealth minus debt (henceforth “home equity”) is for most households as great as financial wealth. Net worth is in turn almost as unevenly distributed among investors as is financial wealth.

We therefore consider four robustness exercises that account for heterogeneity in real estate, each involving a complete recalibration of the model to alternative data moments. In the first two exercises, we target renters and real estate owners separately. Renters have a lower life-cycle trend in labor income. In this exercise, the welfare gain from a customized default design is 1.4% (i.e., slightly smaller than for the full sample), whereas the share captured by the rule of thumb remains essentially unchanged. Real estate owners have a higher life-cycle trend in labor income. In this exercise, the welfare gain from a customized default design is 1.7% (i.e., somewhat greater than for the full sample). The share captured by the rule of thumb is about the same.

We next consider two exercises in which renters and real estate owners are kept together as one sample. We focus on the heterogeneity in net worth. Whether net worth is an important factor depends on how accessible home equity is to investors during retirement. We conjecture that the default design could be more aggressive if it is easy for investors to consume out of home equity, as it would then offer a margin of self-insurance. Conversely, if investors are rooted in their houses and/or face large transaction costs, then home equity may affect the optimal DC asset allocation less.

To avoid additional state variables, we make extreme assumptions as to the properties of the real estate and mortgage markets. First, we assume that house price growth is spanned by the risk-free asset and the equity market. Second, we assume that a mortgage equals a negative position in the risk-free asset. Third, we assume that transactions are costless. We next make different assumptions about the riskiness of housing and moderate the calibration targets accordingly. In the third exercise, we assume that real estate wealth is risk free. Stock market participation is thus unchanged relative to the main calibration but the conditional equity share is lower. Importantly, the calibration now targets a wealth-to-income ratio of 2.63 instead of 0.92, making the DC account less critical in sustaining the retirement phase. This is manifested as a welfare gain of 1.1% (i.e., lower than in the baseline analysis). However, the share achieved by the rule of thumb remains intact. In the fourth exercise, we let the risk premium in the housing market be in line with the literature (see, e.g., Cocco, 2005; Yao and Zhang, 2005). We assume that house price growth carries a risk premium of 1%. Given that the loan-to-value ratio among investors is approximately 0.5, this implies a risk premium on home equity of 2%. We therefore model home equity as 50% risk free and 50% equity. In this exercise, we redefine both participation and the conditional equity share in the calibration. The welfare gain is 1.2%, again lower than in the baseline analysis, but the rule of thumb still accounts for half of the full gain.

## 7 Concluding remarks

We use a life-cycle consumption-savings model with risky labor income and a DC pension plan to examine the effects of different equity exposures in the default fund.

Relative to a common age-based allocation rule for equity exposure, i.e., “100-minus-age,” the average ex ante welfare gain from implementing the optimal asset allocation equals 1.5% during the retirement phase. In addition to the investors age, the optimal asset allocation rule relies heavily on the investors pension account balance and stock market participation status outside the pension plan. Much of the welfare gain is attainable by implementing a simple rule of thumb conditioned on these three observable characteristics. According to the

model, conditioning on the investors pension account balance and stock market participation status is as important as conditioning on the investors age. Our model suggests that 40% of active pension investors who opt out when offered a default fund that invests according to “100-minus-age” would rather choose the default fund if it were invested according to our proposed rule of thumb.

We believe that asset allocation rules are a promising avenue for achieving cost-effective mass customization (see Bodie et al., 2009, for a discussion of the costs of individualized allocations). The pension account balance is particularly useful, as this information is readily available to the pension plan designer. Hence, we encourage pension agencies and plan sponsors to study the practical, legal, and political aspects of designing a default fund based not only on age but also on other observable characteristics.

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**Table 1: Averages of variables**

	All	Passive	Active
<u>Investors</u>			
Number of investors	301,632	182,487	119,145
Fraction of investors	1.000	0.605	0.395
<u>State variables</u>			
Age	46.8	46.6	47.0
Labor income	248,420	224,526	285,017
Financial wealth	248,039	217,846	294,284
<u>Stock market exposure</u>			
Participation dummy	0.520	0.455	0.619
Equity share (unconditional)	0.234	0.196	0.290
Equity share (conditional)	0.449	0.432	0.469
<u>Real estate ownership and net worth</u>			
Real estate dummy	0.708	0.652	0.793
Real estate wealth	893,784	817,972	1,009,899
Net worth	737,760	665,790	847,993
<u>Educational dummies</u>			
Elementary school	0.157	0.184	0.116
High school	0.544	0.539	0.551
College	0.288	0.267	0.320
PhD	0.011	0.010	0.013

The table presents averages of variables for all investors and investor categories in 2007. At the end of 2007, the SEK/USD exchange rate was 6.47. “Passive” refers to investors who are invested in the default fund or who opted out of the default fund when entering the pension system but have since never changed their allocations. Of the passive investors, 94,496 (or 51.8%) are default investors. “Active” refers to investors who, after entering the pension system, made at least one change to their allocations. The number of investors refers to the number of investors in each category. The fraction of investors refers to the number of investors in each category relative to the total number of investors. Labor income refers to gross annual labor income. Financial wealth refers to financial wealth outside the pension system, i.e., bank accounts, direct bond and stock holdings, mutual funds, as well as the balances in private pension accounts and capital insurance. The balance in private pension accounts is imputed by accumulating the net flows since 1991. Hence, we assume a zero balance at the end of 1990. The participation dummy is assigned a value of one if the investor holds either stocks or equity funds outside the pension system. The conditional equity share is for investors who participate in the stock market, where we assume that capital insurance and private pension accounts comprise 60% equities and 40% bonds. The unconditional equity share is the value-weighted equity share over all investors. The real estate dummy is assigned a value of one if the investor owns either a house or an apartment. Real estate wealth is the value of houses and apartments (not conditioning on owning real estate). Net worth is the sum of financial wealth and real estate wealth minus total debt (e.g., mortgages, credit card debt, and student loans). The loan-to-value ratio equals financial wealth plus real estate wealth minus net worth, which is then divided by real estate wealth; it equals 0.45 for both the passive and active investor categories. The educational dummies are assigned a value of one for the investor’s highest obtained education.

**Table 2: Activity and stock market participation**

	Activity dummy		Participation dummy	
	I	II	III	IV
<b>A. Main regressions</b>				
Age	0.095 (0.009)	—	0.275 (0.008)	—
Labor income	0.146 (0.005)	—	0.109 (0.004)	—
Financial wealth	0.050 (0.002)	—	0.279 (0.002)	—
Real estate dummy	0.115 (0.002)	0.067 (0.002)	0.160 (0.002)	0.073 (0.002)
Educational dummies	Yes	Yes	Yes	Yes
Geographical dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Age/income/wealth splines	No	Yes	No	Yes
<i>R</i> -squared	0.050	0.071	0.156	0.292
Number of observations	301,632	301,632	301,632	301,632
<b>B. Residual regressions</b>				
Activity			0.097 (0.002)	0.060 (0.002)
<i>R</i> -squared			0.010	0.005
Number of observations			301,632	301,632

Panel A presents the results of regressions of activity and stock market participation on various variables. Specifications I and II regress an activity dummy (one if the investor is active in the pension system, zero otherwise) on the variables; Specifications III and IV regress a participation dummy (one if the investor participates in the stock market, zero otherwise) on the variables. Specifications I and III use the state variables of a life-cycle portfolio-choice model (i.e., age, labor income, and financial wealth) and a dummy for real estate ownership as regression variables. Age is scaled down by 100, and labor income and financial wealth are scaled down by 1,000,000. All specifications include educational, geographical, and industry dummy variables. Specifications II and IV replace the linear specifications of age, labor income, and financial wealth with piecewise linear splines. For brevity, the coefficients of these variables are not presented in the table. Panel B presents the results of regressions of the residuals from the participation regressions (Specifications III and IV) on the residuals from the activity regressions (Specifications I and II). The sample comprises investors in 2007. At the end of 2007, the SEK/USD exchange rate was 6.47. Standard errors, robust to conditional heteroscedasticity, are reported in parentheses.

**Table 3: Distribution of variables for passive investors**

	10%	25%	50%	75%	90%	Mean
<b>A. All passive investors</b>						
Age	30	38	46	56	64	46.6
Labor income	0	99,911	225,373	303,797	401,252	224,526
Financial wealth	7,135	17,116	68,580	218,505	560,981	217,846
Equity share	0.000	0.000	0.000	0.401	0.634	0.196
Net worth	-151,186	-1,747	272,619	930,412	2,019,479	665,790
<b>B. Participants</b>						
Age	32	39	48	58	65	48.3
Labor income	0	137,245	250,315	336,004	460,812	258,714
Financial wealth	26,272	68,468	176,367	432,910	934,804	374,888
Equity share	0.088	0.234	0.438	0.609	0.764	0.432
Net worth	-48,909	171,004	646,785	1,497,102	2,836,315	1,069,011
<b>C. Non-participants</b>						
Age	30	36	44	54	62	45.2
Labor income	0	72,964	205,647	277,920	350,952	195,969
Financial wealth	7,135	7,135	26,996	83,589	207,063	86,676
Equity share	0.000	0.000	0.000	0.000	0.000	0.000
Net worth	-201,828	-51,387	58,646	466,923	1,147,239	328,996

The table presents the averages of variables for passive investors by percentiles in 2007. At the end of 2007, the SEK/USD exchange rate was 6.47. Panel A refers to all passive investors. Panel B refers to passive investors who participate in the stock market. Panel C refers to passive investors who do not participate in the stock market. Labor income refers to gross annual labor income. A total of 182,487 investors are represented in Panel A, 83,053 in Panel B, and 99,434 in Panel C. Financial wealth includes financial wealth outside the pension system, i.e., bank accounts, direct bond and stock holdings, mutual funds, as well as the balances in private pension accounts and capital insurance. Missing bank account balances have been imputed to SEK 7,135. The equity share in Panel B is for investors who participate in the stock market, where we assume that capital insurance and private pension accounts comprise 60% equities and 40% bonds; the equity share in Panel C is that of investors who do not participate in the stock market and by definition equals zero. Net worth is the sum of financial wealth and real estate wealth minus total debt (e.g., mortgages, credit card debt, and student loans).

**Table 4: Model parameters**

	Notation	Value
<u>Returns</u>		
Gross risk-free rate	$R_f$	1.00
Equity premium	$\mu$	0.04
Standard deviation of stock market return	$\sigma_\varepsilon$	0.18
<u>Labor income and financial wealth</u>		
Standard deviation of idiosyncratic labor income shock	$\sigma_\eta$	0.072
Weight of stock market shock in labor income	$\theta$	0.040
Standard deviation of initial labor income	$\sigma_z$	0.366
Standard deviation of initial financial wealth	$\sigma_A$	1.392
Mean of initial financial wealth		76,800
<u>Contribution rates in pension accounts</u>		
DC account	$\lambda^{\text{DC}}$	7%
Notional account	$\lambda^{\text{N}}$	16%
<u>Life-cycle profiles</u>		
Labor-income profile	$g_t$	—
Survival rates	$\phi_t$	—
<u>Preferences and stock market participation cost</u>		
Elasticity of intertemporal substitution	$1/\rho$	0.500
Discount factor*	$\beta$	0.933
Relative risk aversion*	$\gamma$	14
Ceiling for opt-out cost*	$\bar{\kappa}^{\text{DC}}$	3,600
Ceiling for stock market entry cost*	$\bar{\kappa}$	15,600
Number of layers in the cost distribution*		3

The table presents the parameter values of the model. \* The parameter value has been determined endogenously by simulating the model. The labor-income profiles are discussed in detail in the main text. The survival rates are computed from unisex statistics provided by Statistics Sweden. At the end of 2007, the SEK/USD exchange rate was 6.47.

**Table 5: Matched moments in the data and model**

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	Data	Model
Financial wealth-to-labor income ratio	0.922	0.921
Equity share (conditional)	0.454	0.519
Active (opting out)/non-participation	0.151	0.158
Active (opting out)/participation	0.244	0.255
Passive (default)/non-participation	0.330	0.316
Passive (default)/participation	0.275	0.271

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The table presents matched moments in the data and model. We consider data from the working phase. Activity in the data corresponds to opting out in the model. The table implies that the share of passive (default) investors is 0.605 ( $0.330 + 0.275$ ) in the data and 0.587 ( $0.316 + 0.271$ ) in the model; the share of non-participating investors is 0.481 ( $0.151 + 0.330$ ) in the data and 0.474 ( $0.158 + 0.316$ ) in the model.

**Table 6: DC account equity share in model-simulated data**

	I	II	III	IV	V	VI	VII
Constant	1.746 (0.016)	1.873 (0.015)	1.585 (0.018)	1.738 (0.016)	1.313 (0.013)	1.347 (0.011)	1.266 (0.012)
Age	-0.024 (0.001)	-0.023 (0.001)	-0.018 (0.001)	-0.022 (0.001)	-0.009 (0.001)	-0.008 (0.001)	-0.007 (0.001)
Labor income		-0.760 (0.039)					0.262 (0.025)
Financial wealth			-0.565 (0.041)				-0.096 (0.032)
Participation dummy				-0.233 (0.006)		-0.196 (0.003)	-0.198 (0.004)
DC account balance					-0.666 (0.026)	-0.603 (0.022)	-0.618 (0.017)
<i>R</i> -squared	0.630	0.687	0.740	0.730	0.786	0.855	0.859

The table presents the results of regressions of the model's optimal DC equity share on some of the model's state variables. The simulated data are based on 50 economies, each of which has 11,500 investors (500 individuals each with 23 combinations of stock market participation and opt-out costs) who each work for 40 years. The number of default investors is endogenous (here 58.7% of all investors), giving a total 13,492,000 simulated observations in each of the regressions. Labor income, financial wealth, and DC account balance are scaled down by 1,000,000. Standard errors, robust to conditional heteroscedasticity and clustered over economy and individual, are reported in parentheses.

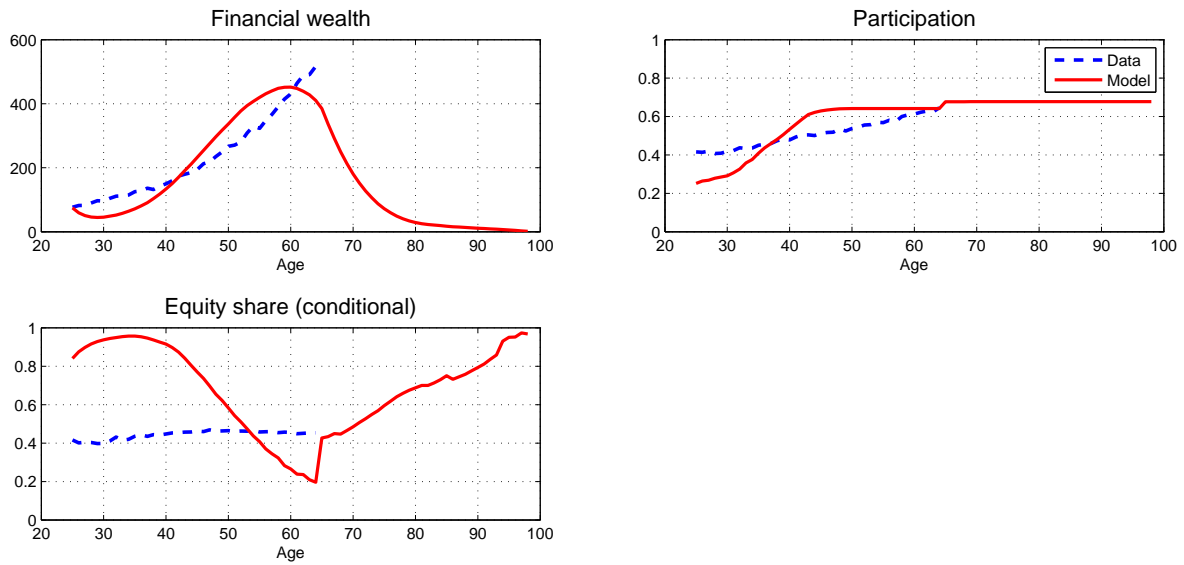
**Table 7: Welfare analysis and endogenously determined default investors**

	“100-minus-age”	Average optimal	Rule of thumb	Optimal
Share of default investors	0.587	0.679	0.753	1.000
Incremental welfare gain	—	0.3%	0.6%	0.6%
Cumulated welfare gain	—	0.3%	0.9%	1.5%
<u>Regressions</u>				
Constant	1.347 (0.011)	1.363 (0.015)	1.384 (0.018)	1.411 (0.022)
Age	-0.008 (0.001)	-0.009 (0.001)	-0.009 (0.001)	-0.010 (0.001)
Participation dummy	-0.196 (0.003)	-0.199 (0.003)	-0.198 (0.003)	-0.195 (0.003)
DC account balance	-0.603 (0.022)	-0.564 (0.027)	-0.533 (0.031)	-0.505 (0.035)
<i>R</i> -squared	0.855	0.855	0.853	0.850
<u>Pension income</u>				
Mean	154,880	155,461	158,952	152,281
Equity risk	0.121	0.122	0.127	0.087
Inequality	0.234	0.233	0.194	0.196

The table presents the effects of the gradual implementation of a more customized default fund. The first column indicates the initial design, “100-minus-age.” The fourth column indicates implementation of the model’s optimal (i.e., fully customized) default allocation. The second and third columns are intermediate allocation steps (i.e., average optimal and rule-of-thumb allocations). The first line reports the share of default investors out of a total population of default plus opt-out investors equal to 11,500. The second line reports the incremental welfare gain in percent during the retirement phase of moving one step toward more customization from the first column. The third line reports the cumulative gain in percent. To obtain welfare gains expressed as a constant gain throughout the life-cycle, the reported gains should be divided by approximately 29, following the discounting in Online Appendix A.7. The regressions follow the regression in Table 6 with default investors generated under respective default design. The first column is identical to column VI of Table 6. The simulated data are based on 50 economies, each of which has 11,500 investors who each work for 40 years. The number of observations in each column is as follows: 13,492,000; 15,624,000; 17,326,000; and 23,000,000. Labor income, financial wealth, and DC account balance are scaled down by 1,000,000. Standard errors, robust to conditional heteroscedasticity and clustered over economy and individual, are reported in parentheses. Pension income refers to pension income at age 65 years. For pension income, the samples in all columns are held constant to the default investors under “100-minus-age” (6,746 individuals). The mean refers to the average over economies and individuals. Equity risk is the standard deviation of the log of average pension income across 50 economies. Inequality is the standard deviation of the log of average pension income across 6,746 individuals.

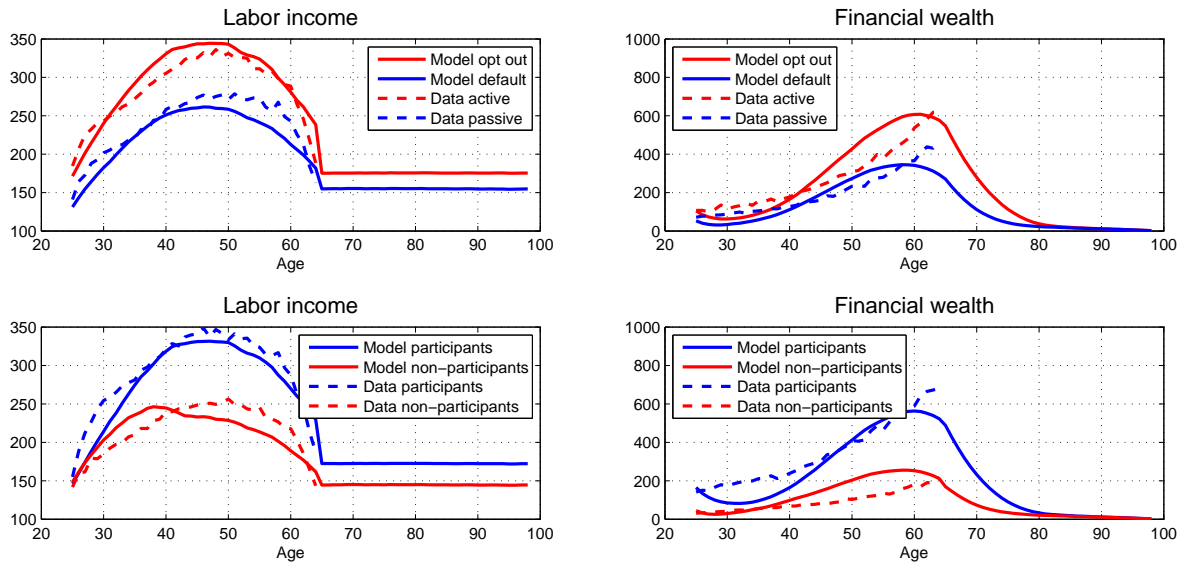


Figure 1: Calibration and model fit



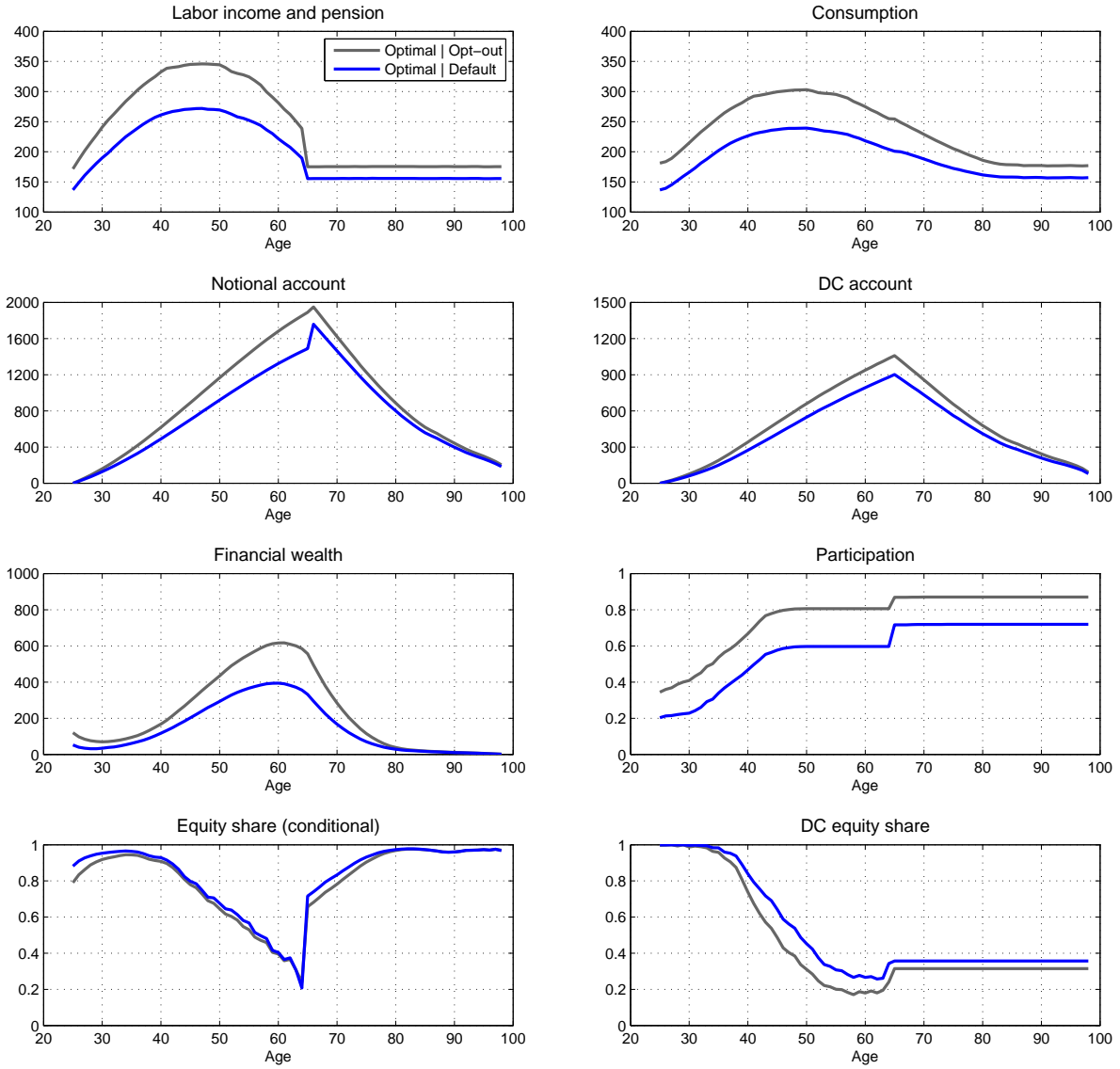
The figure shows the fit of the model to the data. The model simulation is based on 50 economies and 11,500 individuals. Financial wealth is expressed in SEK 1000s.

**Figure 2: Model fit of participants/non-participants and default/opt-out investors**



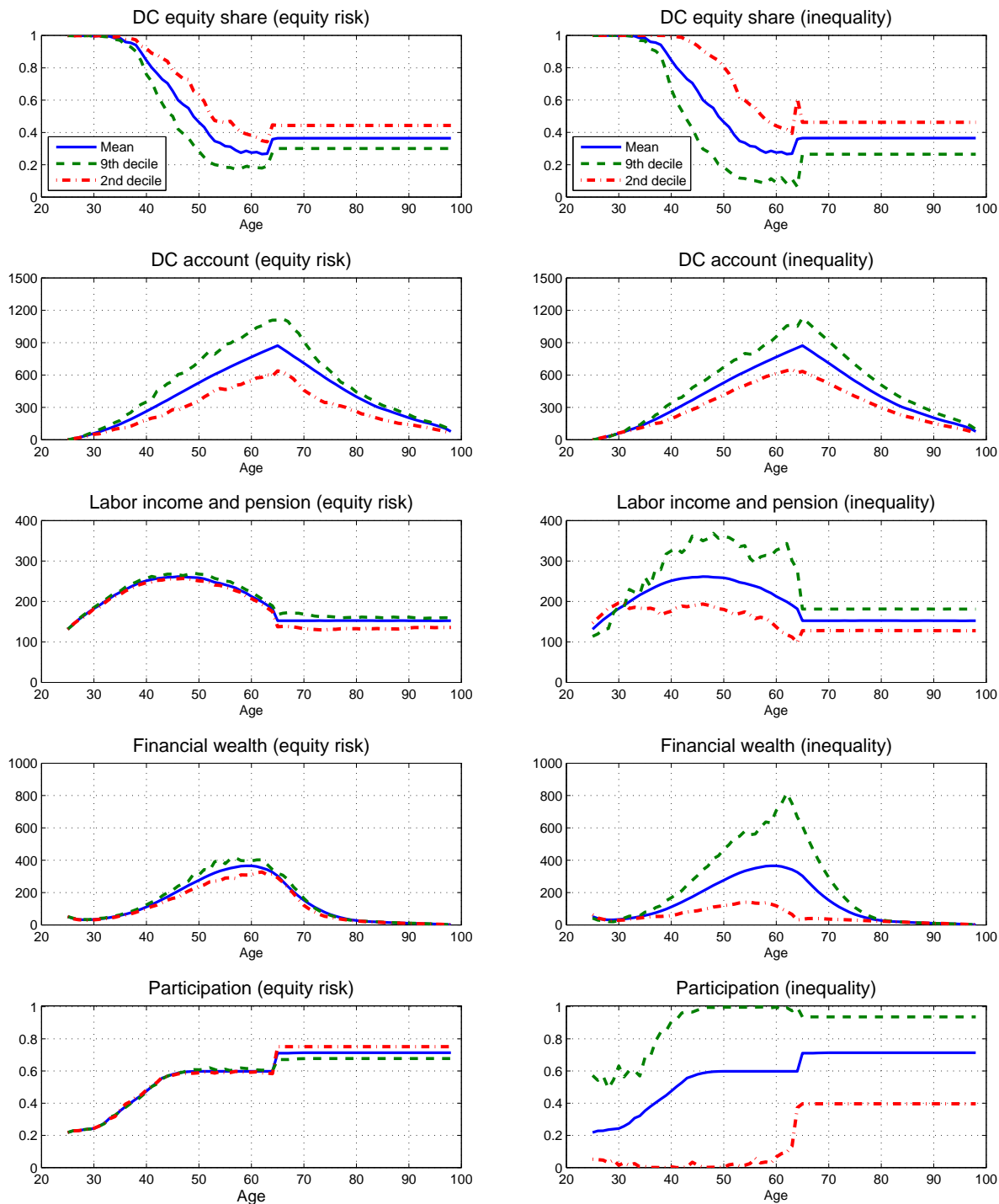
The figure shows the average labor income and financial wealth (both in SEK 1000s) of default/opt-out and participant/non-participant investors. The separation of default/opt-out investors is a result of endogenous choice when investors are exposed to the “100-minus-age” default design (as in the calibration).

**Figure 3: Averages for default and opt-out investors**



The figure shows averages over 50 economies and 11,500 individuals for the optimal asset allocation of opt-out and default investors (4,754 vs. 6,746 individuals). The two groups are a result of endogenous choice when investors are exposed to the “100-minus-age” default design (as in the calibration). Labor income and pension, consumption, notional and DC accounts, and financial wealth are expressed in SEK 1000s.

Figure 4: Aggregate equity risk and inequality implied by the optimal asset allocation



The figure shows the aggregate equity risk and inequality for the optimal asset allocation of default investors. The simulation is based on 50 economies and 11,500 individuals. The left panels show how the averages vary over 50 economies. The second decile refers to the average of economies 6–10 (sorted). The ninth decile refers to the average of economies 41–45 (sorted). The right panels show how the averages vary over individuals who endogenously become default investors. A decile is then 1/10 of these default investors. The same economies and individuals are not tracked over time, i.e., the sorting at one age is independent of the sorting at another age. The DC account, labor income and pension, and financial wealth are expressed in SEK 1000s.

Online Appendix for  
“On the Asset Allocation of a Default Pension Fund”

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April 11, 2017

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# Contents

A.1	Details of LINDA	3
A.2	Supporting empirical evidence	4
A.3	Details of the notional account	4
A.4	Solving the model	5
A.5	Details of the exogenous parameters	6
A.6	Probability of opting out for each type	9
A.7	Welfare calculations	9
A.8	Robustness	11
A.9	Robustness related to real estate	12
	References	13

## List of Tables

A.1	Industry heterogeneity . . . . .	14
A.2	Averages of variables for renters . . . . .	15
A.3	Averages of variables for real estate owners . . . . .	16
A.4	Activity and stock market participation of renters . . . . .	17
A.5	Activity and stock market participation of real estate owners . . . . .	18
A.6	Robustness exercises . . . . .	19
A.7	Robustness exercises related to real estate . . . . .	20

## List of Figures

A.1	Various cohorts for the calibration . . . . .	21
A.2	Calibration (robustness V) . . . . .	22
A.3	Model fit (robustness V) . . . . .	22
A.4	Calibration (robustness VI) . . . . .	23
A.5	Model fit (robustness VI) . . . . .	23
A.6	Calibration for renters (robustness VII) . . . . .	24
A.7	Model fit for renters (robustness VII) . . . . .	24
A.8	Calibration for real estate owners (robustness VIII) . . . . .	25
A.9	Model fit for return for real estate owners (robustness VIII) . . . . .	25
A.10	Calibration for real estate as a bond (robustness IX) . . . . .	26
A.11	Model fit for real estate as a bond (robustness IX) . . . . .	26
A.12	Calibration for real estate as 50% a bond and 50% equity (robustness X) . . . . .	27
A.13	Model fit for real estate as 50% a bond and 50% equity (robustness X) . . . . .	27

## A.1 Details of LINDA

The Longitudinal Individual Data (LINDA) is a widely used dataset in economic research. It is a joint endeavor between the Department of Economics at Uppsala University, the National Social Insurance Board (RFV), Statistics Sweden, and the ministries of Finance and Labor. Edin and Fredriksson (2000) provided a detailed account of the data collection process for LINDA. More information on LINDA is also available from the websites of the Department of Economics, Uppsala University (<http://nek.uu.se/>) and Statistics Sweden (<http://www.scb.se/>).

LINDA is a panel dataset that covers slightly more than three percent of the Swedish population annually. There are approximately 300,000 individuals in the dataset. The starting point for LINDA is a representative, random sample of the Swedish population in 1994, which has been tracked back to 1968 and forward to 2007. New individuals are added to the database each year to ensure that LINDA remains representative of the cross-section of Swedish individuals. In addition, the dataset contains information on all family members of the sampled individual. Thus, LINDA covers all members of approximately 300,000 households in each year. At the core of LINDA are the income registers (Inkomst- och Förmögenhetsstatistiken) and population census data (Folk- och Bostadsräkningen). Each wave of LINDA contains information on taxable income and social transfers (e.g., unemployment benefits) from the Income Registers in a given year. In addition, LINDA contains information on occupation, wages, and educational attainment from separate registers held at Statistics Sweden. We also use the wealth supplement of LINDA, which is available between 1999 and 2007. The wealth supplement contains information on the market value of houses, owned apartments (co-ops), cabins, plots of land, and other forms of real estate. It also reports the value of total debt and the value of student loans.

When Statistics Sweden compiles LINDA, it lacks the information to assign two people that belong to the same household but that are unmarried and without children. Such individuals are treated as two separate households. This leads to undersampling of this particular kind of household.



## A.2 Supporting empirical evidence

We provide some supporting evidence that is mentioned in the paper:

Table A.1 reports on industry heterogeneity;

Tables A.2 and A.3 correspond to Table 1 in the paper, but reported separately for renters and real estate owners; and

Tables A.4 and A.5 correspond to Table 2 in the paper, but reported separately for renters and real estate owners.

## A.3 Details of the notional account

As mentioned in the paper, carrying the balance of the notional account as part of the individual's state is computationally demanding. To avoid this, we proceed as follows. First, we simulate many life-cycle income paths based on our calibration of the labor income process. For each path we calculate the true balance of the notional account according to the exact contribution rate of 16%. Then we regress the account balance on a polynomial of the persistent component of labor income at the time of retirement, i.e.  $z_{65}$ :

$$A_{i65}^N = \beta_0 + \sum_{j=1}^n \beta_j z_{i65}^j + \varepsilon_{i65}. \quad (\text{A1})$$

We choose  $n = 5$ , as a higher-order polynomial provides a better fit. The  $R$ -squared in this regression is 80%. We use the estimated coefficients from this regression to approximate the account balance. With the use a higher-order polynomial, the  $R$ -squared is the same if we used  $\ln(A_{i65}^N)$  as the dependent variable or if we used  $Y_{i65}$  as the independent variable.

This approximation of  $A_{i65}^N$  is applied unless the approximation falls below an implied floor. Since there is a floor of SEK 85,829 in the annuity payment out of the notional account, and since the actuarially fair annuity factor is 5.6%, the implied floor on  $A_{i65}^N$  equals SEK 1,532,661 (SEK 85,829 divided by 0.056). For those individuals for whom the approximation

falls below this floor, we add a one-time transfer (from the government) to the individuals' notional account. Hence, a jump in the average notional account balance is observed at retirement (see Figure 3 in the paper).

## A.4 Solving the model

This section describes the method for solving the investor's problem.

We describe the solution to the active participant's problem during the working phase. The problems of the stock market entrant, non-participant, and retired investors are straightforward variations of the participant's problem. Note that the retired investor has an extra state variable – the choice of the DC equity share at age 65 years. The optimal stock market entry problem is a simple binary problem. The passive investor's problem is similar to the active investor's but does not allow for optimal choice of the DC equity share.

### The state space

The investor's state is determined by age ( $t$ ), cash on hand ( $X$ ), DC account balance ( $A^{DC}$ ), the permanent component of labor income ( $z$ ), participation cost ( $\kappa$ ), and the opt-out cost ( $\kappa^{DC}$ ).

The state space for age runs from 1 to 40. Each cost (opt out or participation) is represented by a grid of five values. Participation is represented by a binary variable. Labor income, cash on hand, and the DC balance are discretized on a grid of size 25, 10, and 15, respectively. The upper support of the DC account balance is SEK 5 million, the upper support of cash on hand is set to SEK 6.25 million, and the support of the permanent component of labor income is set to be between  $-2.5$  and  $+2.0$  standard deviations around the age-dependent mean. The grid used for labor income is equally spaced, while the grid used for the other two variables is based on exponential spacing. The three properties of each grid, i.e., its type, support, and size, are set according to the endogenous support of each variable in the simulations, and are selected to ensure that any changes, such as increases in

grid size, do not matter either qualitatively or quantitatively.

The number of points in the state space is 7.5 million.

## Optimization

We iterate on the choice of the DC equity share over a grid of six equally spaced points between 0.0 and 1.0. For each of the six proposed equity shares, we apply the endogenous grid method developed by Carroll (2006) to solve for consumption and savings outside the pension system.<sup>1</sup> Within that solution, we solve for the optimal equity share outside the pension system, using a bisection search with five iterations over the Euler equation for the excess stock market return.

In the simulations we use a double Hermite-Gauss procedure to integrate over the labor income shocks and the stock market shocks. We use the nodes and the probabilities in Judd (1998)

## A.5 Details of the exogenous parameters

There are six sets of exogenous parameters.

First, we set the equity premium to 4% per year and the standard deviation of the stock market return to 18% per year. These choices are in the range of commonly used parameter values in the literature. We set the simple risk-free rate to zero, which in other calibrations is often set to 1–2%. We argue that this is correct in our model as labor income does not include economic growth. Thus, we deflate the account returns by the expected growth to obtain coherent replacement rates. As replacement rates in our model are a function of returns, rather than a function of final labor income, this choice is more important to the present model than to previous models. Simulations of the labor income process and contributions to the pension accounts validate our strategy. These simulations indicate that replacement

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<sup>1</sup>The grid for financial wealth is set using next years financial wealth rather than current financial wealth. This reformulation of the problem significantly reduces the computational burden.

rates at age 65 years relative to labor income at age 64 are coherent with Swedish Pensions Agency forecasts.

Second, we set labor income according to Swedish data. We estimate the riskiness of the labor income after having added on common transfers (e.g., sick leave, unemployment, and parental leave benefits) and after having subtracted taxes. Then we follow Carroll and Samwick (1997) but include year fixed effects to account for aggregate risk. We find that the standard deviation of permanent labor income equals 0.072.<sup>2</sup> We set the one-year correlation between permanent income growth and stock market returns to 10%. This corresponds to a  $\theta$  of 0.040. We approximate the distribution of initial labor income and financial wealth using log-normal distributions. The mean financial wealth for 25-year-old default investors is set to SEK 76,800. The cross-sectional standard deviations are set to 0.366 ( $\sigma_z$ ) and 1.392 ( $\sigma_A$ ) to match the data for 25-year-old individuals.

Third, we consider the contribution rates. We set the contribution rate for the notional account to 16% and for the DC account to 7%. This mirrors the premium pension account with a contribution rate of 2.5% and the occupational pension account with a typical contribution rate of 4.5%. We depart from the Swedish pension system by ignoring the ceilings on the contributions. However, about 90% of workers have occupational pension plans that compensate for the ceilings in the public plans to achieve high replacement rates even for high-income individuals.

Fourth, we determine the annuity divisor for the notional account in retirement. We use the unisex mortality table of Statistics Sweden to determine  $\phi_t$ . We assume that the notional account continues to be invested in the risk-free bond and allow for inheritances within a cohort from dying to surviving individuals, incorporating those into the returns of the survivors. We then use the standard annuity formula to reach an annuity factor of 5.6% of the account balance at age 65 years. We use the same formulas for the DC account, though we adjust the expected return to the endogenous choice of the DC equity share in retirement.

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<sup>2</sup>Since many transfer programs cover rents or subsidies of rents, we also exclude individuals with a labor income less than SEK 48,000, consistent with the model's income floor.

Fifth, we set the elasticity of intertemporal substitution to 0.5, which is a common value in life-cycle models of portfolio choice (see, e.g., Gomes and Michaelides, 2005).

Finally, we use “100-minus-age” as the DC equity share profile of the calibration. We justify this below.

## Calibration of the DC equity share

This rule takes into account variation in the DC equity share across cohorts. Reform of the pension system occurred in 2000, affecting different birth cohorts differently. We weight all cohorts together at the time of our 2007 data snapshot. Since older cohorts have been, and still are, exposed to less equity, there is a downward-sloping profile by age in 2007. This profile, which we call “Mix of all cohorts” coincides almost perfectly with “100-minus-age.”

To deduce “Mix of all cohorts,” we rely on the following assumptions and calculations:

1. We assume that everyone enters the labor force at age 25 years.
2. All cohorts born after 1973 have the same DC equity share, while individuals born before 1972 have foregone some contributions to equity. The cutoff is at cohort 1973 because contributions started to accrue in 1997 (three years prior to the launch in 2000). Cohort 1973 was 25 years old in 1997.
3. We make the following assumptions about the DC account holdings of cohorts born before 1973:
  - (a) Prior to the reform, the same contribution rate as in the premium pension system, 2.5%, was invested in a risk-free asset.
  - (b) Contributions invested prior to 1997 remain invested in the risk-free asset onward until retirement.
  - (c) Occupational pension plans are the same for all cohorts. The allocation in that pension plan is 60% equity and 40% risk-free assets.
  - (d) Realized equity returns have been equal to 4%.

Based on these assumptions, we can compute cohort-specific allocation profiles for the DC equity share. We then compute an equal-weighted average of these cohorts’ profiles to obtain a single profile for our calibration. At every given age, we include the portion of a cohort’s profile that corresponds to 2007 and later. We include future years since behavior in 2007 is forward-looking and takes into account the future DC equity share.

Appendix Figure A.1 depicts “Mix of all cohorts,” “100-minus-age,” and, for illustrative purposes, the paths for some specific birth cohorts.

## A.6 Probability of opting out for each type

In our baseline calibration, there are 23 types with different combinations of stock market participation cost,  $\kappa$ , and opt-out cost,  $\kappa^{\text{DC}}$ . In Section 6.1 we report some statistics on the opt-out/default choice. We report the probability of opting out for each type below:

	3,600	—	0.026	0.026	0.028	0.030
	2,700	0.094	0.098	0.100	0.114	0.158
$\kappa^{\text{DC}}$	1,800	0.280	0.282	0.302	0.318	0.342
	900	0.432	0.462	0.784	0.806	0.826
	0	1.000	1.000	1.000	1.000	—
		0	3,900	7,800	11,700	15,600
				$\kappa$		

## A.7 Welfare calculations

This section explains how we compute welfare gains associated with a shift from a baseline design (e.g., the “100-minus-age” rule) to a more customized design. Let  $\bar{c}$  denote the certainty-equivalent consumption associated with the baseline rule and, for ease of notation, let  $t = 0$  correspond to age 25 years and  $T = 75$  to age 100. Starting from  $V_T = \bar{c}$ , backward iteration implies the following relationship between the value function at age 25 under the

baseline, denoted by  $V_0$ , and  $\bar{c}$ :

$$V_0 = \bar{c} \left( \sum_{t=0}^T \beta^t \Pi_{k=0}^t \phi_k \right)^{\frac{1}{1-\rho}} \quad (\text{A2})$$

As explained in the main text, we let the welfare gain be concentrated in the retirement period. Therefore, let the certainty-equivalent consumption during the retirement phase be given by  $\bar{c}(1+g)$  (i.e., the welfare gain is denoted by  $g$ ). Backward iteration from  $T$  to age 65 years implies that the value at age 65 under the customized design, denoted by  $V_r^*$ , equals:

$$V_r^* = \bar{c}(1+g) \left( \sum_{j=0}^{34} \beta^j \Pi_{k=0}^j \phi_{40+k} \right)^{\frac{1}{1-\rho}} \quad (\text{A3})$$

Further backward iteration from age 65 to 25 years implies that the value function at age 25 associated with the customized default fund equals:

$$V_0^* = \left( \bar{c}^{1-\rho} \sum_{j=0}^{39} \beta^j \Pi_{k=0}^j \phi_{25+k} + \beta^{40} \Pi_{k=0}^{40} \phi_{25+k} (V_r^*)^{1-\rho} \right)^{\frac{1}{1-\rho}} \quad (\text{A4})$$

After using equation (A2) to obtain  $\bar{c}$  from  $V_0$ , we use (A3) and (A4) to solve for  $g$  as a function of  $V_0^*$  and  $\bar{c}$ :

$$g = \left( \frac{(V_0^*)^{1-\rho} - \bar{c}^{1-\rho} \sum_{j=0}^{39} \beta^j \Pi_{k=0}^j \phi_{25+k}}{\beta^{40} \Pi_{k=0}^{40} \phi_{25+k} \sum_{j=0}^{34} \beta^j \Pi_{k=0}^j \phi_{40+k}} \right)^{\frac{1}{1-\rho}} / \bar{c} - 1 \quad (\text{A5})$$

A gain expressed as a constant increase during the working and retirement phases and a gain expressed as a constant increase during the retirement phase differs by a factor of approximately 29, due to discounting.

## A.8 Robustness

Table A.6 presents the parameters, moments, and results for six of our robustness exercises. They are:

- I. Low equity premium;
- II. Left-skewed stock market returns;
- III. Fixed equity weight outside the pension system;
- IV. Random equity weight outside the pension system;
- V. High correlation between labor income and stock market returns; and
- VI. High correlation between labor income and stock market returns, and left-skewed returns.

As mentioned in the text, the results hold both qualitatively and quantitatively throughout the exercises. In particular, in each of the exercises, the welfare gain is at least 1.4% and the rule of thumb captures at least 50% of the welfare gain, improving the welfare by at least 20% relative to the average optimal. Recall that we recalibrate our model for each of those exercises to provide a good fit to the data under each alternative assumption, and note that the fit remains reasonable in all exercises. The changes in the parameters are driven by the changes in the assumptions in each exercise.

Related to the last two exercises, we also present the fit of the model to the data on the average labor income and financial wealth of default/opt-out and participant/non-participant investors (corresponding to Figures 1 and 2 in the paper). In these figures, financial wealth and labor income are expressed in SEK 1000s. Figures A.2 and A.3 are for Exercise V; Figures A.4 and A.5 are for Exercise VI.

In all of our tabulated analyses, we calibrate the model so that 58.7% of pension investors remain in the default fund. While we argue that this is a fair reflection of the empirical pattern of investors' passivity, we have recalibrated the model so that the share of default



investors reflects the 32.8% of default investors in the data. In untabulated results, we find that the welfare gain of implementing the optimal design increases slightly from 1.5% to 1.7%. Furthermore, the share attainable by the rule of thumb increases from 60% to 65%. We view this as a consequence of default investors becoming more negatively selected.

## **A.9 Robustness related to real estate**

Table A.7 reports four robustness exercises related to real estate:

VII. Renters;

VIII. Real estate owners;

IX. Real estate being a risk-free asset; and

X. Real estate being 50% a risk-free asset and 50% a risky asset.

Related to these exercises, we also present the fit of the model to the data on the average labor income and financial wealth of default/opt-out and participant/non-participant investors (corresponding to Figures 1 and 2 in the paper). Again, financial wealth and labor income are expressed in SEK 1000s. Figures A.6 and A.7 are for Exercise VII; Figures A.8 and A.9 are for Exercise VIII; Figures A.10 and A.11 are for Exercise IX; Figures A.12 and A.13 are for Exercise X.

## References

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**Table A.1: Industry heterogeneity**

	Activity		Participation		Residual regression
	Unconditional fraction	Fixed effect in regression	Unconditional fraction	Fixed effect in regression	
Agriculture	0.365	—	0.598	—	0.035
Mining	0.447	0.005	0.580	-0.031	0.067
Manufacturing	0.439	0.051	0.562	-0.020	0.066
Utilities	0.477	0.062	0.635	-0.022	0.045
Construction	0.411	0.020	0.564	-0.028	0.051
Whole sales	0.408	0.050	0.526	-0.033	0.054
Hotel	0.272	0.001	0.374	-0.048	0.058
Transportation	0.404	0.046	0.505	-0.035	0.069
Financial	0.617	0.208	0.739	0.037	0.063
Consumer products	0.423	0.054	0.565	-0.032	0.060
Public sector	0.478	0.077	0.617	-0.032	0.058
Educational sector	0.386	0.029	0.498	-0.065	0.062
Health	0.413	0.049	0.536	-0.058	0.061
Services	0.378	0.026	0.440	-0.040	0.051

The table presents the activity and stock market participation heterogeneity across 14 industries (formed using two-digit SIC codes). The first column below Activity reports the unconditional fraction of active investors in each industry; the second column reports industry fixed effects in a regression of an activity dummy on piecewise splines of individual characteristics, corresponding to regression (1) in the paper. The first column below Participation reports the unconditional fraction of participating investors; the second column reports industry fixed effects in a regression of a participation dummy on piecewise splines of individual characteristics, corresponding to regression (2) in the paper. The fixed effect are relative to the Agriculture industry. The last column presents the estimated coefficients in the residual regression (3) in the paper for each industry separately. All residual regression coefficients are statistically significant at the 1% level with the exception of the Agriculture, Mining, and Utilities industries, which are significant at the 10% level.

**Table A.2: Averages of variables for renters**

	All	Passive	Active
<u>Investors</u>			
Number of investors	88,133	63,429	24,706
Fraction of investors	1.000	0.720	0.280
<u>State variables</u>			
Age	44.4	43.9	45.7
Labor income	179,362	164,848	216,627
Financial wealth	151,156	128,159	210,200
<u>Stock market exposure</u>			
Participation dummy	0.347	0.296	0.479
Equity share (unconditional)	0.147	0.121	0.213
Equity share (conditional)	0.424	0.410	0.445
<u>Real estate ownership and net worth</u>			
Real estate dummy	0.000	0.000	0.000
Real estate wealth	0	0	0
Net worth	18,766	3,979	56,731
<u>Educational dummies</u>			
Elementary school	0.213	0.235	0.156
High school	0.544	0.535	0.567
College	0.238	0.225	0.270
PhD	0.005	0.005	0.006

The table presents averages of variables for all investors who rent, by investor categories in 2007. At the end of 2007, the SEK/USD exchange rate was 6.47. “Passive” refers to investors who are invested in the default fund or who opted out of the default fund when entering the pension system but have since never changed their allocations. “Active” refers to investors who, after entering the pension system, made at least one change to their allocations. The number of investors refers to the number of investors in each category. The fraction of investors refers to the number of investors in each category relative to the total number of investors. Labor income refers to gross annual labor income. Financial wealth refers to financial wealth outside the pension system, i.e., bank accounts, direct bond and stock holdings, mutual funds, as well as the balances in private pension accounts and capital insurance. The participation dummy is assigned a value of one if the investor holds either stocks or equity funds outside the pension system. The conditional equity share is for investors who participate in the stock market, where we assume that capital insurance and private pension accounts comprise 60% equities and 40% bonds. The unconditional equity share is the value-weighted equity share over all investors. The real estate dummy is assigned a value of one if the investor owns either a house or an apartment and is by definition equal to zero for the sample of renters. Real estate wealth is the value of houses and apartments. Net worth is the sum of financial wealth and real estate wealth minus total debt (e.g., mortgages, credit card debt, and student loans). The educational dummies are assigned a value of one for the investor’s highest obtained education.

**Table A.3: Averages of variables for real estate owners**

	All	Passive	Active
<u>Investors</u>			
Number of investors	213,497	119,058	94,439
Fraction of investors	1.000	0.558	0.442
<u>State variables</u>			
Age	47.8	48.1	47.3
Labor income	276,928	256,319	302,909
Financial wealth	288,033	265,627	316,281
<u>Stock market exposure</u>			
Participation dummy	0.591	0.540	0.655
Equity share (unconditional)	0.269	0.236	0.310
Equity share (conditional)	0.456	0.438	0.474
<u>Real estate ownership and net worth</u>			
Real estate dummy	1.000	1.000	1.000
Real estate wealth	1,262,752	1,253,752	1,274,097
Net worth	1,034,572	1,018,374	1,054,994
<u>Educational dummies</u>			
Elementary school	0.135	0.158	0.105
High school	0.543	0.540	0.547
College	0.308	0.289	0.333
PhD	0.014	0.013	0.015

The table presents averages of variables for all investors who own real estate, by investor categories in 2007. At the end of 2007, the SEK/USD exchange rate was 6.47. “Passive” refers to investors who are invested in the default fund or who opted out of the default fund when entering the pension system but have since never changed their allocations. “Active” refers to investors who, after entering the pension system, made at least one change to their allocations. The number of investors refers to the number of investors in each category. The fraction of investors refers to the number of investors in each category relative to the total number of investors. Labor income refers to gross annual labor income. Financial wealth refers to financial wealth outside the pension system, i.e., bank accounts, direct bond and stock holdings, mutual funds, as well as the balances in private pension accounts and capital insurance. The participation dummy is assigned a value of one if the investor holds either stocks or equity funds outside the pension system. The conditional equity share is for investors who participate in the stock market, where we assume that capital insurance and private pension accounts comprise 60% equities and 40% bonds. The unconditional equity share is the value-weighted equity share over all investors. The real estate dummy is assigned a value of one if the investor owns either a house or an apartment and is by definition equal to one for the sample of real estate owners. Real estate wealth is the value of houses and apartments. Net worth is the sum of financial wealth and real estate wealth minus total debt (e.g., mortgages, credit card debt, and student loans). The educational dummies are assigned a value of one for the investor’s highest obtained education.

**Table A.4: Activity and stock market participation of renters**

	Activity dummy		Participation dummy	
	I	II	III	IV
<b>A. Main regressions</b>				
Age	0.304 (0.013)	—	0.122 (0.013)	—
Labor income	0.402 (0.013)	—	0.281 (0.013)	—
Financial wealth	0.079 (0.004)	—	0.400 (0.004)	—
Educational dummies	Yes	Yes	Yes	Yes
Geographical dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Age/income/wealth splines	No	Yes	No	Yes
<i>R</i> -squared	0.051	0.074	0.151	0.305
Number of observations	88,135	88,135	88,135	88,135
<b>B. Residual regressions</b>				
Activity			0.119 (0.003)	0.075 (0.003)
<i>R</i> -squared			0.014	0.007
Number of observations			88,135	88,135

Panel A presents the results of regressions of activity and stock market participation on various variables for renters. Specifications I and II regress an activity dummy (one if the investor is active in the pension system, zero otherwise) on the variables; Specifications III and IV regress a participation dummy (one if the investor participates in the stock market, zero otherwise) on the variables. Specifications I and III use the state variables of a life-cycle portfolio-choice model (i.e., age, labor income, and financial wealth). Age is scaled down by 100, and labor income and financial wealth are scaled down by 1,000,000. All specifications include educational, geographical, and industry dummy variables. Specifications II and IV replace the linear specifications of age, labor income, and financial wealth with piecewise linear splines. For brevity, the coefficients of these variables are not presented in the table. Panel B presents the results of regressions of the residuals from the participation regressions (Specifications III and IV) on the residuals from the activity regressions (Specifications I and II). The sample consists of investors in 2007. At the end of 2007, the SEK/USD exchange rate was 6.47. Standard errors, robust to conditional heteroscedasticity, are reported in parentheses.

**Table A.5: Activity and stock market participation of real estate owners**

	Activity dummy		Participation dummy	
	I	II	III	IV
<b>A. Main regressions</b>				
Age	-0.053 (0.011)	—	0.350 (0.011)	—
Labor income	0.109 (0.005)	—	0.096 (0.005)	—
Financial wealth	0.049 (0.002)	—	0.249 (0.002)	—
Educational dummies	Yes	Yes	Yes	Yes
Geographical dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Age/income/wealth splines	No	Yes	No	Yes
<i>R</i> -squared	0.025	0.043	0.104	0.237
Number of observations	213,497	213,497	213,497	213,497
<b>B. Residual regressions</b>				
Activity			0.088 (0.002)	0.055 (0.002)
<i>R</i> -squared			0.009	0.004
Number of observations			213,497	213,497

Panel A presents the results of regressions of activity and stock market participation on various variables for real estate owners. Specifications I and II regress an activity dummy (one if the investor is active in the pension system, zero otherwise) on the variables; Specifications III and IV regress a participation dummy (one if the investor participates in the stock market, zero otherwise) on the variables. Specifications I and III use the state variables of a life-cycle portfolio-choice model (i.e., age, labor income, and financial wealth). Age is scaled down by 100, and labor income and financial wealth are scaled down by 1,000,000. All specifications include educational, geographical, and industry dummy variables. Specifications II and IV replace the linear specifications of age, labor income, and financial wealth with piecewise linear splines. For brevity, the coefficients of these variables are not presented in the table. Panel B presents the results of regressions of the residuals from the participation regressions (Specifications III and IV) on the residuals from the activity regressions (Specifications I and II). The sample consists of investors in 2007. At the end of 2007, the SEK/USD exchange rate was 6.47. Standard errors, robust to conditional heteroscedasticity, are reported in parentheses.

**Table A.6: Robustness exercises**

	Robustness exercise						
	Main	I	II	III	IV	V	VI
<u>Preferences and stock market participation cost</u>							
Discount factor*, $\beta$	0.933	0.951	0.933	0.940	0.943	0.938	0.941
Relative risk aversion*, $\gamma$	14	8	14	14	14	12	11
Ceiling for opt-out cost*, $\bar{\kappa}^{DC}$	3,600	3,300	3,700	5,800	5,700	3,900	5,100
Ceiling for stock market entry cost*, $\bar{\kappa}$	15,600	5,200	14,300	5,400	4,200	3,100	1,400
Number of layers in the cost distribution*	3	4	3	4	4	3	3
<u>Labor income</u>							
Weight of stock market shock in labor income, $\theta$	0.040	0.040	0.040	0.040	0.040	0.090	0.090
<u>Moments</u>							
Financial wealth to labor income ratio	0.921	0.932	0.911	0.890	0.913	0.909	0.911
Equity share (conditional)	0.519	0.461	0.485	0.450	0.530	0.408	0.354
Active (opting out)/non-participation	0.158	0.147	0.140	0.150	0.124	0.122	0.128
Active (opting out)/participation	0.255	0.262	0.251	0.254	0.271	0.275	0.275
Passive (default)/non-participation	0.316	0.333	0.343	0.309	0.321	0.316	0.365
Passive (default)/participation	0.271	0.259	0.266	0.287	0.284	0.287	0.233
<u>Main results</u>							
Welfare gain of Optimal	1.5%	1.6%	1.5%	2.1%	2.3%	1.5%	1.4%
Welfare gain of Rule of thumb	0.9%	1.0%	0.9%	1.1%	1.2%	0.8%	0.7%
Share of default investors under Rule of thumb	0.753	0.761	0.767	0.725	0.743	0.752	0.760

Column I reports the main calibration and the main results for reference. The remaining columns display the parameter values of the model under seven robustness exercises and the value of targeted moments. The robustness exercises are: I. Low equity premium (2%); II. Left-skewed stock market returns; III. Fixed equity weight outside the pension system; IV. Random equity weight outside the pension system; V. High correlation between labor income and stock market returns; and VI. High correlation between labor income and stock market returns, and left-skewed returns.

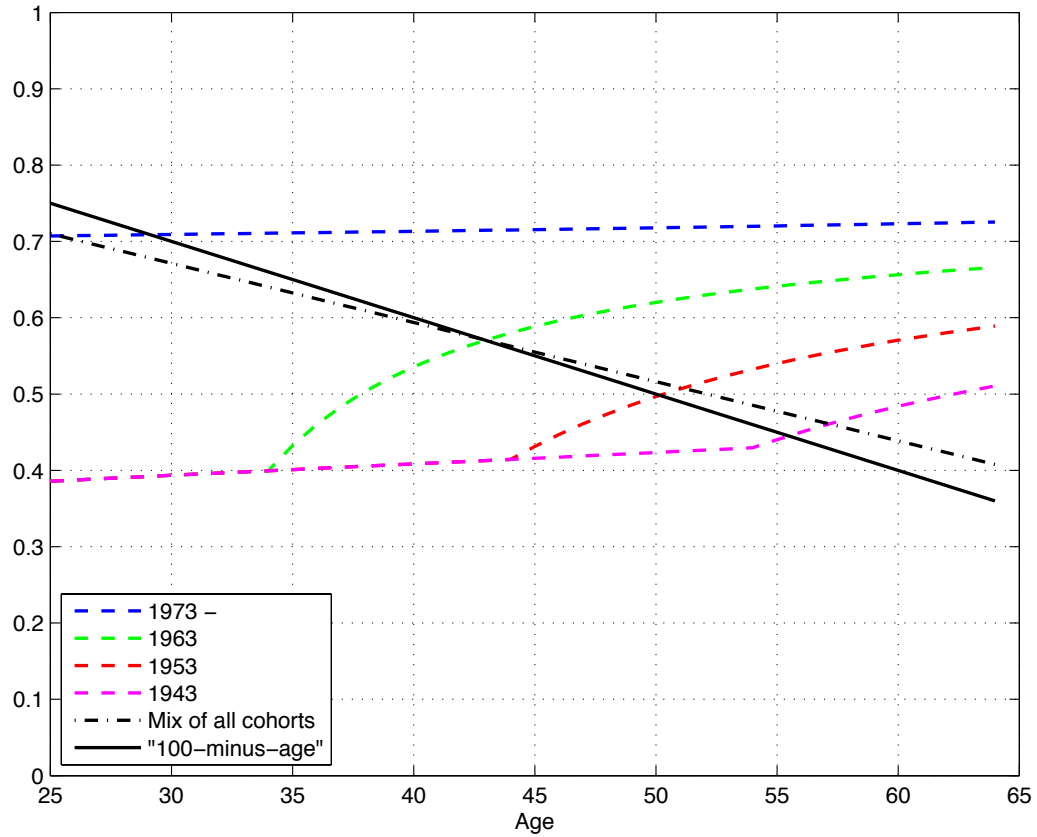


**Table A.7: Robustness exercises related to real estate**

	Robustness exercise				
	Main	VII	VIII	IX	X
<u>Preferences and stock market participation cost</u>					
Discount factor*, $\beta$	0.933	0.936	0.937	0.976	0.982
Relative risk aversion*, $\gamma$	14	15	14	15	11
Ceiling for opt-out cost*, $\bar{\kappa}^{\text{DC}}$	3,600	5,000	4,700	19,000	26,000
Ceiling for stock market entry cost*, $\bar{\kappa}$	15,600	21,500	17,800	45,900	54,600
Number of layers in the cost distribution*	3	3	3	3	3
<u>Labor income</u>					
Weight of stock market shock in labor income, $\theta$	0.040	0.040	0.040	0.040	0.040
<u>Moments</u>					
Financial wealth to labor income ratio	0.921 [0.922]	0.794 [0.797]	0.949 [0.945]		
Net worth to labor income ratio				2.517 [2.627]	2.575 [2.627]
Equity share (conditional)	0.519 [0.454]	0.540 [0.430]	0.508 [0.455]	0.311 [0.300]	0.460 [0.481]
Active (opting out)/non-participation	0.158 [0.151]	0.132 [0.130]	0.150 [0.151]	0.161 [0.151]	0.116 [0.100]
Active (opting out)/participation	0.255 [0.244]	0.122 [0.122]	0.301 [0.287]	0.230 [0.244]	0.279 [0.295]
Passive (default)/non-participation	0.316 [0.330]	0.500 [0.506]	0.269 [0.259]	0.323 [0.330]	0.219 [0.231]
Passive (default)/participation	0.271 [0.275]	0.246 [0.241]	0.280 [0.303]	0.286 [0.275]	0.386 [0.374]
<u>Main results</u>					
Welfare gain of Optimal	1.5%	1.4%	1.7%	1.1%	1.2%
Welfare gain of Rule of thumb	0.9%	0.9%	1.0%	0.6%	0.6%
Share of default investors under Rule of thumb	0.753	0.811	0.735	0.784	0.758

Column 1 reports the baseline calibration and the main results for reference. The remaining columns display the parameter values of the model under four robustness exercises related to real estate and the values of data and targeted moments. The robustness exercises are: VII. Renters; VIII. Real estate owners; IX. Real estate being a risk-free asset; and X. Real estate being 50% a risk-free asset and 50% a risky asset. In these exercises, the targeted data moments differ between exercises and are given in brackets below the model moments.

Figure A.1: Various cohorts for the calibration



The figure shows the DC equity share glide paths for several specific cohorts, a mix of all cohorts (as described in the text), and the baseline calibration “100-minus-age.”

Figure A.2: Calibration (robustness V)

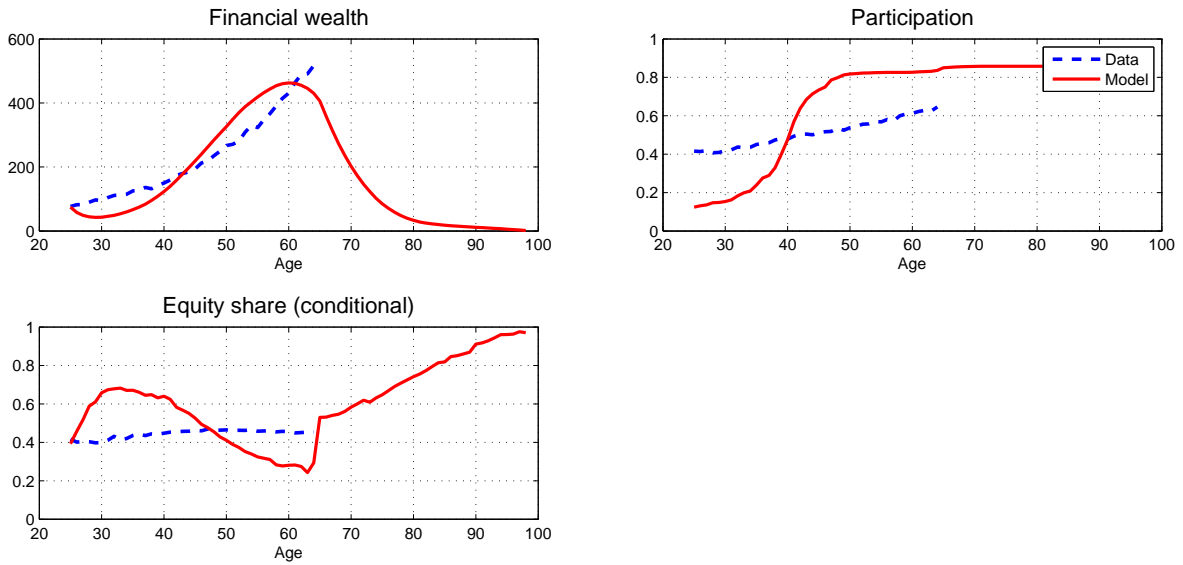


Figure A.3: Model fit (robustness V)

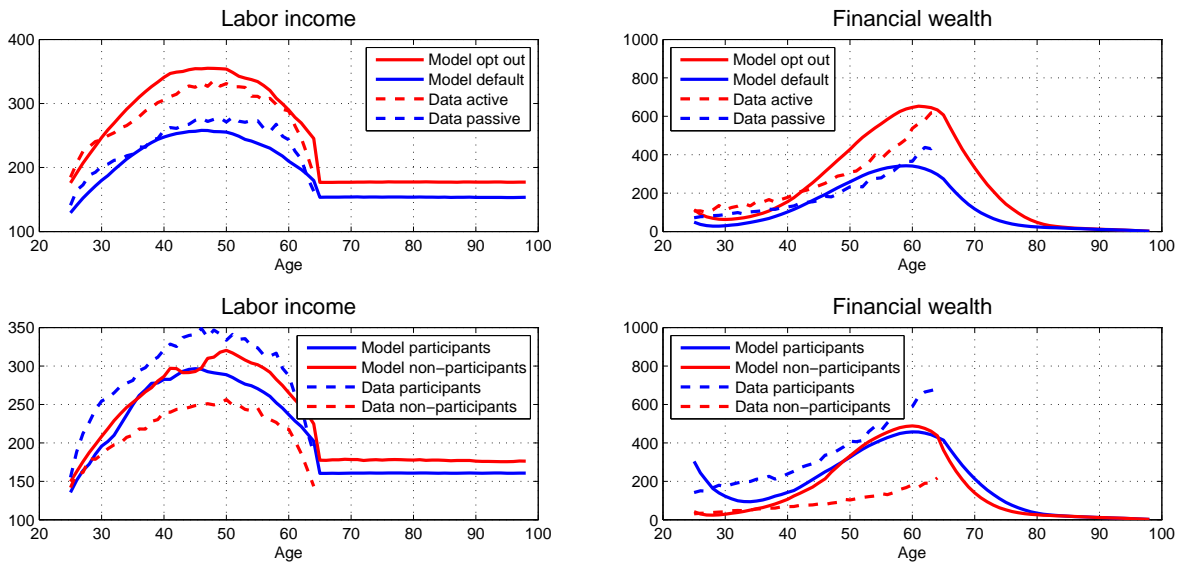


Figure A.4: Calibration (robustness VI)

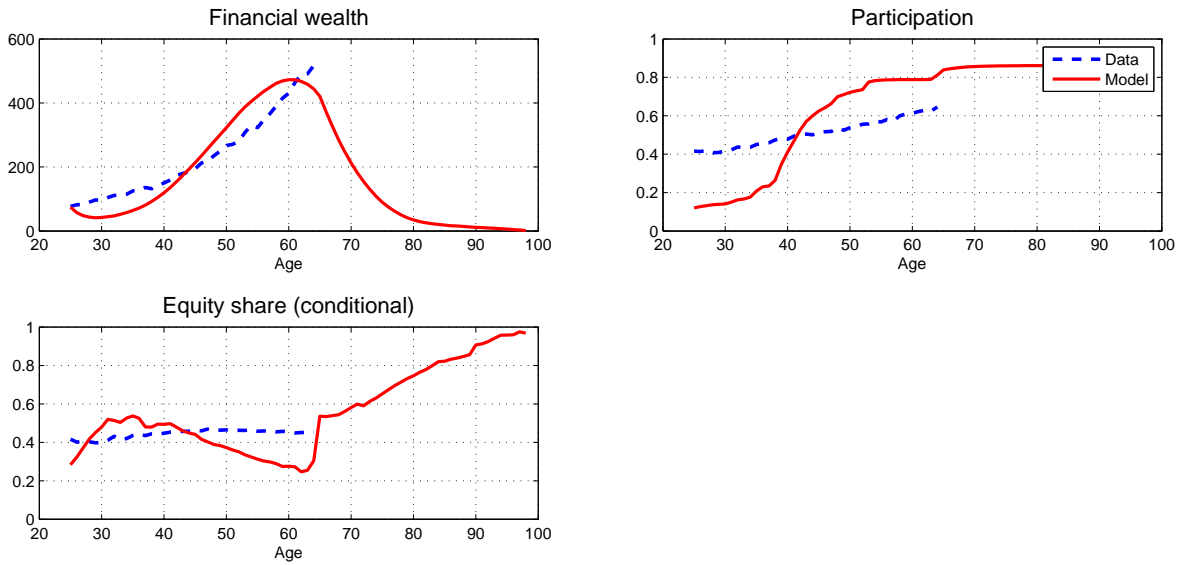


Figure A.5: Model fit (robustness VI)

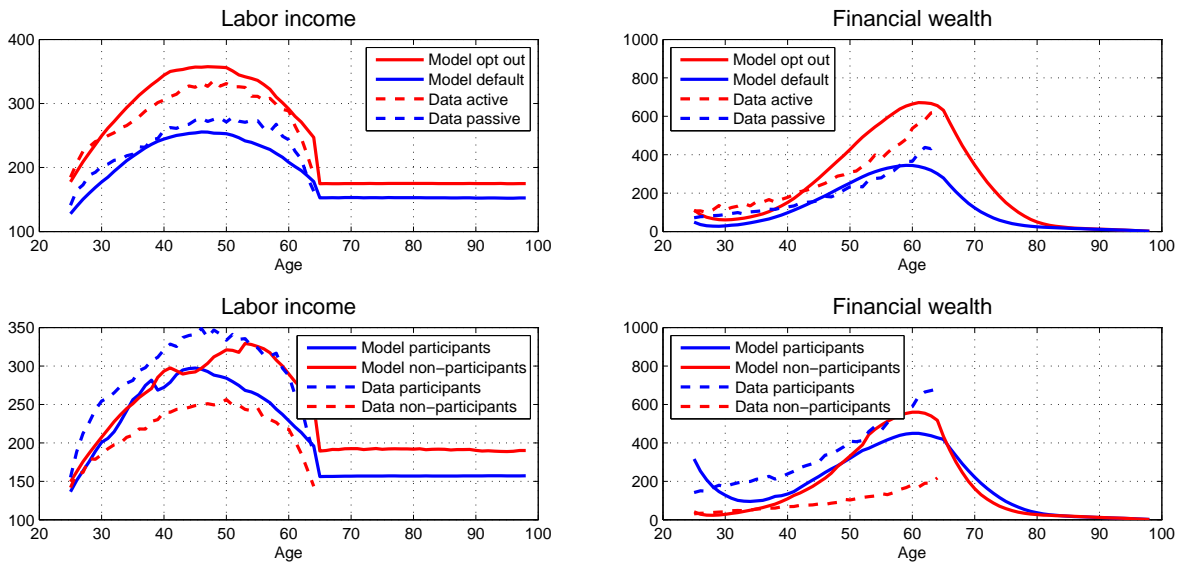


Figure A.6: Calibration for renters (robustness VII)

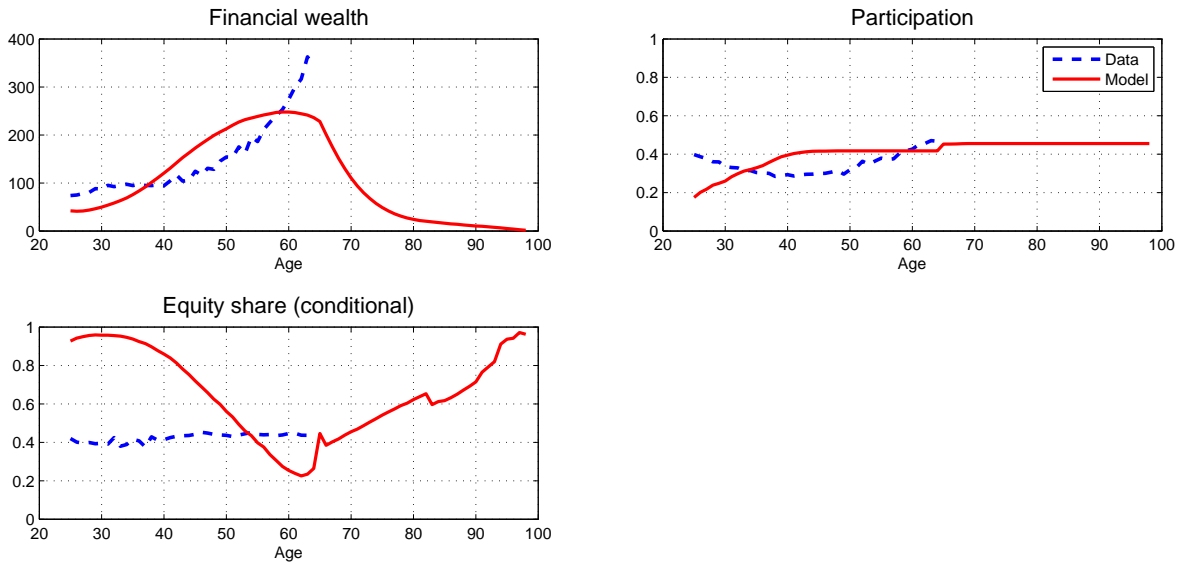


Figure A.7: Model fit for renters (robustness VII)

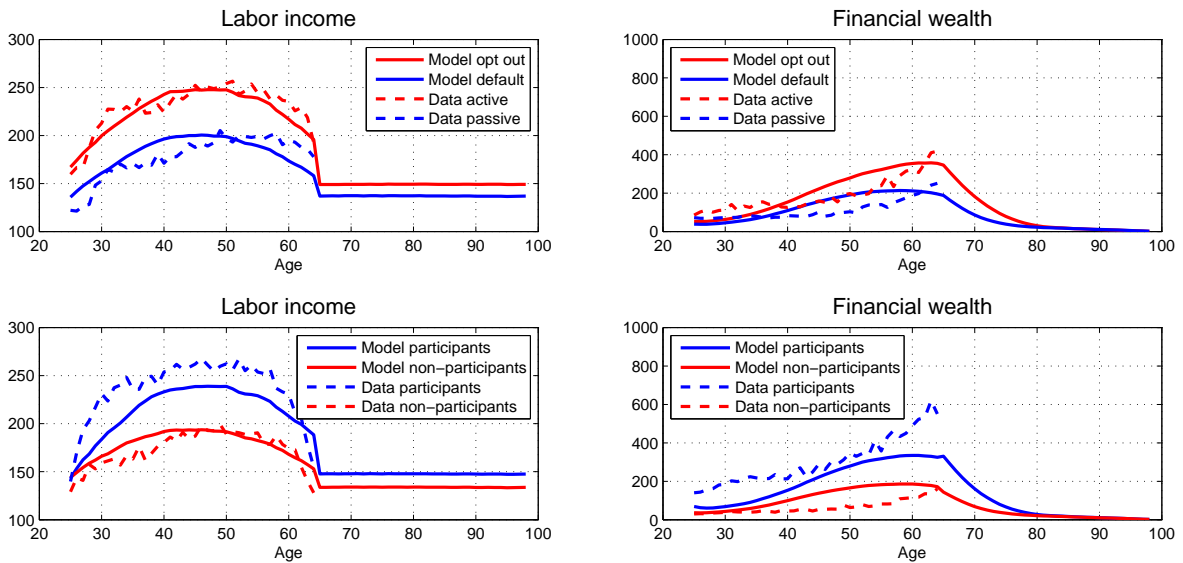


Figure A.8: Calibration for real estate owners (robustness VIII)

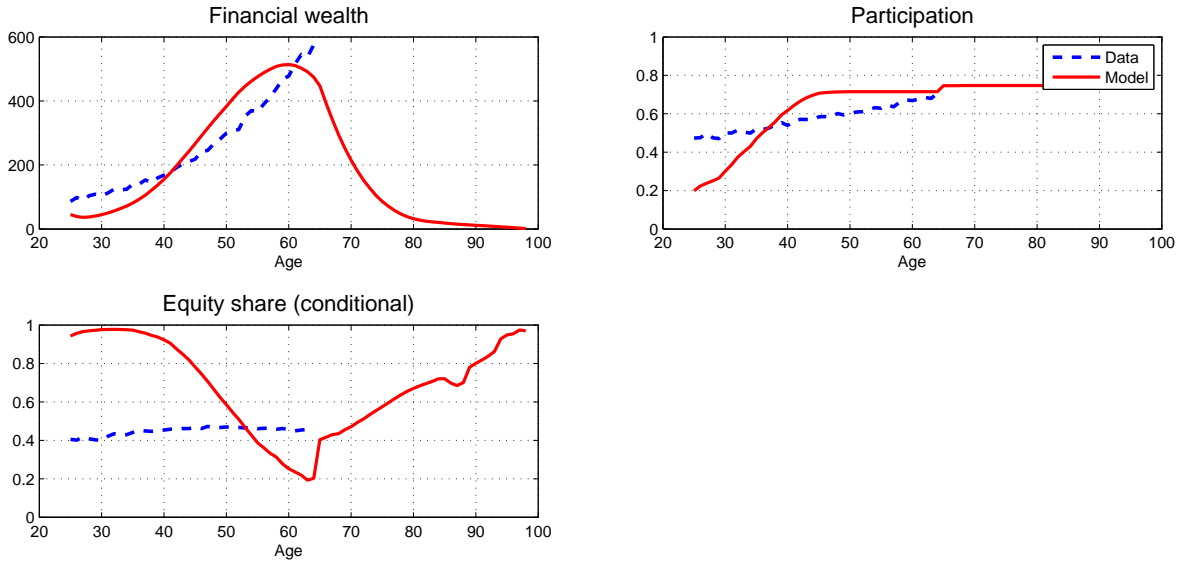


Figure A.9: Model fit for return for real estate owners (robustness VIII)

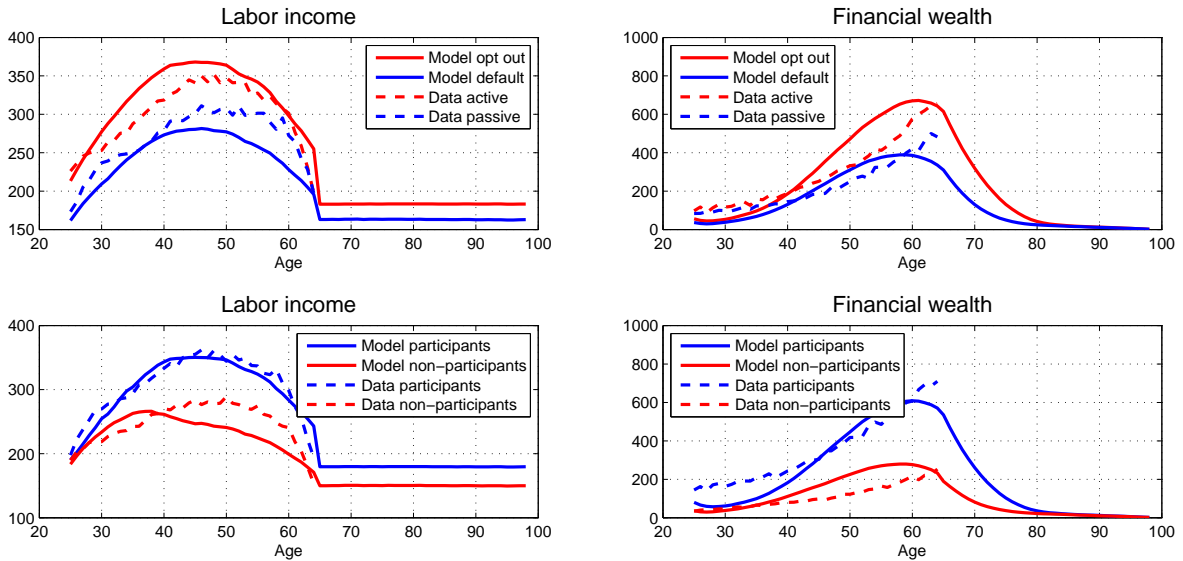


Figure A.10: Calibration for real estate as a bond (robustness IX)

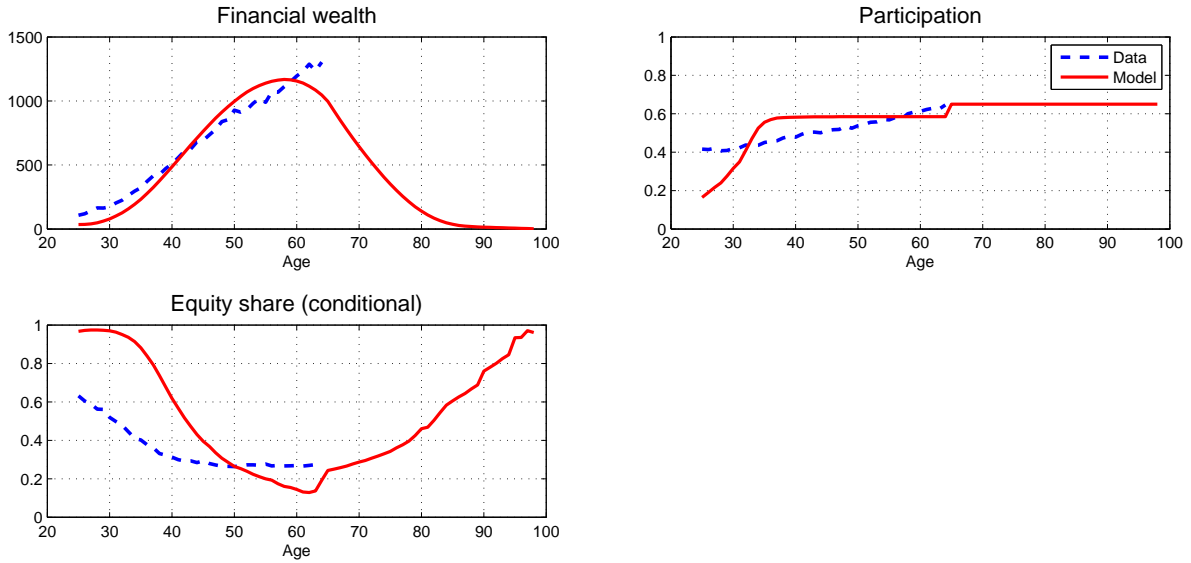


Figure A.11: Model fit for real estate as a bond (robustness IX)

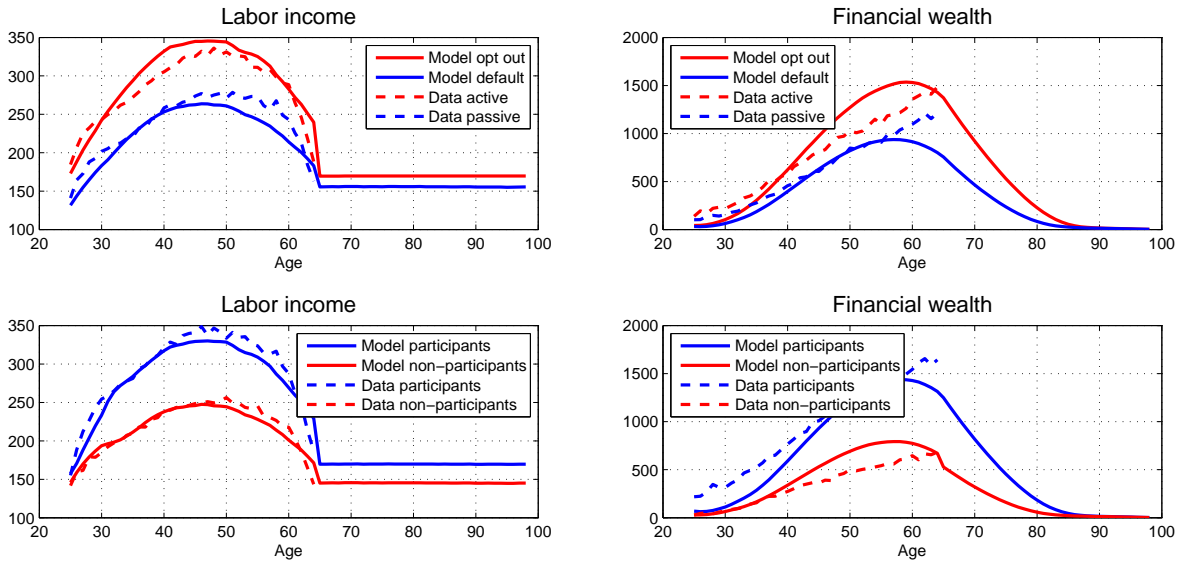


Figure A.12: Calibration for real estate as 50% a bond and 50% equity (robustness X)

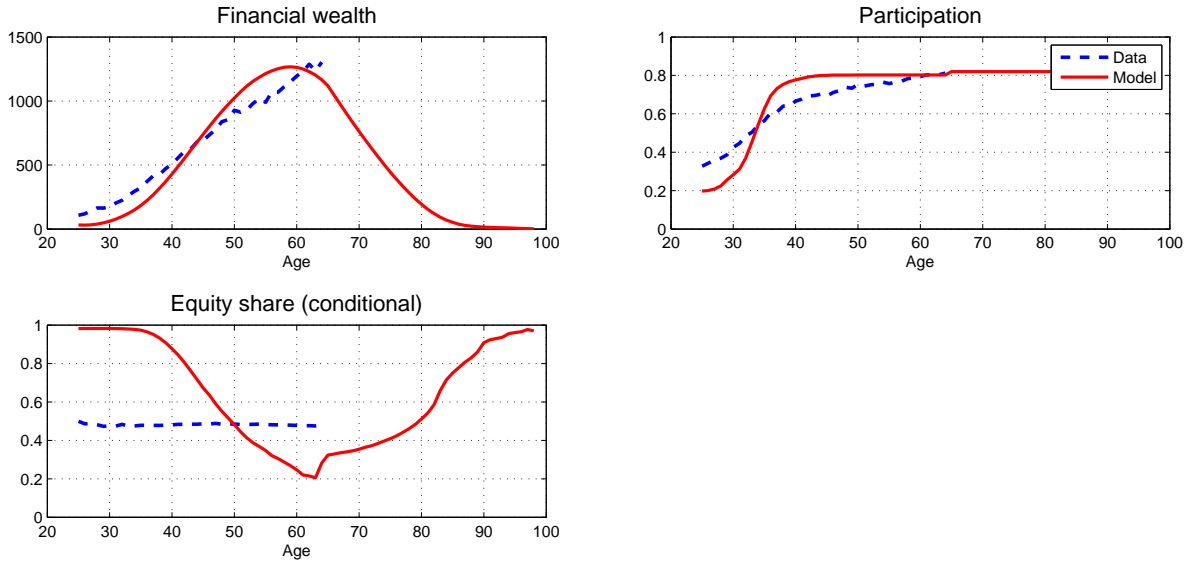


Figure A.13: Model fit for real estate as 50% a bond and 50% equity (robustness X)

