The Shift from Traditional Pensions to 401(k)s: Retirement Risks and the Timing of Retirement*

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December 19, 2025

Abstract

U.S. retirement plans have shifted sharply from defined benefit to defined contribution setups. How has this change affected retirement and savings behavior? We develop a quantitative life-cycle model where retirement plans differ in their exposure to longevity and investment risk. Holding the present-value cost of benefits fixed, these differences generate distinct savings and retirement incentives across plan types. The model replicates observed differences in savings and retirement behavior and implies that the shift from defined benefit to defined contribution plans alone accounts for roughly 92% of the decline in retirement by age 65 since the early 1990s. We then consider a policy that allows retirees to convert accumulated assets into actuarially fair annuities. Access to annuitization increases welfare and induces earlier retirement, with substantially larger effects in an economy that relies more heavily on defined contribution plans.

JEL classification: E21, E24, J26, J32
Keywords: Retirement plans, savings, retirement timing

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1 Introduction

Over the past several decades, U.S. retirement plans have shifted sharply from defined benefit (DB) plans, such as traditional pensions, to defined contribution (DC) plans, such as 401(k)s. This transformation has given individuals greater control over their retirement savings but has also exposed them to new sources of risk. While DB plans provide lifetime income and insure against longevity and market risks, in DC plans, individuals must plan for an uncertain retirement horizon and uncertain asset returns. Following the 1978 Revenue Act[1], which established the legal foundation for 401(k) plans, DC plans rapidly expanded, and are now the most prominent type of retirement plan.[2] Over the same period, labor force participation after age 65 has risen sharply. This paper investigates how the shift from DB to DC retirement plans has contributed to changes in retirement timing and wealth accumulation, focusing on how exposure to longevity and return risk alters savings and retirement behavior.

We begin by introducing a stylized model of savings and retirement timing under DB and DC plans to separately examine the effects of longevity risk (uncertainty about the timing of death, and therefore the retirement planning horizon) and uncertain market returns when the present cost of establishing each plan is held constant. We demonstrate that individuals in DC plans unambiguously save more, while the impact on retirement timing depends on the generosity of the plan. Under moderate plan generosity, both risk channels strengthen the incentive to delay retirement more for those in DC plans, as working longer helps buffer against the possibility of outliving assets or realizing poor investment returns. However, when plan benefits become sufficiently generous, DC participants can accumulate enough resources to smooth consumption across periods and gain flexibility to retire earlier, while DB participants have less ability to shift consumption intertemporally. This stylized model serves as an analytically tractable foundation for the quantitative model that follows.

Next, we use detailed panel data from the Health and Retirement Study (HRS) to document differences in retirement timing by plan type. We find that after controlling for detailed household, asset, occupation, health, and other characteristics, participants in DC plans are consistently less likely to retire than those with a DB plan at each year in their 60s. We then use the data to predict the final retirement age for participants by retirement plan. To address potential endogeneity, retirement plan dummies are instru-

[1]Revenue Act of 1978, Pub. L. No. 95-600, 92 Stat. 2763, 2785 (Nov. 6, 1978)

[2]While the Revenue Act of 1978 did not explicitly create 401(k) plans as we know them today, it laid the legal foundation that allowed these plans to emerge. In 1980, Ted Benna, owner of Pennsylvania benefits consulting company The Johnson Companies, recognized the potential of Section 401(k) to create a formalized retirement savings vehicle. He proposed and implemented the first 401(k) plan, which allowed employees to make pre-tax contributions with matching contributions from employers (Kujawa, 2012; U.S. Department of Labor Employee Benefits Security Administration, 2007).

mented with unionization status.[3] The results indicate that participants enrolled in DC plans tend to have significantly higher predicted retirement ages compared to those in DB plans.

We then construct a quantitative life-cycle model where enrollment in different plan types influences endogenous savings and retirement timing decisions. Agents in the model face an age-dependent death probability each period. Additionally, while all individuals can save in one-period bonds, individual investments and investments made in DC plans are subject to an uncertain rate of return. Retirement plans in the model are structured to mimic the mechanisms of true retirement plans as closely as possible, and all agents are eligible to receive Social Security income. Agents in the model differ by income group and can face job loss, influencing precautionary savings and the distribution of assets before retirement. Just as in the data, it is possible for agents in the model to move between different retirement plans when changing jobs, where the probability of entering a job with a particular plan type is dependent on the agent's income group and is taken from the data. Individuals in DC plans receive an employer contribution to their savings for each period they are employed. By contrast, those with sufficient DB plan tenure are entitled to a fixed retirement benefit, determined by their tenure and earnings, which they receive for the remainder of their lives after reaching retirement age. We show that the model replicates savings behavior and differences in retirement timing observed in the data.

We use our quantitative model to estimate the effects of the shift from DB to DC plans observed in the HRS data from 1992 through 2018. In our model, the shift in retirement plan types alone generates 92.2% of the increase in labor force participation among individuals by age 65 observed in the data since the early 1990s. We find that individuals enrolled in DC plans tend to accumulate significantly more private wealth by age 65 compared to those in DB plans, who are less dependent on individually managed assets for their retirement. However, although those in DC plans accumulate more wealth by age 65, they consume a larger portion of their assets during retirement. Consequently, those primarily in DC plans that survive to age 95 have lower average wealth, having depleted a greater share of their savings in retirement. Overall, the movement towards DC plans and away from DB plans increases the average retirement age and lowers welfare.

To isolate the mechanisms driving these results, we use the model to assess how exposure to longevity risk and return risk contributes to our findings. To do this, we consider the same counterfactual movement away from DB and towards DC plans and separately introduce each source of uncertainty. We find that while uncertain returns significantly delay retirement, longevity risk is the primary driver of welfare losses, as individuals are

[3] To address concerns that individuals with different preferences regarding their retirement timing might seek out different retirement plan types, we document that enrollment in DB plans is closely tied to differences in unionization status (see also Gustman and Steinmeier (1992) and Mishel and Walters (2003)). We use this as an instrument when running our second analysis in Section 4.

forced to over-save to hedge against an uncertain horizon. We also show that these channels interact, magnifying their combined effect. These findings highlight that policies focused solely on mitigating investment risk (e.g., hybrid plans with guaranteed returns) are insufficient to fully replace the security provided by DB plans.

However, the need for longevity risk protection stands in stark contrast with the "annuity puzzle" observed in the data: there is very little voluntary use of annuities among retirees. Hosseini (2015) finds that less than 1% of retirement wealth is annuitized, pointing to adverse selection pushing prices above actuarially fair levels. Similarly, Verani and Yu (2024) shows that the supply of annuities is further constrained by interest rate risk. These market frictions prevent individuals from effectively self-insuring against longevity risk.[4] Given these frictions, we evaluate a counterfactual policy that introduces an endogenous annuitization decision, allowing retirees to annuitize any fraction of their accumulated assets at actuarially fair rates. Our results suggest that such a policy would significantly mitigate the welfare losses associated with the shift to DC plans. In the 2016–2018 economy, where DC plans are prevalent, the option to annuitize increases expected lifetime utility by 13.2% and induces earlier retirement by reducing the need for precautionary labor supply.

The remainder of this paper is outlined as follows: Section 2 discusses the related literature and the contribution of this paper, Section 3 presents the illustrative model, Section 4 discusses our empirical findings, Section 5 presents the quantitative model, Section 6 presents model calibration and counterfactual results, and Section 7 concludes.

2 Related Literature

This paper contributes to the discussion on how variations in retirement plans influence retirement timing. Early work focused on how variations among only DB plans affect retirement decisions, with Stock and Wise (1990) emphasizing that some DB setups incentivize work only up to a regulated retirement age. This early work focused on explaining why DB plans often induced a jump in the retirement rate at specific ages, with subsequent work by Samwick (1998) showing empirically that extended coverage of DB plans accounted for one-fourth of the decline in the labor market participation rate in the postwar period.

With the evolution of the retirement benefit structure, more recent work compares the impact of DB plans relative to DC plans on retirement timing with empirical approaches. Munnell, Cahill and Jivan (2003), Munnell, Triest and Jivan (2004), Friedberg and Webb (2005), and Manchester (2010) find that otherwise identical individuals retire earlier with DB coverage than with DC coverage. Relative to most of the existing empirical work on

[4] This challenge was recently focused on by the 2022 SECURE 2.0 Act, which aimed to reduce barriers to in-plan lifetime income options and expand Qualifying Longevity Annuity Contracts (QLACs).

this subject, our paper takes an innovative approach by using an instrumental variable method for the retirement plan dummies. This approach better addresses endogeneity concerns, specifically the possibility that individuals' retirement timing preferences may drive them to seek jobs with certain types of retirement plans.

Our paper also connects to the literature discussing the non-perfect substitution between retirement plan wealth, which includes both public and private retirement account savings, and private savings. Taking advantage of the Italian pension reform of 1992, which substantially reduced pension wealth, Attanasio and Brugiavini (2003) showed that pension wealth is a substitute for private savings, but the degree of substitution varies across different specifications. Other studies find negative but non-perfect substitution between pension wealth and private savings using data from the U.K. (Attanasio and Rohwedder, 2003), U.S. (Engelhardt and Kumar, 2011), U.K., a combination of 13 European countries (Alessie, Angelini and van Santen, 2013), and Poland (Lachowska and Myck, 2018). Our model successfully replicates the savings behavior observed in these empirical studies. We find that DC plan participants tend to accumulate significantly more private wealth than DB plan holders by age 65, though they consume most of the assets during retirement and leave with lower average wealth by age 95.

Theoretically, our model builds off of previous life-cycle models of savings and retirement decisions, including French (2005), Blau (2008), De Nardi, French and Jones (2010), French and Jones (2011), and Fan, Seshadri and Taber (2024). Our paper adds to this literature by incorporating differences in retirement plan types to allow us to study how the transition from DB to DC plans has influenced aggregate retirement timing decisions. Our work also relates to Samwick (1998), which used a simplified model to study heterogeneity across DB plans, and to Daminato and Padula (2024), which analyzed how Italian pension reforms in the 1990s affected retirement behavior. Whereas their focus is on institutional changes to social security wealth and retirement incentives, our analysis highlights how the shift in retirement plan structure itself alters individual savings and retirement timing.

Our paper is most closely related to Heiland and Li (2012), which investigated how the shift from DB to DC plans impacted senior labor force participation in the U.S. from 1977 to 2010. They highlight how differences in age-related wealth accrual schedules lead DB participants to retire earlier than those with DC plans, incorporating these features into a framework based on French (2005). We build on this work by introducing a model that explicitly links retirement plan design to key sources of uncertainty. In particular, our model allows for both longevity risk and uncertain investment returns, while Heiland and Li (2012) focused primarily on deterministic wealth accrual paths. Calibrated to the U.S. data, our model quantifies how greater DC plan coverage affects retirement timing and decomposes the contribution of each risk source to observed behavioral differences.

Finally, our paper bridges the gap between the life-cycle retirement literature and the literature on the "annuity puzzle". Despite the significant theoretical benefits of longevity insurance, voluntary take-up of life annuities among retirees is remarkably low. While Hosseini (2015) and Verani and Yu (2024) document that adverse selection and interest rate risk prevent individuals from effectively self-insuring against longevity risk, we quantify the effects of these frictions and how they interact with the broader structural shift toward DC plans. We contribute to this discussion by evaluating a counterfactual policy that removes these market barriers, allowing agents to convert accumulated assets into an actuarially fair annuity upon retirement. Our results quantify the substantial welfare costs of the annuity puzzle: in 2016–2018 economy with heavy reliance on DC plans, the option to annuitize increases expected lifetime utility by 13.2% and induces significantly earlier retirement by reducing the need for precautionary labor supply. By comparing the 1992–1994 and 2016–2018 economies, we show that as the U.S. has shifted toward DC plans, the welfare value of fixing the annuity market has more than doubled (from 5.6% to 13.2%), highlighting the increasing policy importance of longevity insurance.

3 Illustrative Model

This section introduces a simple model of savings and retirement decisions under defined benefit (DB) and defined contribution (DC) retirement plans. The illustrative model serves to build intuition ahead of the full quantitative analysis in Section 5. The model compares the optimal decisions for agents with either retirement plan type and shows that agents in DC plans optimally save more than those in DB plans. Furthermore, two channels result in different retirement timing choices between individuals in either plan, holding the present value costs of establishing each plan constant. First, the *uncertain planning horizon channel* means that agents face a probability of not surviving to the next period and are uncertain whether savings for tomorrow will be needed. Next, the *uncertain rate of return channel* means that saved DC plan benefits are subject to an ex ante unknown rate of return, while DB plan holders are paid a fixed amount.

When the role of these retirement plans is primarily to support retirement consumption in the last period, which is the case when the plan generosity is not sufficiently large, we show that these two channels result in those with DC plans retiring later than those with DB plans for the same present value plan cost. Only in cases where the generosity of the plans is significantly large, such that workers carry sufficient resources into the last period and begin to use the plan benefits to fuel earlier consumption, does this relationship reverse so that DC plan holders benefit more from early retirement. This is because when the plan size is large, the DC benefit provides flexibility: workers can consume part of it in period one while still preserving plenty of retirement resources. A DB benefit, however, is only available in period two, so DB participants must continue working if they want to raise first-period consumption.

Consider a simple two-period model with the following timeline. In period one, agents enter with assets a and a retirement plan type $i \in \{B, C\}$, where $i = B$ denotes a defined benefit plan and $i = C$ denotes a defined contribution plan. At the start of the period, a first-period retirement plan benefit f^i is paid, where $f^B = 0$ and $f^C \geq 0$.[5] Agents then decide whether to retire at the start of the first period. Those who continue to work earn income $y > 0$, while those who retire receive a utility benefit of leisure $\ell_R > 0$. After making the first-period retirement decision, agents decide how much to save for the next period. Savings earn an ex ante unknown return, which takes the value r_z with probability p_z, for each $z \in Z$. Agents die and exit the model with probability $\nu \in (0, 1)$ before the start of the second period. All agents retire in the second period, realize the returns on previous savings, and consume their remaining resources. In the second period, a retirement plan benefit x^i is paid, where $x^B \geq 0$ and $x^C = 0$. Everyone exits the model after the second period.

Let $V_1(a)$ denote the value function of an agent in period one with initial assets a and plan type i. The agent chooses at the start of period one to retire ($R = 1$) or not retire ($R = 0$). Assume agents get utility $u(c)$ from consumption c, with $u'(c) > 0$ and $u''(c) < 0$.

$$V_1^i(a) = \max_{R \in \{0,1\}, s \in [0, y(1-R)+f^i+a]} \left\{ u((1-R)y + f^i + a - s) + R\ell_R + \beta(1-\nu)\mathbb{E}[V_2^i(s)] \right\}$$

The agent's budget constraint in the first period is as follows. Their consumption c and savings s equal any income from work y, existing assets a, and any first-period retirement plan payment f^i. Therefore, first-period consumption is $c_1^{iR} = (1-R)y + f^i + a - s$.

In the second period, all agents retire and receive leisure value ℓ_R and consume their remaining assets a plus any second-period retirement plan income x^i. Given that agents do not know the value of the risky rate of return r_z when making their first-period savings decision, the expected period-two value given savings s in period one is as follows.

$$\mathbb{E}[V_2^i(s)] = \ell_R + \sum_{z \in Z} p_z u(x^i + s(1 + r_z))$$

3.1 Savings

Consider the optimal period one savings decision. Our goal is to compare how changes in the DB plan benefit x^B and the DC plan benefit f^C affect the optimal savings decision. The first-order condition, conditional on having chosen to retire or not in the first period,

[5] In this setup, f^i is paid before agents decide whether to retire in the first period. With this assumption, along with the assumption that all agents retire in the second period, the agents' decisions cannot alter their expected plan value. This generates a simple setup where we can hold the present value cost of the plan types fixed and compare the incentives induced by early DC plan benefits versus later DB plan benefits.

is as follows.

$$u'((1-R)y + f^i + a - s) = \beta(1-\nu)\sum_{z\in Z}\left[p_z(1+r_z)u'(x^i + s(1+r_z))\right]$$

This condition tells us that the marginal utility cost of saving one more unit today should equal the discounted expected return-weighted marginal utility benefit in the next period.

Now consider how x^i and f^i affect optimal savings. An increase in f^i reduces the marginal cost of saving in period one, because it directly increases the pool of resources available in this period. Therefore, an increase in f^i raises optimal savings. Alternatively, an increase in x^i reduces the benefit of having an additional dollar saved for period two, because x^i directly increases period-two consumption. Therefore, an increase in x^i decreases optimal savings. Beyond this intuitive explanation, Appendix A.1 formally shows that optimal savings are strictly increasing in f^i and strictly decreasing in x^i.

Let c_1^{iR} denote consumption in period one given retirement choice $R \in \{0,1\}$ and retirement plan $i \in \{B, C\}$. Similarly, let $c_2^{iR}(r_z)$ denote the analogous consumption for period two, given realized return r_z. With this notation, the Euler equation regarding optimal saving can be written more compactly as

$$u'(c_1^{iR}) = \beta(1-\nu)\sum_{z\in Z}\left[p_z(1+r_z)u'(c_2^{iR}(r_z))\right]. \tag{1}$$

3.2 Retirement Timing

Now consider how increasing the present value cost φ^i of providing each type of retirement plan $i \in \{B, C\}$ will affect retirement choices. The present value cost of providing the DC plan benefit paid in period one is simply $\varphi^C = f^C$. To cover the expected DB plan benefit in period two, a firm must set aside an amount φ^B so that $\varphi^B \sum_{z\in Z} p_z(1+r_z) = x^B(1-\nu)$. The two plan types will have the same present-value cost when $\varphi^B = \varphi^C = \frac{x(1-\nu)}{\sum_{z\in Z} p_z(1+r_z)}$. Given the present value cost of providing the plan φ^B, the DB plan benefit in period two is $x^B = \varphi^B\left(\frac{1}{1-\nu}\right)\sum_{z\in Z} p_z(1+r_z)$. Going forward, we will consider how retirement choices respond to changes in the present value plan cost when $\varphi^C = \varphi^B = \varphi$.

Now, letting V_1^{i0} denote the first-period value when choosing to continue working $(R=0)$ with plan type i and V_1^{i1} denote the first-period value when choosing to retire in the first period $(R=1)$, we will consider the value $V_1^{i1}(a) - V_1^{i0}(a)$. If $V_1^{i1}(a) - V_1^{i0}(a) > 0$ the agent will optimally choose to retire in the first period, while if $V_1^{i1}(a) - V_1^{i0}(a) < 0$ they will optimally continue working. To consider the effects of providing either DC or DB plans, we will consider how an increase in the present value cost of providing either plan type affects $V_1^{i1}(a) - V_1^{i0}(a)$.

$$\begin{aligned}\Delta V^i \equiv V_1^{i1}(a) - V_1^{i0}(a) &= \ell_R + u(f^i + a - s^{i1}) - u(y + f^i + a - s^{i0}) \\ &\quad + \beta(1-\nu)\sum_{z\in Z} p_z \left[u(x^i + s^{i1}(1+r_z)) - u(x^i + s^{i0}(1+r_z))\right]\end{aligned}$$

First, consider an agent with a DC plan ($i = C$) where $f^i = f^C \geq 0$ and $x^C = 0$. We will consider how an increase in the present value plan cost $\varphi = f^C$ affects the expected gain of period one retirement.[6] After substituting in the first-order condition regarding optimal savings given by equation (1) and simplifying, we get

$$\frac{\partial \Delta V^C}{\partial \varphi} = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)\left[u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))\right]. \tag{2}$$

Now consider an agent with a DB plan where $f^B = 0$ and $x^B \geq 0$. To be consistent with the DC plan case, we will consider a change in the present value cost φ of providing the DB plan. Recall, given x^B, $\varphi = \frac{x^B(1-\nu)}{\sum\limits_{z\in Z} p_z(1+r_z)}$, so that $x^B = \varphi\left(\frac{1}{1-\nu}\right)\sum\limits_{z\in Z} p_z(1+r_z)$. Similar to the DC plan case, substitute in the first-order condition regarding optimal savings and substitute in $\frac{\partial x^B}{\partial \varphi} = \left(\frac{1}{1-\nu}\right)\sum\limits_{z\in Z} p_z(1+r_z)$ to get

$$\frac{\partial \Delta V^B}{\partial \varphi} = \beta\sum_{z\in Z} p_z(1+r_z)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right]. \tag{3}$$

3.2.1 Uncertain Planning Horizon Channel

Now compare the two cases. First, consider how $\frac{\partial \Delta V^C}{\partial \varphi}$ and $\frac{\partial \Delta V^B}{\partial \varphi}$ compare in the case where there is no uncertainty regarding the rate of return.

$$\begin{aligned}\frac{\partial \Delta V^C}{\partial \varphi} &= \beta(1-\nu)(1+r)\left[u'(c_2^{C1}) - u'(c_2^{C0})\right]. \\ \frac{\partial \Delta V^B}{\partial \varphi} &= \beta(1+r)\left[u'(c_2^{B1}) - u'(c_2^{B0})\right]\end{aligned}$$

This shows us that the death probability $\nu \in (0,1)$ directly reduces the impact of increasing the present value cost of the DC plan benefit on the value of retirement relative to the DB plan.

In this case, $\frac{\partial \Delta V^B}{\partial \varphi} > \frac{\partial \Delta V^C}{\partial \varphi}$ when

$$\begin{aligned}\beta(1+r)\left[u'(c_2^{B1}) - u'(c_2^{B0})\right] &> \beta(1-\nu)(1+r)\left[u'(c_2^{C1}) - u'(c_2^{C0})\right] \\ \frac{1}{1-\nu} &> \frac{u'(s^{C1}(\varphi)(1+r)) - u'(s^{C0}(\varphi)(1+r))}{u'(x(\varphi) + s^{B1}(\varphi)(1+r)) - u'(x(\varphi) + s^{B0}(\varphi)(1+r))} \equiv H(\varphi)\end{aligned} \tag{4}$$

[6] Appendix A derives step-by-step all equations presented in this section.

Intuitively, we can see that for $\varphi = 0$ and small values of φ this inequality holds with $\nu \in (0,1)$. The left-hand side $\frac{1}{1-\nu}$ is fixed for a given death probability, while the right-hand side is a ratio of differences in marginal utilities, which depends on how second-period consumption shifts with φ. When φ is small, both DB and DC benefits contribute little to retirement resources. On the DC side, savings increase with φ. This means a higher φ raises DC period two consumption slightly, which reduces marginal utility, but the effect is modest because φ is small. On the DB side, savings decrease with φ, but $x(\varphi)$ is also a linear function increasing in φ. When φ is small, this DB cumulative change in second-period consumption is relatively small. Thus, the numerator and denominator of the right-hand side ratio are of comparable order for small φ, so the ratio is close to 1. Since $\frac{1}{1-\nu} > 1$, the inequality is satisfied for sufficiently small φ.

However, it is possible for the inequality given by (4) to fail for large retirement plan present cost φ, because as φ grows the scaling of $u'(c_2^{C1}) - u'(c_2^{C0})$ relative to $u'(c_2^{B1}) - u'(c_2^{B0})$ differs. We show formally in Appendix A.2.1 that there exists a unique φ_H^* with $H(\varphi) < \frac{1}{1-\nu}$ if $\varphi < \varphi_H^*$ and $H(\varphi) > \frac{1}{1-\nu}$ if $\varphi > \varphi_H^*$. Intuitively, this condition arises because on the DC side, savings continue to rise with φ, but not linearly. Optimal savings grow in a concave way relative to φ, so DC retirement consumption grows more slowly than φ for larger φ values. On the DB side, optimal savings shrink, but the lump-sum transfer $x(\varphi)$ grows linearly in φ. This dominates the non-linear adjustment in savings, so DB retirement consumption grows much faster with φ than DC retirement consumption for large φ values. Because marginal utility is convex ($u''(c) < 0$), the denominator of the right-hand side falls much more sharply than the numerator. The ratio therefore increases with φ. Eventually, the ratio can exceed $\frac{1}{1-\nu}$ for sufficiently large φ.

3.2.2 Uncertain Rate of Return Channel

Next, consider the case with $\nu = 0$ and only uncertainty regarding the rate of return. Letting $\Delta u'(c_2^i(r_z)) \equiv u'(c_2^{i1}) - u'(c_2^{i0})$ results in

$$\frac{\partial \Delta V^C}{\partial \varphi} = \beta \sum_{z\in Z} p_z(1+r_z)\left[u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))\right] = \beta \mathbb{E}[(1+r_z)\Delta u'(c_2^C(r_z))]$$
$$\frac{\partial \Delta V^B}{\partial \varphi} = \beta \sum_{z\in Z} p_z(1+r_z)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right] = \beta \mathbb{E}\left[1+r_z\right]\mathbb{E}\left[\Delta u'(c_2^B(r_z))\right]$$

Notice that $\frac{\partial \Delta V^C}{\partial \varphi}$ is the expectation of a product while $\frac{\partial \Delta V^B}{\partial \varphi}$ is the product of two expectations.[7] Therefore

$$\frac{\partial \Delta V^C}{\partial \varphi} = \beta \mathbb{E}\left[1+r_z\right]\mathbb{E}\left[\Delta u'(c_2^C(r_z))\right] + \beta \mathrm{Cov}(1+r_z, \Delta u'(c_2^C(r_z))).$$

[7] Recall $\mathbb{E}[XY] = \mathbb{E}[X]\mathbb{E}[Y] + \mathrm{Cov}(X,Y)$.

Note that generally, with concave utility, $\text{Cov}(1+r_z, \Delta u'(c_2^C(r_z))) < 0$. When returns r_z are high, agents have larger period two consumption regardless of whether they worked or not in the first period, so marginal utilities fall. However, marginal utility falls more for the state with the larger savings (working in the first period), which shrinks $\Delta u'(c_2^C(r_z)) = u'(c_2^{i1}(r_z)) - u'(c_2^{i0}(r_z))$. Hence, $1 + r_z$ and $\Delta u'(c_2^C(r_z))$ tend to move in opposite directions. More uncertainty (higher variance of r_z) increases the absolute magnitude of the covariance term. Therefore, the DC derivative shrinks relative to the DB derivative as return uncertainty rises.

In this case, we have $\frac{\partial \Delta V^B}{\partial \varphi} > \frac{\partial \Delta V^C}{\partial \varphi}$ if

$$\beta \mathbb{E}\left[1+r_z\right] \mathbb{E}\left[\Delta u'(c_2^B(r_z))\right] > \beta \mathbb{E}\left[1+r_z\right] \mathbb{E}\left[\Delta u'(c_2^C(r_z))\right] + \beta \text{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))$$

$$\frac{-\text{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]} > \mathbb{E}\left[\Delta u'(c_2^C(r_z))\right] - \mathbb{E}\left[\Delta u'(c_2^B(r_z))\right] \equiv I(\varphi) \tag{5}$$

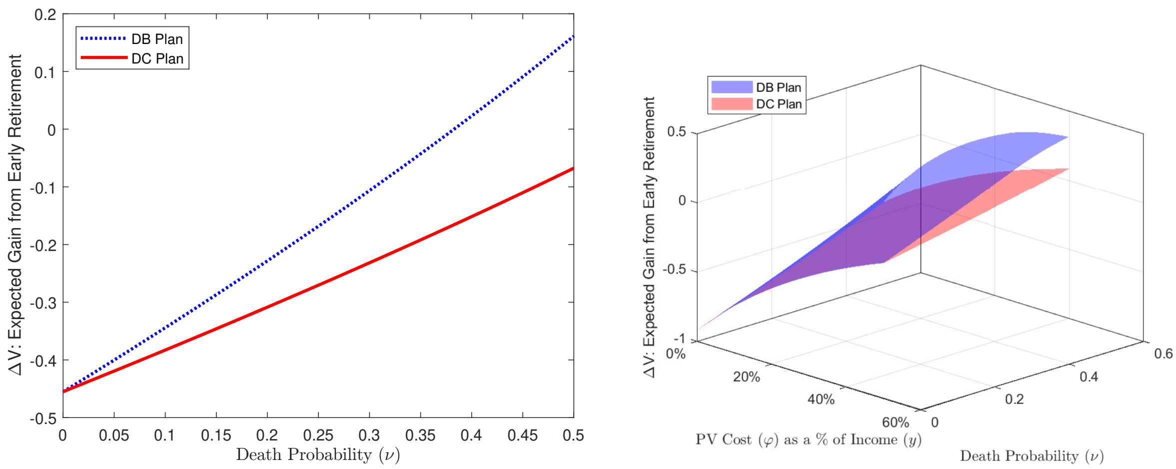
The uncertain rate of return channel also leads to this inequality holding so that $\frac{\partial \Delta V^B}{\partial \varphi} > \frac{\partial \Delta V^C}{\partial \varphi}$ for sufficiently small φ values. Similar to the case discussed in subsection 3.2.1, for small values of φ, the right-hand side of the inequality is close to zero as consumption levels in the two plans are similar for small φ. The left hand side is positive, as $\text{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))$ is negative for $u''(c) < 0$. However, as discussed in 3.2.1, as φ increases $u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))$ falls much more sharply than $u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))$. Therefore, for sufficiently large φ values, the inequality can fail. We show formally in Appendix A.2.2 that there exists a unique φ_I^* with $I(\varphi) < \frac{-\text{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ if $\varphi < \varphi_I^*$ and $I(\varphi) > \frac{-\text{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ if $\varphi > \varphi_I^*$.

3.2.3 Numerical Illustration

This subsection plots $\Delta V^i = V_1^{i1}(a) - V_1^{i0}(a)$ for both plan types $i \in \{B, C\}$. We will fix parameters and consider first how ΔV^B and ΔV^C vary when there is no uncertainty regarding the rate of return, and there is only uncertainty regarding the timing of death.[8] The Figure 1a fixes the present value cost of providing each plan to 20% of y and only considers how the expected gain from period one retirement for each plan type is affected by the death probability. When the death probability is zero, the expected gain from period one retirement is exactly the same for both plan types. Raising the death probability raises the expected gain from retiring in period one, as agents are less likely to benefit from working and saving in period one. However, the effect of raising ν is not as strong for those in DC plans, and we see that as the death probability increases, the gap between ΔV^B and ΔV^C widens. Figure 1b then shows ΔV^B and ΔV^C for varying values

[8]Specifically, we set the discount factor β equal to 0.96, set initial assets a equal to 1, set income from employment y equal to 1, and set the leisure value of retirement ℓ_R equal to 1. Additionally, we assume CRRA utility $u(c) = \frac{c^{1-\theta}}{1-\theta}$ with $\theta = 2$.

Figure 1: Uncertain Horizon Channel

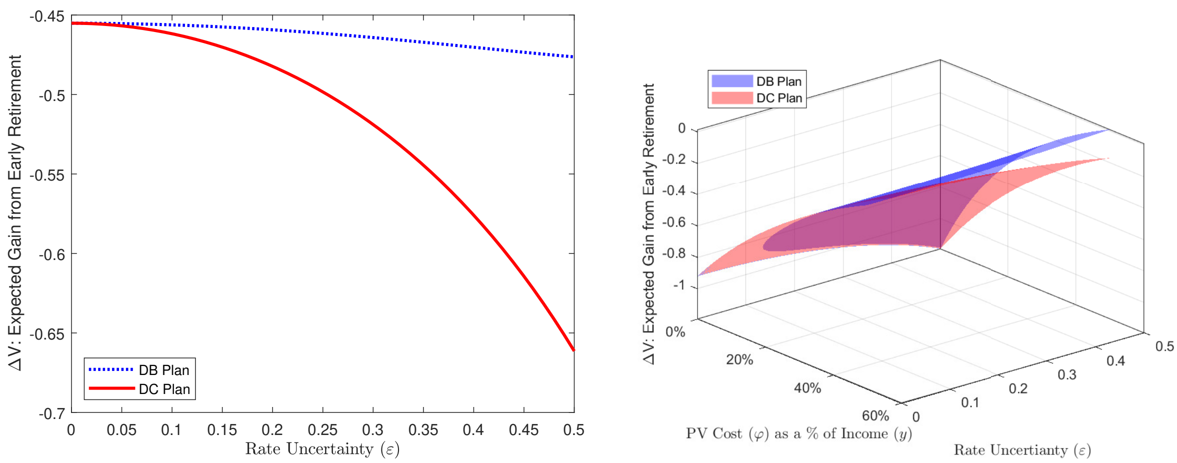


(a) PV Plan Cost φ = 20% of Income (b) Vary PV Plan Cost (φ)

of ν and for different present value costs of providing each plan, with similar results.

Next, Figure 2 shows how ΔV^B and ΔV^C vary when the death probability is zero, so there is no uncertainty regarding agents' planning horizon, but with varying rate of return uncertainty. Specifically, let $Z \in \{L, H\}$ with $p_L = p_H = 0.5$ and $r_L = r_s - \varepsilon$ and $r_H = r_s + \varepsilon$ for $r_s = (1/\beta) - 1$. We then consider variations in ε. Figure 2a fixes the present value cost of providing each plan to 20% of y and considers only how the expected gain of period one retirement is affected by increasing rate of return uncertainty. Notice

Figure 2: Uncertain Returns Channel

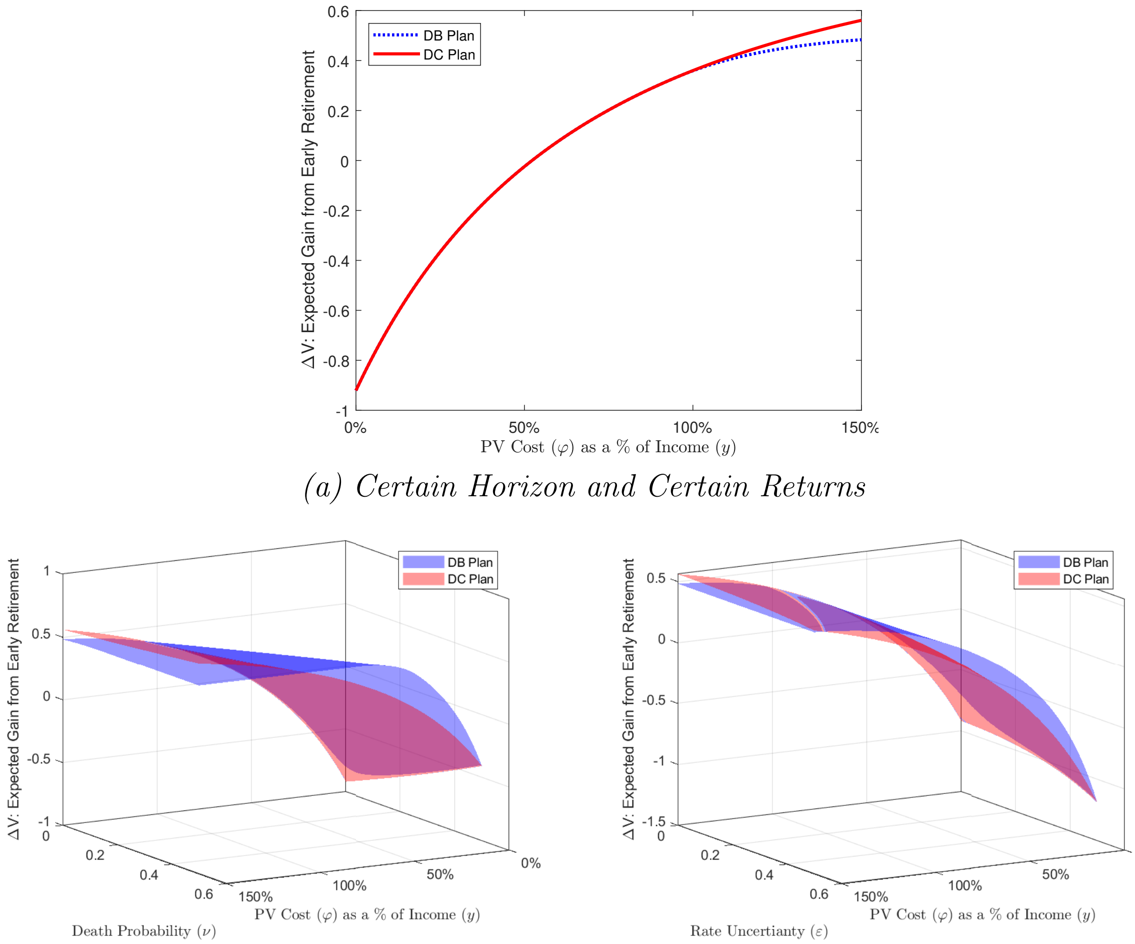


(a) PV Plan Cost φ = 20% of Income (b) Vary PV Plan Cost (φ)

that in the case where $\varepsilon = 0$, both plan types have the same expected gain from retiring in period one. However, increasing the rate of return uncertainty greatly reduces ΔV^C relative to ΔV^B. Figure 2b then shows that the effect of raising ϵ on ΔV^C relative to ΔV^B is consistent with the left panel for various present value costs of providing each plan.

Finally, Figure 3 shows that it is possible under very high retirement plan present value costs for the expected gain of retiring in period one to be higher for those in the DC plan relative to those in the DB plan. When the present value cost of the plan is

Figure 3: Results Under High φ Values



(a) Certain Horizon and Certain Returns

(b) Uncertain Horizon Channel

(c) Uncertain Returns Channel

small, the primary role of the benefit is to support retirement consumption in period two. A DB plan is more effective at this because the promised payment is guaranteed. This makes early retirement relatively more attractive under a DB when the plan size is sufficiently small. By contrast, when the plan's size is large, the DC benefit provides flexibility: workers can consume part of it in period one and still carry sufficient resources into retirement. When the plan sizes are so large that their primary use is no longer to fund period two consumption, early retirement becomes less feasible under a DB plan.

First, Figure 3a shows that under very high retirement plan generosity (φ), differences in the value of early retirement start to appear even without uncertain horizon or uncertain return risks. This is due to DC plans allowing individuals to access and consume their retirement benefits in period one with greater ease. Next, Figures 3b and 3c demonstrate that even when the uncertain horizon and uncertain returns channels are introduced into the model, it is still possible for those in DC plans to gain more from early retirement than those in DB plans when the plan generosity is high enough.

The results in this section show that when the present value cost of a plan is relatively low, uncertainty in investment returns and in the planning horizon lead individuals with DB plans to gain more from retiring early than those with DC plans. However, under sufficiently high plan generosity, the ranking can reverse, with DC participants benefiting more from early retirement than their DB counterparts. In the next section, we provide empirical evidence that, after controlling for detailed individual and job characteristics, workers with DB plans tend to retire earlier than those with DC plans. This finding indicates that, in the U.S. context, plan generosity is low enough that the two uncertainty channels highlighted here make early retirement more attractive for DB plan holders.

4 Empirical Evidence

The empirical evidence supports the mechanisms highlighted in the illustrative model. In particular, in this section, we present four observations consistent with the model's prediction that for reasonable levels of plan generosity, individuals in DC plans tend to retire later than those in DB plans. First, there has been a significant transition from DB retirement plans towards DC plans among individuals age 50 and older since the early 1990s. Second, individuals in DB plans are more likely to transition into retirement relative to those in DC plans, after controlling for observables such as age, household characteristics, wealth, health, etc. Third, participants enrolled in DC plans tend to have significantly higher predicted retirement ages compared to those in DB plans. Finally, at the same time as the shift towards DC plans, there was an almost 8 percentage point decline in the fraction of individuals age 65 or older who were retired and an increase in labor force participation at age 65 by 18.54 percentage points.

4.1 Data Description and Retirement Plan Categorization

The primary dataset used in this section is the Health and Retirement Study (HRS) spanning 1992 to 2020. The HRS is a longitudinal household survey collecting participants' retirement plan and employment information.[9] Participants in the study include individuals over age 50 and their spouses, regardless of the spouse's age. Interviews began in 1992 and were conducted biannually, covering seven cohorts with participants entering and exiting in each round. The HRS dataset includes detailed information on individual demographics, employment history, income sources, and social security income, along with detailed retirement plan enrollment information from current jobs.

The original HRS dataset contains 280,343 unique individuals with valid responses in surveys. From this dataset, we exclude respondents missing key demographic information, such as age, race, or census region of residence in each wave. Since our project focuses on

[9] We use RAND HRS Longitudinal File 2020 (V2).

how retirement plan enrollment affects retirement decisions, we also remove participants who were already retired before their first interview. Additionally, participants must have valid data on labor force participation status, retirement plans for their current main job, retirement status, health status, and union coverage. During the interviews, individuals are asked to report detailed retirement plans for up to four current jobs, ranked by importance. In this study, we focus solely on each individual's current main job and categorize the corresponding retirement plans into four broad types: no plan, Defined Benefit (DB) plan, Defined Contribution (DC) plan, and Hybrid plan. Table 1 provides a summary of the detailed plans reported in the HRS and the four broad categories that we sort them into. While it is possible for participants to change their retirement plans over time, around 86% of participants never switch plans during the years they work.[10]

Table 1: Categorization of Detailed Retirement Plans

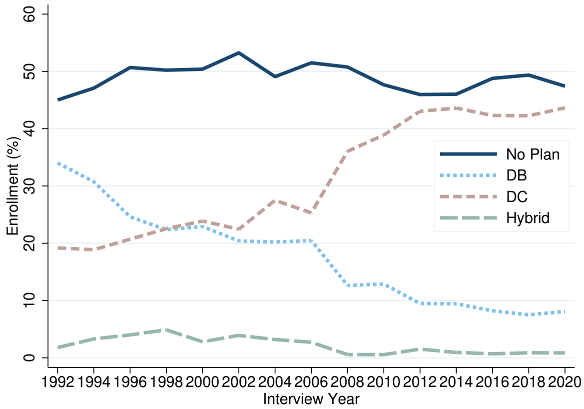
Types of Retirement Plans	Detailed Types
No Plan	No retired plans or only health plan mentioned
Defined Benefit Plan	Defined benefit plan
Defined Contribution Plan	Defined contribution plan; 401k plan; 401a plan; 403b plan; 457 plan; thrift/savings plan (tsp); profit-sharing plan; employee stock ownership; money purchase plan; employee stock purchase; sep or simple plan
Hybrid	Combination plan; cash balance plan

Finally, there are no missing values for marital status (ever married or never married), household wealth, and capital income for each participant. Table 11 in Appendix B.1 outlines the sample selection process step by step, including a summary of the remaining individuals and observations after each step. The sample includes 33,036 unique participants and 233,095 observations, representing over 83% of the original dataset. Our sample comprises nearly equal proportions of females and males, with the majority being White or Caucasian. As the HRS survey targets individuals over age 50 and their spouses, over half have a high school education or less, while about 23% have attended some college. Table 12 in Appendix B.2 provides a detailed description of the sample characteristics.

Figure 4 displays retirement plan inclusion over time for participants in our sample. This figure displays our first motivating observation, showing that there was a significant transition from DB into DC retirement plans since the early 1990s. The proportions of participants with no retirement plan or a hybrid plan from their main job remained relatively stable across the years observed. However, we observe that the share of participants enrolled in defined contribution plans increased by more that 20 percentage points from

[10]Appendix B.2 provides further information regarding the frequency of retirement plan switches in the data.

Figure 4: Retirement Plans of Current Main Job in Each Interview Year



Notes: Data displayed is from the Health and Retirement Study (HRS). The categorization of possible detailed retirement plan types into defined benefit (DB), defined contribution (DC), or hybrid categories is described in Table 1.

the early 1990s to 2020. Along this same time-frame, the share of participants enrolled in defined benefit plans decreased by more than 20 percentage points.

4.2 Differences in Retirement Timing by Plan Type

We first examine the relationship between retirement plan type and the probability of transitioning from employment to retirement. Using a logistic regression, we estimate the employment to retirement transition probability for individuals aged 60 to 69. Table 2 summarizes the regression results for transitions between employment and retirement among participants aged 60 to 69 by retirement plan types. The regression also accounts for educational degree, occupation, industry, year, and residence location effects, which are controlled for but not reported in the table for brevity. The results reveal that enrollment in a DC plan, rather than the excluded comparison group of enrollment in a DB plan is associated with a lower probability of transitioning into retirement, controlling for age and other detailed characteristics.

Figure 5 illustrates the predicted probability of transitioning from employment to retirement for participants aged 60 to 69, categorized by retirement plan type at the time of the decision. Panel (a) shows that participants enrolled in a hybrid plan are not significantly more likely to retire compared to those with a Defined Benefit (DB) plan.[11] In contrast, panel (b) indicates that participants with a defined contribution (DC) plan are consistently less likely to retire than those with a DB plan across all ages.

A potential concern is that retirement plan type may be correlated with employment sector: public-sector jobs predominantly offer DB plans, whereas private-sector jobs more commonly provide DC plans. If retirement behavior systematically differs in the public

[11]The large confidence interval for participants enrolled in hybrid plans is due to the small number of participants in this group.

Table 2: Employment to Retirement Transitions Among Ages 60-69

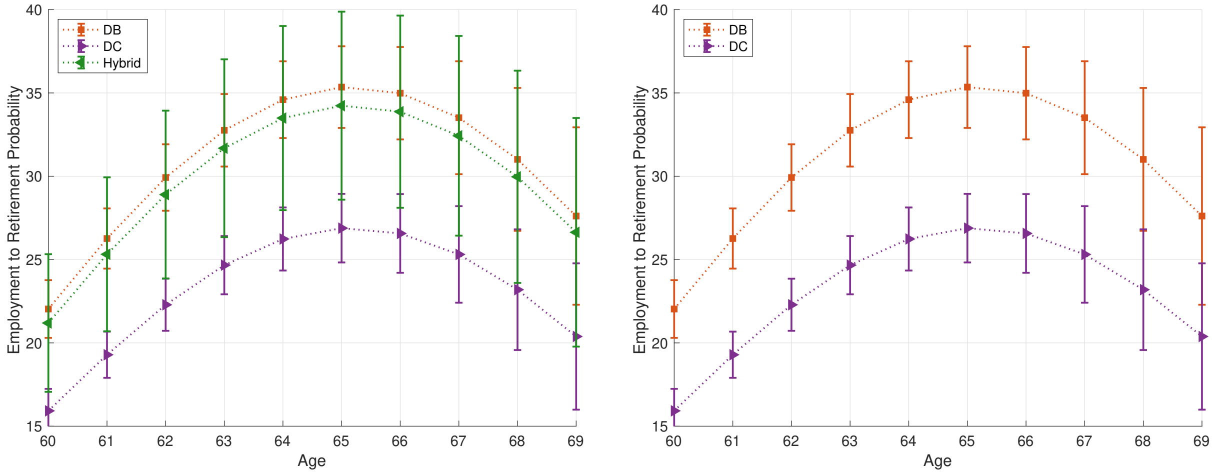
	Estimates	S.E.
Retirement Plans		
DC	**-0.410*****	0.061
Hybrid	-0.051	0.133
Demographic Controls		
Age	3.317***	0.439
Age squared	-0.025***	0.003
Female	0.167**	0.071
Never married	-0.505	0.817
Race: Black/African American	-0.133	0.097
Race: Other	-0.316**	0.152
Income Controls		
Hourly wage	0.004**	0.002
Hourly wage squared	-0.000*	0.000
Income from retirement plans	0.000**	0.000
Income from retirement plans squared	-0.000	0.000
Income from Social Security	0.000	0.000
Income from Social Security squared	0.000	0.000
Household wealth (incl. house)	-0.000	0.000
Health Controls		
Self-reported health: very good	0.173**	0.086
Self-reported health: good	0.385***	0.088
Self-reported health: fair	0.511***	0.113
Self-reported health: poor	0.618***	0.224
Spouse health: very good	0.032	0.089
Spouse health: good	-0.063	0.091
Spouse health: fair	-0.163	0.108
Spouse health: poor	0.082	0.144
Constant	-108.839***	13.814
Observations	7,849	

Notes: The table shows the results of a logistic regression using HRS sample. Estimations are adjusted by the HRS personal-level weights. The regression also controls the participant's educational degree, occupation, industry, as well as region and year fixed effects. The reference category is married White males with excellent self-reported health, whose spouses also report excellent health, and who are enrolled in a DB retirement plan in their current main job. Robust standard errors are presented. Stars denote statistical significance $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

sector for reasons unrelated to plan design, this composition could bias the estimated association between plan type and retirement transitions. Our baseline specification already includes comprehensive controls to mitigate this concern. In addition, we re-estimate the model after excluding workers employed in Public Administration and obtain similar results. The robustness check is reported in Appendix C.1.

Next, we examine the predicted retirement age for individuals enrolled in either DB

Figure 5: Employment to Retirement Probability



(a) By Retirement Plans *(b) DB and DC only*

Notes: The figure shows predicted probability of entering retirement from employment at each age based on retirement plan type. The predicted probabilities are estimated using the results of the logistic regression using data from the Health and Retirement Study (HRS) displayed in Table 2. Vertical bars indicate 95% confidence intervals.

or DC plans using the following specification[12]:

$$RetireAge_i = \alpha + \boldsymbol{\beta}'\boldsymbol{RetirePlan}_i + \boldsymbol{\gamma}'\boldsymbol{X}_i + \epsilon_i \tag{6}$$

where $RetireAge_i$ denotes the final retirement age of individual i. Because the retirement age represents the individual's last exit from the labor force, we use the most frequent (primary) retirement plan observed for each person rather than time-varying plan enrollment over the life cycle. The variable $\boldsymbol{RetirePlan}_i$ is a vector of dummy variables indicating the individual's dominant plan type, DB plan and DC plan, and $\boldsymbol{X}_i$ is a vector of control variables, including household total wealth, pre-retirement wage and its square, and dummies for health status, gender, race, education, marital status, region, pre-retirement occupation and industry, and retirement year.

To address potential endogeneity in retirement plan choice, we instrument the retirement plan dummies using union status. This addresses the concern that individuals with different preferences for retirement timing may self-select into occupations or firms that offer their preferred type of retirement plan, thereby biasing OLS estimates. In Appendix C.3, we provide supporting evidence using a difference-in-differences approach, examining the impact of Right-to-Work (RTW) laws, which reduce union coverage, on DB plan enrollment. We find that the introduction of RTW laws is associated with a significant

[12] In the data, around 20% of individuals receive retirement income from multiple retirement plans. To minimize potential bias arising from multiple benefit types, we restrict the sample to those who report receiving income from only one plan type. We assume this income originates from the individual's primary retirement plan, identified as the plan type most frequently observed during their career after age 50, since the sample primarily consists of individuals over 50.

decline in DB plan participation, consistent with union status being a strong and relevant instrument for retirement plan type.[13]

Table 3 illustrates the predicted final retirement age for individuals with different retirement plans. The results indicate that participants enrolled in DC plans tend to have significantly higher predicted retirement ages compared to those in DB plans on average.

Table 3: Predicted Retirement Age by Retirement Plans

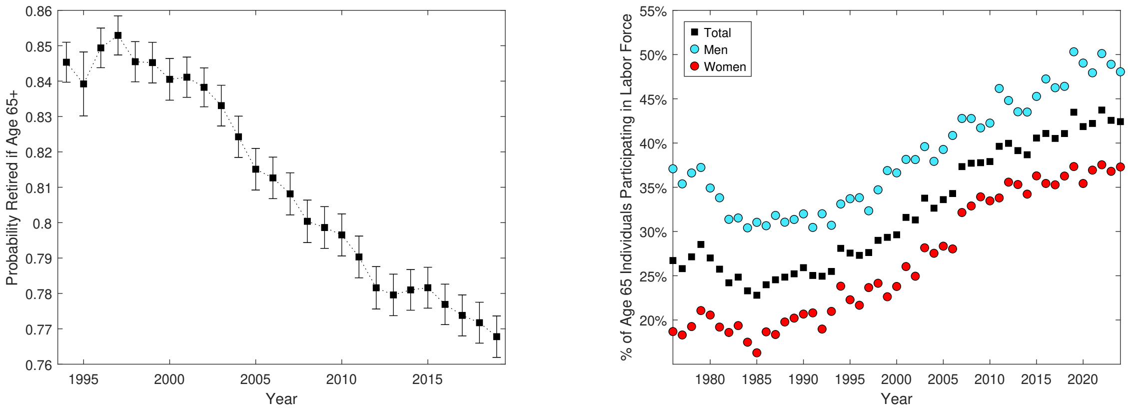
	Predicted Age	95% Confidence Interval
DB	61.692***	[60.763, 62.621]
	(0.474)	
DC	66.346***	[64.737, 67.955]
	(0.821)	

Notes: The table presents the predicted retirement ages for participants enrolled in Defined Benefit (DB) and Defined Contribution (DC) retirement plans, estimated using instrumental variable regression, based on HRS sample. The main regression model is specified in Equation (6). Robust standard errors are reported in parentheses. Statistical significance is indicated by asterisks: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

4.3 Decline in Retirement Among Age 65 and Older

Finally, we document our final motivating empirical observation, a decline in retirement among individuals age 65 and older and at exactly age 65. First, the left panel of Figure 6 shows the probability of an individual reporting that they are retired if age 65 or older by year in the Current Population Survey (CPS). We see from the early 1990s the probability of retirement among this age group has declined by 7.76 percentage points.

Figure 6: Decrease in Retirement at Age 65



(a) Probability of Retirement if Age 65+ *(b) Age 65 Participation Rate*

[13] Moreover, the first-stage F-statistics indicate strong instrument relevance, with p-values close to zero.

With this initial observation, it is possible that the decline in retirement could have been brought about by demographic shifts. For example, a change in the age composition among the total population age 65 or older. To better control for any demographic shifts, we also plot the percentage of the population who are still participating in the labor force at exactly age 65 by gender in the right panel of the figure. Interestingly, there is a slight decrease in participation at age 65 from the late-1970s to the mid-1980s.[14] Then, starting around the early 1990s there is a notable increase in participation at age 65 for both genders. In Appendix C.2 we show that the increase in participation persists when separately analyzing college graduates and non-graduates of either gender.

5 Quantitative Model

The illustrative model and empirical evidence together suggest that the shift from DB to DC retirement plan coverage has meaningful implications for savings decisions and retirement timing. To quantify the relative importance of the mechanisms outlined in Section 3 and assess their aggregate implications, we now turn to a full quantitative model. The model formalizes the trade-offs faced by agents who may be enrolled in no plan, a defined benefit (DB) plan, a hybrid plan, or a defined contribution (DC) plan. Agents face uncertainty over both lifespan and investment returns, and the relevance of each risk depends on plan type. DB and hybrid plans protect against investment return risk by offering fixed or formula-based benefits, while DC benefits are subject to uncertain returns. Only DB plans, however, insure against longevity risk by providing fixed lifetime benefits. These distinctions allow the model to quantify how plan design shapes optimal saving and retirement decisions.

5.1 Model Environment

5.1.1 Setting

Time is discrete and continues forever, with each period in the model representing one quarter. Agents who populate the model may live to terminal age $\overline{a}$ but face a death probability dependent on age (a), ν_a. Each period, a unit mass of age 30 agents enters the model while a unit mass dies at various ages. An agent could be employed, unemployed, or retired in any period. When agents enter the model, they draw a fixed income type $y \sim F(y)$. Income equals y when employed, and the unemployment benefit equals a fraction ϕ of employment income. Agents are heterogeneous in their age (a), income type (y), current labor force status, level of assets (b), accumulated DB plan tenure (γ_B), and current retirement plan type (i_p) with $i_p \in$

[14] The data does not allow us to see if respondents report being "retired" before 1994, although we observe their participation status.

$\{N \text{ (None)}, B \text{ (DB Plan)}, H \text{ (Hybrid)}, C \text{ (DC plan)}\}$.

Just as in the data, it is possible for agents in the model to move between different retirement plan types when changing jobs. Let $p(i_p|y)$ be the probability of a new job offering retirement plan type i_p given the agent's income type y. Agents with DC, hybrid, or no retirement plan will accumulate benefits through their assets (b). For individuals in a DB plan, the benefit received in retirement will depend on their income type and their accumulated DB plan tenure.[15]

5.1.2 Movements Between Employment States and Retirement Plans: Endogenous Retirement

Employed agents face exogenous job loss probability δ_a, while the probability of regaining employment if unemployed is η_a. These probabilities depend on the agent's age a, as data displays significant differences over the life-cycle in these probabilities. While movements between employment and unemployment are exogenous, the choice to retire is endogenous. At the end of each period, agents decide to continue in employment or unemployment into the next period or to retire.

5.1.3 Consumption and Savings Decisions

Agents get utility $u(c, \ell)$ from consumption c and leisure ℓ. Let ℓ_P denote leisure enjoyed if participating in the labor force via employment or unemployment, and ℓ_R denote leisure enjoyed in retirement. All individuals enter the model with zero assets and can save in one-period bonds.[16] However, individual investments and investments made in DC plans are subject to an uncertain rate of return r_r with $r_r = r_s + \epsilon$ and $\epsilon \sim \mathcal{N}(0, \sigma_\epsilon^2)$.

All agents can choose to save in one-period bonds offering a risky rate of return r_r that is unrealized at the time of investment, just as in reality, all individuals may make personal investments. Those in DC plans, however, get an extra payment equal to fraction f_c of their employment income when employed invested into the risky asset from their employer (e.g., an employer contribution to a 401(k)). Only those in DB and hybrid retirement plans can contribute a portion of their income in exchange for a certain outcome. Those with a DB plan receive payment $x_B(a, y, \gamma_B)$ each period in retirement, while those with a hybrid plan have their employer contributions $f_c \times y$ invested at a safe

[15]We assume no uncertainty in DB plan payments, as the Pension Benefit Guaranty Corporation provides federal insurance for most private pensions against default risk arising from plan sponsor insolvency.

[16]The model assumes only savings but no borrowing as in most of the related literature: French (2005), De Nardi, French and Jones (2010), French and Jones (2011), and Heiland and Li (2012). We also assume that agents enter the model at age 30, after having paid off any debt.

interest rate r_s.[17] In retirement, all agents receive a benefit from the government κ_a, that they can access at a certain age (representing social security benefits).

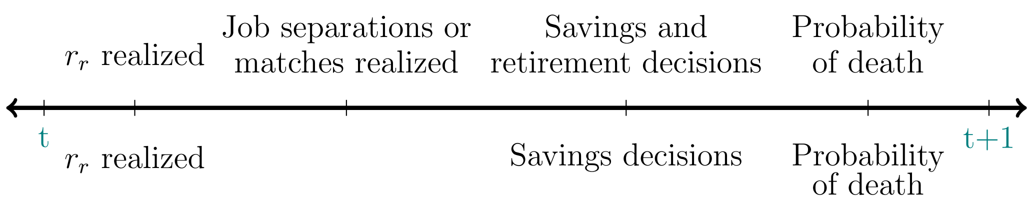
Finally, agents receive a utility value from leaving bequests (dying with positive asset values). This assumption is common in the literature (see Gourinchas and Parker (2002), De Nardi, French and Jones (2010), Daminato and Padula (2024), among others) and will allow our model to more closely match savings behavior over the life-cycle and the observation that many individuals die with non-trivial positive levels of assets. Let $\zeta(b, y, \gamma_B)$ denote the value of dying with assets b, income y, and DB plan tenure γ_B. As many DB plans offer benefits to spouses after the death of the plan-holder, we include average expected spousal DB plan payments in the value of bequests.

5.1.4 Timing

Figure 7 summarizes the timing of events in the model. At the beginning of each period, agents observe the actual risky rate of return r_r that they receive on the investments made in the last period. Notice that when making savings and retirement decisions in the current period, agents do not know the actual rate of return r_r that they will realize on their investments. After observing the realized value of r_r, an agent who is not retired

Figure 7: Model Timing

Not Retired:



Retired:

could lose their job if they entered the period employed. Similarly, agents could find a job if they entered the period unemployed. Agents then decide how much to consume and save in the current period. Still, the level of assets available in the next period is uncertain and depends on the agent's savings and the next-period realization of r_r. At this time, individuals in the labor force decide whether or not they want to remain in the labor force or retire in the next period. Finally, at the end of each period, all agents face an age-dependent probability of death ν_a.[18]

[17] In the model, this mimics cash-balance "hybrid" plans where individuals with these plans get access to a known amount of assets in retirement, and the amount is not subject to any uncertain rate of return or other source of risk.

[18] Appendix E considers two alternative model setups where we allow for agents to re-enter the labor force after retirement and where we consider a Social Security design where Social Security income depends not only on working income but also on the age of retirement. We show that the main results are robust to these extensions.

5.2 Value Functions

Let $V_a^E(y, b, i_p, \gamma_B)$ denote the value of employment for an age a individual of income type y who has assets b, retirement plan i_p, and accumulated DB plan tenure γ_B.

$$V_a^E(y, b, i_p, \gamma_B) = \max_{s, R \in \{0,1\}} \big\{ u(c, \ell_P) + \nu_a \beta \mathbb{E}\left[\zeta(b'_E(s, i_p), y, \gamma_B)\right]$$
$$+(1-R)(1-\nu_a)\beta\left[(1-\delta_{a+1})\mathbb{E}\left[V_{a+1}^E(y, b'_E(s, i_p), i_p, \gamma'_B)\right] + \delta_{a+1}\mathbb{E}\left[V_{a+1}^U(y, b'_E(s, i_p), i_p, \gamma'_B)\right]\right]$$
$$+R(1-\nu_a)\beta\mathbb{E}\left[V_{a+1}^R(y, b'_E(s, i_p), i_p, \gamma'_B)\right]\big\} \tag{7}$$

Agents choose how much to save s and whether to remain in the labor force or retire before the next period $R \in \{0, 1\}$. The budget constraint for the employed is as follows: consumption and savings equal the amount of assets the agent has, b, plus income y.

$$c + s = b + y \tag{8}$$

Agents choose how much to save s, but the amount of assets they end up with in the next period is subject to the risky rate of return r_r, which is not observed until the start of the next period. Let $b'_E(s, i_p)$ denote realized assets in the next period given savings s made when employed with a retirement plan of type i_p. In addition to the individual's personal savings, those enrolled in a DC or hybrid plan also receive an employer contribution of $f_c \times y$ to savings. The employer contribution is invested at the risky rate of return for those in a DC plan, while agents with a hybrid retirement plan have their employer contribution invested at a guaranteed safe rate of return r_s.

$$b'_E(s, i_p) = (1 + r'_r)(s + y f_c(\mathbb{1}_{i_p=C})) + (1 + r_s) y f_c(\mathbb{1}_{i_p=H}) \tag{9}$$

After making savings and retirement decisions, agents face a probability $(1-\nu_a)$ of surviving into the next period. If the agent does not survive, they receive value $\mathbb{E}[\zeta(b'_E(s, i_p), y, \gamma_B)]$, the expected utility value from the bequests they will leave. Employed workers who survive and who did not choose to retire then become unemployed with probability δ_{a+1} and remain employed with probability $(1 - \delta_{a+1})$.

Next, let $V_a^U(y, b, \gamma_B)$ denote the value of unemployment for an age a individual of income type y who has assets b, and accumulated DB plan tenure γ_B.

$$V_a^U(y, b, \gamma_B) = \max_{s, R \in \{0,1\}} \big\{ u(c, \ell_P) + \nu_a \beta \mathbb{E}\left[\zeta(b'_U(s), y, \gamma_B)\right] + R(1-\nu_a)\beta\mathbb{E}\left[V_{a+1}^R(y, b'_U(s), \gamma_B)\right]$$
$$+ (1-R)(1-\nu_a)\beta\,(1-\eta_{a+1})\,\mathbb{E}\left[V_{a+1}^U(y, b'_U(s), \gamma_B)\right]$$
$$+(1-R)(1-\nu_a)\beta\eta_{a+1} \sum_{i_p \in \{N,B,H,C\}} p(i_p|y)\mathbb{E}\left[V_{a+1}^E(y, b'_U(s), i_p, \gamma_B)\right] \Bigg\} \tag{10}$$

Agents choose how much to save s and whether to remain in the labor force or retire before the next period $R \in \{0,1\}$. The budget constraint for the unemployed is as follows.

$$c + s = b + y\phi \tag{11}$$

Unemployed agents receive unemployment income $y\phi$. Their consumption and savings equal their income plus their pool of existing assets. Let $b'_U(s)$ denote realized next-period assets given savings s and realized next-period risky rate of return r'_r when unemployed.

$$b'_U(s) = (1 + r'_r)s \tag{12}$$

After making savings and retirement decisions, these agents face a probability $(1 - \nu_a)$ of surviving into the next period. Unemployed agents who survive and who did not choose to retire then become employed in the next period with probability η_{a+1} and remain unemployed with probability $(1 - \eta_{a+1})$. When agents enter employment, they also realize a retirement plan type associated with their new job. The probability that their new job will have retirement plan type $i_p \in \{N, B, H, C\}$ is $p(i_p|y)$.

Finally, $V_a^R(y, b, \gamma_B)$ denotes the value of retirement for an age a agent of income type y with assets b and accumulated DB plan tenure γ_B.

$$\begin{aligned} V_a^R(y, b, \gamma_B) = \max_s \{ & u(c, \ell_R) + \nu_a \beta \mathbb{E}\left[\zeta(b'_R(s), y, \gamma_B)\right] \\ & + R(1 - \nu_a)\beta \mathbb{E}\left[V_{a+1}^R(y, b'_R(s), \gamma_B)\right] \} \end{aligned} \tag{13}$$

In retirement, the agent receives an age-dependent benefit from the government, replacing κ_a of their employment income. Specifically, $\kappa_a = 0$ for all a values lower than the minimum age set by the government to receive this retirement benefit and $\kappa_a = \kappa$ for all ages a at and above the minimum age.[19] Consumption plus savings equals the government retirement income plus the agent's existing pool of assets b. Additionally, agents may receive DB plan income $x_B(a, y, \gamma_B)$, which depends on their age, income type, and DB plan tenure.

$$c + s = y\kappa_a + b + x_B(a, y, \gamma_B) \tag{14}$$

[19]We assume all retired agents receive social security income after a certain age. Although there are papers that discuss how a relatively small fraction of employees do not participate in social security (Morrill and Westall, 2019; Kim et al., 2024), several studies show that the impact of social security benefits on average retirement age is relatively small (Diamond and Hausman, 1984; Samwick, 1998; Kim et al., 2024). Furthermore, our focus is to compare optimal decisions made under DB versus DC plans. Appendix E considers a model extension where Social Security income depends not only on employment income, but also on the age of retirement. This appendix shows that our main results are robust to this modeling change.

In retirement, if agents save s, then their realized assets in the next period given realized next-period rate of return r'_r are as follows.

$$b'_R(s) = (1 + r'_r)s \tag{15}$$

At the end of each period, the agent faces age-dependent death probability ν_a.

Finally, the state of the economy can be summarized by $\psi = (m^E, m^U, m^R)$, where the first element of ψ is a function with $m^E(a, y, b, i_p, \gamma_B)$ denoting the mass of individuals employed at age a of income type y with retirement plan i_p, assets b, and accumulated DB plan tenure γ_B. The second element is a function $m^U(a, y, b, \gamma_B)$ denoting the mass unemployed at age a of income type y with accumulated assets b and DB plan tenure γ_B. Similarly, the final element is a function $m^R(a, y, b, \gamma_B)$ denoting the mass of retired individuals with these characteristics.

5.3 Equilibrium

Definition 1: *A Recursive Equilibrium (RE) is given by the following.*

1. *Value functions* $\{V_a^E(y, b, i_p, \gamma_B), V_a^U(y, b, \gamma_B), V_a^R(y, b, \gamma_B)\}$

2. Optimal savings policy functions $s_a^{E*}(y, b, i_p, \gamma_B)$, $s_a^{U*}(y, b, \gamma_B)$, $s_a^{R*}(y, b, \gamma_B)$ and optimal retirement policy functions $R_a^{E*}(y, b, i_p, \gamma_B)$, $R_a^{U*}(y, b, \gamma_B)$ solve (7), (10), and (13).

3. Transition probability functions determine the aggregate state of the economy $\psi = (m^E(a, y, b, i_p, \gamma_B), m^U(a, y, b, \gamma_B), m^R(a, y, b, \gamma_B))$ and are consistent with the equilibrium optimal savings functions and optimal retirement policy functions.

6 Results

6.1 Calibration

We solve the model introduced in Section 5 under the following assumption regarding agents' utility. If agents are employed or unemployed, they receive utility $u(c, \ell_P) = \frac{c^{1-\theta}-1}{1-\theta} + \ell_P$, while retired agents enjoy utility $u(c, \ell_R) = \frac{c^{1-\theta}-1}{1-\theta} + \ell_R$. Notice that when comparing the utility of labor force participation and retirement, what is relevant is the difference between leisure values $\ell_R - \ell_P$. It is for this reason that we normalize $\ell_P = 0$ and estimate the value of ℓ_R relative to this normalization. Following De Nardi, French and Jones (2010), the value of bequests $\zeta(b, y, \gamma_B)$ is derived from agents' utility from consumption so that the value of leaving bequests totaling a discounted expected value of z brings bequest value $\zeta_c \frac{(z+\chi)^{1-\theta}-1}{1-\theta}$.

We calibrate the model to the 1990s before much of the transition to DC plans occurred. We will then use the calibrated model to simulate the movement towards DC plans that followed. Table 4 lists the directly assigned model parameters. β is the quarterly discount factor for which we choose a standard value corresponding to an annual 4% risk-free rate of return, with the quarterly risk-free rate of return $r_s = (1/\beta) - 1$. As previously discussed, we normalize $\ell_P = 0$ and will later estimate the value of ℓ_R. We normalize the median income earned when employed to equal 1, and take the relative 25th and 75th percentile values from the Bureau of Labor Statistic's Occupational Employment and Wage Statistics (OEWS).[20] This results in $y \in \{0.6704, 1, 1.5610\}$.

Following the data, other income sources, such as social security income, are based on the fraction of employment income that they replace on average. Values for the average unemployment insurance and social security replacement rates are taken from estimates provided by the U.S. Department of Labor[21] and the U.S. Social Security Administration[22] respectively. While employer contributions to DC plans can vary, we set f_c to reflect that the average employer contribution has been 4.6% of employee income, as reported by Vanguard (2024).

Similarly, while DB plan benefits can vary, most follow a benefit formula where the payout in retirement is equal to a benefit multiplier times the final average salary, multiplied by the years of service. The typical benefit multiplier is 0.015 to 0.02, so we apply a benefit multiplier of 0.0175. Furthermore, many plans require a minimum of seven years of service in order for an individual to receive benefits, and impose a maximum of around 30 years of service after which benefits stop accruing (National Council on Aging, 2024; Sundin, 2025). We follow this formula carefully, imposing a minimum of 7 years of service and a maximum of 30 years of service, after which individuals are free to continue working, but their DB benefit in retirement remains fixed.

The quarterly age-dependent unemployment-to-employment (UE) and employment-to-unemployment (EU) transition probabilities are estimated using CPS data, and these

[20]While we use 1992-1994 data wherever possible, the OEWS estimates for all industries on 25th, 50th, and 75th percentile annual earnings is only first available in 2001. While we rely on the earliest available 2001 estimates for the relative income values, it is worth noting that these estimates do not notably change from year to year.

[21]The average unemployment insurance replacement rate is computed by the U.S. Department of Labor (DOL) (see https://oui.doleta.gov/unemploy/ui_replacement_rates.asp). We take the earliest available data from 1997, using the replacement rate computed under the DOL "Replacement Ratio 1" measure computed as the weighted average of the claimants' weekly benefit amount divided by the product of the claimants normal hourly wage and 40 hours per week, where ratios greater than or equal to 2 are excluded as outliers.

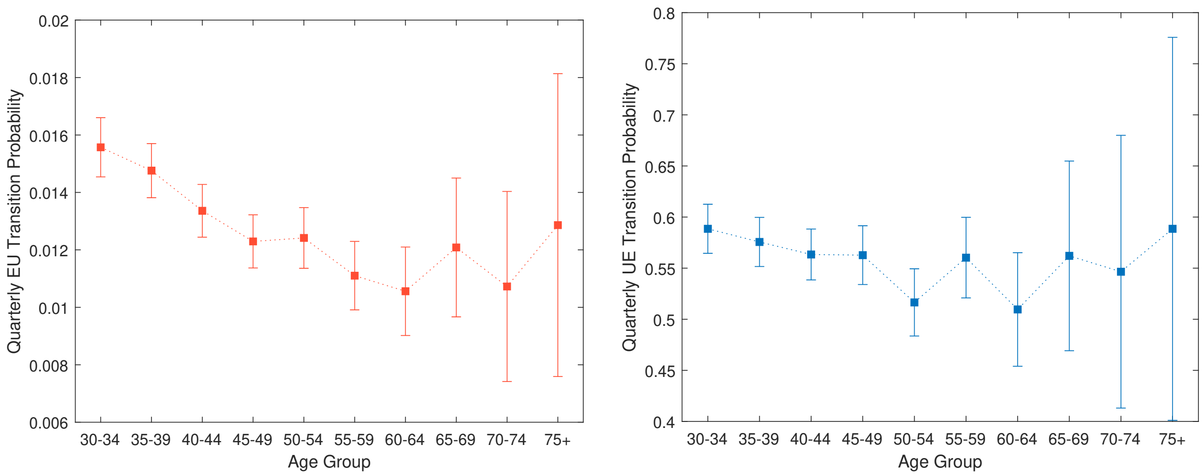
[22]While social security benefits vary by individuals' employment income, retirement age, and other factors, the U.S. Social Security Administration reports that "On average, Social Security will replace about 40% of your annual pre-retirement earnings" (SSA Publication No. 05-10706: https://www.ssa.gov/myaccount/assets/materials/workers-61-69.pdf).

Table 4: Directly Assigned Parameter Values

Parameter	Description	Value/Source
β	Quarterly discount factor	0.990 (Standard, 4% annual risk-free return)
ϕ	Unemployment insurance replacement rate	0.459 (U.S. Department of Labor)
κ	Social security replacement rate	0.400 (Average from Social Security Admin.)
f_c	Employer DC/hybrid plan contribution	0.046 (Vanguard, 2024)
η_a	Age-dependent UE probability	CPS estimate (*Figure 8*)
δ_a	Age-dependent EU probability	CPS estimate (*Figure 8*)
ν_a	Age-dependent death probability	Social Security Admin. Actuarial Life Table
$p(i_p\|y)$	Pr. of drawing each retirement plan	HRS estimates (1992–1994)
$x_B(a, y, \gamma_B)$	DB benefit formula	National Council on Aging (2024), Sundin (2025)

results are displayed in Figure 8.[23] The age-dependent death probabilities in the model are taken directly from the U.S. Social Security Administration's Actuarial Life Table[24] and adjusted to reflect quarterly probabilities. Finally, the probabilities of drawing each of the four retirement plans when entering a job, conditional on income, are taken from the HRS data spanning 1992-1994, before the notable switch from DB towards DC plans.

Figure 8: Estimated Quarterly Transition Probabilities by Age from CPS



(a) Quarterly EU Transition Probability *(b) Quarterly UE Transition Probability*

After assigning the model parameters listed in Table 4, we jointly calibrate the remaining parameters to align the model with relevant features of the data. Table 5 displays the parameters in the model that are jointly calibrated, their estimated values, descriptions, and a comparison of the targeted data moments and corresponding model-generated moments. In calibrating the standard deviation σ_ϵ of shocks to the risky rate of return, we target the coefficient of variation of quarterly returns from the NASDAQ

[23]The CPS data used spans 1992-1999. Estimates using only 1992-1994 data do not greatly differ. We chose the longer time horizon for the significantly larger sample size, resulting in narrower confidence intervals.

[24]https://www.ssa.gov/oact/STATS/table4c6.html

Composite Index.[25] Next, the key parameter in the model driving the incentive to retire is the retirement leisure value ℓ_R. This parameter is calibrated targeting the percent of the population retired if age 65+ in 1992, estimated from the Current Population Survey. The bequest value parameter ζ_c is an important parameter influencing incentives to spend vs. save in retirement. A higher ζ_c value increases agents' bequest motive and results in agents consuming a smaller fraction of the savings built up before retirement. ζ_c therefore targets the percentage change in median net worth between ages 55-64 and age 75+ computed from the Survey of Consumer Finances. The agents' risk aversion θ is

Table 5: Jointly Calibrated Parameter Values

Parameter	Estimate	Targeted Moment	Data	Model
σ_ϵ	0.0318	Quarterly returns coefficient of variation	3.69	3.69
ℓ_R	0.8073	Percent retired if age 65+	84.53%	84.60%
ζ_c	7.9433	% Change median net worth 55–64 to 75+	-23.64%	-22.22%
θ	1.1371	Age 55–64 median net worth to income ratio	4.81	4.82
χ	0.0295	Percent retired: age 70–74 to 65–69	1.17	1.16

also an important parameter affecting savings, not only in retirement but throughout the life-cycle. The risk aversion parameter θ is chosen so that the model reasonably matches the median age 55-64 net worth to income ratio.[26] Finally, the parameter χ affects the curvature of the bequest function, following De Nardi, French and Jones (2010). We calibrate χ by targeting the fraction of individuals who are retired between ages 70–74 relative to those between 65–69. A larger χ reduces the marginal utility cost of setting aside modest bequests, making late-life consumption and leisure relatively more attractive. In contrast, a smaller χ implies a stronger incentive to continue working in order to accumulate larger bequests. Thus, the choice of χ directly affects the model's predictions for labor force participation at older ages. Calibrating χ to match observed retirement behavior in the 65–74 age range ensures that the model captures how bequest motives interact with late-life labor supply decisions.

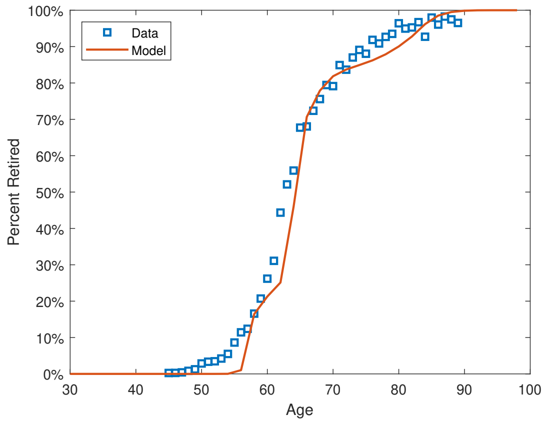
6.2 Model Dynamics

In addition to the targeted moments displayed in Table 5, the model is able to match the percent of all individuals retired at each age reasonably well. As in the data, some early retirement occurs, with around 20% of agents retiring by age 60. The percentage of individuals retired increases drastically around the age of 65, and then levels off, with some individuals continuing to work into their 70s.

[25]NASDAQ OMX Group, NASDAQ Composite Index [NASDAQCOM], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/NASDAQCOM. The estimated coefficient of variation does not notably change when excluding 2020 data.

[26]For the third and fourth moments, we use data from the 1992 wave of the Survey of Consumer Finances (SCF) https://www.federalreserve.gov/econres/scfindex.htm.

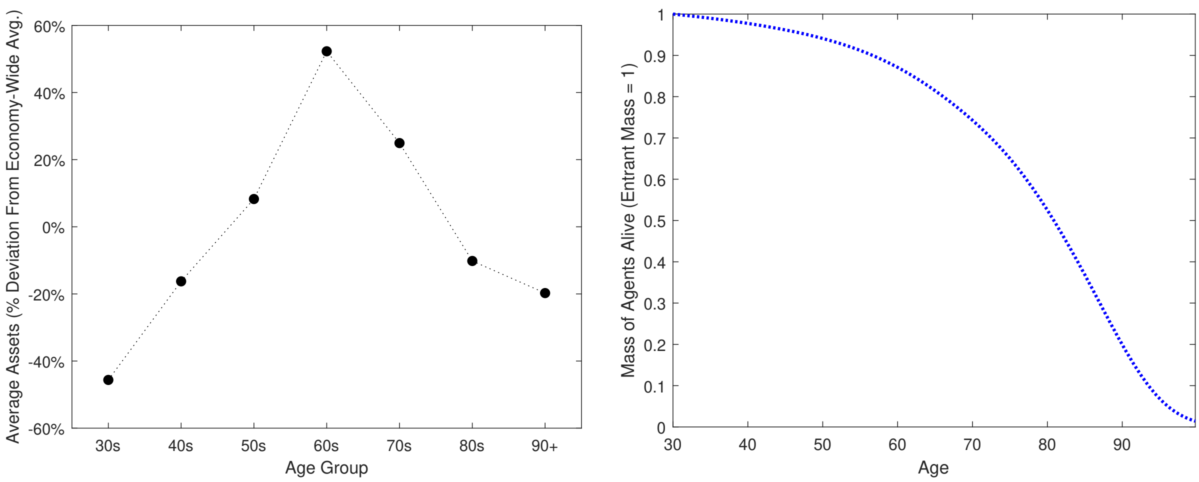
Figure 9: Percent Retired by Age (Untargeted)



Note: The data displayed in this figure is from the Current Population Survey in 1994, as we calibrate the model to the early 1990s. Prior to 1994, there was no information available regarding whether individuals were not in the labor force due to retirement or due to another reason.

Another important feature of the model is that agents accumulate assets for retirement as they age. The left panel of Figure 10 shows that the average level of assets conditional on age increases significantly as individuals enter the model at age 30 until they reach their 60s. After entering their 60s, many individuals will start to retire, where they will begin to consume some of their accumulated assets. Thus, we see average assets decline as individuals move from their 60s into their 80s and beyond.

Figure 10: Saving Over the Life-Cycle



(a) Average Assets by Age *(b) Mass Remaining Alive by Age*

When considering this and other figures that compare individuals of different ages in the model, it is important to remember that agents in the model die and exit the model with age-dependent probability ν_a. The right panel of Figure 10 plots the share of individuals who have not yet died and exited the model at each age. Recall that a unit mass of agents enters the model at age 30 and then faces death probabilities taken from the Social Security Administration's Actuarial Life Table. The probability of death is relatively low from age 30 to around age 50, after which it notably increases with age.

While all individuals face the same death probabilities, the retirement plan they draw when entering the model has a significant impact on when agents choose to retire. In our calibration, we chose no empirical targets relating to different behaviors between individuals enrolled in different retirement plan types. In our model, agents in DC plans

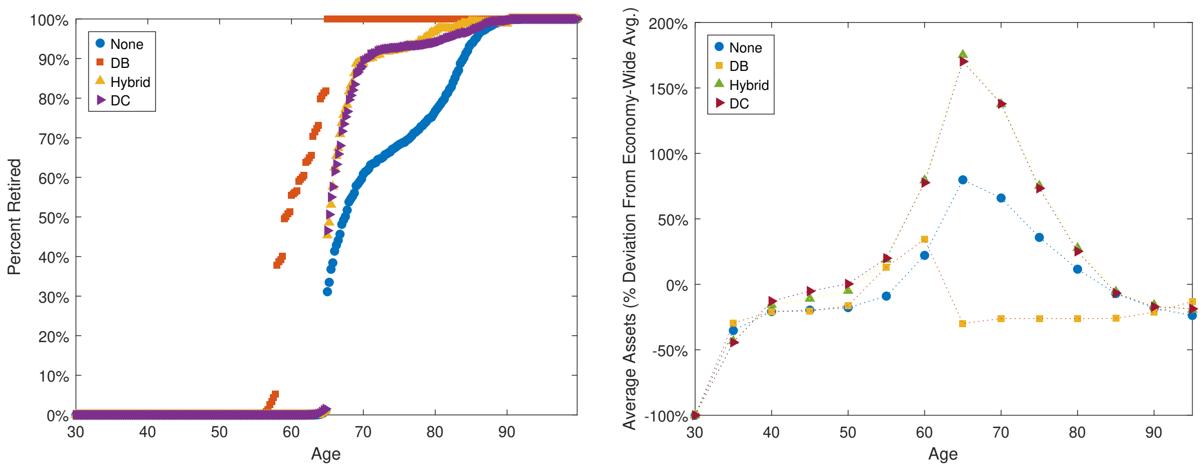
Table 6: Predicted Retirement Age by Plan Type (Untargeted)

Retirement Plan	Model	Data (See Table 3)
Defined Benefit (DB)	60.87	61.69
		[60.76, 62.62]
Defined Contribution (DC)	66.96	66.35
		[64.74, 67.96]

are free to use the employer contributions made towards their private wealth to fund retirement at earlier ages than those in DB plans can access their retirement benefits. However, the behavior that the model predicts aligns with the data, showing that those in DC plans tend to work longer.

The left panel of Figure 11 provides additional detail by plotting the percentage of individuals with each retirement plan who are retired by age. The average retirement age in the model for those in hybrid retirement plans is 67.04, very similar to the average DC plan retirement age. Unsurprisingly, those with no retirement plan have the highest predicted retirement age of 70.03 in the model.

Figure 11: Savings and Retirement Timing Effects: DB vs. DC Plan



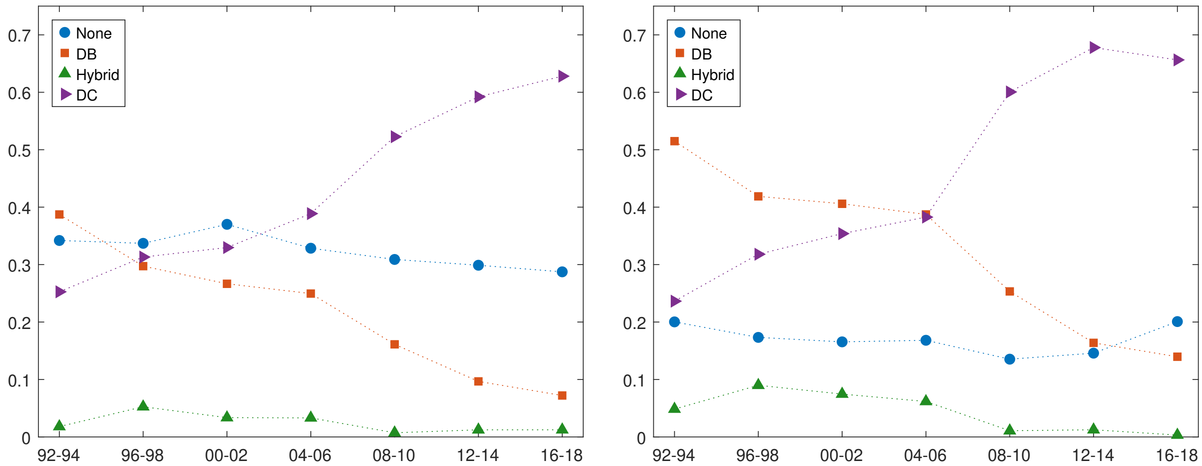
(a) Percent Retired by Retirement Plan *(b) Average Assets by Retirement Plan*

The right panel of the figure explains much of this behavior by comparing the non-pension wealth (accumulated assets b) for those enrolled in each plan at different ages. Those enrolled in DC plans endogenously accumulate significantly more wealth on average by the age of 65, relative to those in DB plans who are not as reliant on individually managed wealth to fund their retirement. When comparing the accumulated wealth of individuals with no retirement plan, it is important to remember that agents with lower income are more likely to enter a job with no plan. Additionally, those with DC and hybrid plans receive a contribution from their employer equal to 4.6% of their employment income into their pool of assets. These two factors lead to agents with no retirement plan accumulating fewer assets on average relative to those in DC plans, explaining why they also tend to retire later.

6.3 Counterfactual: Movement from DB to DC Plans

Now, we use our model to evaluate the effects of the movement from DB to DC retirement plans from 1992 through 2018. Figure 12 shows the change in retirement plan enrollment rates in the HRS data since the early 1990s by earnings percentile.[27] While the probability of enrollment in a DC plan increased notably for all earnings groups, the percentage enrolled in a hybrid plan or no retirement plan remained relatively fixed but also fluctuated. This subsection compares three counterfactual economies, the first with

Figure 12: Changes in Retirement Plan Enrollment: HRS Data



(a) 50th Percentile Earnings *(b) 75th Percentile Earnings*

the 1992-94 enrollment probabilities used in subsections 6.1 and 6.2, the second with the new retirement plan enrollment probabilities observed in 2016-18 (see Table 7), and the

[27]In the HRS data, the percentage enrolled in each plan type differs by income, just as in the model. Specifically, the enrollment probabilities in 1992-94 and 2016-18 for those in the 25th, 50th, and 75th earnings percentiles were as follows.

Table 7: Plan Enrollment Probabilities: 1992–94 to 2016–18

	25th Percentile		50th Percentile		75th Percentile	
	1992–94	2016–18	1992–94	2016–18	1992–94	2016–18
No Plan	0.6932	0.6713	0.3420	0.2874	0.2003	0.2008
DB Plan	0.1565	0.0776	0.3873	0.0721	0.5149	0.1396
Hybrid Plan	0.0141	0.0031	0.0180	0.0124	0.0485	0.0032
DC Plan	0.1363	0.2480	0.2527	0.6280	0.2363	0.6564

third with no plan and hybrid plan enrollment rates fixed to their 1992-94 values while the shift out of DB plan enrollment is accounted for by an increase in DC plan enrollment (see Table 8). The purpose of considering this last counterfactual economy is to isolate the effects of the shift out of DB plans alone, without the smaller fluctuations in no plan and hybrid plan enrollment occurring simultaneously.[28]

Table 9 displays the result of the shifting retirement plan enrollment rates. First, notice that the effects of considering all plan enrollment changes that occurred versus only considering the transition out of DB towards DC plans are very similar. Unsurprisingly, the percentage of agents retired at ages ranging from 62-70+ is lower in the steady state of the economy with higher DC plan enrollment. The effect is greatest when looking at

Table 9: Estimated Effects of Retirement Plan Transition

	All Plan Enrollment Changes 1992–2019	Only transition out of DB
% Retired at Age 62-64	-21.2pp	-21.2pp
% Retired at Age 65	-17.7pp	-17.1pp
% Retired at Age 70+	-0.4pp	-0.4pp
Average Age 55 Assets	+14.8%	+14.1%
Average Age 80 Assets	+25.8%	+25.3%
Average Age 95 Assets	-2.5%	-2.5%
Expected Lifetime Utility (Including Bequests)	-28.3%	-30.3%

earlier retirement at and before age 65, as we saw in Figure 11 that those whose primary plan is a DB plan tend to retire before 65. This relatively large drop in the percentage of individuals retired at age 65 is consistent with the CPS data shown in Figure 6. From 1992 to 2019, the data showed non-participation at age 65 dropped 18.54 percentage points. The model implies that the shift out of DB and into DC plans alone explains 92.2% of this data trend.

Next, the table shows that average assets at age 55, when agents are primarily still

[28]Specifically, in the third counterfactual economy where no plan and hybrid plan enrollment rates are fixed to their 1992-94 values and the shift out of DB plan enrollment is accounted for by an increase in DC plan enrollment the plan enrollment rates are as in the 2016-18 columns of Table 8.

Table 8: Plan Enrollment Probabilities: Shift Out of DB Plans Only

	25th Percentile		50th Percentile		75th Percentile	
	1992–94	2016–18	1992–94	2016–18	1992–94	2016–18
No Plan	0.6932	0.6932	0.3420	0.3420	0.2003	0.2003
DB Plan	0.1565	0.0776	0.3873	0.0721	0.5149	0.1396
Hybrid Plan	0.0141	0.0141	0.0180	0.0180	0.0485	0.0485
DC Plan	0.1363	0.2152	0.2527	0.5678	0.2363	0.6117

Notice in this case, the no plan and hybrid plan enrollment probabilities are unchanged from their 1992-94 values, the DB plan enrollment probabilities reflect the estimated 2016-18 values, and the DC plan enrollment probabilities are then set so that total enrollment probabilities sum to one.

working and saving for retirement, and at age 80, when the majority of agents are retired and consuming their plan benefits and savings, are higher after the transitions away from DB plans. This increase in savings reflects that with the shift away from DB plans, individuals rely more on their own savings to fund retirement. However, average assets for those who make it to age 95 are lower, as individuals with greater reliance on DC plans consume a larger portion of their savings if they reach later retirement.

The last row of Table 9 compares agents' discounted expected lifetime utility when entering the model before and after the change in enrollment rates. The table shows that the change in enrollment probabilities from 1992 through 2018 decreases expected lifetime utility (including the utility value of leaving bequests) by around 28%. Individuals not enrolled in DB plans face greater risk when planning for retirement, both due to the uncertain planning horizon and uncertain rates of return. This result indicates that greater exposure to these risks can significantly reduce total expected utility.[29]

To isolate the mechanisms driving the changes observed in the transition from DB to DC plans, Appendix D considers the same counterfactual movement away from DB and towards DC plans, and separately introduces each source of uncertainty. We show that uncertainty in investment returns primarily delays retirement, whereas longevity risk accounts for the bulk of welfare losses by inducing individuals to over-save to hedge against an uncertain retirement horizon. These two channels interact in a nontrivial way, magnifying their overall impact. Consequently, policies aimed only at reducing investment risk, such as hybrid plans that guarantee returns, cannot fully substitute for the insurance embodied in traditional DB plans.

6.4 Counterfactual: Effects of Option to Convert Assets to Actuarially Fair Annuity Upon Retirement

Next, we analyze the effects of a policy that permits agents to convert a portion of their accumulated assets (b) upon retirement into an actuarily fair annuity that pays a fixed benefit each quarter. In the period of retirement, agents choose how much of their accumulated assets to trade for a single-life annuity at an actuarially fair price. To purchase an annuity with quarterly payment p_N, an agent entering retirement at age a will have to give up assets $b_N(a, p_N)$, totaling the expected discounted annuity payments

[29]In Appendix E we show that the results presented in this section are robust to alternative model specifications that allow agents to re-enter the workforce and adjust Social Security income based on retirement age.

over their remaining lifetime.

$$
\begin{aligned}
b_N(a, p_N) =& p_N + (1-\nu_a)\beta p_N + (1-\nu_a)(1-\nu_{a+1})\beta^2 p_N + ... \\
b_N(a, p_N) =& p_N + p_N \sum_{k=1}^{\bar{a}-a} \beta^k \prod_{j=0}^{k-1} (1-\nu_{a+j})
\end{aligned} \tag{16}
$$

Let $V_a^{R1}(y, b, \gamma_b)$ denote the value of first entering retirement at age a with assets b and accumulated DB plan tenure γ_B. When initially entering retirement, agents now choose p_N, their fixed quarterly annuity payment. To receive p_N, the agent gives up $b_N(a, p_N)$ in assets.

$$
V_a^{R1}(y, b, \gamma_B) = \max_{p_N \geq 0} \left\{ V_a^R(y, b - b_N(a, p_N), \gamma_B, p_N) \right\} \tag{17}
$$

Once retired with chosen payment p_N, the retired agent's value function is almost identical to that in the baseline economy (13), except that p_N now becomes a state variable. Notice that p_N does not enter the expected value of bequests, as we assume the agent purchases only a single-life annuity that is terminated upon the agent's death.

$$
\begin{aligned}
V_a^R(y, b, \gamma_B, p_N) = \max_s & \left\{ u(c, \ell_R) + \nu_a \beta \mathbb{E} \left[\zeta(b_R'(s), y, \gamma_B) \right] \right. \\
& \left. + R(1-\nu_a)\beta \mathbb{E} \left[V_{a+1}^R(y, b_R'(s), \gamma_B, p_N) \right] \right\}
\end{aligned} \tag{18}
$$

Similarly, the retired agent's budget constraint differs from (14) only in that the budget now includes the quarterly payment p_N.

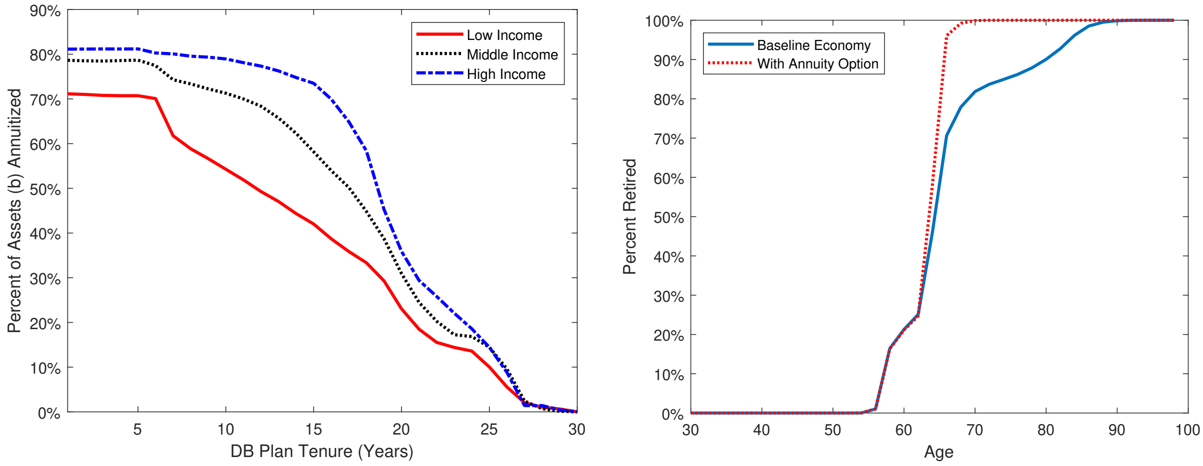
$$
c + s = y\kappa_a + p_N + b + x_B(a, y, \gamma_B) \tag{19}
$$

Finally, the values of employment and unemployment, previously given by (7) and (10) respectively, now include a transition to V_{a+1}^{R1} rather than V_{a+1}^R upon initial retirement. We write this change to V_a^E in the following equation, and the change to V_a^U follows analogously.

$$
\begin{aligned}
& V_a^E(y, b, i_p, \gamma_B) = \max_{s, R \in \{0,1\}} \left\{ u(c, \ell_P) + \nu_a \beta \mathbb{E} \left[\zeta(b_E'(s, i_p), y, \gamma_B) \right] \right. \\
& + (1-R)(1-\nu_a)\beta \left[(1-\delta_{a+1}) \mathbb{E} \left[V_{a+1}^E(y, b_E'(s, i_p), i_p, \gamma_B') \right] + \delta_{a+1} \mathbb{E} \left[V_{a+1}^U(y, b_E'(s, i_p), i_p, \gamma_B') \right] \right] \\
& \left. + R(1-\nu_a)\beta \mathbb{E} \left[V_{a+1}^{R1}(y, b_E'(s, i_p), i_p, \gamma_B') \right] \right\}
\end{aligned} \tag{20}
$$

Figure 13 displays the effects of the fair annuity option policy in the baseline economy, where enrollment in each retirement plan type matches 1992-94 enrollment probabilities. Figure 13a shows the average percent of assets b that agents choose to annuitize when they first enter retirement, conditional on DB plan tenure and income type. We see that those who have high DB plan tenure, and so already receive a high annuity-type payment in retirement, choose to annuitize a smaller portion of assets. This figure also shows that

Figure 13: Effects of Annuity Policy in Baseline (1992-94) Economy



(a) Percent of Assets Annuitized Upon Retirement

(b) Percent Retired by Age Comparison

lower-income agents annuitize a smaller portion of wealth relative to high-income agents, and there is no group that chooses to annuitize all of their assets. Notice that annuitized wealth does not enter the expected value of leaving bequests $\mathbb{E}\left[\zeta(b'_E(s, i_p), y, \gamma_B)\right]$ because the payments p_N are assumed to be solely for a single-life annuity. Agents do not annuitize all of their wealth because doing so would mean leaving no bequests, and with the curvature in the bequest function specified and calibrated in section 6.1, this would weigh heavily on their total expected discounted continuation value. The motive to leave some assets as bequests results in lower wealth agents, who are more likely to be low-income, annuitizing a smaller fraction of their assets. Figure 13b shows the effect of the fair annuity policy on retirement timing, with a much larger mass of agents choosing to retire at 65 relative to the baseline economy, as the ability to annuitize assets reduces the motive to work longer as a precaution against uncertainty.

Table 10 displays the aggregate effects of introducing the actuarially fair annuity option in the baseline economy, where retirement plan enrollment probabilities match those observed in 1992-94, and the effects of introducing the annuity option after the transition into DC plans, where retirement plan enrollment probabilities match those observed in 2016-18. The first column shows that introducing the policy in the baseline economy increases expected lifetime utility by 5.6% and greatly increases the percent of agents who are retired at age 65. Average assets before typical retirement at age 55 are higher, as the value of asset accumulation is greater when there is an option to annuitize. After typical retirement, at age 80, agents on average hold fewer non-annuitized assets, as they choose to annuitize a portion of their wealth. However, those who live until age 95 have higher non-annuitized wealth, as they rely on consuming this wealth less in retirement.

Table 10: Effects of Offering Actuarially Fair Annuity Option Upon Retirement

	Baseline Economy (1992–94 Enrollment)	After DC Transition (2016–18 Enrollment)
% Retired at Age 62–64	-0.5pp	-0.2pp
% Retired at Age 65	+22.5pp	+29.4pp
% Retired at Age 70+	+10.8pp	+11.2pp
Average Age 55 (Non-Annuitized) Assets	+15.8%	+16.7%
Average Age 80 (Non-Annuitized) Assets	-21.9%	-34.7%
Average Age 95 (Non-Annuitized) Assets	+10.2%	+17.1%
Expected Lifetime Utility (Including Bequests)	+5.6%	+13.2%

Next, the last column of Table 10 displays the effects of introducing the annuity option in the economy after the transition away from DB and into DC plans, where retirement plan enrollment probabilities match those observed in 2016-2018. There is greater DC plan enrollment in the 2016-2018 economy, and we unsurprisingly find that the benefit of introducing the annuity option is greater in this case, when fewer agents can get annuity-like benefits from a DB retirement plan. Introducing the option to convert assets into an actuarially fair annuity upon retirement in the 2016-2018 increases agents' expected lifetime utility by 13.2% and has a notable impact on inducing agents to retire at earlier ages on average. Similar to introducing the annuity option in the baseline economy, we observe that agents initially save more on average by age 55, when they can benefit more from asset accumulation with the option to annuitize those assets. Non-annuitized assets are lower on average at age 80, but we see that those who live to age 95 rely less on non-annuitized wealth to fund retirement consumption and have greater amounts of non-annuitized assets on average after the policy is introduced.

7 Conclusion

The transition from defined benefit (DB) to defined contribution (DC) plans has significantly altered retirement planning in the United States. Our analysis highlights how this shift has increased individual control over retirement savings, while also raising exposure to risks associated with retirement planning, including uncertainties related to investment returns and the expected time spent in retirement. Using detailed panel data from the Health and Retirement Study (HRS) and a calibrated life-cycle model, we show that the rise of DC plans has significantly contributed to the observed decline in retirement rates among individuals aged 65 and older since the early 1990s.

DC plans incentivize higher private wealth accumulation prior to retirement relative to DB plans, reflecting individuals' need to self-insure against uncertain planning horizons and investment risks. However, those in DC plans exhibit more rapid wealth depletion in later years compared to DB participants, leading to lower average wealth among the oldest age groups. The model reveals that much of the increase in labor force participation among older individuals is driven by the heightened exposure to planning horizon/lifespan uncertainty under DC plans, underscoring the challenges associated with managing retirement under this framework. Given these findings, we evaluate a policy counterfactual that allows agents to convert accumulated assets into an actuarially fair annuity upon retirement. We find that removing the frictions associated with voluntary annuitization significantly mitigates the welfare losses of the DC transition and encourages earlier retirement by reducing the need for precautionary labor supply.

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A Additional Illustrative Model Results

This appendix derives step-by-step the results stated in Section 3. First, A.1 solves for the savings Euler equation and shows formally that optimal savings is strictly increasing in DC plan generosity and strictly decreasing in DB plan generosity. Next, A.2 derives equations (2) and (3) in the main text and formally shows that the conditions given by (4) and (5) hold under standard CRRA utility for modest levels of plan generosity φ, but can fail for sufficiently high φ.

Recall the period one and expected period two values.

$$\begin{aligned} V_1^i(a) &= \max_{R\in\{0,1\},s} \left\{ u((1-R)y + f^i + a - s) + R\ell_R + \beta(1-\nu)\mathbb{E}[V_2^i(s)] \right\} \\ \mathbb{E}[V_2^i(s)] &= \ell_R + \sum_{z\in Z} p_z u(x^i + s(1+r_z)) \end{aligned}$$

Therefore, given the choice of R, the agents solve the following optimal savings problem.

$$V_1^i(a) = \max_s \left\{ u((1-R)y + f^i + a - s) + R\ell_R + \beta(1-\nu)\ell_R + \beta(1-\nu)\sum_{z\in Z} p_z u(x^i + s(1+r_z)) \right\}$$

A.1 Optimal Savings

The first-order condition for optimal savings is

$$\frac{\partial V_1^i(a)}{\partial s} = -\,u'((1-R)y + f^i + a - s) + \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(x^i + s(1+r_z)) = 0.$$

This gives us the Euler equation in the main text

$$u'((1-R)y + f^i + a - s) = \beta(1-\nu)\sum_{z\in Z}\left[p_z(1+r_z)u'(x^i + s(1+r_z))\right].$$

Proposition 1: *$\frac{\partial s}{\partial f^i} > 0$ and $\frac{\partial s}{\partial x^i} < 0$ if $u''(c) < 0$.*

Proof. Define $G(s, f^i, x^i)$ as the first-order condition residual

$$G(s, f^i, x^i) \equiv u'((1-R)y + f^i + a - s) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(x^i + s(1+r_z))$$

where an interior optimum s satisfies $G(s, f^i, x^i) = 0$. Now compute the partial derivatives of $G(s, f^i, x^i)$, using $u'(c) > 0$ and $u''(c) < 0$.

$$\frac{\partial G(s,f^i,x^i)}{\partial s^i} = -u''((1-R)y+f^i+a-s) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)^2 u''(x^i+s(1+r_z))$$
$$\frac{\partial G(s,f^i,x^i)}{\partial f^i} = u''((1-R)y+f^i+a-s)$$
$$\frac{\partial G(s,f^i,x^i)}{\partial x^i} = -\beta(1-\nu)\sum_{z\in Z} p_z(1+r_z) u''(x^i+s(1+r_z))$$

Recall the standard concave utility assumption assumption $u'(c) > 0$ and $u''(c) < 0$ we made in the main text, and apply the implicit function theorem. The implicit function theorem tells us that

$$\frac{\partial s}{\partial f^i} = -\left(\frac{\partial G(s,f^i,x^i)}{\partial s^i}\right)^{-1}\left(\frac{\partial G(s,f^i,x^i)}{\partial f^i}\right)$$
$$\frac{\partial s}{\partial x^i} = -\left(\frac{\partial G(s,f^i,x^i)}{\partial s^i}\right)^{-1}\left(\frac{\partial G(s,f^i,x^i)}{\partial x^i}\right).$$

Therefore

$$\frac{\partial s}{\partial f^i} = \frac{-u''((1-R)y+f^i+a-s)}{-u''((1-R)y+f^i+a-s) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)^2 u''(x^i+s(1+r_z))}$$

With $u''(c) < 0$, both numerator and denominator are positive. $u''((1-R)y+f^i+a-s) < 0$ so that $-u''((1-R)y+f^i+a-s) > 0$ and $u''(x^i+s(1+r_z)) < 0$ so that $-u''((1-R)y+f^i+a-s) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)^2 u''(x^i+s(1+r_z)) > 0$. Therefore

$$\frac{\partial s}{\partial f^i} > 0 \quad \text{if} \quad u''(c) < 0.$$

Similarly,

$$\frac{\partial s}{\partial x^i} = \frac{-1\times\left[-\beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u''(x^i+s(1+r_z))\right]}{-u''((1-R)y+f^i+a-s) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)^2 u''(x^i+s(1+r_z))}$$

With $u''(c) < 0$, the denominator is positive, as in $\frac{\partial s}{\partial f^i}$. Then, since $u''(x^i+s(1+r_z)) < 0$ the numerator $-1\times\left[-\beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u''(x^i+s(1+r_z))\right]$ is less than zero. Thus

$$\frac{\partial s}{\partial x^i} < 0 \quad \text{if} \quad u''(c) < 0.$$

□

A.2 Optimal Retirement

As in the main text, define

$$\Delta V^i \equiv V_1^{i1}(a) - V_1^{i0}(a) = \ell_R + u(f^i + a - s^{i1}) - u(y + f^i + a - s^{i0}) + \beta(1-\nu)\sum_{z\in Z} p_z \left[u(x^i + s^{i1}(1+r_z)) - u(x^i + s^{i0}(1+r_z))\right].$$

First, consider an agent with a DC plan ($i = C$) where $f^C \geq 0$ and $x^C = 0$. We will consider how ΔV^C changes when the present value cost of providing the DC plan ($\varphi = f^C$) increases.

$$\frac{\partial \Delta V^C}{\partial \varphi} = u'(c_1^{C1})\left(1 - \frac{\partial s^{C1}}{\partial \varphi}\right) - u'(c_1^{C0})\left(1 - \frac{\partial s^{C0}}{\partial \varphi}\right) + \beta(1-\nu)\sum_{z\in Z} p_z \left[u'(c_2^{C1}(r_z))(1+r_z)\left(\frac{\partial s^{C1}}{\partial \varphi}\right) - u'(c_2^{C0}(r_z))(1+r_z)\left(\frac{\partial s^{C0}}{\partial \varphi}\right)\right]$$

Now substitute in the savings first-order condition where $i = C$ for $R \in \{0, 1\}$.

$$u'(c_1^{C1}) = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C1}(r_z))$$
$$u'(c_1^{C0}) = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C0}(r_z))$$

$$\frac{\partial \Delta V^C}{\partial \varphi} = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C1}(r_z))\left(1 - \frac{\partial s^{C1}}{\partial \varphi}\right) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C0}(r_z))\left(1 - \frac{\partial s^{C0}}{\partial \varphi}\right) + \beta(1-\nu)\sum_{z\in Z} p_z \left[u'(c_2^{C1}(r_z))(1+r_z)\left(\frac{\partial s^{C1}}{\partial \varphi}\right) - u'(c_2^{C0}(r_z))(1+r_z)\left(\frac{\partial s^{C0}}{\partial \varphi}\right)\right]$$

$$\frac{\partial \Delta V^C}{\partial \varphi} = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C1}(r_z))\left(1 - \frac{\partial s^{C1}}{\partial \varphi}\right) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C0}(r_z))\left(1 - \frac{\partial s^{C0}}{\partial \varphi}\right) + \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C1}(r_z))\left(\frac{\partial s^{C1}}{\partial \varphi}\right) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C0}(r_z))\left(\frac{\partial s^{C0}}{\partial \varphi}\right)$$

Notice that the terms multiplied by $\left(\frac{\partial s^{C0}}{\partial \varphi}\right)$ and $\left(\frac{\partial s^{C1}}{\partial \varphi}\right)$ cancel, and we are left with

$$\frac{\partial \Delta V^C}{\partial \varphi} = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C1}(r_z)) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{C0}(r_z))$$
$$\frac{\partial \Delta V^C}{\partial \varphi} = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)\left[u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))\right].$$

Next, consider an agent with a DB plan where $f^B = 0$ and $x^B \geq 0$. To be consistent with the DC plan case, we will consider a change in the present value cost of providing the DB plan

φ. Recall $\varphi = \frac{x^B(1-\nu)}{\sum\limits_{z\in Z} p_z(1+r_z)}$, so that $x^B = \varphi\left(\frac{1}{1-\nu}\right)\sum\limits_{z\in Z} p_z(1+r_z)$.

$$\frac{\partial \Delta V^B}{\partial \varphi} = \left(\frac{\partial x}{\partial \varphi}\right)\left[u'(c_1^{B1})\left(-\frac{\partial s^{B1}}{\partial x^B}\right) - u'(c_1^{B0})\left(-\frac{\partial s^{B0}}{\partial x^B}\right)\right]$$
$$+\beta(1-\nu)\left(\frac{\partial x^B}{\partial \varphi}\right)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z))\left[1+(1+r_z)\frac{\partial s^{B1}}{\partial x^B}\right] - u'(c_2^{B0}(r_z))\left[1+(1+r_z)\frac{\partial s^{B0}}{\partial x^B}\right]\right]$$

Now substitute in the savings first order condition conditional on this plan type.

$$u'(c_1^{B1}) = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{B1}(r_z))$$
$$u'(c_1^{B0}) = \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{B0}(r_z))$$

This results in

$$\frac{\partial \Delta V^B}{\partial \varphi} = \left(\frac{\partial x^B}{\partial \varphi}\right)\left[\beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{B1}(r_z))\left(-\frac{\partial s^{B1}}{\partial x^B}\right) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u'(c_2^{B0}(r_z))\left(-\frac{\partial s^{B0}}{\partial x^B}\right)\right]$$
$$+\beta(1-\nu)\left(\frac{\partial x^B}{\partial \varphi}\right)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z))\left[1+(1+r_z)\frac{\partial s^{B1}}{\partial x^B}\right] - u'(c_2^{B0}(r_z))\left[1+(1+r_z)\frac{\partial s^{B0}}{\partial x^B}\right]\right]$$

$$\frac{\partial \Delta V^B}{\partial \varphi} = \beta(1-\nu)\left(\frac{\partial x^B}{\partial \varphi}\right)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z))(1+r_z)\left(-\frac{\partial s^{B1}}{\partial x^B}\right) - u'(c_2^{B0}(r_z))(1+r_z)\left(-\frac{\partial s^{B0}}{\partial x^B}\right)\right]$$
$$+\beta(1-\nu)\left(\frac{\partial x^B}{\partial \varphi}\right)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z))\left[1+(1+r_z)\frac{\partial s^{B1}}{\partial x^B}\right] - u'(c_2^{B0}(r_z))\left[1+(1+r_z)\frac{\partial s^{B0}}{\partial x^B}\right]\right]$$

Notice that terms multiplied by $(1+r_z)\left(\frac{\partial s^{B1}}{\partial x^B}\right)$ and $(1+r_z)\left(\frac{\partial s^{B0}}{\partial x^B}\right)$ cancel out, resulting in

$$\frac{\partial \Delta V^B}{\partial \varphi} = \beta(1-\nu)\left(\frac{\partial x^B}{\partial \varphi}\right)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right]$$

Finally, because $x^B = \varphi\left(\frac{1}{1-\nu}\right)\sum\limits_{z\in Z} p_z(1+r_z)$ for present value cost of providing the plan φ, we can substitute in $\frac{\partial x^B}{\partial \varphi} = \left(\frac{1}{1-\nu}\right)\sum\limits_{z\in Z} p_z(1+r_z)$.

$$\frac{\partial \Delta V^B}{\partial \varphi} = \beta(1-\nu)\left(\frac{1}{1-\nu}\right)\sum_{z\in Z} p_z(1+r_z)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right]$$
$$\frac{\partial \Delta V^B}{\partial \varphi} = \beta\sum_{z\in Z} p_z(1+r_z)\sum_{z\in Z} p_z\left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right]$$

A.2.1 Uncertain Planning Horizon Channel

Consider how $\frac{\partial \Delta V^C}{\partial \varphi}$ and $\frac{\partial \Delta V^{DB}}{\partial \varphi}$ compare in the case where there is no uncertainty regarding the rate of return. For this case, assume that there is only one possible rate of return r.

Specifically $Z = \{1\}$, $p_1 = 1$, and $r_1 = r$. In this case, $\frac{\partial \Delta V^C}{\partial \varphi}$ and $\frac{\partial \Delta V^B}{\partial \varphi}$ simplify to

$$
\begin{aligned}
\frac{\partial \Delta V^C}{\partial \varphi} &= \beta(1-\nu)(1+r)\left[u'(c_2^{C1}) - u'(c_2^{C0})\right]. \\
\frac{\partial \Delta V^B}{\partial \varphi} &= \beta(1+r)\left[u'(c_2^{B1}) - u'(c_2^{B0})\right]
\end{aligned}
$$

This shows us that the uncertain life-expectancy, with death probability $\nu \in (0,1)$ directly reduces the impact of increasing the present value cost of the DC plan benefit on the value of retirement.

In this case, $\frac{\partial \Delta V^B}{\partial \varphi} > \frac{\partial \Delta V^C}{\partial \varphi}$ when

$$
\begin{aligned}
\beta(1+r)\left[u'(c_2^{B1}) - u'(c_2^{B0})\right] &> \beta(1-\nu)(1+r)\left[u'(c_2^{C1}) - u'(c_2^{C0})\right] \\
\frac{1}{1-\nu} &> \frac{u'(s^{C1}(\varphi)(1+r)) - u'(s^{C0}(\varphi)(1+r))}{u'(x(\varphi) + s^{B1}(\varphi)(1+r)) - u'(x(\varphi) + s^{B0}(\varphi)(1+r))} \equiv H(\varphi).
\end{aligned}
$$

Proposition 2: *Under the assumption of constant relative risk averse (CRRA) utility, $u(c) = \frac{c^{1-\theta}}{1-\theta}$ for $\theta > 0$, there exists a φ_H^* such that $H(\varphi) < \frac{1}{1-\nu}$ if $\varphi < \varphi_H^*$ and $H(\varphi) > \frac{1}{1-\nu}$ if $\varphi > \varphi_H^*$.*

Proof. Apply the intermediate value theorem: if $H(0) < \frac{1}{1-\nu}$ and $\lim_{\varphi \to \infty} H(\varphi) > \frac{1}{1-\nu}$ then there is at least one crossing φ_H^* where $H(\varphi_H^*) = \frac{1}{1-\nu}$. We will show i) $H(\varphi)$ is a continuous function in φ so that the intermediate value theorem applies, ii) $H(0) < \frac{1}{1-\nu}$, and iii) $\lim_{\varphi \to \infty} H(\varphi) > \frac{1}{1-\nu}$.

1. First, we show $H(\varphi)$ is a continuous function in φ so that the intermediate value theorem applies. Recall our assumption of CRRA utility, so the utility function is twice continuously differentiable ($u \in C^2$), $u'(c) > 0$, and $u''(c) < 0$.

   Note that each $s^{iR}(\varphi)$ is continuously differentiable in φ by the Implicit Function Theorem. In the proof of Proposition 1 we derived the explicit derivative formulas, showing the derivatives exist and are continuous given $u \in C^2$. Therefore, each mapping $\varphi \mapsto s^{C1}(\varphi), s^{C0}(\varphi), s^{B1}(\varphi), s^{B0}(\varphi)$ is continuous. Then, because $u'(c)$ and $x(\varphi)$ are continuous (recall $x(\varphi)$ is a linear function of φ), the four mappings $\varphi \mapsto u'(s^{C1}(\varphi)(1+r)), u'(s^{C0}(\varphi)(1+r)), u'(x(\varphi) + s^{B1}(\varphi)(1+r)), u'(x(\varphi) + s^{B0}(\varphi)(1+r))$ are continuous. Therefore, the numerator and denominator of $H(\varphi)$ are both continuous functions of φ.

   Furthermore, the denominator of $H(\varphi)$ is nonzero. Strict concavity and the fact that first period income differs across R imply that optimal savings under $R = 1$ and $R = 0$ differ, resulting in the two marginal utilities to differ. Hence, the quotient of two continuous functions where the denominator is nonzero yields a continuous function $H(\varphi)$.

2. Now we show $H(0) < \frac{1}{1-\nu}$ for $\nu \in (0,1)$. At $\varphi = 0$ both DB and DC plan payments are zero ($f^C = 0$ and $x^B = 0$). Therefore, agents with either plan type have savings Euler equation

$$
u'((1-R)y + a - s) = \beta(1-\nu)\left[(1+r)u'(s(1+r))\right].
$$

Therefore, with $\varphi = 0$, the optimal savings choices coincide across plan types in each retirement state. That is, for $\varphi = 0$

$$s^{B0}(0) = s^{C0}(0) \quad \text{and} \quad s^{B1}(0) = s^{C1}(0).$$

Consequently the two marginal-utility differences in the definition of $H(\varphi)$ are equal

$$u'(s^{C1}(0)(1+r)) - u'(s^{C0}(0)(1+r)) = u'(x^B(0) + s^{B1}(0)(1+r)) - u'(x^B(0) + s^{B0}(0)(1+r)).$$

Thus, for $\nu \in (0,1)$,

$$H(0) = 1 < \frac{1}{1-\nu}.$$

3. Finally, we show $\lim\limits_{\varphi\to\infty} H(\varphi) > \frac{1}{1-\nu}$.

   First, consider the savings Euler equation where there is no uncertainty regarding the rate of return, so $r_z = r$ for all z, and when utility is CRRA.

$$\begin{aligned} u'((1-R)y + f^i + a - s^{iR}) &= \beta(1-\nu)(1+r)u'(x^i + s^{iR}(1+r)). \\ ((1-R)y + f^i + a - s^{iR})^{-\theta} &= \beta(1-\nu)(1+r)(x^i + s^{iR}(1+r))^{-\theta}. \\ (1-R)y + f^i + a - s^{iR} &= (\beta(1-\nu)(1+r))^{\frac{-1}{\theta}}\,(x^i + s^{iR}(1+r)). \end{aligned}$$

   Let $K \equiv [\beta(1-\nu)(1+r)]^{\frac{1}{\theta}} > 0$.

$$\begin{aligned} \big((1-R)y + f^i + a - s^{iR}\big)\,K &= x^i + s^{iR}(1+r). \\ \big((1-R)y + f^i + a\big)\,K - x^i &= s^{iR}(1+r) + Ks^{iR}. \\ s^{iR} &= \frac{\big((1-R)y + f^i + a\big)\,K - x^i}{1+r+K}. \end{aligned}$$

   Recall

$$H(\varphi) = \frac{u'(s^{C1}(\varphi)(1+r)) - u'(s^{C0}(\varphi)(1+r))}{u'(x^B(\varphi) + s^{B1}(\varphi)(1+r)) - u'(x^B(\varphi) + s^{B0}(\varphi)(1+r))}$$

   Under CRRA utility this is

$$H(\varphi) = \frac{(s^{C1}(\varphi)(1+r))^{-\theta} - (s^{C0}(\varphi)(1+r))^{-\theta}}{(x^B(\varphi) + s^{B1}(\varphi)(1+r))^{-\theta} - (x^B(\varphi) + s^{B0}(\varphi)(1+r))^{-\theta}}$$

   Now substitute in $x^B = \varphi\frac{1+r}{1-\nu}$, $f^C = \varphi$ and the optimal savings rules s^{iR} that we solved for

$$H(\varphi) = \frac{\left(\frac{(\varphi+a)K(1+r)}{1+r+K}\right)^{-\theta} - \left(\frac{(y+\varphi+a)K(1+r)}{1+r+K}\right)^{-\theta}}{\left(\varphi\frac{1+r}{1-\nu} + \frac{(aK-\varphi\frac{1+r}{1-\nu})}{1+r+K}(1+r)\right)^{-\theta} - \left(\varphi\frac{1+r}{1-\nu} + \frac{((y+a)K-\varphi\frac{1+r}{1-\nu})}{1+r+K}(1+r)\right)^{-\theta}}$$

$$H(\varphi) = \frac{\left(\frac{K(1+r)}{1+r+K}\right)^{-\theta}\left[(a+\varphi)^{-\theta} - (y+\varphi+a)^{-\theta}\right]}{\left(\frac{K(1+r)}{1+r+K}\right)^{-\theta}\left[\left(\varphi\frac{1}{1-\nu}+a\right)^{-\theta} - \left(\varphi\frac{1}{1-\nu}+(y+a)\right)^{-\theta}\right]}$$

$$H(\varphi) = \frac{(a+\varphi)^{-\theta} - (y+a+\varphi)^{-\theta}}{\left(a+\varphi\frac{1}{1-\nu}\right)^{-\theta} - \left(y+a+\varphi\frac{1}{1-\nu}\right)^{-\theta}}$$

First, factor out $\varphi^{-\theta}$ in the numerator

$$(a+\varphi)^{-\theta} - (y+a+\varphi)^{-\theta} = \varphi^{-\theta}\left[\left(\frac{a}{\varphi}+1\right)^{-\theta} - \left(\frac{y+a}{\varphi}+1\right)^{-\theta}\right]$$

Similarly, factor out $\frac{\varphi}{1-\nu}$ from the denominator

$$\begin{aligned}&\left(a+\varphi\frac{1}{1-\nu}\right)^{-\theta} - \left(y+a+\varphi\frac{1}{1-\nu}\right)^{-\theta}\\ &= \left(\frac{\varphi}{1-\nu}\right)^{-\theta}\left[\left(\frac{a(1-\nu)}{\varphi}+1\right)^{-\theta} - \left(\frac{(y+a)(1-\nu)}{\varphi}+1\right)^{-\theta}\right]\end{aligned}$$

Let $z \equiv \frac{\varphi}{1-\nu}$ so $\varphi = z(1-\nu)$ and consider the limit when $z \to \infty \Rightarrow \varphi \to \infty$. Substitute $\varphi = z(1-\nu)$ and write $H(\varphi)$ in terms of z.

$$H(\varphi) = \frac{\varphi^{-\theta}\left[\left(\frac{a}{\varphi}+1\right)^{-\theta} - \left(\frac{y+a}{\varphi}+1\right)^{-\theta}\right]}{\left(\frac{\varphi}{1-\nu}\right)^{-\theta}\left[\left(\frac{a(1-\nu)}{\varphi}+1\right)^{-\theta} - \left(\frac{(y+a)(1-\nu)}{\varphi}+1\right)^{-\theta}\right]}$$

$$H(z) = \frac{(z(1-\nu))^{-\theta}\left[\left(\frac{a}{z(1-\nu)}+1\right)^{-\theta} - \left(\frac{y+a}{z(1-\nu)}+1\right)^{-\theta}\right]}{(z)^{-\theta}\left[\left(\frac{a}{z}+1\right)^{-\theta} - \left(\frac{y+a}{z}+1\right)^{-\theta}\right]}$$

$$H(z) = (1-\nu)^{-\theta}\frac{\left[\left(\frac{a}{z(1-\nu)}+1\right)^{-\theta} - \left(\frac{y+a}{z(1-\nu)}+1\right)^{-\theta}\right]}{\left[\left(\frac{a}{z}+1\right)^{-\theta} - \left(\frac{y+a}{z}+1\right)^{-\theta}\right]}$$

Now take the limit as $z \to \infty$, noting that $(1+\frac{\text{constant}}{z})^{-\theta} \to 1$, so that

$$\lim_{z\to\infty}\frac{\left[\left(\frac{a}{z(1-\nu)}+1\right)^{-\theta} - \left(\frac{y+a}{z(1-\nu)}+1\right)^{-\theta}\right]}{\left[\left(\frac{a}{z}+1\right)^{-\theta} - \left(\frac{y+a}{z}+1\right)^{-\theta}\right]} \to \frac{y}{y(1-\nu)} = \frac{1}{1-\nu}$$

Thus

$$\lim_{\varphi\to\infty} H(\varphi) = (1-\nu)^{-\theta}(1-\nu)^{-1} = (1-\nu)^{-(\theta+1)}.$$

Therefore

$$\lim_{\varphi\to\infty} H(\varphi) = (1-\nu)^{-(\theta+1)} = \frac{1}{(1-\nu)^{\theta+1}} > \frac{1}{1-\nu}.$$

This holds when $\nu \in (0,1)$ and $\theta > 0$.

$\square$

Proposition 3: φ_H^* *is unique.*

Proof. From the proof of Proposition 2, we showed that

$$H(\varphi) = \frac{(a+\varphi)^{-\theta} - (y+a+\varphi)^{-\theta}}{\left(a+\varphi\frac{1}{1-\nu}\right)^{-\theta} - \left(y+a+\varphi\frac{1}{1-\nu}\right)^{-\theta}}$$

under the assumption that $u(c) = \frac{u^{1-\theta}}{1-\theta}$ and defining $K \equiv [\beta(1-\nu)(1+r)]^{\frac{1}{\theta}} > 0$. Now we show that $H(\varphi)$ is strictly increasing in φ.

Apply the Fundamental Theorem of Calculus, which gives us $(a+\varphi)^{-\theta} - (y+a+\varphi)^{-\theta} = \theta\int_{a+\varphi}^{y+a+\varphi} t^{-\theta-1}dt$ and $(a+\varphi\frac{1}{1-\nu})^{-\theta} - (y+a+\varphi\frac{1}{1-\nu})^{-\theta} = \theta\int_{a+\varphi\frac{1}{1-\nu}}^{y+a+\varphi\frac{1}{1-\nu}} t^{-\theta-1}dt$. Therefore, the function $H(\varphi)$ can be written as

$$H(\varphi) = \frac{\int_{a+\varphi}^{y+a+\varphi} t^{-\theta-1}dt}{\int_{a+\varphi\frac{1}{1-\nu}}^{y+a+\varphi\frac{1}{1-\nu}} t^{-\theta-1}dt} \equiv \frac{H_N(\varphi)}{H_D(\varphi)}.$$

Differentiate the numerator $H_N(\varphi)$ and denominator $H_D(\varphi)$ using Leibniz rule for differentiation under the integral sign. $H_N'(\varphi) = (y+a+\varphi)^{-\theta-1} - (a+\varphi)^{-\theta-1}$ and $H_D'(\varphi) = \frac{1}{1-\nu}\left[(y+a+\varphi\frac{1}{1-\nu})^{-\theta-1} - (a+\varphi\frac{1}{1-\nu})^{-\theta-1}\right]$. Using the quotient rule:

$$H'(\varphi) = \frac{H_D(\varphi)H_N'(\varphi) - H_N(\varphi)H_D'(\varphi)}{(H_D(\varphi))^2}$$

Both $H_D(\varphi) > 0$ and $H_N(\varphi) > 0$, so to show $H'(\varphi) > 0$ we need to show

$$H_D(\varphi)H_N'(\varphi) - H_N(\varphi)H_D'(\varphi) > 0$$
$$\frac{H_N'(\varphi)}{H_N(\varphi)} > \frac{H_D'(\varphi)}{H_D(\varphi)}$$

Notice that $\frac{H_N'(\varphi)}{H_N(\varphi)}$ is the slope of $t^{-\theta}$ over an interval of length y divided by the average $t^{-\theta-1}$ over the same interval. Because $t^{-\theta}$ is convex, this ratio decreases as the starting point $a+\varphi$ increases. $\frac{H_D'(\varphi)}{H_D(\varphi)}$ is the same ratio, except with starting point $a+\varphi\frac{1}{1-\nu}$. Since $a+\varphi\frac{1}{1-\nu} > a+\varphi$, $\frac{H_N'(\varphi)}{H_N(\varphi)} > \frac{H_D'(\varphi)}{H_D(\varphi)}$. Therefore $H'(\varphi) > 0$, so $H(\varphi)$ is strictly increasing, making φ_H^* unique.

To formally show $\frac{H_N'(\varphi)}{H_N(\varphi)} > \frac{H_D'(\varphi)}{H_D(\varphi)}$ define $A(u) = \int_u^{u+y} t^{-\theta-1}dt$ and $B(u) = u^{-\theta-1} - (u+y)^{-\theta-1}$. Letting $u_1 = a+\varphi$ and $u_2 = a+\varphi\frac{1}{1-\nu}$, the inequality $\frac{H_N'(\varphi)}{H_N(\varphi)} > \frac{H_D'(\varphi)}{H_D(\varphi)}$ becomes $\frac{A(u_2)}{B(u_2)}(1-\nu) < \frac{A(u_1)}{B(u_1)}$. Since $u_2 > u_1$ and $\nu \in (0,1)$, this inequality holds if we show $\frac{A(u)}{B(u)}$ is decreasing in u.

To show $\frac{A(u)}{B(u)}$ is decreasing in u, define $g(t) = t^{-\theta-1}$ so that $A(u) = \int_0^y g(u+s)ds$, $B(u) = g(u) - g(u+y) > 0$ and $A'(u) = -B(u)$. Then, since $A'(u) = -B(u)$,

$$\frac{\partial \frac{A(u)}{B(u)}}{\partial u} = \frac{B(u)A'(u) - A(u)B'(u)}{B(u)^2} = \frac{-B(u)^2 - A(u)\left(g'(u) - g'(u+y)\right)}{B(u)^2} \equiv \frac{\mathcal{N}(u)}{B(u)^2}$$

Note that $B(u) > 0$ so the denominator is positive, so $\frac{\partial \frac{A(u)}{B(u)}}{\partial u} < 0$ if $\mathcal{N}(u) < 0$. To more easily evaluate the numerator, rewrite $N(u) = \frac{1}{2}\int_0^y \int_0^y \left(g'(u+s) - g'(u+t)\right)\left(g(u+s) - g(u+t)\right) dsdt$. Then for any s,t where $s \neq t$, we have that the terms $\left(g'(u+s) - g'(u+t)\right)$ and $\left(g(u+s) - g(u+t)\right)$ will have opposite signs (because g' is strictly increasing while g is strictly decreasing), making their product negative. Thus, we have $\frac{\partial \frac{A(u)}{B(u)}}{\partial u} < 0$ so that $\frac{H_N'(\varphi)}{H_N(\varphi)} > \frac{H_D'(\varphi)}{H_D(\varphi)}$, resulting in $H(\varphi)$ being strictly increasing in φ. □

A.2.2 Uncertain Return Channel

Next, consider the case with $\nu = 0$ and only uncertainty regarding the rate of return. Letting $\Delta u'(c_2^i(r_z)) \equiv u'(c_2^{i1}) - u'(c_2^{i0})$ results in

$$\begin{aligned}
\frac{\partial \Delta V^B}{\partial \varphi} &= \beta \sum_{z\in Z} p_z(1+r_z) \sum_{z\in Z} p_z \left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right] \\
&= \beta \mathbb{E}\left[1+r_z\right] \mathbb{E}\left[\Delta u'(c_2^B(r_z))\right] \\
\frac{\partial \Delta V^C}{\partial \varphi} &= \beta \sum_{z\in Z} p_z(1+r_z) \left[u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))\right] \\
&= \beta \mathbb{E}[(1+r_z)\Delta u'(c_2^C(r_z))] \\
&= \beta \mathbb{E}\left[1+r_z\right] \mathbb{E}\left[\Delta u'(c_2^C(r_z))\right] + \beta \mathrm{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))
\end{aligned}$$

In this case, we have $\frac{\partial \Delta V^B}{\partial \varphi} > \frac{\partial \Delta V^C}{\partial \varphi}$ if

$$\beta \mathbb{E}\left[1+r_z\right] \mathbb{E}\left[\Delta u'(c_2^B(r_z))\right] > \beta \mathbb{E}\left[1+r_z\right] \mathbb{E}\left[\Delta u'(c_2^C(r_z))\right] + \beta \mathrm{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))$$
$$\frac{-\mathrm{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]} > \mathbb{E}\left[u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))\right] - \mathbb{E}\left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right] \equiv I(f)$$

Proposition 4: *Under the assumption of CRRA utility, there exists an φ_I^* with $I(\varphi) < \frac{-Cov(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ if $\varphi < \varphi_I^*$ and $I(\varphi) > \frac{-Cov(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ if $\varphi > \varphi_I^*$.*

Proof. Apply the intermediate value theorem: if $I(0) < \frac{-\mathrm{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ and $\lim_{\varphi\to\infty} I(\varphi) > \lim_{\varphi\to\infty} \frac{-\mathrm{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ then there is at least one crossing φ_I^* where $I(\varphi_I^*) = \frac{-\mathrm{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$. We will show i) $I(\varphi)$ and $\frac{-\mathrm{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ are continuous functions in φ so that the intermediate value theorem applies, ii) $I(0) < \frac{-\text{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$, and iii) $\lim_{\varphi\to\infty} I(\varphi) > \frac{-\text{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$.

1. First, we show $I(\varphi)$ and $\frac{-\text{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ are continuous functions in φ so that the intermediate value theorem applies. Recall our assumption of CRRA utility $u(c) = \frac{c^{1-\theta}}{1-\theta}$ for $\theta > 1$ implies that the utility function is twice continuously differentiable and concave ($u \in C^2$), $u'(c) > 0$, and $u''(c) < 0$.

   We start by showing $I(\varphi)$ is continuous in φ using similar arguments as the proof of Proposition 2. Note again that each $s^{iR}(\varphi)$ is continuously differentiable in φ by the Implicit Function Theorem. Therefore, each mapping $\varphi \mapsto s^{C1}(\varphi), s^{C0}(\varphi), s^{B1}(\varphi), s^{B0}(\varphi)$ is continuous. Then, because $u'(c)$ and $x(\varphi)$ are continuous (recall $x(\varphi)$ is a linear function of φ), the four mappings $\varphi \mapsto u'(s^{C1}(\varphi)(1+r_z)), u'(s^{C0}(\varphi)(1+r_z)), u'(x(\varphi)+s^{B1}(\varphi)(1+r_z)), u'(x(\varphi)+s^{B0}(\varphi)(1+r_z))$ are continuous. Therefore, the function $I(\varphi)$, which is a linear combination of these terms, is also a continuous function of φ.

   Next, we show $\frac{-\text{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ is a continuous function of φ. Recall $\text{Cov}(1+r_z, \Delta u'(c_2^C(r_z))) = \mathbb{E}\left[(1+r_z)\Delta u'(c_2^C(r_z))\right] - \mathbb{E}[1+r_z]\mathbb{E}\left[\Delta u'(c_2^C(r_z))\right]$. Each expectation is a finite sum of continuous terms (because $(1+r_z)$ is a fixed scalar for each z and we showed $\Delta u'(c_2^C(r_z))$ is continuous in φ). Finally, $\mathbb{E}[1+r_z]$ is a constant that is independent of φ, so dividing by it preserves continuity. Therefore, the ratio $\frac{-\text{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$ is continuous in φ.

2. Here we show that $I(0) < \frac{-\text{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$. At $\varphi = 0$ both DB and DC plan payments are zero. Therefore, agents with either plan type have savings Euler equation

   $$u'((1-R)y + a - s) = \beta(1-\nu)\left[(1+r)u'(s(1+r))\right].$$

   Therefore, with $\varphi = 0$, the optimal savings choices coincide across plan types in each retirement state. That is, for $\varphi = 0$

   $$s^{B0}(0) = s^{C0}(0) \quad \text{and} \quad s^{B1}(0) = s^{C1}(0).$$

   Consequentially, $\mathbb{E}\left[u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))\right] - \mathbb{E}\left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right] = 0$ so that $I(0) = 0$. Therefore, it is sufficient to show that $I(0) = 0 < \frac{-\text{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$, or $0 > \text{Cov}(1+r_z, \Delta u'(c_2^C(r_z)))$.

   We will show that $\Delta u'(c_2^C(r_z))$ is decreasing in r_z, so that it is negatively correlated with $1+r_z$. Here $\Delta u'(c_2^C(r_z)) = u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))$ where $c_2^{CR}(r_z) = s^{CR}(\varphi)(1+r_z)$. Now differentiate $u'(c_2^C(r_z))$ with respect to r_z.

   $$\frac{\delta \Delta u'(c_2^C(r_z))}{\delta r_z} = s^{C1}(\varphi)u''(c_2^{C1}(r_z)) - s^{C0}(\varphi)u''(c_2^{C0}(r_z)) \tag{21}$$

   Then $\frac{\delta \Delta u'(c_2^C(r_z))}{\delta r_z} < 0$ when $s^{C1}(\varphi)u''(c_2^{C1}(r_z)) - s^{C0}(\varphi)u''(c_2^{C0}(r_z)) < 0$, which is when $s^{C1}(\varphi)u''(c_2^{C1}(r_z)) < s^{C0}(\varphi)u''(c_2^{C0}(r_z))$.

With CRRA utility and $\theta > 1$ this is

$$\begin{aligned}
s^{C1}(\varphi)(-\theta)(s_2^{C1}(\varphi)(1+r_z))^{-\theta-1} &< s^{C0}(\varphi)(-\theta)(s_2^{C0}(\varphi)(1+r_z))^{-\theta-1} \\
s^{C1}(\varphi)(s^{C1}(\varphi))^{-\theta-1} &> s^{C0}(\varphi)(s^{C0}(\varphi))^{-\theta-1} \\
\frac{1}{s^{C1}(\varphi)^{\theta}} &> \frac{1}{s^{C0}(\varphi)^{\theta}}
\end{aligned}$$

Which holds when

$$s^{C0}(\varphi) > s^{C1}(\varphi).$$

Recall the savings Euler equation, assuming CRRA utility and in this case $\nu = 0$.

$$\begin{aligned}
\left(y+\varphi+a-s^{C0}(\varphi)\right)^{-\theta} &= \beta \sum_{z\in Z} p_z(1+r_z)\left(s^{C0}(\varphi)(1+r_z)\right)^{-\theta} \\
\left(\varphi+a-s^{C1}(\varphi)\right)^{-\theta} &= \beta \sum_{z\in Z} p_z(1+r_z)\left(s^{C1}(\varphi)(1+r_z)\right)^{-\theta}
\end{aligned}$$

It follows that the optimal savings of those who work in the first period $s^{C0}(\varphi)$ is strictly greater than the optimal savings of those who retire in the first period $s^{C1}(\varphi)$ for $y > 1$ in order for the period one marginal utility to equalize to the expected discounted period two marginal utility.

3. Finally, we show $\lim_{\varphi\to\infty} I(\varphi) > \lim_{\varphi\to\infty} \frac{-\mathrm{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$. Recall

$$I(\varphi) = \mathbb{E}\left[\Delta u'(c_2^C(r_z))\right] - \mathbb{E}\left[\Delta u'(c_2^B(r_z))\right]$$

Furthermore, $-\mathrm{Cov}\left(1+r_z,\Delta u'(c_2^C(r_z))\right) = \mathbb{E}[1+r_z]\mathbb{E}[\Delta u'(c_2^C(r_z))] - \mathbb{E}\left[(1+r_z)\Delta u'(c_2^C(r_z))\right]$, so that

$$\frac{-\mathrm{Cov}\left(1+r_z,\Delta u'(c_2^C(r_z))\right)}{\mathbb{E}[1+r_z]} = \mathbb{E}[\Delta u'(c_2^C(r_z))] - \frac{\mathbb{E}\left[(1+r_z)\Delta u'(c_2^C(r_z))\right]}{\mathbb{E}[1+r_z]}. \tag{22}$$

So to show $\lim_{\varphi\to\infty} I(\varphi) > \lim_{\varphi\to\infty} \frac{-\mathrm{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}$, we need to show

$$\lim_{\varphi\to\infty} \mathbb{E}\left[\Delta u'(c_2^C(r_z))\right] - \mathbb{E}\left[\Delta u'(c_2^B(r_z))\right] > \lim_{\varphi\to\infty} \mathbb{E}[\Delta u'(c_2^C(r_z))] - \frac{\mathbb{E}\left[(1+r_z)\Delta u'(c_2^C(r_z))\right]}{\mathbb{E}[1+r_z]}$$

$$\lim_{\varphi\to\infty} \mathbb{E}[1+r_z]\mathbb{E}\left[u'(c_2^{B1}(r_z)) - u'(c_2^{B0}(r_z))\right] < \lim_{\varphi\to\infty} \mathbb{E}\left[(1+r_z)\left(u'(c_2^{C1}(r_z)) - u'(c_2^{C0}(r_z))\right)\right]$$

Where $\Delta u'(c_2^i(r_z)) = u'(c_2^{i1}) - u'(c_2^{i0})$. Substituting in $c_2^{B1}(r_z) = x^B(\varphi) + s^{B1}(\varphi)(1+r_z)$, $c_2^{B0}(r_z) = x^B(\varphi) + s^{B0}(\varphi)(1+r_z)$, $c_2^{C1}(r_z) = s^{C1}(\varphi)(1+r_z)$, $c_2^{C0}(r_z) = s^{C0}(\varphi)(1+r_z)$,

$x^B(\varphi) = \varphi\mathbb{E}[1+r_z]$, and assuming CRRA utility ($u(c) = \frac{c^{1-\theta}}{1-\theta}$) the relevant inequality is

$$\lim_{\varphi\to\infty} \mathbb{E}[1+r_z]\mathbb{E}\left[(\varphi\mathbb{E}[1+r_z] + s^{B1}(\varphi)(1+r_z))^{-\theta} - (\varphi\mathbb{E}[1+r_z] + s^{B0}(\varphi)(1+r_z))^{-\theta}\right]$$
$$< \lim_{\varphi\to\infty} \mathbb{E}\left[(1+r_z)\left((s^{C1}(\varphi)(1+r_z))^{-\theta} - (s^{C0}(\varphi)(1+r_z))^{-\theta}\right)\right]$$

We will show that this inequality holds by proceeding in two steps: 1) we will show that the left-hand side involving B-terms approaches zero as $\varphi \to 0$, and 2) we will show that the right-hand side involving C-terms approaches a value strictly greater than zero.

To show $\lim_{\varphi\to\infty} \mathbb{E}[1+r_z]\mathbb{E}\left[(\varphi\mathbb{E}[1+r_z] + s^{B1}(\varphi)(1+r_z))^{-\theta} - (\varphi\mathbb{E}[1+r_z] + s^{B0}(\varphi)(1+r_z))^{-\theta}\right] = 0$. Recall the derivatives of optimal savings with respect to φ derived in the proof of Proposition 1. For those in a DB plan ($i = B$) making retirement choice $R \in \{0,1\}$

$$\frac{\partial s^{BR}}{\partial \varphi} = \frac{\mathbb{E}[1+r_z]\beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)u''(\varphi\mathbb{E}[1+r_z] + s^{B0}(\varphi)(1+r_z))}{-u''(y(1-R)+a-s^{B0}(\varphi)) - \beta(1-\nu)\sum_{z\in Z} p_z(1+r_z)^2 u''(\varphi\mathbb{E}[1+r_z] + s^{B0}(\varphi)(1+r_z))}.$$

Under CRRA utility, $u''(c) = -\theta c^{-\theta-1}$. The numerator contains $u''(\varphi\mathbb{E}[1+r_z] + s^{B0}(\varphi)(1+r_z)) = -\theta(\varphi\mathbb{E}[1+r_z] + O(1))^{-\theta-1}$. Hence the numerator is $O(\varphi^{-\theta-1})$. The denominator has two terms. The first term $-u''(y(1-R)+a-s^{B0}(\varphi))$ is positive and bounded away from zero because $y(1-R)+a-s^{B0}(\varphi)$ approaches $y(1-R)+a$ as we showed $s^{B0}(\varphi)$ is strictly decreasing in φ. The second denominator term involves the same term as the numerator $u''(\varphi\mathbb{E}[1+r_z]+s^{B0}(\varphi)(1+r_z)) = -\theta(\varphi\mathbb{E}[1+r_z]+O(1))^{-\theta-1}$, which is $O(\varphi^{-\theta-1})$. Therefore $\frac{\partial s^{BR}}{\partial\varphi} = O(\varphi^{-\theta-1})$ as $\varphi \to \infty$. This means that the rate at which $s^{BR}(\varphi)$ changes becomes vanishingly small, and the difference between the two savings choices $s^{B1}(\varphi) - s^{B0}(\varphi)$ must also approach zero as $\varphi \to \infty$ because both savings functions are monotone and their slopes shrink like $\varphi^{-\theta-1}$. Now consider

$$(\varphi\mathbb{E}[1+r_z] + s^{B1}(\varphi)(1+r_z))^{-\theta} - (\varphi\mathbb{E}[1+r_z] + s^{B0}(\varphi)(1+r_z))^{-\theta}$$

As φ grows $\varphi\mathbb{E}[1+r_z]$ grows without bound, and the difference between the two terms approaches zero as $s^{B1}(\varphi) - s^{B0}(\varphi)$ approaches zero. Therefore, $\lim_{\varphi\to\infty} \mathbb{E}[1+r_z]\mathbb{E}\left[(\varphi\mathbb{E}[1+r_z] + s^{B1}(\varphi)(1+r_z))^{-\theta} - (\varphi\mathbb{E}[1+r_z] + s^{B0}(\varphi)(1+r_z))^{-\theta}\right] = 0$. The second and final step is now to show

$$\lim_{\varphi\to\infty} \mathbb{E}\left[(1+r_z)\left((s^{C1}(\varphi)(1+r_z))^{-\theta} - (s^{C0}(\varphi)(1+r_z))^{-\theta}\right)\right] > 0.$$

Recall optimal DC plan ($i = C$) savings behavior given retirement choice $R \in \{0,1\}$:

$$u'((1-R)y + \varphi + a - s^{CR}) = \beta(1-\nu)\sum_{z\in Z}\left[p_z(1+r_z)u'(s^{CR}(1+r_z))\right]$$

so that with CRRA utility savings when working in the first period $s^{C0}(\varphi)$ are greater than savings when retiring in the first period $s^{C1}(\varphi)$. Further more, we found in the proof of Proposition 1 that

$$\frac{\partial s^{CR}(\varphi)}{\partial \varphi}=\frac{-u''(y(1-R)+\varphi+a-s^{C0}(\varphi))}{-u''(y+\varphi+a-s^{C0}(\varphi))-\beta(1-\nu)\sum_{z\in Z}p_z(1+r_z)^2u''(s^{C0}(\varphi)(1+r_z))}$$

so $s^{C0}(\varphi)$ and $s^{C1}(\varphi)$ do not explode with φ and $\frac{\partial s^{CR}(\varphi)}{\partial \varphi}\to 0$ as $\varphi\to\infty$. Given boundedness of $s^{C0}(\varphi)$ and $s^{C1}(\varphi)$, and the ordering $s^{C0}(\varphi)>s^{C1}(\varphi)$, the difference $\left((s^{C1}(\varphi)(1+r_z))^{-\theta}-(s^{C0}(\varphi)(1+r_z))^{-\theta}\right)$ is positive and bounded away from zero. Multiplying and taking the expectation preserves positivity so that
$\lim_{\varphi\to\infty}\mathbb{E}\left[(1+r_z)\left((s^{C1}(\varphi)(1+r_z))^{-\theta}-(s^{C0}(\varphi)(1+r_z))^{-\theta}\right)\right]>0.$

□

Proposition 5: φ_I^* *is unique.*

Proof. Here we show that $\Phi(\varphi)\equiv I(\varphi)-\left(\frac{-\mathrm{Cov}(1+r_z,\Delta u'(c_2^C(r_z)))}{\mathbb{E}[1+r_z]}\right)$ has the property $\Phi'(\varphi)>0$.

Recall

$$I(\varphi)=\mathbb{E}\left[\Delta u'(c_2^C(r_z))\right]-\mathbb{E}\left[\Delta u'(c_2^B(r_z))\right]$$

$$\frac{-\mathrm{Cov}\left(1+r_z,\Delta u'(c_2^C(r_z))\right)}{\mathbb{E}[1+r_z]}=\mathbb{E}[\Delta u'(c_2^C(r_z))]-\frac{\mathbb{E}\left[(1+r_z)\Delta u'(c_2^C(r_z))\right]}{\mathbb{E}[1+r_z]}.$$

Therefore

$$\Phi(\varphi)=\frac{\mathbb{E}\left[(1+r_z)\Delta u'(c_2^C(r_z))\right]}{\mathbb{E}[1+r_z]}-\mathbb{E}\left[\Delta u'(c_2^B(r_z))\right]$$

$$\Phi(\varphi)=\frac{\mathbb{E}\left[(1+r_z)\left(u'(c_2^{C1}(r_z))-u'(c_2^{C0}(r_z))\right)\right]}{\mathbb{E}[1+r_z]}-\mathbb{E}\left[u'(c_2^{B1}(r_z))-u'(c_2^{B0}(r_z))\right]$$

Now, taking the derivative

$$\Phi'(\varphi)=\frac{\mathbb{E}\left[(1+r_z)\left(u''(c_2^{C1}(r_z))\frac{\partial c_2^{C1}}{\partial\varphi}-u''(c_2^{C0}(r_z))\frac{\partial c_2^{C0}}{\partial\varphi}\right)\right]}{\mathbb{E}[1+r_z]}-\mathbb{E}\left[u''(c_2^{B1}(r_z))\frac{\partial c_2^{B1}}{\partial\varphi}-u''(c_2^{B0}(r_z))\frac{\partial c_2^{B0}}{\partial\varphi}\right]$$

Looking at the consumption derivatives, we have $\frac{\partial c_2^{B1}}{\partial\varphi}=\frac{\mathbb{E}[1+r_z]}{1-\nu}+(1+r_z)\frac{\partial s^{B1}}{\partial\varphi}$, $\frac{\partial c_2^{B0}}{\partial\varphi}=\frac{\mathbb{E}[1+r_z]}{1-\nu}+(1+r_z)\frac{\partial s^{B0}}{\partial\varphi}$, $\frac{\partial c_2^{C1}}{\partial\varphi}=(1+r_z)\frac{\partial s^{C1}}{\partial\varphi}$, and $\frac{\partial c_2^{C0}}{\partial\varphi}=(1+r_z)\frac{\partial s^{C0}}{\partial\varphi}$.

$$\begin{aligned}\Phi'(\varphi)&=\frac{\mathbb{E}\left[(1+r_z)^2\left(u''(c_2^{C1}(r_z))\frac{\partial s^{C1}}{\partial\varphi}-u''(c_2^{C0}(r_z))\frac{\partial s^{C0}}{\partial\varphi}\right)\right]}{\mathbb{E}[1+r_z]}\\&-\mathbb{E}\left[u''(c_2^{B1}(r_z))\left[\frac{\mathbb{E}[1+r_z]}{1-\nu}+(1+r_z)\frac{\partial s^{B1}}{\partial\varphi}\right]-u''(c_2^{B0}(r_z))\left[\frac{\mathbb{E}[1+r_z]}{1-\nu}+(1+r_z)\frac{\partial s^{B0}}{\partial\varphi}\right]\right].\end{aligned}$$

With CRRA utility $u''(c)=-\theta c^{-\theta-1}$ for $\theta>1$. Additionally, from Proposition 1, $\frac{\partial s^{CR}}{\partial\varphi}>$

$\frac{\partial s^{BR}}{\partial \varphi}$. Since $u''(c) < 0$ and $\frac{\partial s}{\partial \varphi} > 0$, each bracketed term in $\Phi'(\varphi)$ is negative. Let A denote the DC term and D the DB term, so that $\Phi'(\varphi) = A - D$. Both A and D are negative, but the DB term is larger in absolute value because it contains the constant multiplier $\frac{\mathbb{E}[1+r_z]}{1-\nu}$ in addition to the savings-response component. Hence $D < A$ and $\Phi'(\varphi) = A - D > 0$. Therefore, $\Phi'(\varphi) > 0$ for all φ, so $\Phi(\varphi)$ is strictly increasing. Since $\Phi(\varphi)$ is strictly increasing in φ, φ_I^* is unique.

□

B Additional HRS Data Details

B.1 Sample Selection

The original HRS dataset includes 280,343 unique observations of 42,405 individuals. We exclude participants missing key demographic information (age, race, or region), those already retired at their first interview, and those lacking valid data on labor force status, retirement plans, retirement status, health, or union coverage. Table 11 summarizes the sample size changes at each step.

Table 11: Sample Selection from HRS, 1992 to 2020

Sample Selection	**# of Obs.**	**# of Ind.**
Original panel	280343	42405
Drop participants without age info	280341	42404
Drop participants without race info	279908	42290
Drop participants without location info	279883	42281
Drop participants that completed retired since their first interview	237015	33271
Drop obs without labor force participation info	236358	33230
Drop obs if pension information is missing	235468	33173
Drop obs without retirement info	234801	33098
Drop obs without reported health info	234799	33096
Drop obs without union coverage info	233095	33036

B.2 Additional Sample Descriptions

Table 12 summarizes the demographic composition of participants in the sample with individual weights adjustment. The sample contains almost equal proportions of female and male. The majority participants are White or Caucasian. Since the HRS survey primarily targets individuals over age 50 and their spouses, over half of the participants have a high school education or less, while around 23% have attended some college. Additionally, more than 92% of participants have been married at least once before exiting the study, indicating the importance of accounting for family or household effects when analyzing the impact of retirement plan choices on savings and retirement decisions.

Table 12: Compositions of Participants in Sample

Characteristics	**Proportion**
Gender	
Male	49.07%
Female	50.93%
Race & Ethnicity	
White/Caucasian	79.09%
Black/African American	11.73%
Other	9.18%
Highest Degree	
No Degree	16.64%
GED	4.58%
HS	26.89%
HS/GED	18.92%
AA	6.78%
BA	16.60%
MA/MBA	7.98%
Law/MD/PhD	1.59%
Marital History	
Ever Married	92.50%
Never Married	7.50%

Table 13 reports the distribution of participants by the total number of observed retirement plan switches. The results indicate that the vast majority of participants (86 percent) never change their retirement plan, while approximately 2 percent experience three or more switches. These patterns suggest that most individuals in the sample maintain the same retirement plan type for their main jobs.

Table 13: Distribution of Participants on Total Switches of Retirement Plans

Total Switch	**Proportion**
0	85.61%
1	8.17%
2	4.21%
3	1.33%
4	0.50%
More than 4	0.17%

C Further Empirical Results

C.1 Robustness Check: Differences in Retirement Timing by Plan Types

This section presents a robustness check that removes government workers from the HRS sample. We re-estimate the baseline model after excluding individuals employed in Public Administration. Table 14 reports the regression results for transitions between employment to retirement among participants aged between 60 to 69 by retirement plans. The estimated effects remain similar in magnitude and statistical significance to those in the baseline specification reported in Table 2, indicating that our main findings are not driven by the presence of government workers in the sample.

Table 14: Employment-to-Retirement Transitions Among Ages 60-6 (Robustness Check)

	Estimates	S.E.
Retirement Plans		
DC	-0.418***	0.063
Hybrid	-0.029	0.139
Demographic Controls		
Age	3.369***	0.452
Age squared	-0.026***	0.004
Female	0.196***	0.074
Never married	-0.464	0.819
Race: Black/African American	-0.112	0.102
Race: Other	-0.352**	0.158
Income Controls		
Hourly wage	0.004*	0.002
Hourly wage squared	0.000	0.000
Income from retirement plans	0.000***	0.000
Income from retirement plans squared	0.000	0.000
Income from Social Security	0.000	0.000
Income from Social Security squared	0.000	0.000
Household wealth (incl. house)	-0.000	0.000
Health Controls		
Self-reported health: very good	0.175**	0.089
Self-reported health: good	0.378***	0.092
Self-reported health: fair	0.508***	0.117
Self-reported health: poor	0.563**	0.236
Spouse health: very good	0.039	0.092
Spouse health: good	-0.058	0.094
Spouse health: fair	-0.159	0.112
Spouse health: poor	0.117	0.148
Constant	-110.578***	14.217
Observations	7,318	

Notes: This table reports coefficients from a robustness specification that excludes workers employed in Public Administration from the HRS sample. Estimations are adjusted by the HRS personal-level weights. The regression also controls the participant's educational degree, occupation, industry, as well as region and year fixed effects. The reference category is married White males with excellent self-reported health, whose spouses also report excellent health, and who are enrolled in a DB retirement plan in their current main job. Robust Standard errors are reported in the right column. Stars denote statistical significance $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 15 reports predicted final retirement ages by retirement plan type and shows results that are similar with those in Table 3. Participants enrolled in DC plans have significantly higher predicted retirement ages than those enrolled in DB plans.

Table 15: Predicted Retirement Age by Retirement Plans (Robustness Check)

	Predicted Age	95% Confidence Interval
DB	61.779^{***}	[60.728, 62.831]
	(0.537)	
DC	66.448^{***}	[64.806, 68.090]
	(0.838)	

Notes: The table reports the predicted retirement ages for participants enrolled in defined benefit (DB) and defined contribution (DC) plans, estimated using the specification described in Equation (6). The estimation uses the HRS sample excluding workers employed in Public Administration. Robust standard errors are reported in parentheses. Statistical significance is indicated by asterisks: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

In addition to DB and DC plans, a small share of participants in the HRS report enrollment in hybrid plans. We do not include this group in the earlier analysis because the sample size is limited. For completeness, we also estimate predicted final retirement ages for all three plan types using the specification in Equation (6). Since this specification includes indicators for three retirement plan categories, we rely on a broader set of instruments. In particular, we use both union status and pre-retirement job type (industry, occupation) as instruments for retirement plan enrollment.

For occupation and industry to serve as valid instruments, the identifying assumption requires that they influence retirement age only through their effects on retirement plan type and not through any independent channel. This assumption is plausible for two reasons. First, the regression includes controls for factors that could mediate the relationship between occupation or industry and retirement incentives, including self-reported health status, which captures variation in physical capacity and health-related motives for early or delayed retirement. Second, by conditioning on union status and retirement plan type, the specification absorbs the institutional and financial incentives that differ across jobs and sectors.

The estimation results based on this specification indicate no significant difference in predicted retirement ages between participants enrolled in hybrid plans and those enrolled in DB or DC plans. However, individuals with DC plans tend to retire later than individuals with DB plans on average, similar with the findings reported in the main text.

Table 16: *Predicted Retirement Age by Retirement Plans*

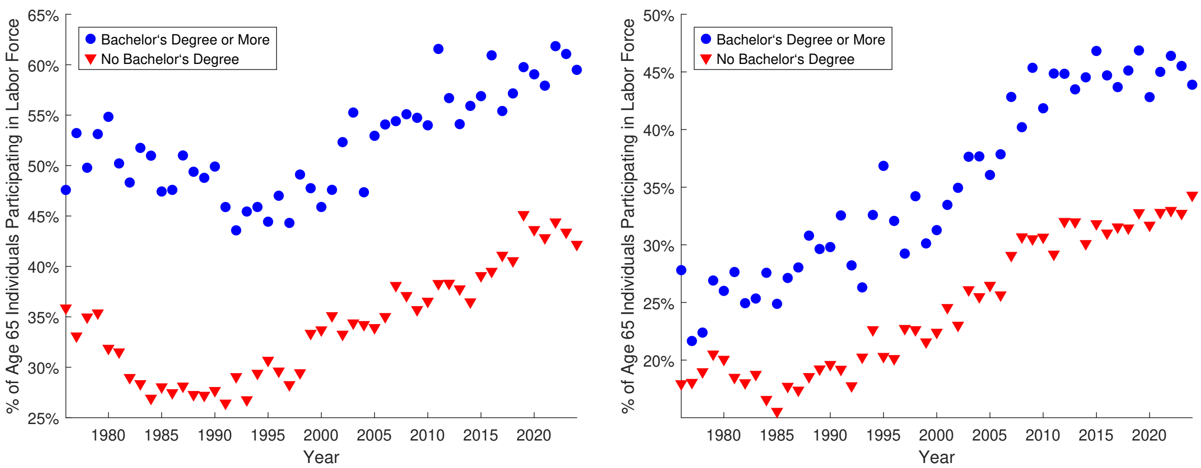
	Predicted Age	95% Confidence Interval
DB	61.495***	[60.729, 62.262]
	(0.391)	
DC	66.313***	[65.057, 67.568]
	(0.641)	
Hybrid	69.242***	[59.225, 79.259]
	(5.111)	

Notes: Data from the HRS sample. The main regression model is specified in Equation (6) and union status, pre-retirement industry, occupation are instrument variables. Robust standard errors are reported in parentheses. Statistical significance is indicated by asterisks: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

C.2 Decline in Retirement at Age 65

Figure 6 in the main text showed that the participation rate among age 65 individuals has been rising since the 1990s in the United States. Could some of this increase be due to difference in educational attainment during that time-frame, with more educated individuals tending to participate in the labor force later into the life-cycle? The following figure shows that the trend displayed in Figure 6 is robust when separately looking at men and women with different levels of educational attainment.

Figure 14: Labor Force Participation at Age 65 by Education and Gender



(a) Men *(b) Women*

C.3 Empirical evidence related to Changes in Right-to-Work (RTW) Laws

This section applies a difference-in-differences approach to estimate the impact of the passage of the RTW laws, which is associated with a cut in union coverage (Fortin, Lemieux and Lloyd, 2005), on the coverage of DB plans. As mentioned in Section 4, this exercise provides additional evidence that union status is a strong instrument for the retirement plan type when estimating the Equation (6). The empirical strategy is shown in the Equation (23). $Y_{i,s,t}$ is the

Table 17: Timetable for the passage of RTW laws in the U.S.

State	Year	State	Year
Alabama	1953	Nevada	1952
Arizona	1947	North Carolina	1947
Arkansas	1944	North Dakota	1948
Florida	1944	Oklahoma	2001
Georgia	1947	South Carolina	1954
Idaho	1985	South Dakota	1947
Indiana	2012	Tennessee	1947
Iowa	1947	Texas	1947
Kansas	1958	Utah	1955
Kentucky	2017	Virginia	1947
Louisiana	1976	Wisconsin	2015
Michigan	2012	West Virginia	2016
Mississippi	1954	Wyoming	1963
Nebraska	1946		

Data source: National Right to Work Committee website and state government websites.

response variable to indicate DB plan inclusion. Table 17 summarizes the passage time of RTW laws in the U.S., which is used as the cutoff year to define the treatment group and control group. Since the passage of the RTW laws is more likely to affect the retirement plan for the new employees than the existing ones, we define the dummy variable, *postRTW*, as 1 if it is 30 years after the passage of the RTW laws.

$$Y_{i,s,t} = \beta postRTW_{s,t} + \boldsymbol{X_{i,s,t}} + \delta_t + \alpha_s + \epsilon_{i,s,t} \tag{23}$$

Table 18 demonstrates the difference-in-differences estimates of the impact of RTW laws on DB plan inclusion. Column (1) uses a stricter definition of DB plan inclusion than column (2). Nevertheless, the coefficients for the treatment in both columns show that fewer workers use DB plans as their first or second source of retirement income after the passage of RTW laws.

Table 18: Impact of RTW Laws on Inclusions of DB Plans

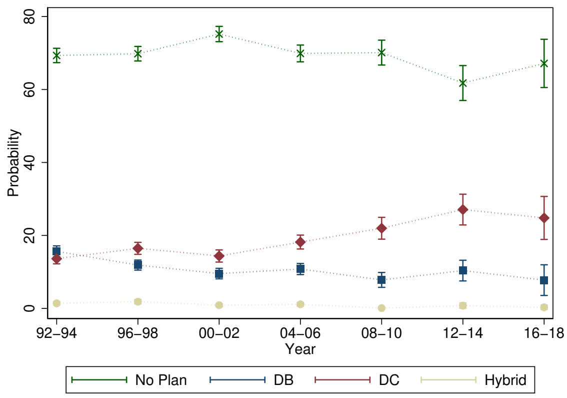
	(1)	(2)
	First source DB	First or second source DB
30 years after the RTW	-0.0304***	-0.0302***
	(0.0055)	(0.0055)
Age	0.0014***	0.0014***
	(0.0001)	(0.0001)
Male	0.0365***	0.0365***
	(0.0019)	(0.0019)
Black	0.0376***	0.0375***
	(0.0031)	(0.0031)
Asian	-0.0092	-0.0092
	(0.0071)	(0.0071)
Other single race	-0.0109	-0.0111
	(0.0115)	(0.0114)
Two or more races	0.0154**	0.0153**
	(0.0069)	(0.0069)
Wage and salary income, mil	-0.3809***	-0.3808***
	(0.0413)	(0.0411)
Constant	0.8109***	0.8109***
	(0.0081)	(0.0081)
Observations	209008	209008

Notes: Data is from the CPS Annual Social Economic Supplement. Standard errors are clustered at the state level. Stars denote statistical significance $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Regressions include year fixed-effects and state fixed-effects. Estimations are adjusted by the ASEC weights. The sample age is from 18 to 75. The inclusion of DB plan is defined as 1 if the retirement income source is Company or Union pension, Federal Government retirement Pension, US Military retirement pension, State or local Gov't retirement pension, or US Railroad retirement pension.

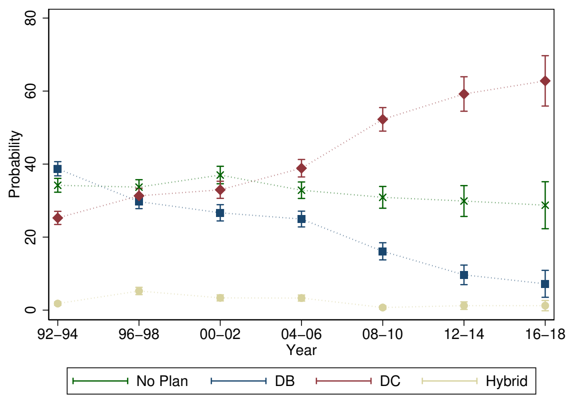
C.4 Plan Enrollment Probabilities by Years and Earning Percentiles

To examine how the likelihood of enrolling in different types of retirement plans varies across the earnings distribution and over time, we estimate a multinomial logit model of retirement plan enrollment. We begin by grouping survey waves into seven two-year periods from 1992 to 2018 and constructing earnings quantiles separately within each year to ensure that the quantile assignments are not influenced by changes in the aggregate earnings distribution over time. Participants are classified into three earnings quantiles within each survey year based on their real labor income. We then estimate a multinomial logit specification in which the dependent variable is the individual's primary retirement plan type (no plan, defined benefit, defined contribution, or hybrid). The model includes age, earnings quantile, a full set of interactions between earnings quantile and year group, the real hourly wage, and demographic characteristics such as gender, race, education, marital status, and region. We also control for occupation, industry, and year-group fixed effects, and all estimations apply the personal-level sampling weights from the HRS. Figure 15 plots the predicted probabilities of enrolling in each of the four retirement plan types over time for individuals in the three earnings quantiles.

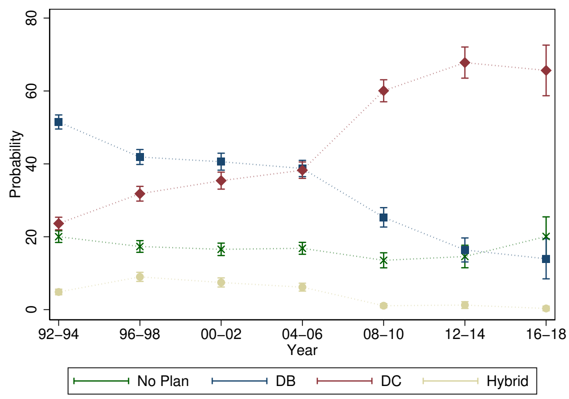
Figure 15: Changes in Retirement Plan Enrollment Probability: HRS Data



(a) 25th Percentile Earnings



(b) 50th Percentile Earnings

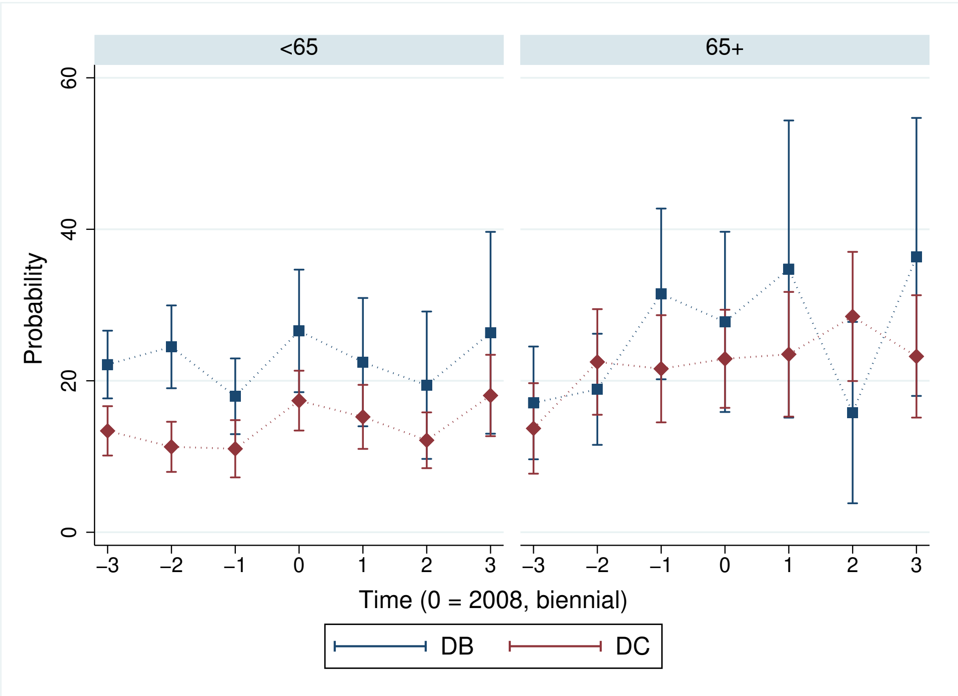


(c) 75th Percentile Earnings

C.5 Effect of Risky Returns on Retirement Decisions by Retirement Plans

A related question is whether individuals enrolled in DC plans respond differently to fluctuations in the market rate of return than those enrolled in DB plans. To investigate this, we focus on years in which investment returns were very low or negative, such as 2008, and examine whether the probability of transitioning from employment to retirement changes differentially for DC participants relative to DB participants. Consistent with the earlier analysis, we restrict the sample to individuals between ages 50 and 70. We estimate a logistic regression in which the dependent variable is an indicator for transitioning from employment to retirement between survey waves. The key explanatory variables are a set of event-time indicators around the 2008 crisis year, retirement plan type dummies (DB and DC), and age-group indicators (younger than 65 and 65 or older). We include the full set of interactions among these variables, which allows the effect of the crisis year to vary jointly by plan type and age group. The regression additionally controls for participants' earnings, household's wealth, self-reported health, gender, race, educational attainment, marital status, occupation, industry, and region, and applies personal-level sampling weights. Standard errors are clustered at the individual level to account for repeated observations within persons.

Figure 16: Predicted Employment to Retirement Probability Around 2008 Recession by Plans



Using the estimated coefficients from this model, we compute the predicted probability of a transition from employment to retirement by retirement plan type and event time, separately for each age group. Figure 16 shows no statistically significant differences in the response of employment-to-retirement transitions across plan types for all ages.

D Additional Model Results: Decomposing Effects of Uncertain Horizon and Uncertain Returns

To better understand how and why the shift from DB to DC plans results in a lower retirement rates and affects savings behavior, this subsection revisits the results in Table

9 while systematically removing each of the two main sources of risk associated with retirement planning under a DC plan, as discussed in Section 3. Specifically, we separately eliminate (i) uncertainty about lifespan, and thus the planning horizon, and (ii) uncertainty about returns on private and DC plan investments.

First, to isolate the effects of these two channels alone apart from any differences in DB vs. DC plan generosity, we consider an economy where both sources of risk are eliminated and set the DC plan employer contribution f_c so that agents are indifferent between entering the 1992-94 economy and the economy after the transition out of DB plans occurs (with plan enrollment rates set as in Table 8).[30] Notice that while agents are indifferent between entering the two economies, there are some differences in terms of retirement timing and saving that result from moving toward DC plans. In the model, as well as in most DC plans in reality, employees receive an employer contribution towards their pool of assets regardless of age. This additional incentive to continue working modestly reduces the percentage of agents retired by age 65 after the shift towards DC plans, shown in the first column of Table 19.

Table 19: Comparing Effects of Uncertain Return and Uncertain Horizon Channels

	Certain Horizon & Returns	Uncertain Horizon	Uncertain Returns	Uncertain Horizon & Returns
% Retired at Age 65	-5.1pp	-7.0pp	-31.3pp	-30.4pp
% Retired at Age 70+	+0.0pp	-2.3pp	-0.3pp	-4.2pp
Average Age 55 Assets	+8.0%	+19.0%	-4.8%	+11.3%
Expected Lifetime Utility	+0.0%	-6.5%	-0.1%	-7.5%

Next, the second and third columns of Table 19 separately consider the effects of including the uncertain horizon and returns channels in the model. In the certain horizon version of the model, agents know that they will exit the model at age 77, while with an uncertain horizon agents face age-dependent death probabilities as in Section 6.1.[31] The second and third columns show that the uncertain horizon channel plays the largest role in affecting how the movement towards DC plans affected agents' expected lifetime utility, while the uncertain returns channel plays a larger role in influencing the percentage of agents retired by 65. Notice that both channels affect savings in opposite ways. When agents face an uncertain horizon, they save more in anticipation of potentially living longer than average, while when facing only uncertain returns, agents are much more likely to work past 65 and save less by 55. The effects of the two channels can magnify one another, with the last column of Table 19 showing that the combined effects of the

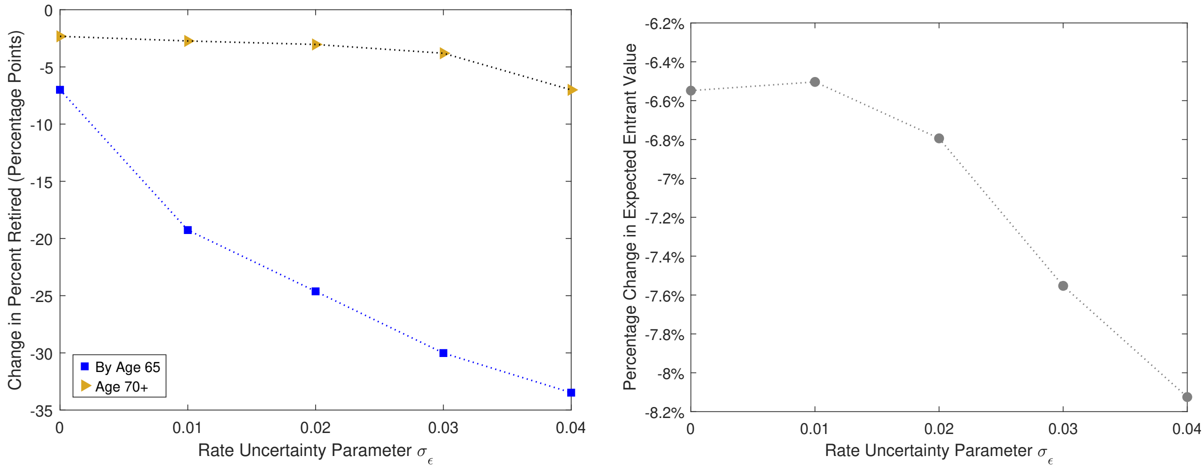
[30]The value of f_c where agents are indifferent between entering either economy is 0.1103, indicating that even without uncertain horizon and return risks there are plan differences in generosity that make agents prefer living in the 1992-94 economy.

[31]In the certain horizon version of the model, agents die at 77 as this is the life-expectancy averaged over the life-expectancies for men and women in the Social Security Administration's Actuarial Life Table from which we retrieved the age-dependent death probabilities $\nu(a)$.

two channels on expected lifetime utility are greater than the sum of the two channels when isolated.

Figure 17 further illustrates the effects of adding the uncertain returns channel by increasing the rate uncertainty parameter (σ_ϵ) gradually from 0. We see that by intro-

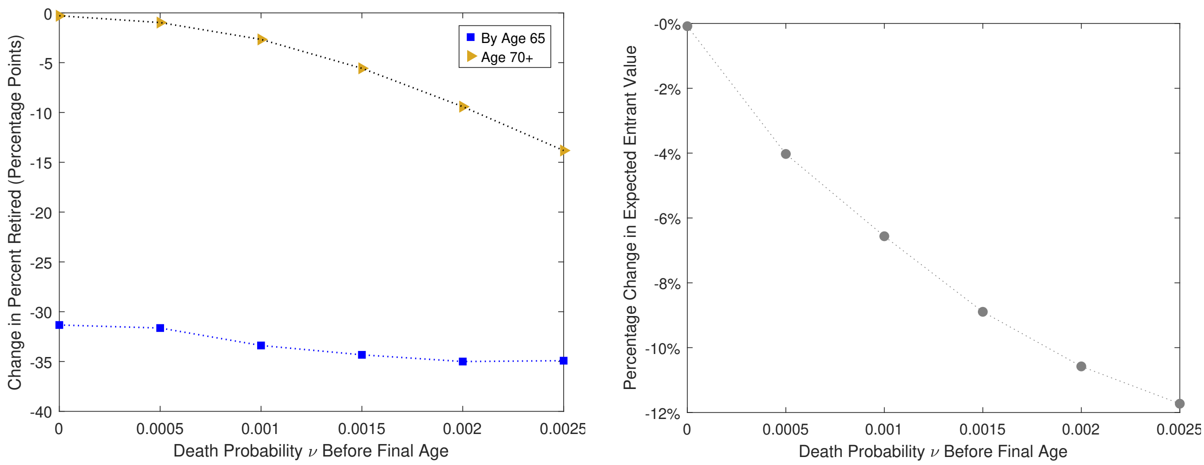
Figure 17: Effects of Uncertain Returns Channel in Quantitative Model



(a) Retirement at 65 and 70+ *(b) Expected Lifetime Utility*

ducing return uncertainty to the model, the effect of the transition towards DC plans on retirement by 65 is greatly amplified, while there is also a notable negative impact on expected lifetime utility, particularly at larger σ_ϵ values. Figure 18 illustrates the effects of including an uncertain horizon channel, going from the full model where all agents exit with certainty at age 77, and gradually introducing a constant death probability ν such that the expected age of exit remained constant. The figure shows that the uncertain horizon channel is the primary channel through which the movement towards DC plans reduced expected lifetime utility. While the channel does not greatly impact how the

Figure 18: Effects of Uncertain Horizon Channel in Quantitative Model



(a) Retirement at 65 and 70+ *(b) Expected Lifetime Utility*

transition affects retirement by age 65, which is already largely affected by the uncertain returns channel, there is still a sizeable impact on retirement later in the life-cycle.

These results suggest that expanding the use of hybrid retirement plans (such as cash balance or pension equity plans) may only slightly address the welfare losses associated with the shift away from DB plans. While hybrid plans can reduce exposure to market return risk by providing some degree of guaranteed accumulation or smoothing of investment outcomes, they do little to mitigate the uncertain horizon channel, which our results indicate accounts for the majority of the decline in expected lifetime utility following the transition. Because hybrid plans still require individuals to manage the risk of outliving their accumulated balances, they cannot fully replicate the longevity insurance inherent in DB plans. From a policy perspective, this underscores the importance of mechanisms that insure against longevity risk, such as expanding access to annuitized payout options within DC and hybrid plans or strengthening the role of Social Security in providing lifetime income protection.

E Model Extensions

This appendix presents two model extensions, each relaxing one baseline assumption at a time, and demonstrates that the main results are robust to these assumptions.

E.1 Labor Force Reentry

In the main text model, agents can not reenter the labor force once they choose to retire. However, in reality, people can return to work after retirement. The model extension in this section allows for labor force reentry while keeping other assumptions the same as the quantitative model in the main text.

E.1.1 Value Functions

In this setup, the retired agents can choose to stay retired or reenter the labor market. Once reentering, the workers face the same job finding rate as the unemployed. Meanwhile, those rejoining the labor force are subject to a one-time entry cost, c_e. As a result, the value function for the retired is changed as below.

$$\begin{aligned}
V_a^R(y, b, \gamma_B) = \max_{s, R\in\{0,1\}} \{ & u(c, \ell_R) + (1-R)c_e + \nu_a \beta \mathbb{E}[\zeta(b'_R(s), y, \gamma_B] + \\
& R(1-\nu_a)\beta \mathbb{E}[V_{a+1}^R(y, b'_R(s), \gamma_B)] + \\
& (1-R)(1-\nu_a)\beta(1-\eta_{a+1})\mathbb{E}[V_{a+1}^U(y, b'_R(s), \gamma'_B)] + \\
& (1-R)(1-\nu_a)\beta\eta_{a+1}\sum_{i_p\in P} p_i(y, i_p)\mathbb{E}[V_{a+1}^E(y, b'_R(s, i_p), i_p, \gamma'_B)]\}
\end{aligned}$$

E.1.2 Calibration

The jointly calibrated parameters shown in Table 5 are recalibrated with the new assumption of reentry. In addition, the newly added one-time entry cost c_e is also jointly calibrated. This parameter is calibrated targeting the percent of retired people who reentered the labor force between age 50 and 60 in 1994-1999[32], estimated from the CPS data.

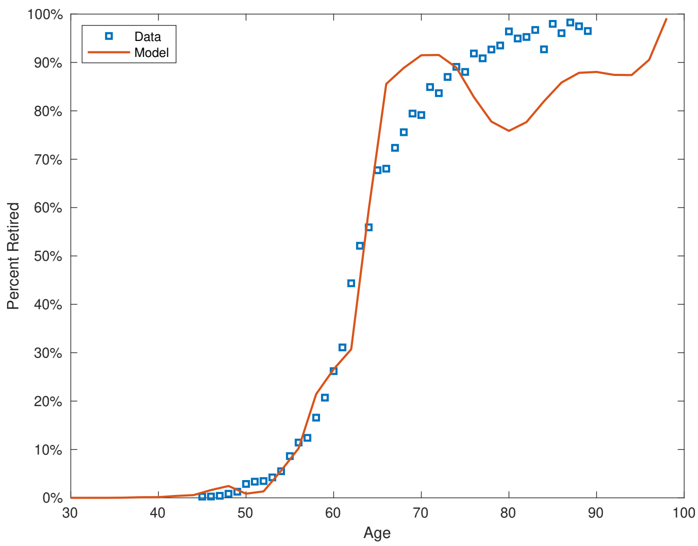
Table 20: Jointly Calibrated Parameter Values

Parameter	Estimate	Targeted Moment	Data	Model
σ_ϵ	0.0318	Quarterly returns coefficient of variation	3.69	3.69
ℓ_R	0.8744	Percent retired if age 65+	84.53%	85.33%
ζ_c	4.7469	% Change median net worth 55–64 to 75+	-23.64%	-24.24%
θ	1.3056	Age 55–64 median net worth to income ratio	4.81	4.41
χ	0.0298	Percent retired: age 70–74 to 65–69	1.17	1.06
c_e	2.1318	Percent of reentry: age 50–60	7.22%	7.10%

E.1.3 Key Result Replications

Similar to the main text quantitative model's results, this model extension can also match the percent of the retired agents by age reasonably well (see Figure 19). Different from Figure 9, as the retired can reenter the labor force, a notable percent of the retired go back to work after age 70.

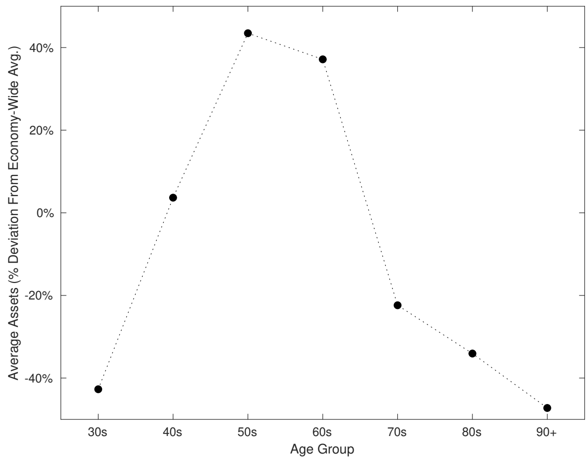
Figure 19: Percent Retired by Age (Untargeted)



Note: The data displayed in this figure is from the Current Population Survey in 1994, as we calibrate the model to the early 1990s. Prior to 1994, there was no information available regarding whether individuals were not in the labor force due to retirement or due to another reason.

[32] Prior to 1994, there was not information available regarding whether the individual were not in the labor force due to retirement or not.

Figure 20: Saving Over the Life-Cycle



(a) Average Assets by Age

Agents in this economy also accumulate assets for retirement as they age as shown in Figure 20. Different from the main text model, the incentives to save is much lower, as agents can go back to work to earn income even after retirement. Specifically, savings peak at a much lower level and the peak occurs earlier when agents are in their 50s. Agents also consume their savings more aggressively after retirement.

Table 21: Estimated Effects of Retirement Plan Transition

	All Plan Enrollment Changes 1992–2019	Only transition out of DB
% Retired at Age 62-64	-25.5pp	-25.5pp
% Retired at Age 65	-8.5pp	-9.2pp
% Retired at Age 70+	-12.6pp	-12.1pp
Average Age 55 Assets	-5.3%	-5.2%
Average Age 80 Assets	+23.7%	+23.6%
Average Age 95 Assets	+39.8%	+40.1%
Expected Lifetime Utility (Including Bequests)	-37.5%	-39.0%

Table 21 replicates the counterfactual movement from DB to DC plans. Consistent with the main text results, with labor force reentry, the percentage of agents retired at ages ranging from 62 to 70+ in the economy with higher DC plan enrollment remains lower. Moreover, the change in the labor force participation rate for agents age 70 and above is even higher than that in the baseline model. This further exhibits that higher DC plan enrollment introduces more exposure to longevity and uncertain return risks, thus more retired senior agents choose to go back to work.

Next, the change in average assets at age 55 is slightly lower following the shift to DC plans with this model extension. This is partly because a sizable fraction of people (about 10% before the plan shift) retire in their early 50s and begin to draw down retirement savings earlier. As more people are enrolled in a DC plan, the consumption of retirement savings accelerates. However, since the retired individuals can return to the labor force, more agents choose to go back to work. As a result, the average assets at ages 80 and 95 increase substantially in this higher-DC-enrollment economy. Consistent with Table 9, expected lifetime utility also decreases, with a large decline of nearly 40% under the shift from a DB to a DC plan.

E.2 Age-Dependent Social Security Income

In the baseline quantitative model, retired agents receive a uniform social security benefit after age 65. This section extends the model by introducing a more realistic benefit structure and demonstrates that the main results remain robust to this alternative specification.

In this economy, retired agents start to receive social security benefits from age 62. The amount of the benefit depends on their retirement age. Agents can receive full retirement benefits if they retire at the full retirement age (FRA), which is 65[33]. For early retirement, the benefit payment is reduced. For delayed retirement, agents receive additional credit for each extra month they work, up to age 69.

E.2.1 Value Functions

The value function for the retired now depends on both the current age, a, and the retirement age, a_r.

$$V_a^R(y, b, \gamma_B, a_r) = \max_s \{u(c, l_R) + \nu_a \beta \mathbb{E}[\zeta(b'_R(s), y, \gamma_B)] \tag{24}$$

$$+ R(1 - \nu_a)\beta \mathbb{E}[V_{a+1}^R(y, b'_R(s), \gamma_B, a_r)]\} \tag{25}$$

The social security income, $\kappa_a(a_r)$, also depends on the two states. For instance, if a worker retires before age 62, the worker will not receive social security benefits until the age of 62. If a worker retires early, the social security payment is subject to a an early-retirement penalty. The detailed social security benefit schedule is specified below:

$$\kappa_a(a_r) = \begin{cases} 0, & a < 62 \\ \kappa_a(1 - \Delta(a_r = 62)), & a >= 62, a_r < 62 \\ \kappa_a(1 - \Delta(a_r)), & a >= 62, 62 \leq a_r < 65 \\ \kappa_a(1 + \Delta(a_r)), & a >= 62, 65 \leq a_r < 70 \\ \kappa_a(1 + \Delta(a_r = 69)), & a >= 62, a_r \geq 70 \end{cases}$$

[33] In 1983, the congress change the full retirement age from 65 to 67. For people born after 1960, the FRA is 67. For people born between 1938 to 1959, the full retirement increased in increments. For people born before 1938, the FRA is 65.

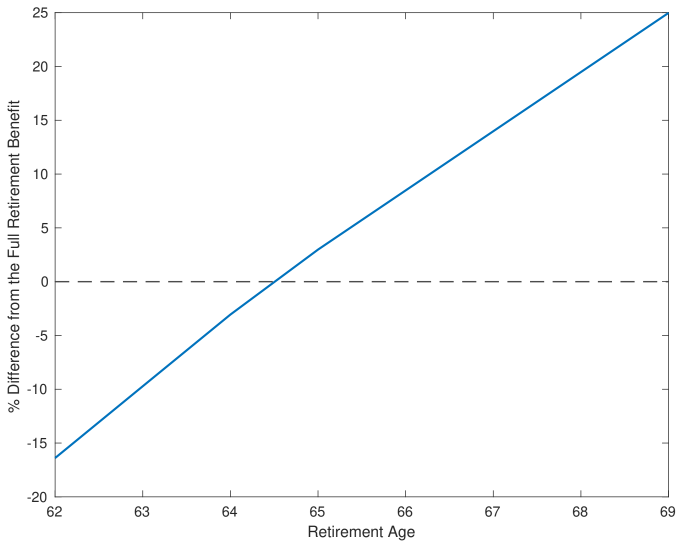
E.2.2 Calibration

The detailed social security benefit schedule is calculated according to the Social Security Administration's website[34]. The annual average incremental of income is shown in Figure 21. The jointly calibrated parameters are recalibrated in this model extension as presented in Table 22.

Table 22: Jointly Calibrated Parameter Values

Parameter	Estimate	Targeted Moment	Data	Model
σ_ϵ	0.0318	Quarterly returns coefficient of variation	3.69	3.69
ℓ_R	1.0880	Percent retired if age 65+	84.53%	92.85%
ζ_c	7.0760	% Change median net worth 55–64 to 75+	-23.64%	-26.32%
θ	1.1684	Age 55–64 median net worth to income ratio	4.81	5.08
χ	0.0280	Percent retired: age 70–74 to 65–69	1.17	1.37

Figure 21: Social Security Income Schedule



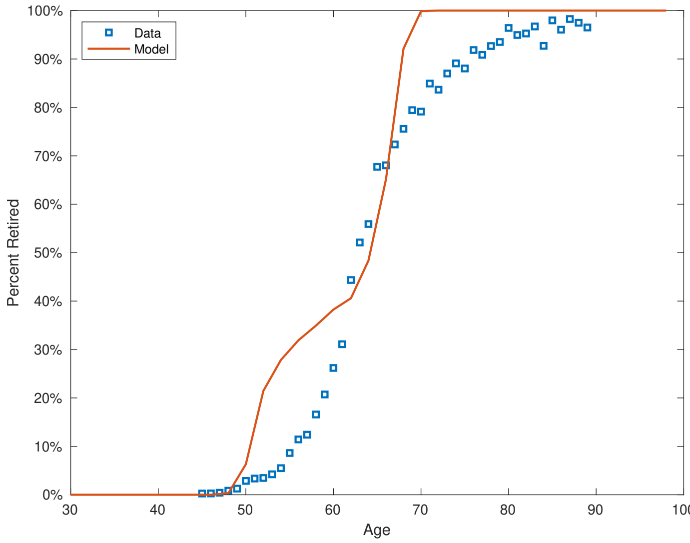
Note: Annual average changes.

E.2.3 Key Result Replications

The untargeted percentage of retirees by age in the model still follows a pattern similar to that in the data (Figure 22). Compared with the baseline model in the main text, a larger share of agents retire early, particularly in their early 50s. This is due to the change of social security payment schedule. Although agents who retire earlier face a penalty relative to the full retirement benefit, they also begin receiving social security income three years earlier than in the baseline model. This early access to social security benefits motivates agents to retire earlier in this model extension.

[34] https://www.ssa.gov/OACT/quickcalc/early_late.html.

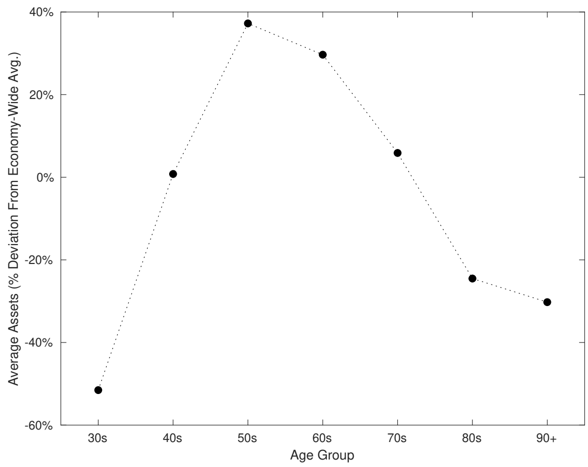
Figure 22: Percent Retired by Age (Untargeted)



Note: The data displayed in this figure is from the Current Population Survey in 1994, as we calibrate the model to the early 1990s. Prior to 1994, there was no information available regarding whether individuals were not in the labor force due to retirement or due to another reason.

The average savings over life cycle presents in Figure 23 follows a pattern consistent with that in the main text model.

Figure 23: Saving Over the Life-Cycle



(a) Average Assets by Age

Table 23 reports the counterfactual analysis results with the shift from DB to DC plan. Similar to the main text findings, the shift in enrollment decreases the percentage of the retired at age 62 to 70+. Although the average assets at age 55 are lower, assets at age 80 remain higher than in an economy with more DB enrollment. Regarding the expected lifetime utility, the last row of the table shows that greater exposure to risks associated with DC plan decreases individuals' utility by about 25%.

Table 23: Estimated Effects of Retirement Plan Transition

	All Plan Enrollment Changes 1992–2019	Only transition out of DB
% Retired at Age 62-64	-30.3pp	-30.3pp
% Retired at Age 65	-34.2pp	-34.2pp
% Retired at Age 70+	+0.0pp	+0.0pp
Average Age 55 Assets	-22.6%	-22.8%
Average Age 80 Assets	+19.9%	+19.8%
Average Age 95 Assets	+0.6%	+0.6%
Expected Lifetime Utility (Including Bequests)	-24.3%	-25.0%