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HEALTH COST RISK: A POTENTIAL SOLUTION TO THE ANNUITY PUZZLE*

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We find that health cost risk lowers optimal annuity demand at retirement. If medical expenses can be sizeable early in retirement, full annuitisation at retirement is no longer optimal because agents do not have enough time to build a liquid wealth buffer. Furthermore, large deviations from optimal annuitisation levels lead to small utility differences. Our results suggest that health cost risk can explain a large proportion of empirically observed annuity choices. Finally, allowing additional annuitisation after retirement results in welfare gains of at most 2.5% when facing health cost risk, and negligible gains without this risk.

As a consequence of an ageing population in many countries, much attention (both by policymakers and academics) is directed towards providing and optimising financial security during retirement. In this respect, the most important risks elderly face are longevity and health cost risk. Longevity risk can be hedged using annuities. Health cost,[1] and the risk therein, have increased substantially over the last decades, in all Western countries. The main goal of pension policies, and social security in general, is to provide financial security to the elderly. Thus health risk, as one of the major financial risks for these individuals, should be taken into account when designing such a system. In spite of health risks being actively discussed in the public policy debate, few papers examine what asset allocation policy is optimal when retirees face health risk. In this article, we attempt to fill this gap and examine to what extent individuals can still annuitise their wealth when facing health risk. We thus study the trade-off between longevity risk insurance and saving for unexpected liquidity needs due to health cost. We explore the impact of health cost, taking into account not only health cost but also health state dependence of utility and high end-of-life health cost.

Prior research has shown that full annuitisation is optimal for individuals who only face uncertainty about their time of death. Yaari (1965) shows that agents, with no

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[1] We use the words health cost instead of health care cost for readability. However, health care cost would be more accurate than health cost because it is health care what individuals buy, not health.

desire to leave a bequest, find it optimal to hold their entire wealth in actuarially fair annuities, when longevity is the only risk factor. However, in fact, a relatively small number of individuals voluntarily purchases annuity products when they enter retirement age.

We build a life-cycle model for consumption and portfolio choice to examine whether health cost risk can explain the low empirically observed annuity levels. Out-of-pocket medical expenses raise the need for liquidity and, hence, give incentives for precautionary saving (Palumbo, 1999; Dynan *et al.*, 2004; De Nardi *et al.*, 2010). As a consequence, uncertain medical cost can reduce the attractiveness of annuities since they impair the ability to smooth consumption in the case of high and unexpected health cost. In our baseline model, retirees optimally choose the fraction of wealth annuitised at retirement and follow optimal consumption and asset allocation strategies afterwards, facing capital markets risk (including inflation) and (correlated) longevity and health cost risk. We also study the effect when agents can buy additional annuities after retirement. In the literature, a wide variety of health cost models are proposed and are estimated using different data sets. Our main goal is not to estimate the most accurate health cost model but to explore the potential implications of health cost risk on annuity demand. To that end we simulate health cost using different models allowing us to experiment on what specific features of health cost drive annuitisation. As our baseline, we use medical cost estimated in Ameriks *et al.* (2011), however, we also use estimates from De Nardi *et al.* (2010) and estimate our own health cost model.

We find that optimal annuity demand at retirement is lowered due to health cost risk (see Table 2). People facing health cost risk optimally annuitise zero of liquid wealth on a voluntary basis, compared to 90% when not facing health cost risk. The optimal annuitisation level at retirement as a function of total wealth (instead of liquid wealth) is 70%, where total wealth is pre-annuitised wealth and liquid wealth. Optimal annuitisation levels are lower in bad health compared to good health, which is due to higher health cost risk and lower life expectancy for people in bad health (annuities are priced according to average life expectancy). Especially the tail of health cost risk early in retirement is important. When annuitisation takes place only once at retirement, the amount of health cost after about five years following the annuitisation decision is mostly irrelevant. If the health cost risk is moderate early in retirement, it is optimal for agents to annuitise all wealth at retirement and save out of the annuity income to build a liquid wealth buffer for high out-of-pocket medical expenses later in retirement. If, instead, out-of-pocket expenses can already be high early in retirement, agents prefer to keep a certain amount of wealth liquid, to smooth consumption in case of a sizeable health cost shock. We provide summary statistics and other additional evidence showing that health cost risk indeed is high early in retirement.

Furthermore, the welfare effects of annuitisation are reduced sizeably by medical expenditure risk (see Figure 2). A woman in good health will at most find a reduction in welfare of 1% if she annuitises at any level between 41% and 94% of total wealth. This range is between 0% and 90% for a woman in bad health. Furthermore, we compare the predicted annuity levels with the data and find that a life-cycle model including health cost and optimal annuitisation once at retirement can explain a large fraction of the annuitisation levels observed in the data. These results are robust to health state dependence of utility and large end-of-life health cost (see Table 4).

When allowing additional annuitisation after retirement, agents optimally reduce annuity demand at younger ages due to high health cost risk early in retirement, but after age 75 reach and keep an optimal fraction of total wealth annuitised of around 90% (compared to about 75% in the data, see Figure 3). Hence health cost risk can explain why agents do not annuitise around retirement but it cannot explain why they do not buy annuities in the private market at more advanced ages. Again, the welfare losses are limited when annuitising substantially less (or more) than the optimal level. Furthermore, we estimate the welfare gains from more flexible annuitisation timing, both when facing health cost risk and not facing this risk. We find that, when facing health cost risk, allowing extra annuitisation at age 80, on top of annuitising at age 65, results in a welfare gain of 0.4%. Gains from allowing further optimal annuitisation at every age are about 2.5%, compared to annuitisation only at age 65. These welfare gains become negligible when not facing health cost risk. The reason that the additional flexibility is more valuable when facing health cost risk, is that the flexibility allows people to keep wealth liquid and to postpone their annuitisation decision when more information about their future health status (and related cost) is known. At a certain age the mortality credit becomes such that it is nevertheless optimal to annuitise a large fraction of total wealth.[2]

Ameriks *et al.* (2011) examine a similar question as in our article, while De Nardi *et al.* (2010) focus on precautionary savings due to health expenses. Among other contributions, Ameriks *et al.* (2011) take as an example a fairly wealthy woman and determine whether she would optimally buy an annuity of such a size that it increases the percentage of total wealth annuitised from 55% to 70%. We expand on Ameriks *et al.* (2011) on multiple dimensions. We determine the optimal annuity level instead of the willingness to participate in the annuity market (which is a zero/one decision). Moreover, we explore the implications for different health states, health state dependence of utility and high end-of-life health cost. Furthermore, we allow annuitisation after retirement, and explore welfare gains.

Health cost can be viewed as either exogenous or endogenous. We assume they are fully exogenous. However, part of out-of-pocket medical expenses might be a choice, hence health cost is overstated to a certain degree. Yogo (2012) examines the optimal allocation to health care and financial assets, and assumes (fully) endogenous investments in health capital. He finds that medical expenses can partly explain the annuity puzzle. His setup, however, implies in part that agents can influence their health status and survival probabilities by increasing their health expenditures.[3] This is contradicted by many empirical studies that find, at most, weak evidence that higher health care utilisation leads to an increase in survival probabilities (Brook *et al.*, 1983; Finkelstein and McKnight, 2008).

Furthermore, we assume implicitly that health cost is (partly) uninsurable. If a perfect market for health cost insurance were to exist, then it would be optimal for an

[2] However, loads due to adverse selection become larger with age. Finkelstein and Poterba (2002) show that the money's worth using the population mortality table decreases with age.

[3] Endogenous investment in health in a broader sense can also include time-intensive investments like cooking and exercising.

agent to buy insurance which fully covers medical cost. However, since the market for private care insurance fails to a certain degree, we take as a given that health cost is only partially insured. See Brown and Finkelstein (2007) for an analysis of the supply-side and demand-side factors for the lack of private insurance against long-term care cost. Our approach of implicitly assuming partly uninsurable health cost and people facing out-of-pocket medical expenses is taken in a number of papers (Palumbo, 1999; De Nardi *et al.*, 2010; Pang and Warshawsky, 2010; Ameriks *et al.*, 2011). This article builds on a vast literature that focuses on the 'annuity puzzle'. Pashchenko (2013) explores the low participation in voluntary annuity markets by revisiting several potential impediments to annuitisation; pre-annuitised wealth levels, adverse selection, bequest motives, medical expense uncertainty, means-tested transfers, illiquidity of housing wealth and minimum purchase requirements for annuities. Similar to a part of our analysis, she models medical expenses using the specification in De Nardi *et al.* (2010), and reaches the same conclusion that medical expenses do not lower annuity demand in that specific case. We take a different approach to Pashchenko (2013) by focusing solely on health cost, using three different models for out-of-pocket medical expenses, health state dependence of utility and high end-of-life health cost to explore the impact on annuitisation levels. This leads us to reach a different conclusion when modelling health cost via the specification in Ameriks *et al.* (2011), namely that high health cost risk early in retirement lowers annuity demand. Similar to Pashchenko (2013), Pang and Warshawsky (2010) model health cost using De Nardi *et al.* (2010) and explore the impact on annuitisation while allowing for flexible annuitisation timing. They find that health cost risk increases annuity demand slightly. We find the opposite result because in our baseline case health cost risk can be high early in retirement and keeping a larger fraction liquid at young ages is optimal since then the mortality credit is not that high. Mitchell *et al.* (1999) examine actuarially unfair annuities as a potential driver of deviation from full annuitisation, and Inkmann *et al.* (2011) and Lockwood (2012) look at bequest motives. We abstract from bequest motives, because the evidence on the strength of bequest motives is mixed (Brown, 2001; De Nardi, 2004; Kopczuk and Lupton, 2007). Furthermore, several behavioural explanations have been posited, such as framing of the annuity choice (Brown *et al.*, 2008), complexity of the annuity product (Brown *et al.*, 2013) and mental accounting (Hu and Scott, 2007).

Closely related to our article, Turra and Mitchell (2008), Poterba *et al.* (2010) and Hugonnier *et al.* (2013) show the effect of health cost risk on portfolio choice, whereas Berkowitz and Qiu (2006) and Love and Smith (2010) focus on the influence of health status on portfolio allocation decisions. Furthermore, there are several papers that examine the relation between health risk and retirement timing (French, 2005; Bound *et al.*, 2010). In this article, we expand on this literature by examining the effect of uninsured health cost on annuity demand.

In many countries, there has been a transition towards lower annuitisation through classical defined benefit pension schemes and social security. Furthermore, pension systems give larger flexibility to pensioners regarding annuitisation timing. In the new reform in the UK, which came into effect in April 2015, pensioners are no longer obliged to annuitise any of their pension wealth and they can withdraw at any point after the age of 55. This article predicts that some flexibility in decumulating pension wealth has the potential to improve welfare, since we find that the welfare differentials of annuitisation levels above 50% of total wealth are low when agents face medical expenditure risk. For those of which pre-annuitised first pillar government pensions are substantial, the welfare gains of annuitising optimally are at most 1%. Furthermore, the additional flexibility on annuitisation timing in the new reform results in welfare gains of at most 2.5%.

The remainder of the article is organised as follows. Section 1 describes the life-cycle model during the retirement phase. In Section 2, we present the health cost models that we use to determine optimal annuity demand. The main findings are given in Section 3 and Section 4 concludes.

1. The Retirement Phase Life-cycle Model

1.1. *An Individual's Maximisation Problem*

We restrict our analysis to individuals during retirement. We consider a life-cycle investor of age $t \in 1, \ldots, T$, where $t = 1$ is the retirement date and T is the maximum age possible. In our benchmark specification, individuals maximise utility over real consumption and preferences are represented by a time-separable, constant relative risk aversion expected utility function over real consumption (C_t). Lifetime utility is then:

$$V = \mathrm{E}_0\left\{\sum_{t=1}^{T}\beta^{t-1}\left[\prod_{s=1}^{t}p_s(S_{s-1})\right]u(C_t|S_t)\right\}, \text{ with} \quad (1)$$

$$u(C_t|S_t) = (1+\eta S_t)(C_t^{1-\gamma})/(1-\gamma), \quad (2)$$

where β is the time preference discount factor, γ the degree of risk aversion and C_t is the real amount of wealth consumed at the beginning of period t. S_t is the health status of the agent at time t and ηS_t induces state-dependent utility, because it allows the health state to affect the marginal utility of consumption. For example $\eta = 0.1$ implies that the marginal utility of consumption is 10% lower in bad health $(S_t = 0)$, compared to in good health $(S_t = 1)$. The probability of surviving to age t, conditional on having lived to period $t-1$, depends on the health status at time $t-1$ and is indicated by $p_t(S_{t-1})$.

The fraction w_t invested in equity is chosen optimally and yields a gross nominal return R_{t+1} over year $t+1$. The remainder of liquid wealth is invested in a riskless bond with yield R_t^f. Moreover, the agent may decide to buy additional annuities. We will vary this assumption throughout this article. Next period's wealth, in nominal terms, is thus given by:

$$W_{t+1} = (W_t + Y_t - H_t - C_t\Pi_t - D_t + G_t)[1 + R_t^f + (R_{t+1} - R_t^f)w_t], \text{ where} \quad (3)$$

$$Y_t = \frac{\Pi_t}{\Pi_{t-1}}(Y_{t-1} + D_{t-1}/z_{t-1}), \text{ and} \quad (4)$$

$$G_t = \max\{0, C_{min}\Pi_t + H_t - Y_t - W_t\}, \text{ and} \tag{5}$$

$$D_t \leq W_t + Y_t - H_t - C_{min}\Pi_t. \tag{6}$$

The amount of wealth at time t is W_t, Y_t is the annual income from the real annuities, but in nominal terms, D_t is annuities bought, G_t is Medicaid government transfers, z_t is the annuity factor, Π_t is the price index at time t and health cost is denoted by H_t. The timing of decisions is as follows. First, the individual receives his annuity income and pays health cost. After this exogenous shock, the agent decides how much to consume and subsequently decides whether to buy (additional) annuities and, if so, how many (D_t/z_t). Finally, agents invest remaining liquid wealth, choosing the equity exposure w_t optimally. If the annuity income plus wealth at the beginning of any period is insufficient to pay for health expenses and consumption, the individual receives a low minimum real consumption level, C_{min}, since almost all western countries have a minimum consumption floor. Furthermore, the medical expenses that the individual cannot pay out-of-pocket, will be paid by Medicaid (more details on Medicaid in subsection 3.1). In that case the retiree is left with zero next period wealth, which reflects being bankrupt. The decision frequency is annually.

Consumption and asset allocation are chosen optimally subject to a number of constraints. First, we assume that the retiree faces borrowing and short-sales constraints:

$$w_t \geq 0 \text{ and } 1 \leq w_t. \tag{7}$$

Second, we make the standard assumption that the investor is liquidity constrained:

$$C_t\Pi_t \leq W_t, \tag{8}$$

which implies that the individual cannot borrow against future annuity income to increase consumption today. The reason that we impose a borrowing constraint is that it is often difficult to get a loan for elderly persons. Third, we make the assumption that annuities cannot be resold:

$$D_t \geq 0. \tag{9}$$

1.2. *Financial Markets*

We assume that the asset menu of an investor consists of two assets: a riskless one-year nominal bond and a risky stock. The return on the stock is lognormally distributed with an annual mean nominal return μ_R and a standard deviation σ_R. To allow for interest rate risk, we assume that the nominal term structure is generated by a Vasicek model. The real yield is equal to the nominal yield minus expected inflation and an inflation risk premium.

In our market, the instantaneous expected inflation rate follows:

$$\pi_{t+1} = \pi_t + a_\pi(\pi_t - \mu_\pi) + \epsilon^\pi_{t+1}, \tag{10}$$

where a_π is the mean reversion parameter, μ_π is long run expected inflation and the error term $\epsilon^\pi_t \sim \mathrm{N}(0, \sigma^2_\pi)$. Subsequently, the price index Π follows from:

$$\Pi_{t+1} = \Pi_t \exp(\pi_{t+1} + \epsilon^\Pi_{t+1}), \tag{11}$$

where $\epsilon_t^{\Pi} \sim \mathrm{N}(0, \sigma_{\Pi}^2)$ captures unpredictable shocks to the price index. We assume there is a positive correlation between the expected inflation and the instantaneous short interest rate.

We consider single-premium immediate life-contingent annuities with real payouts. The single premium is equal to the present value of benefits paid to the annuitant assuming actuarially fair pricing. This annuity conversion factor z_t is exogenously specified and term structure dependent:

$$z_t = \sum_{u=t+1}^{T} \exp\left[-(u-t)R_t^{(u)}\right] \mathrm{E}_t \prod_{s=t+1}^{u} p_s(S_{s-1}), \tag{12}$$

where $R_t^{(u)}$ is the real time-t yield on a zero coupon bond maturing at time u. Note that the annuity factor at time t prices the first payment at time $t + 1$ and a final payment at time T. The survival probabilities applied to calculate the annuity factor are unconditional on the specific health status of the agent. Instead, we use the fraction of agents in a good and bad health status to determine this annuity factor. We estimate, using the Health and Retirement Study (HRS) data set, that 70% are in good health at age 65 and the remainder are in bad health. The annuity factor is conditional on gender. The survival probabilities $p_t(S_{t-1})$ are generated via various health risk models and we assume a certain death by age 100. In our base setup, we assume that the annuity decision can only be made once, at retirement. We do this for several reasons. First of all, in several countries the decision whether to annuitise your pension account or take a lump sum takes place at retirement, due to tax legislation. Second, loads due to adverse selection become larger with age (Finkelstein and Poterba, 2002). Also, in reality people make financial decisions very infrequently. Agarwal *et al.* (2009) show that the capability of individuals to make financial decisions declines dramatically at higher ages, hence it seems optimal to make these decisions at younger ages when a person is still able to do so. Nevertheless, in many countries individuals may annuitise additionally after retirement as well and, thus, in a second set of results we assume that additional annuities can be bought at a later moment in retirement or even every year. In that the case the annuity factor will depend on the survival probabilities of the subset of the surviving population and the prevailing term structure of interest rates. Results are provided in subsection 3.2.

This life-cycle problem is computationally burdensome as we have three choice variables, two endogenous state variables and four exogenous state variables. Therefore, we rely on recent numerical techniques to solve for the optimal consumption, investment and annuitisation part. To run one set of parameters on an i7 processor with 4GB of RAM takes eight days for the fully flexible annuitisation model. Additional annuitisation moments are especially costly numerically. The method we use to solve our life-cycle problem is described in the online Appendix. Furthermore, programs and data sets are available online.

1.3. *Parameter Values*

We do not estimate the financial market and preference parameters ourselves but employ common values used within the life-cycle literature. As in Pang and Warshawsky

(2010) and Yogo (2012), we set β, the time preference discount factor, equal to 0.96. The risk aversion coefficient γ is 5. The parameter for the health state dependence of the utility function, η, is zero in the baseline case. The baseline initial wealth level is equal to \$220,000, which is the median total wealth level for a single woman US household (authors own calculation using HRS), where total wealth consists of pre-annuitised wealth and liquid financial wealth. The minimum consumption level guaranteed by the government is set equal to \$7,000 annually, which is close to the consumption floor identified by Ameriks *et al.* (2011).

In accordance with historical stock returns we assume a mean annual nominal return of 8% and an annual standard deviation of 20%. The mean instantaneous short rate is set equal to 4%, the annual standard deviation to 1% and the mean reversion parameter to -0.15. The inflation risk premium to determine the real yield is 0.5%. The correlation between the instantaneous short rate and the expected inflation is 0.4. Mean inflation is equal to 2%, and the standard deviation of the instantaneous inflation rate is equal to 1.3%, the standard deviation of the price index equals 1.3% and the mean reversion coefficient equals -0.15. Time ranges from $t = 1$ to time T, which correspond to ages 65 and 100 respectively.

2. Health Cost Models for Expenditures

Health is one of the major risks the elderly face and a large part of health cost in the US is paid out-of-pocket. As we show in the analysis, the possibility of extreme health cost early in retirement is of particular importance. Hence in the next Section, we describe the data and models used, focusing mostly on that aspect of health cost. To that end we need to make a distinction between long-term care cost and other health cost. The largest health cost risk that agents face is for long-term care, since nursing homes are expensive and being 'in need of long-term care' is a persistent health status. Therefore, when assessing the risk early in retirement, utilisation rates of nursing homes during those ages are relevant, and are discussed in subsection 2.2.

2.1. *Who Pays for Health Cost in the US*

Brown and Finkelstein (2009) note that for the health sector as a whole 17% of the cost is paid out-of-pocket. Focusing on long-term care specifically, Brown and Finkelstein (2011) document that one-third of the expenditures on long-term care is paid out-of-pocket. Only 4% of long-term care cost is covered by private insurance, 25% by Medicare and (the remainder) more than one-third by Medicaid. Insurance policies for long-term care do exist but the contract typically purchased covers only about one-third of the individual's expected present discounted value of long-term care cost (Brown and Finkelstein, 2007).[4] Medicaid is means tested and allows the individual to keep very little income or assets to finance non-care consumption.

[4] This limited coverage is mostly due to a \$100 constant nominal daily benefit cap.

2.2. *Utilisation Rates of Long-term Care Facilities*

Brown and Finkelstein (2011) estimate that between 35% and 50% of 65-year olds will enter a nursing home during their lifetime. However, the probability of going to a nursing home at a young age is also substantial. Using a relatively healthy subsample of the population, Brown and Finkelstein (2007) estimate the probability that a 65-year old who is out of care and healthy enough to be eligible for long-term care insurance is in a nursing home or assisted living in the first month of turning 70. They estimate this to be 0.7% and 0.5% for, respectively, women and men, which is of similar, albeit slightly smaller, magnitude as the 99th percentile of health cost risk in Ameriks *et al.* (2011) (see Figure 1 in subsection 2.5). These nursing home utilisation numbers are likely to be underestimated as they are conditional on being eligible for purchasing long-term care insurance. Murtaugh *et al.* (1995) estimate that about 12–23% of the 65-year olds would be rejected for private long-term care insurance. Hence the risk of going to a nursing home early in retirement is much higher than 0.7%, since this number is based on the least risky 65-year olds. Furthermore, the cost associated with living in a nursing home amounts to about $87,000 a year for a semi-private room (Metlife, 2012).

2.3. *Summary Statistics on Out-of-pocket Health Cost*

Table 1 shows summary statistics on two-year out-of-pocket health cost estimated from the HRS data from 1996 to 2010. Unfortunately, no questions on health cost paid by Medicaid are asked of respondents (in subsection 2.4 we detail the need for Medicaid expenditures). Upon entering the HRS, individuals are non-institutionalised. However, at any time they can be admitted to a long-term care facility. In that case the HRS tries to follow-up on them to get an estimate of out-of-pocket expenses also during nursing home stays. In the case of death, a proxy interview is attempted with the next of kin to obtain estimates on health cost prior to death. Table 1 shows that the median two-year

Table 1
Two-year Out-of-pocket Health Cost (× $1000)

	Mean	Median	95th percentile	99th percentile
Panel (a): Women				
Age 65–70	4	1	13	75
Age 71–80	6	1	17	84
Age 81–90	11	2	44	138
Age 91–100	21	2	113	239
Panel (b): Men				
Age 65–70	4	0	19	58
Age 71–80	7	1	25	130
Age 81–90	9	2	39	164
Age 91–100	22	2	83	224

Notes. We use data from 1996 to 2010 on single, retired households. Out-of-pocket expenses are the sum of what the individual spends out-of-pocket on insurance premia, drug cost, hospital stays, nursing home care, doctor visits, dental visits and outpatient care. Medical expenses covered by insurance, either public or private, are not included.

out-of-pocket health cost ranges from \$0 to \$2,000, however, the 99th percentile is sizeable and ranges from \$58,000 to \$239,000 depending on age and gender.

2.4. *Specification of Three Health Cost Models*

Ideally, we would have data on out-of-pocket expenses and expenses paid by Medicaid for a representative sample of the elderly population. The rationale for needing not just out-of-pocket medical expenses is that, in reality, when agents are faced with medical cost which they cannot afford, Medicaid pays. This is similar to our model, where in the case where wealth is insufficient to pay expenses, the individual will receive government transfers from Medicaid which pay for the leftover medical expenses. Moreover, the agent will receive the minimum consumption level, essentially be bankrupt, and start with zero wealth in the next period. This can be seen from (3)–(6). Thus, also in our model only a part of health cost is actually paid out-of-pocket, as wealth might be insufficient. Hence, as also discussed in De Nardi *et al.* (2010), using a health cost process estimated based on just out-of-pocket expenses underestimates the medical expense risk. In our benchmark specification only half of the health cost simulated is actually paid out-of-pocket, the other half is paid by Medicaid transfers (5). This is similar to the empirical fraction paid by Medicaid versus out-of-pocket and also shows that using a health cost process estimated only on the basis of out-of-pocket expenses will underestimate the true health cost risk by about a factor of two.

Several papers estimate medical expenses, though the estimated dynamics for health cost risk differ substantially. The difference in data sets and models used results in different medical expense profiles and no approach has advantages on all dimensions. Note that our goal is to determine which aspect of out-of-pocket medical expenditures influences optimal annuity demand and to assess whether health cost risk can potentially explain the annuity puzzle. For this reason we focus on three models. As our baseline we use the process of health expenses from Ameriks *et al.* (2011), as a second we use the estimates in De Nardi *et al.* (2010) and as a third we use our own estimated health cost process. These three models vary according to how the stochastic process for health cost is specified and/or the data set employed.

2.4.1. *Ameriks et al.* (2011)

Our baseline model is that in Ameriks *et al.* (2011) as it is based on both out-of-pocket expenses and Medicaid expenses. Ameriks *et al.* (2011) model four health states: good health, medical problems but no long-term care, long-term care and death. They assume the health status follows a Markov chain with an age-varying one-period transition matrix. Hence the survival probabilities depend on the health state of the agent. The parameters in the transition matrix are set to match four age-dependent mortality rates and eight statistics on long-term care utilisation taken from Brown and Finkelstein (2008). This is done separately for men and women. States where the agent is alive are associated with a deterministic health cost. The health cost if the agent is in good health status is \$1,000, in the intermediate health status the associated cost is \$10,000, and if the agent is in need of long-term care the annual cost is assumed to be \$50,000. The deterministic health cost in the first two states is calibrated in such a way as to match estimates in French and Jones (2004) with the health status transition matrix. To determine the health cost in the long-term care health status, Ameriks *et al.* (2011) use Metlife's estimates for costs for a semi-private room in a LTC facility in 2006. The cost is $143 per day and Medicare covers the full cost of LTC for 20 days each year and the daily cost in excess of $109.50 for an additional 80 days. This amounts to a total of $46,700[5] for a year of long-term care for an agent without long-term care insurance (only 4% of the elderly have long-term care insurance). If the agent has sufficient wealth and income this will be paid out-of-pocket, if not Medicaid pays. This model allows for sizeable health cost risk early in retirement (see Figure 1(*b*)). In subsection 3.1 we show that the discrete age-independent nature of the assumed health cost in each state does not affect our results.

2.4.2. *De Nardi et al.* (2010)

De Nardi *et al.* (2010) use data from 1994 to 2006 from the Assets and Health Dynamics of the Oldest Old (AHEAD) data set, which is a part of the HRS. The individuals who are in the AHEAD data set in 1994 are 70 years or older and non-institutionalised, which thus presents a relatively healthy subsample of the population and health cost early in retirement are likely to be underestimated. Unfortunately, the data contain only out-of-pocket medical cost, not Medicaid expenditures. Individuals face three sources of risk, which are treated as exogenous: survival uncertainty, health status uncertainty and medical expense uncertainty.[6]

2.4.3. *Own estimates*

We estimate a similar health cost model to that in De Nardi *et al.* (2010), however, we expand on their data set. In addition to the AHEAD data set, we also use other parts of the HRS, as well as the exit interviews in the HRS. Exit interviews are attempted with a proxy informant for panel members who have died. To the greatest extent possible, proxy informants are knowledgeable about the health, family and financial situation of the deceased (often the proxy is a widow, widower or some other family member). Furthermore, our data set is from 1996 to 2010. As in De Nardi *et al.* (2010), we consider only single, retired individuals in the analysis. This leaves us with 4,144 households, of whom 3,180 are women and 934 are men. More details on our own estimated model are in Appendix A and details for the other two health cost models can be found in the respective papers.

A key feature of all three models is that, at a point in time, health cost and survival probabilities are negatively correlated, which is in contrast to the specification used in Pang and Warshawsky (2010).[7] The correlation between health cost and survival probabilities also allows us to study the effect of high end-of-life health cost, see subsection 3.4. Both the medical expenditures and survival probabilities depend on the

[5] 80 days times $109.50 plus 265 days times $143.00.

[6] The transition probabilities between health states and survival probabilities depend on the previous health status, gender, permanent income and age. The health status can be either good or bad. Expected health cost and health cost risk depend on gender, health status, permanent income and age. Moreover, idiosyncratic health cost shocks are autocorrelated and the variance of the log medical expenses thus depend on gender, health status, permanent income and age.

[7] They use the model by De Nardi *et al.* (2010) but to avoid tracking the health status, they take the average mortality rates and health expenses across people in each income decile.

health status of the agent. So in the case where the agent is in bad health, expected medical expenses are higher and life expectancy is lower. This is particularly important when examining the effect of health cost on annuity demand. Namely, the negative correlation between medical expenses and remaining life expectancy makes annuities relatively more attractive, as, after having incurred large health expenses, the agent is more likely to die. This makes the depletion of wealth due to medical expenses less costly in utility terms. However, for a married couple, the surviving spouse would be left with no wealth and forced to consume a subsistence consumption level. This potentially increases the need for a large wealth buffer even further, which reduces annuity demand. Furthermore, whether or not a person is in need of long-term care is partly a function of marital status and, since women live longer than men, more often women are widowed and do not have a partner to take care of them. Although an important factor, Goda *et al.* (2013) find that only one-third of the difference in out-of-pocket health cost between men and women is due to marital status. For simplicity we focus on single households, as in De Nardi *et al.* (2010). Exploring a two person household is interesting but would potentially require modelling a household utility function, joint decisions on annuitisation and consumption, a joint-life annuity and correlated survival probabilities and health cost.

2.5. *Dynamics and Distribution of Health Cost*

Figure 1 displays the means and the 99th percentiles of medical expenses for the three health cost specifications. Most importantly, we show that both the amount and pattern of health cost over the life cycle differs substantially between the two models. Panel (*a*) shows the mean health cost, and we can see that it increases substantially with age in the De Nardi *et al.* (2010) model. This pattern also holds for the 99th percentile displayed in panel (*b*). The health cost according to our baseline health cost model (Ameriks *et al.*, 2011) show a different shape. When focusing on the 99th percentile, we see that the Ameriks *et al.*, 2011 specification implies a large health cost risk already, early in retirement, but less risk later in retirement compared to the health cost model by De Nardi *et al.* (2010). Furthermore, the shape of the curves differ because the health cost according to the Ameriks *et al.* (2011) specification takes on only discrete levels ($1,000, $10,000 and $50,000). The health cost according to our own specification shows a large potential cost early in retirement (but slightly lower than Ameriks *et al.*, 2011). Furthermore, at more advanced ages the 99th percentile of health cost is high and we assume maximum annual health expenditures of $300,000. Health cost for men are a bit lower than for women, in all models (also in line with Goda *et al.* (2013) and Table 1). Life expectancy is lower for men compared to women in both models.

2.6. *Discussion Health Cost Models and Data*

As mentioned before, ideally, we would have data on general medical expenses and long-term care cost, including expenses paid by Medicaid, of a representative sample of the elderly population. We not only need out-of-pocket health expenses but also Medicaid expenses because, in practice, when agents face medical cost which they cannot afford, Medicaid pays. This is similar in our simulation model, as when wealth is

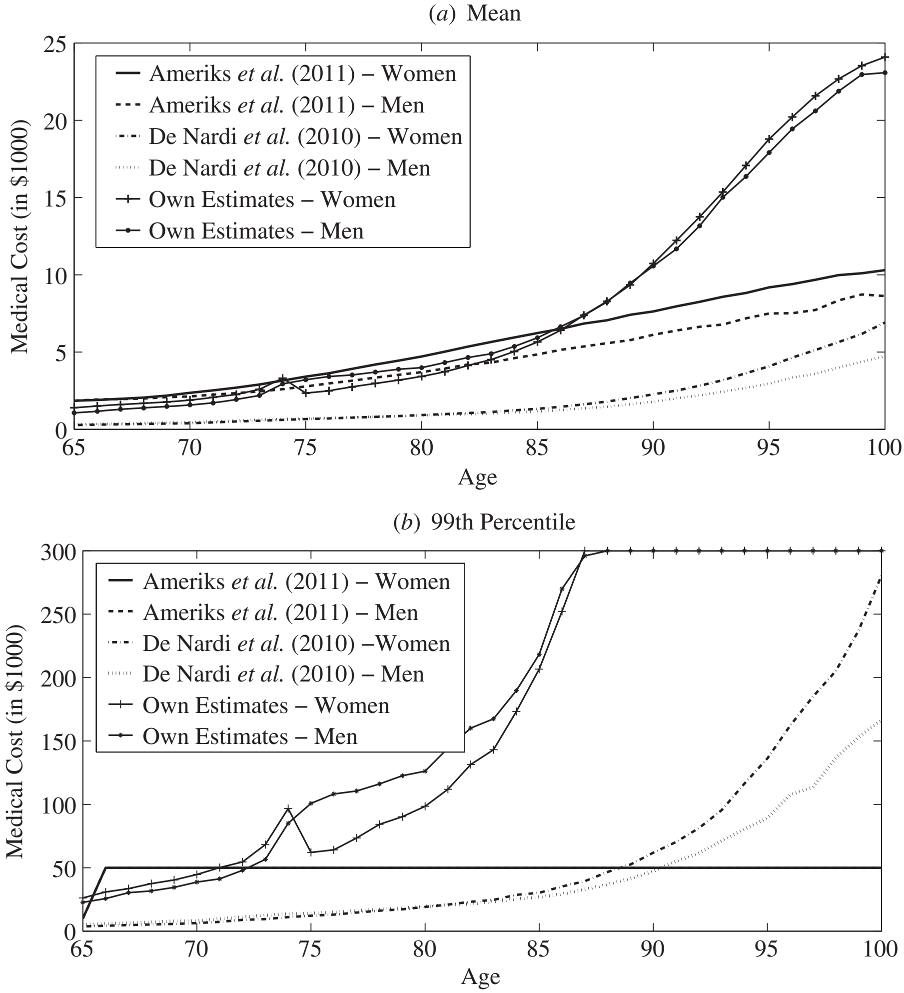

Fig. 1. *Simulated Annual Health Cost from Age 65 to 100*

Notes. This graph displays the mean and 99th percentile of health cost for three models; (1) Ameriks *et al.* (2011), (2) De Nardi *et al.* (2010) and (3) own estimates. In the simulations 70% of people starts with good health and 30% with intermediate health, similar to the fraction observed in the HRS data set.

insufficient to pay expenses, Medicaid will pay the remaining health cost. The agent will receive a minimum consumption level, essentially be bankrupt and start with zero wealth in the next period. For that reason, in the simulations only a fraction of simulated health cost is actually paid out-of-pocket, as wealth might be insufficient.

We use as our baseline model the estimates by Ameriks *et al.* (2011) as this captures out-of-pocket expenses and expenses paid by Medicaid for the largest part. To be more precise, it captures long-term care cost paid both by Medicaid and out-of-pocket but not the Medicaid expenditures on regular health cost. Ameriks *et al.* (2011) estimate a health status transition matrix capturing transition probabilities into long-term care, which is the largest cost. Then, the cost in this long-term care health status is calibrated to capture not only out-of-pocket expenses but also the part picked up by Medicaid, which, as outlined, is exactly what we need for our simulation experiment. A disadvantage of this health cost process is that health cost is discrete and can take only three values, depending on the specific health status of the person. Hence, we do several tests to show that our results do not hinge on the discrete nature of the health cost process in Ameriks *et al.* (2011). These results are shown in subsection 3.1.

A disadvantage of the model by De Nardi *et al.* (2010) is that, for our goal, it underestimates the health cost risk individuals face, in particular, early in retirement. The reason is partly that the data set used to estimate the process does not include Medicaid expenses and contains a relatively healthy subsample of the elderly population. Individuals in the AHEAD data set, which is a part of the HRS, are non-institutionalised and over 70 at the start of the survey in 1994. Also in our own estimated model Medicaid expenses are not included. Another disadvantage of our own estimated model is that we had to split the sample based on age to get a better estimate of the tail of health cost risk at younger ages. More details on this are in Appendix A.

Part of the difference between the three specifications is also due to the difference in modelling, namely continuous health cost versus discrete health cost. Furthermore, the cost in each health state is independent of age in Ameriks *et al.* (2011). We use our own health cost model to assess the sensitivity of our main results to the discreteness of the specification of Ameriks *et al.* (2011) and the age-independent cost in each state.

For many individuals, health cost risk early in retirement can be high. However, we do not know whether the actual health cost risk coincides with the perceived health cost risk of individuals. Furthermore, for several groups, health cost risk early in retirement will deviate from the 'average' risk; for instance, wealthy individuals tend to live longer and are in better health than less wealthy agents. Hence, for some groups high/full annuitisation can still be optimal. Another caveat is that out-of-pocket expenditure risk is not very high in every country, while in most countries voluntary annuitisation levels are indeed low. This fact makes the argument that high health cost risk can explain the annuity puzzle less appealing. However, it should be noted that generally countries with low health cost risk also have higher pre-annuitised wealth levels. This could explain part of the low voluntary annuitisation levels in countries with low health cost risk.

3. Annuity Levels and Health Cost Risk

3.1. *Optimal Annuity Demand at Retirement with Health Cost Risk*

Full annuitisation is optimal in a world where individuals only face longevity risk (Yaari, 1965). However, this result may no longer hold if individuals face substantial health cost risk which raises liquidity needs. In Table 2, we present the optimal annuitisation levels at age 65, adopting optimal post-retirement consumption and asset allocation strategies. The optimal annuity levels are presented in two different formats: panel (*a*) shows the percentage in annuities as a fraction of liquid financial wealth and panel (*b*) shows the optimal percentage in annuities as a fraction of total wealth, where total wealth is the sum of pre-annuitised wealth and liquid financial wealth. Using the HRS data, we estimate that the average fraction of total wealth pre-annuitised is 80%.[8]

In Table 2, we see that the optimal annuitisation level is reduced due to health cost risk. Focusing on panel (*a*), we find that a woman in good health optimally annuitises none of her liquid wealth when facing medical cost risk according to the baseline health cost model by Ameriks *et al.* (2011), compared to 90% when not facing this risk. The benefits of insurance against longevity risk and receiving the mortality credit are outweighed by the (initial) reduction in liquidity leading to very low consumption if large health cost does indeed materialise. This result is similar for men and women, and in bad and good health, using our baseline health cost model by Ameriks *et al.* (2011).[9]

While the model by Ameriks *et al.* (2011) is more suitable for our analysis, we can use the health cost process in De Nardi *et al.* (2010) as an experiment to disentangle the drivers of annuity demand. We see that the optimal annuity demand is almost 100% when people face health cost risk according to the estimates in De Nardi *et al.* (2010).

Table 2

Optimal Annuitisation Levels for Women and Men in Good and Bad Health Status

	Women			Men		
	Total (%)	Good health (%)	Bad health (%)	Total (%)	Good health (%)	Bad health (%)
Panel (a): annuitisation as a fraction of liquid financial wealth						
Ameriks health cost model – baseline	0	0	0	20	30	0
De Nardi health cost model	90	85	95	100	100	100
Own estimates health cost model	0	0	0	40	45	25
No health cost	90	90	90	100	100	100
Panel (b): annuitisation as a fraction of total wealth (liquid financial wealth plus pre-annuitised wealth)						
Ameriks health cost model – baseline	70	74	62	84	86	79
De Nardi health cost model	98	97	99	100	100	100
Own estimates health cost model	72	75	65	88	89	85
No health cost	98	98	98	100	100	100

Notes. We show the optimal annuitisation levels for people in good health and bad health, both for women and men. Panel (*a*) shows the optimal annuitisation as a fraction of liquid financial wealth only and panel (*b*) as a fraction of total wealth (sum of liquid financial wealth and pre-annuitised wealth). Using the HRS, we estimate that the average fraction of total wealth pre-annuitised is 80%. Hence, if then, for instance, the optimal fraction of total wealth annuitised is 86% (panel (*b*); men in good health facing health cost according to Ameriks *et al.* (2011), presented as a fraction of liquid financial wealth, this is 30% (panel (*a*)). In the column labelled 'total' we show the overall optimal annuitisation level, which we calculate using the fraction of people in good health and bad health observed in the HRS data, which is 70% and 30% respectively.

[8] The annuity income consists of (employer) pension and annuity income, social security retirement income and supplemental social security income. This income is converted into pre-annuitised wealth by calculating the present discounted value of pension income by taking the survival probabilities into account and by using the same discount rate as in the annuity pricing equation (see (12)). Total wealth consists of pre-annuitised wealth, financial wealth, business wealth and IRAs (individual retirement accounts).

[9] The optimal conditional fraction allocated to stocks is about 75% in the simulations compared to about 50% in the data. Including a small participation fee would bring this number more in line with the data, since in the simulations many individuals have little wealth and invest this fully in stocks. However, to keep our model parsimonious we did not include this feature, as it would not alter our main result.

The rationale of this apparent difference in results for the two health cost models lies in the timing of health cost. In the Ameriks *et al.* (2011) health cost model, sizeable cost can already occur early in retirement while this is not possible under the De Nardi *et al.* (2010) specification (Figure 1). In the case of low health cost risk early in retirement, the retiree has enough time to build a large buffer out of the annuity income to insure against health cost later in life and thus can still profit from the mortality credit. However, if out-of-pocket medical expense risk is already high early in retirement, an individual cannot save enough in the first years of retirement to insure against almost immediate high expense risk. Since the cost in utility terms of receiving the minimum consumption level is high, an individual will only annuitise part of her wealth to be able to smooth consumption in case of high health cost.

One potential worry could be that the previous results are driven by either the discrete nature of the health cost in Ameriks *et al.* (2011) or the slowly increasing nature of health cost in De Nardi *et al.* (2010). We can test this using our own continuous health cost model which is similar in spirit to the model in De Nardi *et al.* (2010) but uses a more comprehensive data set.[10] In this model health cost is continuous and high early in retirement. This allows us to test whether our results are not driven by the discrete nature of the health cost in Ameriks *et al.* (2011). Furthermore, health cost risk early in retirement using our estimates is high but increases slowly with age. This also allows us to test the second concern, namely, that the low annuitisation levels using the estimates in Ameriks *et al.* (2011) compared to De Nardi *et al.* (2010) are due to the slowly changing nature of the cost in De Nardi *et al.* (2010) and not to its low level. Panel (*a*) in Table 2 shows that the optimal annuity demand is reduced substantially. We find that women facing large health cost risk early in retirement optimally reduce their annuity demand. Women in good health and bad health optimally annuitise none of their liquid wealth. Hence both concerns are alleviated; previous results using our baseline health cost specification are not driven by either the discreteness of the health cost process in Ameriks *et al.* (2011), or, relatedly, the non-slow changing nature of the health cost in that model.

Panel (*b*) shows the optimal annuitisation levels as a fraction of total wealth, where total wealth consists of pre-annuitised wealth and liquid financial wealth. This provides additional information, as we can determine whether the optimal annuitisation levels are close to the pre-annuitised levels. We find that optimal annuitisation levels using the baseline health cost model by Ameriks *et al.* (2011) range between 62% and 86%, which is roughly in line with the empirically observed average fraction pre-annuitised of 80%. The optimal levels using our baseline model are slightly lower for people in bad health, compared to good health. The reason is twofold; first when in bad health the survival probabilities are lower while the annuity is priced according to survival probabilities of the average person. Second, health cost risk is higher when in bad health. The previous results also hold for men. The optimal annuity demand is reduced substantially due to out-of-pocket medical expenses but to a slightly lesser extent than for women. This is not surprising since men face lower out-of-pocket

[10] We do not use our own estimates as the baseline health cost model as they suffer from several drawbacks, which our baseline model by Ameriks *et al.* (2011) does not suffer from. Details are in subsection 2.6 and Appendix A.

medical expenses, hence need less liquid wealth to cover these expenses (nursing home utilisation is higher for women (Brown and Finkelstein, 2007)). Throughout the article we show optimal annuitisation levels as a fraction of total wealth, as this allows us to assess whether the optimal levels are substantially different from pre-annuitised levels.

Health cost risk decreases the attractiveness of annuitisation due to the trade-off it creates between longevity risk insurance and the need for liquidity. This trade-off also potentially limits the welfare differences if people hold suboptimal levels. Figure 2 shows the welfare differences due to deviations from the exact point estimate of optimal annuitisation. The black bars are the optimal level, which correspond with the optimal levels in Table 2. The grey areas are the welfare boundaries, and the darker the area, the higher the welfare boundaries. In panel (*a*), we can see that a woman in good health who faces medical expense risk according to Ameriks *et al.* (2011), has at most a loss in welfare of 1% if she annuitises at any level between 41% and 93% of total wealth. These boundaries can be thought of as indifference bounds, which shows that large deviations from optimal levels will result in relatively small reductions in welfare. Mitchell *et al.* (1999) estimate welfare gains from annuitisation (optimal versus no annuitisation) of around 35% when agents do not face health cost.[11] For both men and women, in either bad or good health, the gains from annuitisation largely dissipate for people facing these large health cost risks early in retirement. When people are not exposed to health cost risk, the 1% welfare loss boundary ranges from 86% to 100% and the 10% loss boundary from 55% to 100%. In this case large deviations from the optimal can result in large welfare losses. Similar welfare losses are estimated when health cost risk is low early in retirement, as in De Nardi *et al.* (2010). This is intuitive as large health cost risk late in life does not have large utility consequences, as the probability of survival to that age is low. Thus welfare losses are similar to those when not facing health cost risk at all. In contrast, when facing health cost, as estimated using our own health cost model, we see that the welfare differences are small. This is intuitive as the health cost risk is already high early in life, similarly as in our baseline health cost model by Ameriks *et al.* (2011).

3.2. *Flexible Annuitisation after Retirement*

In the previous Section, we assumed that agents can annuitise once, at age 65. However, in principle in most countries agents can buy annuities at every point in time. Figure 3 shows the optimal annuitisation pattern and 3% welfare loss region when agents are able to buy annuities at every age. This analysis and subsequent analysis are shown for our baseline health cost model (Ameriks *et al.*, 2011) only.[12] If an agent annuitises at any level within this region, the maximum welfare loss is 3%.[13] We assume that it is never possible to resell annuities in this analysis. Panel (*a*) shows the results when agents face health cost risk, whereas panel (*b*) shows the results when agents do

[11] We estimate welfare gains of 31% when agents do not face health cost.
[12] The results using the other two health cost models are available upon request
[13] To compare, the welfare losses estimated in the annuitisation literature are often more than 30% (Mitchell *et al.*, 1999).

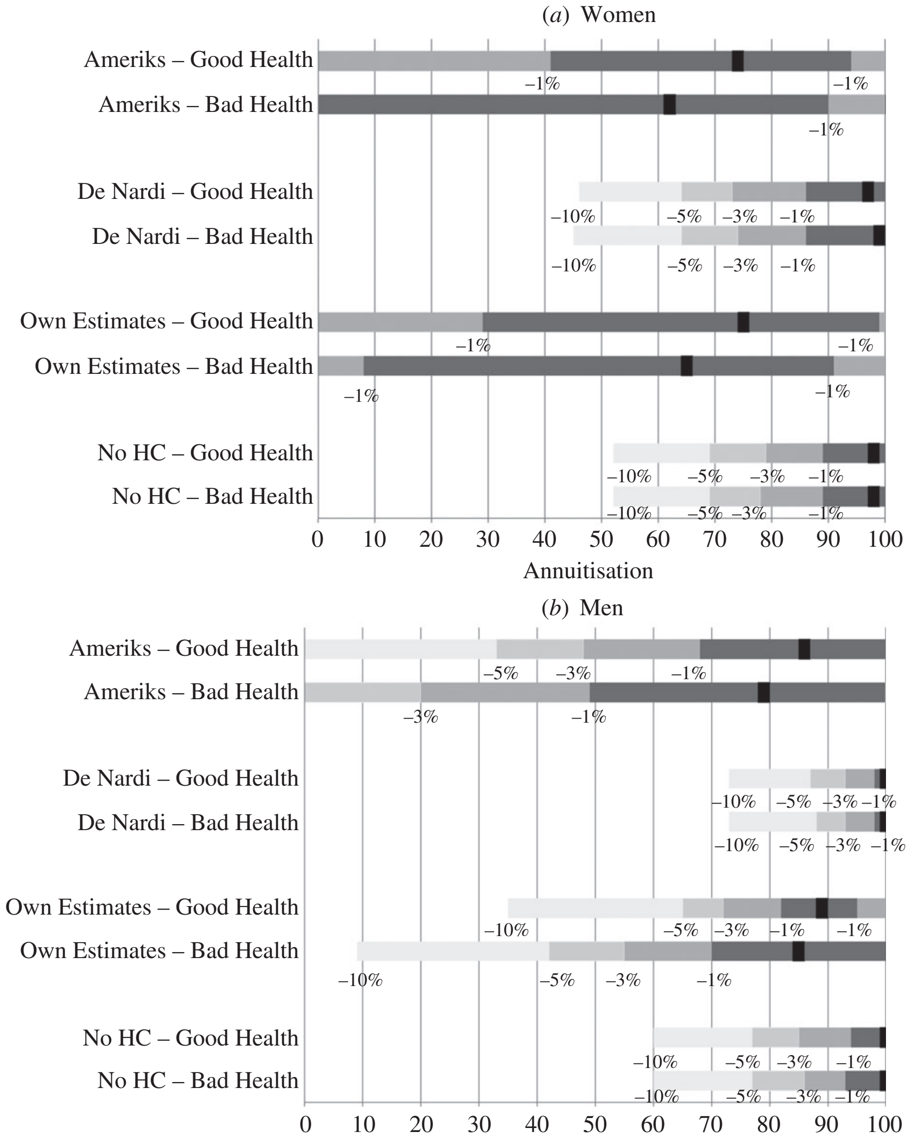

Fig. 2. *Welfare Losses for Various Annuitisation Levels*

Notes. The Figure displays welfare boundaries for annuitisation levels. Panel (*a*) shows the results for women, panel (*b*) for men. The black bars present the optimal annuitisation levels and the grey bars the welfare boundaries. The darker the bar, the lower the welfare loss.

not face this risk. The stars in the graphs present the average empirically observed annuitisation levels for different ages. Focusing on panel (*a*), we see that it is optimal to annuitise little of total wealth early in retirement but, after a couple of years, when the mortality credit starts rising, it is optimal to annuitise about 90% of total wealth. This is intuitive, as due to the health cost risk it is optimal to keep a large amount of wealth

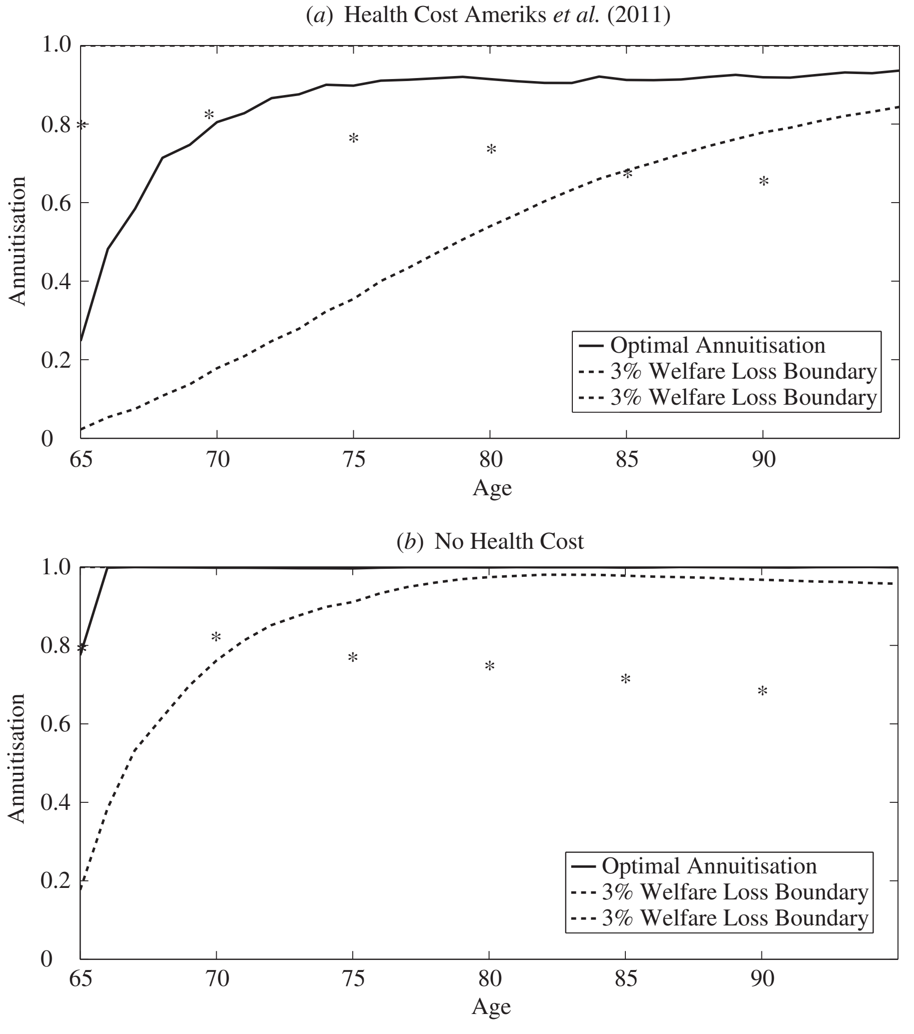

Fig. 3. *Annuitisation Levels over the Life-cycle with Flexible Annuity Timing*

Notes. We show optimal annuitisation levels and a 3% welfare loss region for agents that have the possibility to annuitise additionally at every age. Any annuitisation level within this region leads to a welfare loss of at most 3%. Panel (*a*) shows the results when agents face health cost risk, panel (*b*) shows the results when agents do not face this risk. The stars in the graphs present the average empirically observed annuitisation levels (using the HRS data set). We use the HRS data to estimate pre-annuitised wealth levels. The annuity income consists of (employer) pension and annuity income, social security retirement income and supplemental social security income. This income is converted into pre-annuitised wealth by calculating the present discounted value of pension income by taking the survival probabilities (women) into account and by using the same discount rate as in the annuity pricing equation (see (12)). Total wealth consists of pre-annuitised wealth, financial wealth, business wealth and IRAs.

liquid as a buffer, since it is still possible to annuitise at a later age. However, at one point the mortality credit is such (due to low survival probabilities) that it becomes optimal to invest in annuities instead of liquid stocks. Therefore, health cost risk can explain why people do not buy annuities early in retirement, but it cannot explain why these annuities are not bought in the private market at more advanced ages.

In panel (*b*) we see that, when not facing health cost risk, the optimal annuitisation level is much higher and the 3% welfare loss region much smaller, thereby not matching the empirically observed annuity levels well. We find almost immediate full annuitisation, which differs from the more gradual switching into full annuitisation in Horneff *et al.* (2008). The reason is that they do not model inflation risk and hence inflation risk protection is not offered by real annuities, as is the case in our specification. In our model annuities have a more favourable risk-return trade-off, since annuities offer not only the mortality credit but also inflation risk protection.

In several countries more flexible annuity timing is implemented and debated. In Table 3, we explore the welfare implications of this flexible annuity timing, where the baseline is optimal annuitisation at age 65, and no annuitisation afterwards. When facing health cost risk according to Ameriks *et al.* (2011), the welfare gain from being able to annuitise optimally also at age 80 is 0.4%. Allowing additional flexibility by adding age 70 and 75 to the possible ages to annuitise improves welfare by 1% compared to the baseline. Fully flexible annuity timing increases welfare by 2.5%. The welfare gains are negligible when agents do not face health cost risk.[14] The reason for this difference in welfare gains is that, when facing health cost risk, delaying annuitisation to keep more wealth liquid and to annuitise when more information is known about a person‘s health, is welfare improving. However, when not facing health cost risk, the only reason in our model not to annuitise fully is to capture the equity premium. Almost immediately at retirement annuities dominate stocks in terms of risk-return trade-off, due to the mortality credit and inflation risk protection that annuities provide. After annuitisation the agent optimally consumes all his income and there is no wealth to annuitise. Hence the possibility to annuitise at a later age is not used. Horneff *et al.* (2008) find larger welfare gains from additional flexibility when not facing health cost risk. The reason for this difference is that, as specified before, they do not have inflation risk in their model hence more gradual annuitisation is optimal. In their case the option of delaying annuitisation and buying additional annuities is valuable.

Pang and Warshawsky (2010) use the health cost model of De Nardi *et al.* (2010), and find that annuity demand increases slightly due to these health cost. The reason for this seemingly contrasting result is that their results are based on the health cost

Table 3
Welfare Gains from Flexible Annuitisation Timing

	Age 65 and 80	Age 65, 70, 75, and 80	Every age
Health cost risk (%)	0.4	1.0	2.5
No health cost risk (%)	0.0	0.0	0.0

Notes. We show the welfare gains from the possibility to annuitise at multiple moments during retirement. The welfare gains are relative to the baseline of optimal annuitisation only at age 65. Welfare gains are calculated for people not facing health cost risk and facing health cost risk according to Ameriks *et al.* (2011).

[14] The welfare gains are of the magnitude of 0.01%.

model by De Nardi *et al.* (2010), which implies that they do not need liquidity in the first part of retirement as then health cost risk is low. Furthermore, overall they find a more gradual annuitisation when not facing health cost risk, because inflation risk is not taken into account, a 15% load on annuities is assumed, and the real return on the riskless asset and real return on equity is, respectively, 1% and 0.5% higher compared to our returns.

3.3. *Optimal Annuitisation for Various Wealth Levels*

In this subsection, we determine the optimal annuity demand for different wealth levels using our baseline health cost model by Ameriks *et al.* (2011). Furthermore, we present the findings for people not facing health cost risk. The results are displayed in Figure 4. The black bars display the optimal annuitisation levels and the grey bars the 3% welfare loss regions. Any annuitisation level within this region leads to a welfare loss of at most 3%. The stars in the graphs present the average empirically observed annuitisation levels (estimated using the HRS data set), for the respective total wealth levels, and the percentage above every bar displays the percentage of individuals in the data that have pre-annuitised levels that fall within the 3% welfare loss region. Panel (*a*) shows the results when agents face health cost risk, whereas Panel (*b*) shows the results when agents do not face this risk. We see that, when facing health cost, the optimal annuitisation level is zero for a total wealth level of \$100,000 and 58% or higher for wealth levels at or above \$200,000. The point estimate of the optimal level differs from the average pre-annuitised level observed in the data for certain wealth levels. However, the percentage of people that falls within the 3% welfare loss region is large, ranging from 78% to 100%. For instance we see that 89% of women in the HRS data set with a wealth level between 350,000 and 450,000 fall within the welfare region when facing health cost.[15] When not facing health cost, only 60% fall within this boundary. Hence when taking into account health cost, a larger fraction of the data is matched.

Ameriks *et al.* (2011) estimate the willingness to pay (WTP) for an annuity with a price of \$85,000 which generates an income of \$5,000 per year, for a healthy 62-year old woman who has about 55% of wealth pre-annuitised.[16] They find a WTP for this annuity of 0.94.[17] We extend on Ameriks *et al.* (2011) by:

(*i*) estimating optimal annuity levels for a variety of health cost specifications;
(*ii*) performing this analysis for varying wealth levels;
(*iii*) exploring the welfare impact of deviations from the optimal level; and
(*iv*) the welfare impact of flexible annuitisation timing.

[15] The percentage of people who are over-annuitised compared to the point estimate of the optimal annuitisation level is 100%, 93%, 69%, 42% and 13% for the respective total wealth levels ranging from \$100,000 to \$600,000.

[16] The income from this pre-annuitised wealth corresponds to net present value of about \$375,000 and her liquid wealth is \$300,000. Hence total wealth is \$675,000. In effect the agent is choosing between annuitising 55% of wealth or annuitising about 70% of wealth.

[17] The willingness to pay reflects the load on top of the actuarially fair price that the individual is willing to pay for this product. Hence a WTP of 0.94 means that the individual would even need a 6% bonus to hold the annuity.

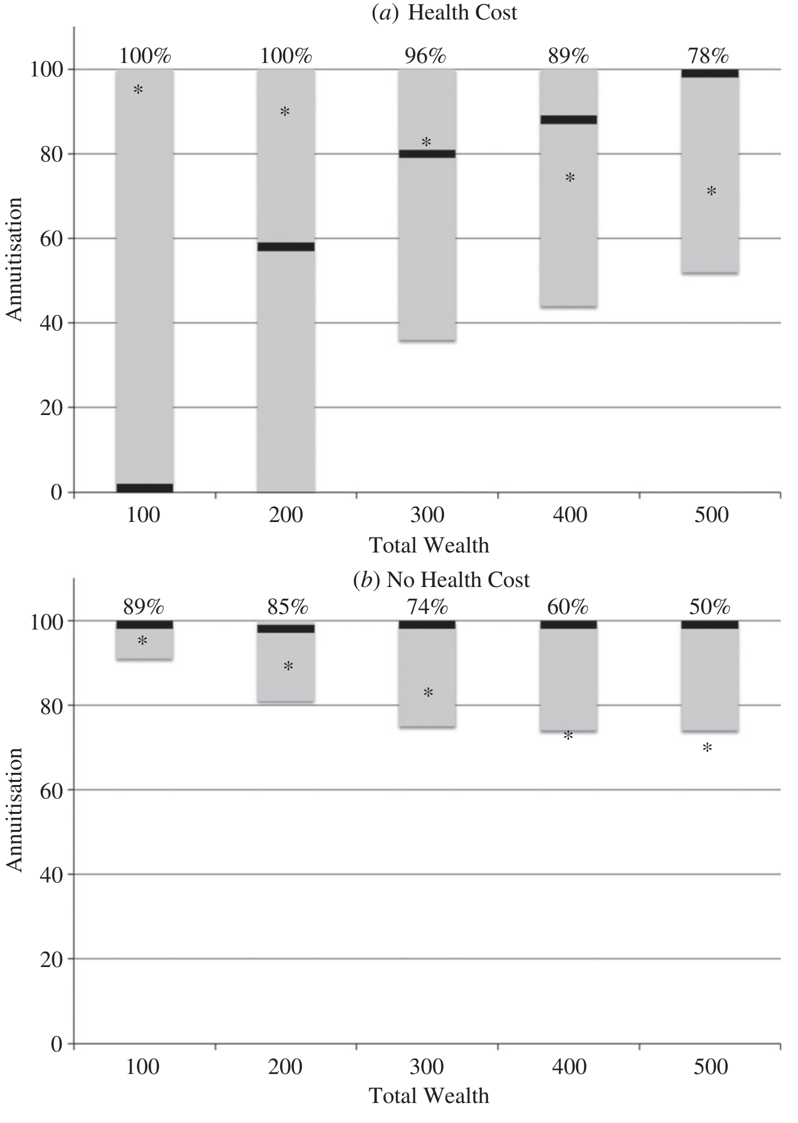

Fig. 4. *Annuitisation Levels for Different Wealth Levels*

Notes. The black bars display the optimal annuitisation levels and the grey bars the 3% welfare loss regions. Any annuitisation level within this region leads to a welfare loss of at most 3%. Panel (*a*) shows the results when agents face health cost risk, panel (*b*) shows the results when agents do not face this risk. The stars in the graphs present the average empirically observed annuitisation levels (using the HRS data set), for the respective total wealth levels, and the percentage above every bar displays the percentage of individuals in the data that have pre-annuitised levels that fall within the 3% welfare boundary. We use the HRS data to estimate pre-annuitised wealth levels. The annuity income consists of (employer) pension and annuity income, social security retirement income and supplemental social security income. This income is converted into pre-annuitised wealth by calculating the present discounted value of pension income by taking the survival probabilities into account and by using the same discount rate as in the annuity pricing equation (see (12)). Total wealth consists of pre-annuitised wealth, financial wealth, business wealth and IRAs.

3.4. *Sensitivity Analysis*

In this subsection, we examine the influence of end-of-life health cost and state-dependent utility on optimal annuitisation levels. Furthermore, we will perform a robustness analysis with respect to several features of the model and parameters. More specifically, we will examine the sensitivity to the possibility of liquidating housing wealth, minimum consumption level, risk aversion, equity premium and the discount factor. There are several other factors which we will not explore that could potentially impact optimal annuity demand as well; for instance bequest motives or a load on the price of the annuity. However, our analysis predicts large precautionary savings and these savings will lead to a bequest in most instances. Furthermore, a load on the annuity price will reduce the predicted annuitised fraction slightly, which in any case would strengthen our result that out-of-pocket medical expense risk can potentially explain the annuity puzzle.

Research has shown that near the time of death health cost is substantially higher. Among others, Werblow *et al.* (2007) find that proximity to death is a more important determinant of health cost than age.[18] There is a wide variety of estimates of the size of this difference in health cost prior to death. For instance de Meijer *et al.* (2011) find that the ratio of predicted care expenditures among decedents to survivors decreases from 18 at age 55 to 1.7 at age 90, and Felder *et al.* (2000) find an average factor of 5.6. End-of-life cost is likely to be captured well in Ameriks *et al.* (2011), since a positive correlation between health cost and mortality probabilities is modelled.[19] Even so, we analyse the sensitivity of our results to end-of-life health cost by altering the model by Ameriks *et al.* (2011). Namely, we inflate the medical cost in two different experiments. In one experiment we increase the expenses in the year prior to death with a age-independent factor of 3, and in a second we increase the cost with a factor ranging from 12 at age 65 to 6.45 at age 100 (the factor decreases with 0.15 with every additional year). In Table 4, we see that the optimal annuity demand when we add end-of-life cost did not change substantially. The optimal levels are approximately 60% of total wealth, instead of 68% in our baseline result.[20]

We did not include state dependence of marginal utility in the baseline case, because there is no consensus in the literature on the relative change in marginal utility or even on whether the marginal utility is higher or lower in a bad health status (Viscusi and Evans, 1990; Edwards, 2008).[21] Finkelstein *et al.* (2013) find that marginal utility declines as the health state deteriorates and estimate that a one-standard deviation

[18] This strand of literature does not focus particularly on estimating out-of-pocket medical expenses but looks at the impact of population ageing on total health care expenditures, not only uninsured expenses (Felder *et al.*, 2000; Shang and Goldman, 2007; Felder *et al.*, 2010; Baal and Wong, 2012).

[19] The AHEAD data set, which is used in De Nardi *et al.* (2010), potentially underestimates the end-of-life health cost. The AHEAD survey does exit interviews with relatives after the survey respondent dies. However, these answers are prone to error.

[20] The baseline optimal annuitisation level to compare results from the sensitivity analysis to is 68% instead of 70%, which was the average optimal annuitisation level in Table 2. The reason is that in Table 4 we run the simulations starting 70% of trajectories with good health and 30% with bad health. However, in Table 2 we run separate simulations for people in good health and bad health, and later combine both results using the same fraction of health status in the population at age 65 (70% in good health, 30% in bad health).

[21] An overview of this literature is provided in Finkelstein *et al.* (2009).

Table 4

Sensitivity Analysis – Optimal Annuitisation Levels for Women

	Fraction of liquid wealth (%)	Fraction of total wealth (%)
Baseline model	0	68
End-of-life cost higher by factor 12-6	0	63
End-of-life cost higher by factor 3	0	60
Marginal utility 20% higher in bad health	0	69
Marginal utility 20% lower in bad health	0	64
Housing as source liquidity	5	81
Minimum consumption level $5,000	0	75
Equity premium 2%	0	79
Equity premium 6%	0	0
Risk aversion 8	0	63
Risk aversion 2	0	0
Time discount rate 0.98	10	82
Time discount rate 0.94	0	52

Notes. We perform sensitivity analysis for end-of-life health cost, health state dependent marginal utility, housing as a source of liquidity, minimum consumption level, equity premium, risk aversion and time discount rate.

increase in the number of chronic diseases leads to a decline in marginal utility of 10–25%.[22] In Table 4, we display the optimal annuitisation levels when the marginal utility in the bad health state declines by 20% or increases by 20%. We find that the optimal annuity demand is altered little hence our main results are unaffected by health state dependence of the utility from consumption.

In our baseline case, we abstract from housing wealth as a way to get liquidity for a number of reasons. First, it is generally costly to get a reverse mortgage. Closing costs are on average about 6.8% of the property value (Davidoff and Welke, 2007). That paper also notes that these high closing costs are cited as one of the major reasons for the relative small demand for reverse mortgages. Rodda *et al.* (2000) report that a Home Equity Conversion Mortgage (HECM) borrower has a median adjusted property value of about $102,000, median initial principal limit of $54,000 and median closing cost of $3,400. Second, empirical evidence shows that retirees generally do not sell their house, which would also be a way to liquidate housing wealth. Yang (2009) finds that transaction costs are a major factor in the slow downsizing of the housing stock later in life. This is further supported by Davidoff (2010) and Venti and Wise (2000) who show that retirees typically only sell their house when they move to a long-term care facility. Individuals appear to attach a high value to staying in their home and not having to move.

As a robustness test we assume that half of housing wealth can be made liquid without incurring cost. We use the HRS data to obtain housing wealth for our baseline total wealth level. The median net housing wealth is about $50,000. We see that the optimal voluntary annuitisation level is still almost zero, however, presented as a

[22] Their measure of health status is the number of chronic diseases that an individual has ever been told by a doctor that she has had. The seven chronic diseases used are hypertension, diabetes, cancer, heart disease, chronic lung disease, stroke and arthritis.

fraction of total wealth the optimal annuity demand is slightly higher when half of housing wealth can be made liquid. This is intuitive, as part of the house can be made liquid in the event of health cost shocks, and thus less liquid financial wealth is needed as a buffer. In accordance with our results, Pashchenko (2013) finds that the effect of housing wealth on participation in the annuity market is limited.

Since the consumption floor varies per country, we determine how that changes optimal annuity demand. We see that for the baseline wealth level the optimal annuity demand is higher for a lower minimum consumption level. Pashchenko (2013) finds a similar result, the minimum consumption level substitutes for annuities, hence, the lower the minimum consumption level, the less good the substitution.

Focusing on the equity premium, we see that the optimal annuitisation level decreases with the equity premium. This is intuitive since if the return on equity is very high, it is optimal for agents to keep more wealth liquid and invest this in stocks.

In the case of higher risk aversion, optimal annuity demand is basically unchanged. However, in the case of low risk aversion, zero annuitisation is optimal. Risk aversion has two main effects; low risk averse people have less incentive to smooth health cost shocks and keep a liquid wealth buffer. This can lead to higher optimal annuity demand. On the other hand, lower risk aversion makes stocks more attractive which is an alternative investment to annuities. We find that low risk aversion leads to less annuitisation, hence the latter effect dominates. As in the robustness analysis regarding the equity premium, we see that stock investments can be important for optimal annuitisation decisions.

If the rate of time preference is 0.98, the optimal annuitisation level is slightly higher, 82% of total wealth. The reason is that the agent puts relatively more weight on older ages compared to in our baseline model. This makes annuity income more valuable at future ages, and thus annuities more attractive.

4. Conclusion

We examine the effect of medical expenses on optimal annuity demand. Medical expense risk increases the need for liquidity, which could induce households to annuitise less and keep wealth liquid. We find that health cost risk can reduce optimal annuity demand at retirement. We perform several experiments using different health cost models and uncover that health cost risk, especially early in retirement, is important. If health cost can already be high in early retirement it is not optimal to annuitise all wealth, since the retiree cannot save enough out of the annuity income in a few years to cover these expenses. The only way to have a buffer against these expenses in early years, is to reduce the annuitisation level. In contrast, if the medical expense risk is only moderately high, it is optimal to annuitise fully and subsequently save sizeable amounts out of the annuity income to build up a buffer. This buffer at the same time can be used to profit from the equity premium. If in that case the agent is hit by a health shock later in retirement, the savings are high enough to pay the health expenses and smooth consumption. Furthermore, we provide empirical evidence for high health cost risk early in retirement.

The welfare losses from large deviations from optimal are small when agents face health cost risk. When comparing the simulation results to the data, we find that a model with health cost risk can explain a large fraction of the annuitisation levels observed in the data. Our results are robust to allowing additional annuitisation after retirement; agents annuitise less at retirement. However, after age 75 they annuitise optimally around 90% of total wealth, as the mortality credit becomes very high at more advanced ages. Hence we cannot explain why many people do not buy annuities at older ages. Furthermore, we find that the welfare gains from having the possibility of buying additional annuities at age 80, on top of at age 65, is 0.4% when facing health cost risk. Allowing annuitisation every year increases welfare by 2.5% compared to only at age 65. When people do not face health cost risk, the welfare gains from the possibility of additional annuitisation after retirement are negligible.

Our article also shows the sensitivity of optimal annuitisation decisions to the exact specification of the medical expense process. This highlights a need for further improvements in available data to estimate medical expense risk and assess the impact of these cost on financial decisions.

Appendix A. Details Own Health Cost Model Estimates

A brief supplementary description is provided in subsection 2.4. Health cost is the sum of what individuals spend out-of-pocket on insurance premia, drug cost, cost for hospital, nursing home care, doctor visits, dental visits and outpatient care. Individuals face three sources of risk, which are treated as correlated but exogenous: survival uncertainty, health status uncertainty and medical expense uncertainty.

- Health status uncertainty. A person can be in a good or bad health status. The transition probabilities between health states depend on the previous health status (h), gender (g) and age (a).
- Survival uncertainty. The probability that a person is alive the next period depends on his health status, age and gender.
- Medical expense uncertainty. Expected health cost and health cost risk depend on gender, health status and age. Moreover, idiosyncratic health cost shocks are autocorrelated.

Both the mean and the variance of the log medical expenses thus depend on gender, health status, permanent income and age:

$$\ln m_t = m(g, h, a) + \sigma(g, h, a)\psi_t, \tag{A.1}$$

where ψ_t is modelled as:

$$\psi_t = \varsigma_t + \xi_t, \quad \xi_t \sim \mathrm{N}(0, \sigma_\xi^2),$$
$$\varsigma_t = \rho_m \varsigma_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim \mathrm{N}(0, \sigma_\varepsilon^2).$$

Here ξ_t and ε_t are serially and mutually independent. This setup allows for empirically observed autocorrelation patterns in expenses.

We estimate the process for medical expenses separately for age 65–74 and for age 75–100, and we find different parameters using the two samples. The reason for splitting the sample is that we are particularly interested in the tail of health cost risk at young ages, which can be better estimated by splitting the sample in two. In the data set as a whole, the numbers of respondents between the ages of 65 and 74 are only 16% of the total data set, whereas in reality this is a much larger fraction of older Americans.[23] Using the entire sample would put relatively less weight on

[23] Survey weights are not available for institutionalised individuals nor for the exit interviews.

young ages and results in an underestimation of health cost risk at these younger ages, which is exactly what we are trying to capture. Hence we estimate the model separately for the 65–74 year olds, and the 74–100 year olds. The estimates are available upon request.

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Additional Supporting Information may be found in the online version of this article:

Appendix B. Numerical Method to Solve the Life-cycle Problem.
Data S1.

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