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Abstract

This paper develops an equilibrium model of the annuities market where agents have private information about their mortality, and where the predictive value of this information decays over time. The paper shows that in this case, insurance companies will observe a duration-related trend in the mortality of annuitants under certain conditions. This effect is tested for using a Cox proportional hazards methodology and data from the South African annuities market, which since the early 1990's has permitted phased withdrawals of retirement savings instead of mandating pure annuitisation. Evidence is equivocal: substantial differences are found between the duration-related mortality trends of different insurance companies, data problems seem to have some effect, and factors outside the model which might change the results cannot be excluded. However, the presence of a strong duration-related trend cannot be decisively rejected. The observed trend indicates that mortality at earlier policy durations is better than at later durations by the equivalent of about 6 years of age, although data factors cannot be precluded as a cause of this trend.

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1. Introduction

Private annuity markets are an important area of study for economists. Annuities are relevant to many different aspects of economic behaviour - including the demand for insurance, asymmetric information, bequest motives, and investment and consumption behaviour. The shift in many countries from defined benefit to defined contribution pension plans, which will continue to reduce the proportion of assets held by future retirees that is already annuitised, gives greater importance to the study of private annuity markets. Yaari (1965) pointed out the tremendous insurance benefits that annuities offer purchasers. These benefits are so large that simple models predict they should be prepared to sacrifice a large fraction of their wealth in order to purchase annuities. Yet, in virtually every country, individuals need to be forced to purchase annuities. Various explanations have been offered for this. These include the fact that individuals are able to insure themselves against living too long because they are married or because they have children who will support them in old age (Brown and Poterba, 2000), the presence of bequest motives (Bernheim, 1991), the fact that a large fraction of wealth is pre-annuitised anyway (Mitchell *et al.*, 1999), and precautionary motives that might cause individuals to prefer liquid assets over annuities, such as the possibility of health shocks (Brown, 2001). A summary of this literature can be found in McCarthy and Neuberger (2003).

One other factor that is often cited to explain low annuity purchase rates is that asymmetric information causes a failure in the annuities market. The theory states that individuals have private knowledge about their longevity. Individuals who perceive that annuities are better value - *i.e.* those who believe that they will live for a long time - will purchase more annuities than those who do not - which will cause annuities to be more expensive than they would be if everyone had no knowledge about their longevity or if insurance companies were able to measure the information that people had about their own longevity absolutely perfectly. Various studies (e.g. McCarthy and Mitchell, 2002) have documented the lower mortality of annuity purchasers relative to the general population in virtually every annuity market. However, commentators remain divided about the extent to which this difference is the result of asymmetric information in the annuities market or merely a reflection of the different characteristics of annuity purchasers that are, at least in principle, observable, such as wealth and employment status. This distinction may have important implications for economic policy on mandating annuity purchase from individual account-type pension schemes.

This study uses a new data set and a novel technique to test for the presence of adverse selection in the South African annuities market. The South African annuities market is an interesting case study for reasons which will be discussed below. Section 2 will discuss the theory underlying the method used to test for adverse selection, section 3 will discuss the data used in more detail and section 4 will present results. Section 5 will be a conclusion.

2. Theory

Several techniques have been used to test for adverse selection in insurance and annuities markets. Three papers are Cawley and Philipson (1999), Finkelstein and Poterba (2002) and Mitchell and McCarthy (2002). The method adopted here bears closest resemblance to Finkelstein and Poterba (2002). Cawley and Philipson (1999) use data from the US life insurance market. They test for various implications of a Rothschild-Stiglitz-type separating equilibrium in the life insurance market: a positive relationship between self-perceived risk and the price of insurance, the absence of bulk discounts, a negative relationship between risk and quantity of insurance purchased and the prediction that individuals should hold only one insurance contract. They find convincing evidence that none of these predictions hold in their data and conclude that the Rothschild-Stiglitz theory does not apply to the US life insurance market. Finkelstein and Poterba (1999) test for adverse selection in the UK annuities market. They demonstrate that purchasers of different annuity products in the UK have different mortality risk profiles, and show that these differences are priced into the annuity products. They take this as evidence that there is a separating equilibrium in the UK life annuities market, by product type. McCarthy and Mitchell (2002) illustrate that purchasers of annuities have different mortality profiles to the general population in most countries where annuities are sold, and that there are regular patterns to these differences across countries. Neither of the two papers that deal with annuities markets is able to demonstrate that the difference between the mortality profiles of purchasers of different annuity types (or of purchasers and non-purchasers) is the result of asymmetric information or of factors that may be correlated with unobserved factors underlying the decision to purchase an annuity, such as risk aversion, wealth, and the presence of a bequest motive.

This paper uses a different methodology to test for asymmetric information. The effect underlying the test is the decline in the predictive value of a given set of information over time. This decline is probably best understood by an example: the level of the stock market today tells one a great deal about the level of the stock market tomorrow, but it tells one almost nothing about the level of the stock market in 20 years. A similar example is the information that insurance companies collect during underwriting about the likely mortality of individuals who apply for life insurance. Individuals who pass a certain health standard are permitted to buy insurance at standard rates, other individuals are not. The predictive power of this information on mortality rates is initially high but declines over time. In the case of insurance, one can actually observe the effect: individuals who have recently purchased their insurance policies have lighter mortality than those who are identical in every other respect save for the fact that they purchased their insurance policies earlier. An example of this effect, taken from real data collected from life insurance companies in the United Kingdom, is shown in Figure 1. It shows the mortality of life insurance purchasers aged 50 who purchased their insurance policies at age 50, 46-49 and before age 46. The procession of fitted mortality is then shown as the different individuals age. Initially, recent purchasers of life insurance have mortality very much lighter than the average for all those who are their age who have purchased insurance, but that this difference gets smaller as individuals age. One explanation for this effect is due to the decline in the value of the information that the insurance company collected about the individual's state of health at the time of purchase, for explaining the health status of the individual many years later. Of course, it is also possible that some other factor correlated with mortality and the decision to purchase insurance declines in a similar way. For instance, it might be that wealthy individuals purchase insurance and that if one is wealthy when one purchases insurance it says relatively little about whether one will be wealthy in the future. Also, another factor may be operating in the life insurance market: because individuals do not commit to purchase insurance indefinitely, but can choose to lapse their policies if they so wish, it may be that individuals with lower probabilities of dying have less need for insurance and so selectively lapse their policies. Of course, one needs to posit some factor that explains why they only realise this after they have purchased the policy as opposed to before!

However, the example raises an interesting question: if we make the assumption that the private information one had about one's mortality at a certain point becomes less and less useful at predicting one's mortality as one ages, what implication does this have for the observed pattern of mortality in a pool of annuitants? In the next few paragraphs, we formalise some of the ideas discussed here and answer this question.

To model this effect, let us assume that we have a continuum of individuals. Individuals differ from each other in two ways: some people are healthy (type h) and some are unhealthy (type u), and each individual has a fixed parameter θ which affects how willing they are to annuitise their assets, which will be discussed later. Other than this, individuals are initially assumed to be identical to each other.

Assume that healthy individuals can either become unhealthy (with probability λ) or die (with probability q_h) in each period. Similarly, unhealthy individuals can either become healthy (with probability η) or die (with probability q_u) in each period. Assume that these probabilities are independent of θ, and that they remain constant until all individuals in a given cohort are dead. An illustration of this model is shown in Figure 2. We could introduce a time trend in the mortality probabilities to mimic the effect of population ageing, but this would add unnecessary complications.

Assume that individuals know their own type but that this is private information: outsiders cannot observe what type they are. Each individual's θ is also assumed to be private information.

Under certain very mild conditions discussed in appendix A, in this model there exists a steady state proportion of individuals who are healthy, which, once reached, will not change from year to year. Let us assume that these mild conditions hold, and that the proportion of individuals who are healthy is at the steady state, p. This is simply equivalent to saying that, over time, the proportion of individuals in our population who are classified as healthy or unhealthy (relative to their peers) does not change. This is slightly artificial, but given that the emphasis of the model is on relative health within a given population, rather than on some absolute standard of health, it is not too onerous.

Into this environment, we introduce a market for life annuities which pay constant units of consumption until the death of the individual, and we offer a one-off option to purchase a life annuity to all population members. The parameter θ affects each individual's demand for annuities. For convenience, suppose that θ represents the fixed cost of purchasing an annuity - it could equally represent a bequest motive, or the extent to which the individual's wealth is pre-annuitised. Assume that the distribution of θ in the population of healthy and unhealthy people is identical, and that each individual's θ does not change over time. Let θ be defined over the range $[0, \theta_{max}]$, and let the distribution of θ be represented by the density function p_θ. The fact that θ is private information implies that individuals do not reveal their health type to annuity companies when they purchase annuities.

Let a_h denote the present value of a life annuity for an individual who is in the 'healthy' state and let a_u denote the present value of an annuity for an individual who is currently 'unhealthy'. Note that these values do not depend on the age of the individual as our individuals are assumed not to age. Assume for convenience that the risk free interest rate is constant equal to r, and that the annuity payments are made at the end of each time period rather than continuously.

To derive formulae for the expected discounted present value of annuities for individuals who are currently healthy (a_h) and unhealthy (a_u), we note that if the healthy individual is alive at the end of the first period (probability, $1-q_h$), we need to pay him an annuity payment of 1. If the individual is healthy (probability, $1-\lambda-q_h$), the value a_h will be sufficient to buy out all future annuity payments. If the individual is unhealthy, (probability λ) then the value a_u will be sufficient to buy out all future payments, while if the individual is dead, (probability q_h) then the value of all future payments will be 0.

This reasoning, and similar reasoning for the case of the individual who is currently unhealthy, yields a set of simultaneous equations in a_u and a_h:

$$(1+r)a_h = 1\cdot(1-q_h)+a_h\cdot(1-\lambda-q_h)+a_u\cdot\lambda+0\cdot q_h \quad (1)$$

$$(1+r)a_u = 1\cdot(1-q_u)+a_u\cdot(1-\eta-q_u)+a_h\cdot\eta+0\cdot q_u$$

These equations can be solved to yield the following equations for a_u and a_h:

$$a_h = \frac{(1-q_u)\lambda+(1-q_h)(\eta+q_u+r)}{(\lambda+q_h+r)(\eta+q_u+r)-\eta\lambda} \quad (2)$$

$$a_u = \frac{(1-q_h)\eta+(1-q_u)(\lambda+q_h+r)}{(\lambda+q_h+r)(\eta+q_u+r)-\eta\lambda}$$

By taking simple differences, it will be seen that $a_h > a_r \Leftrightarrow q_h < q_u$ as we would expect.

The implication of this is that the expected discounted present value of a level annuity in the hands of a currently healthy individual is worth more than the same annuity in the hands of a currently unhealthy individual.

Now, if we make the assumption that the insurance company cannot observe the total quantity of annuities that an individual has purchased then a separating equilibrium in the annuities market, along the lines of Rothschild and Stiglitz (1976), is impossible. This is because their result depends on the insurance company being able to observe the value of the loss and the quantity of insurance purchased. Following Abel (1986), we therefore must have a pooling equilibrium. Each insurance company must charge a single price for annuities, and assuming a competitive market, each must charge the value that will ensure that it makes no profit. If we assume that the proportion of individuals of a given cohort who purchase annuities who are in healthy is $x_{h,0}$, and that the proportion of individuals of a given cohort who purchase annuities who are in poor health is $x_{u,0} = 1 - x_{h,0}$, then the single price charged by the insurance company must be:

$$a = x_{h,0} a_h + (1 - x_{h,0}) a_h = a_{u,0} + x_{h,0}(a_h - a_u) \geq a_u .$$

Similarly, it can be shown that: (3)

$$a = (1 - x_{u,0}) a_h + x_{u,0} a_u = a_h - x_{u,0}(a_h - a_u) \leq a_h .$$

Now we present an annuity demand model for each type of individual. Let the expected discounted total utility of a healthy individual who optimises consumption at each future time point, conditional on an equilibrium annuity price *a*, non-annuitised wealth *w* and amount of annuity purchased, *α*, be denoted:

$$V_h(w, \alpha \mid a) = \max_{\{C_i\}} E \sum_{i=0}^{\infty} \beta^i (p_{hh}^i u(C_{h,i}) + p_{hu}^i u(C_{u,i})), \tag{4}$$

where p_{hh}^i is the probability that an individual healthy at time 0 is still healthy at time *i*, and similarly for p_{hu}^i, and $C_{h,i}$ is optimal consumption if individual is healthy at time *i*, and $C_{u,i}$ is optimal consumption if the individual is unhealthy at time *i*, and *β* is the individual's discount factor. When individuals decide how much to consume, they take into account three state variables: the amount of wealth they have on hand (*w*), the amount of annuity income they receive (*α*) and their state of health. Consumption in each period is constrained to be less than wealth in that period. All the individual's wealth is invested in an asset that pays a risk-free return of *r* per period. Hence, the individual's wealth at time *i*, denoted W_i, follows the following process:

$$W_{i+1} = (W_i - C_i)(1 + r) + \alpha . \tag{5}$$

At time 0, the individual exchanges $\alpha a + \theta$ units of wealth for an annuity that pays an annual payment of α. If the individual chooses not to annuitise any wealth, then they do not pay the fixed cost *θ*. The optimal values of *α* for individuals in different states are therefore given by:

$$\hat{\alpha}_h(a, \theta) = \arg\max_{\alpha} V_h(w_0 - \alpha a - \theta 1_{\alpha > 0}, \alpha \mid a), \text{ and}$$

$$\hat{\alpha}_u(a,\theta) = \arg\max_{\alpha} V_u(w_0 - \alpha a - \theta 1_{\alpha>0}, \alpha \mid a)\,. \tag{6}$$

We assume that $\hat{\alpha}_h(a,\theta_{\max}) = 0$: in other words, there is at least one healthy individual for whom purchasing an annuity is so expensive that the optimal purchase amount is 0. Further, we know from Yaari (1965) that $\hat{\alpha}_h(a,0) = W_0 / a$: given annuities that are at least fairly priced, individuals will annuitise all their wealth in simple models like this if there are no transactions costs.

Model solution

Our agents choose consumption according to the following program:

$$V_h(w_0,\alpha \mid a) = \max_{\{C_i\}} E\sum_{i=0}^{\infty} \beta^i (p_{hh}^i u(C_{h,i}) + p_{hu}^i u(C_{u,i}))\,, \tag{7}$$

$$V_u(w_0,\alpha \mid a) = \max_{\{C_i\}} E\sum_{i=0}^{\infty} \beta^i (p_{uh}^i u(C_{h,i}) + p_{uu}^i u(C_{u,i}))$$

Remembering that the level of *a* is given, the Bellman equations for the agents in each state are:

$$\begin{aligned} V_u(w,\alpha) = \max_{C_u(w,\alpha)} & u(C_u(w,\alpha)) + \beta(1-q_u-\eta)V_u((w-C_u(w,\alpha))(1+r)+\alpha,\alpha) \\ & + \beta\eta V_h((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)\,. \end{aligned} \tag{8}$$

$$\begin{aligned} V_h(w,\alpha) = \max_{C_h(w,\alpha)} & u(C_h(w,\alpha)) + \beta(1-q_h-\lambda)V_h((w-C_h(w,\alpha))(1+r)+\alpha,) \\ & + \beta\lambda V_u((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)\,. \end{aligned}$$

Differentiating with respect to $C_u(w,\alpha)$ and $C_h(w,\alpha)$ gives the first order conditions of each equation, and setting these equal to 0 for a maximum yields the following two equations:

$$\begin{aligned} u'(C_u(w,\alpha)) &= \beta(1-q_u-\eta)(1+r)V_u'((w-C_u(w,\alpha))(1+r)+\alpha,\alpha) \\ &\quad + \beta\eta(1+r)V_h'((w-C_u(w,\alpha))(1+r)+\alpha,\alpha) \end{aligned} \tag{9}$$

$$\begin{aligned} u'(C_h(w,\alpha)) &= \beta(1-q_h-\lambda)(1+r)V_h'((w-C_h(w,\alpha))(1+r)+\alpha,\alpha) \\ &\quad + \beta\lambda(1+r)V_u'((w-C_h(w,\alpha))(1+r)+\alpha,\alpha) \end{aligned}$$

However, using the envelope theorem to differentiate the Bellman equations w.r.t. w yields:

$$\begin{aligned}V_u'(w,\alpha) &= \beta(1-q_u-\eta)(1+r)V_u'((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)\\ &\quad+\beta\eta(1+r)V_h'((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)\\ V_h'(w,\alpha) &= \beta(1-q_h-\lambda)(1+r)V_h'((w-C_h(w,\alpha))(1+r)+\alpha,\alpha)\\ &\quad+\beta\lambda(1+r)V_u'((w-C_h(w,\alpha))(1+r)+\alpha,\alpha)\end{aligned} \tag{10}$$

Combining these equations with the first order conditions yields:

$$\begin{aligned}u'(C_u(w,\alpha)) &= V_u'(w,\alpha)\\ u'(C_h(w,\alpha)) &= V_h'(w,\alpha).\end{aligned} \tag{11}$$

Since these hold for all levels of wealth, these imply that:

$$\begin{aligned}u'(C_u((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)) &= V_u'((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)\\ u'(C_u((w-C_h(w,\alpha))(1+r)+\alpha,\alpha)) &= V_u'((w-C_h(w,\alpha))(1+r)+\alpha,\alpha)\\ u'(C_h((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)) &= V_h'((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)\\ u'(C_h((w-C_h(w,\alpha))(1+r)+\alpha,\alpha)) &= V_h'((w-C_h(w,\alpha))(1+r)+\alpha,\alpha)\end{aligned} \tag{12}$$

Substituting these four identities into the first order conditions yields the Euler equations that a solution to the dynamic programming problem must satisfy:

$$\begin{aligned}u'(C_u(w,\alpha)) &= \beta(1-q_u-\eta)(1+r)u'(C_u((w-C_u(w,\alpha))(1+r)+\alpha,\alpha))\\ &\quad+\beta\eta(1+r)u'(C_h((w-C_u(w,\alpha))(1+r)+\alpha,\alpha))\\ u'(C_h(w,\alpha)) &= \beta(1-q_h-\lambda)(1+r)u'(C_h((w-C_h(w,\alpha))(1+r)+\alpha,\alpha))\\ &\quad+\beta\lambda(1+r)u'(C_u((w-C_h(w,\alpha))(1+r)+\alpha,\alpha))\end{aligned} \tag{13}$$

This is a pair of simultaneous equations in the functions $C_u(w,\alpha)$ and $C_h(w,\alpha)$. If the value of β is less than $\min(\frac{1}{(1-q_u)(1+r)},\frac{1}{(1-q_h)(1+r)})$ then the value function will be finite and the conditions of the verification theorem will hold[1]. Hence a solution to (11) will be a solution to the overall problem. Unfortunately, it is well known that no analytic solution for a problem of this type exists owing to the borrowing constraint on wealth and the infinite time horizon[2]. Merton (1969) and Samuelson (1969) have demonstrated analytic solutions to similar problems (with only one health state) where the time horizon is finite and there are no borrowing constraints.

Some insight about the properties of these functions can be derived from considering a pair of equations similar to (13), but where individuals do not switch from type to type, that is, where $\lambda = \eta = 0$:

$$u'(C_u(w,\alpha)) = \beta(1-q_u)(1+r)u'(C_u((w-C_u(w,\alpha))(1+r)+\alpha,\alpha)) \tag{14}$$
$$u'(C_h(w,\alpha)) = \beta(1-q_h)(1+r)u'(C_h((w-C_h(w,\alpha))(1+r)+\alpha,\alpha))$$

Here we have two independent problems. Since $\beta < \min(\frac{1}{(1-q_u)(1+r)}, \frac{1}{(1-q_h)(1+r)})$, the verification theorem will hold for both problems. It is relatively easy to see that, for all levels of w and α, $C_u(w,\alpha) > C_h(w,\alpha)$ owing to the fact that $q_h < q_u$, which implies that the individual in state *u* discounts the future more heavily than the individual in state *h*. Since the functions $C_u(w,\alpha)$ and $C_h(w,\alpha)$ change continuously with λ and η, we can

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[1] See the first chapter of Fleming and Mete Soner (1991) for details.

[2] If the discount rates are allowed to differ by state of health, and $\beta_h = [(1+r)(1-q_h)]^{-1}$ and $\beta_u = [(1+r)(1-q_u)]^{-1} < \beta_h$ then it can be verified that a solution to the above equations for all concave utility functions is given by:

$$C_u(w,\alpha) = C_h(w,\alpha) = (rw+\alpha)(1+r)^{-1}.$$

Even though the verification theorem does not hold in this case (the value functions will be infinite), this is a solution to the above problem as can be seen by solving a finite-horizon problem and allowing the time to tend to infinity. The rest of this section assumes that this approach has been adopted. In this model, $\hat{\alpha}_h(a,\theta) = \hat{\alpha}_u(a,\theta) \forall \alpha, \theta$. This implies that, $x_{h,0}$, the proportion of individuals who choose to purchase annuities who are healthy, is equal to *p*, the steady-state proportion of healthy individuals in the population. The equilibrium annuity price in this model is therefore $a = pa_h + (1-p)a_u$. Also, $x_{0,t} = p$ implies that $x_{h,t} = p \forall t$, from the definition of *p*. Therefore there will be no duration-related trend in the average observed mortality of annuity purchasers, as we would expect.

see that $C_u(w,\alpha) > C_h(w,\alpha)$ for at least a neighbourhood of (λ,η) around (0,0). Intuitively, we can see that the two equations $C_u(w,\alpha)$ and $C_h(w,\alpha)$ must become more similar as λ and η increase, and since if $\lambda = \lambda_{\max} = 1 - q_h$ and $\eta = \eta_{\max} = 1 - q_u$ (in other words, individuals alternate between different states in each period) then $C_u(w,\alpha)$ is still greater than $C_h(w,\alpha)$ for all w and α, owing to the higher mortality probability in state u.

Similarly, in the main problem, we must have $C_u(w,\alpha) > C_h(w,\alpha)$ for all admissible values of λ and η: unhealthy individuals consume more that all levels of wealth and annuitisation than healthy individuals, as they have higher mortality probabilities and there are no bequest motives. Anything else would result in a contradiction. From equation (11), and the concavity of the utility function u this implies that $V_u^{'}(w,\alpha) = u'(C_u(w,\alpha)) < u'(C_h(w,\alpha)) = V_h^{'}(w,\alpha)$: healthy individuals value an extra unit of wealth more highly than unhealthy individuals.

From this we can extract the conclusion we need. Two effects will affect annuity purchase behaviour: the wealth effect and the substitution effect. In a previous section we have shown that the wealth effect is unambiguous: healthy people will value a given annuity at a given price more highly than unhealthy people. The result we have shown here about the consumption functions of healthy and unhealthy people shows that unhealthy individuals will value a level annuity weakly less than healthy individuals because they would prefer an annuity with more steeply decreasing payments, and they may have more difficulty than healthy people (because of borrowing constraints) in altering their consumption pattern sufficiently to undo the undesirable payment pattern in the level annuity with a given present value. Therefore both effects are unambiguous: in the absence of constraints on the amount of annuities that can be purchased, healthy individuals will purchase more level annuities than unhealthy individuals[3].

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[3] Brown (2003) examines the issue of annuity demand with mortality heterogeneity and finds that poorer people find the insurance element of annuities to be greater than richer people, to some extent canceling out the wealth effect. In this paper we are assuming that wealth is the same across mortality types. The description here may need to be made more precise, especially if wealth is allowed to differ.