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The Option Value Model in the Retirement Literature: The Trade-off between Computational Complexity and Predictive Validity

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Abstract

This study gives an overview of retirement modelling, starting from the single-period consumption/leisure model up to the recent life-cycle multiple-decisions and joint retirement models, paying particular attention to the role played by the option value model in the economic literature on retirement.

The option value model was initially interpreted as a sub-optimal solution of the dynamic programming rule. But its simpler implementation and similar theoretical background soon attracted economists' attention to the trade-off between computational complexity and predictive validity in retirement modelling. Supporters of the option value model underlined how "complex specifications may presume computational facility that is beyond the grasp of most real people ..." (Lumsdaine, Stock, and Wise, 1992). Moreover, they provided evidence that the option value model was at least as good as the dynamic programming in terms of predictive validity.

A comparison between option value and more recent models, which explain much more than the first dynamic programming applications, depends on the specific context of the analysis. Even if, in many cases, it is likely that more complex models better approximate reality, there can be situations in which rules governing actual behaviour are simpler and more suitably modelled within the option value framework. At the same time, the option value itself can to some extent be modified and adapted to given circumstances.

Keywords: retirement, option value model, dynamic programming.

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Empirical analysis often raises questions of approximations to underlying individual behavior. Closer approximation may require more complex statistical specifications. On the other hand, more complex specifications may presume computational facility that is beyond the grasp of most real people and therefore less consistent with the actual rules that govern their behavior, even though economic theory may push analysts to increasingly more complex specifications. Thus the issue is not only whether more complex models are worth the effort, but also whether they are better.

Lumsdaine, Stock, and Wise (1992)

1. Introduction

When the option value model was introduced in the late 80s, retirement literature was going through a crucial period. The first static models were already outdated, and the stochastic dynamic programming rule had already been introduced. The empirical implementation of dynamic programming models was however clashing with their computational complexity and with software and hardware limitations. Strong simplifying assumptions had to be imposed on the models' structure to facilitate estimation, and potential capabilities could not be exploited in practice.

The option value model was initially interpreted as a sub-optimal solution of the dynamic programming rule. Its simpler implementation and similar theoretical background however soon attracted economists' attention to the trade-off between computational complexity and predictive validity in retirement modelling. If there was almost complete agreement on the fact that reduced form models were much simpler but also had a much worse predictive validity than structural models, the comparison between option value and dynamic programming rules was debated far more. Supporters of the option value model underlined how "(...) complex specifications may presume computational facility that is beyond the grasp of most real people and therefore less consistent with the actual rules that govern their behaviour (...)"(Lumsdaine, Stock, and Wise 1992). Moreover, they provided evidence that the option value model was at least as good as the dynamic programming in terms of predictive validity. They therefore claimed that the trade-off did not exist, because the option value model was both more tractable and better than dynamic programming in approximating actual retirement behaviour.

More recently, economic theory pushed research towards much more complex specifications. Health, family characteristics, wealth, wages, social security and pension dynamics are captured in almost omni-comprehensive and highly stochastic frameworks. Their empirical implementation is helped and speeded-up by the availability of powerful computers and prepared routine packages. At the same time, the option value model has been modified and improved with respect to its original version. Its role should therefore be revised in light of these important changes.

In this study we provide an overview of retirement modelling, starting from the single-period consumption/leisure model up to the recent life-cycle multiple-decisions and joint retirement models (section 2). We devote particular attention to the role played by the option value model in the economic literature on retirement. In particular, while in section 3.1 we describe its characteristics, in section 3.2 we compare it with other models, focusing on the relation with dynamic programming in terms of computational complexity and predictive validity. In section 3.3 we describe its developments with respect to the original Stock and Wise version, and we give an overview of the reduced form applications derived from its structural version. Section 4 draws some conclusions.

2. The evolution of retirement modelling

Induced by the long run decreasing trend in the participation rates of older workers, the analysis of the economic determinants of retirement started in the 70s in the US. Since then, its progress has continued without interruption. It is possible to distinguish three main evolutionary phases. The first, which lasts 20 years until the end of the 80s, is characterised by important theoretical improvements. It starts with the static one-period consumption/leisure framework, in which retirement was no more than the special case of labour supply equal to zero, and it ends with the first dynamic life-cycle models. The second phase, carried out mostly in the 90s, is characterised by empirical improvements. It introduces and develops the stochastic dynamic programming rule, and the option value model. Uncertainty about future outcomes such as wealth, income and health status is part of the most developed applications in this phase. In the third phase some important assumptions are relaxed, such as the assumption of imperfect credit markets, which allows for some models to optimise jointly with respect to consumption and retirement age. Retirement starts to be seen as a choice taken in the family context.

2.1 From standard labour supply to life-cycle models

At the beginning of the 70s, retirement was modelled as a standard labour supply choice. The one-period consumption/leisure framework imposes strong restrictions on the lifetime utility function $U = U(L_1, C_1, .., L_t, C_t, .., L_T, C_T)$, where L_t and C_t are leisure and consumption at time t, and T is the maximum age.

Assuming separability, such that $U = U_1(C_1, L_1) + .. + U_t(C_t, L_t) + .. + U_T(C_T, L_T)$, and imposing no borrowing and no saving, each year is treated separately from the others. Full 'retirement' occurs in this theoretical framework when leisure equals the total available time (i.e. labour supply is equal to zero). The relation between U_t and U_{t-1} is not specified and leisure is not bunched. What distinguishes the decisional environment of older workers from the others is the budget constraint, which is kinked if pensions are earnings-tested. The 'cost' of leisure can thus be lower (or even zero) above a given threshold of income if wages and pensions can be only partially (or not at all) cumulated. The existence of a pension system therefore, according to this model, increases leisure through both an income and a substitution effect.[1]

[1] First applicants of this kind of modelling are, for example, Feldstein (1974), Boskin (1977) and Pellechio (1978).

Model simplifications are often at odds with the peculiarity of the retirement choice. For example, leisure is modelled in the same way both before and after retirement, generating inconsistent results. Suppose that an earnings-test is applied only to workers up to a given age. Through a relaxation of the budget constraint, the model would predict an increase in the labour supply above that age, which is clearly in contrast with empirical evidence. Moreover, suppose that a fully-funded pension system, generating a mere intertemporal shifting of wealth, was introduced. It would perhaps not induce any income effect, and retirement would be overestimated by the model.

Starting from Feldstein (1974), the intrinsic life-cycle nature of retirement – and how both present and future income opportunities affect it – is already a clear concept. In Burkhauser (1979) early retirement depends on the ratio between the current pension and the pension at normal retirement age. Along this line, Reimers (1977) includes every ratio between the current and future retirement ages as determinants of retirement. A slightly different approach is taken by Bulow (1981), who borrows the concept of 'true wage' from the literature on human capital accumulation. The true wage, given by the wage plus the pension accrual, is considered better than the market wage for retirement studies because it takes into account the value of fringe benefits. Its extension from pension accrual to social security accrual, broadly applied nowadays in the literature of "money's worth measures", is proposed by Burkhauser (1980).

Empirical applications in the first phase are mostly based on OLS estimation of reduced form models. Fewer studies apply the newly developed hazard model and 'lifetime budget constraint' approach. The proportional hazard model, borrowed from the studies on the duration of unemployment spells, is proposed in Hausman and Wise (1985). It is characterised by two important innovations. First, dynamic aspects can enter into the analysis without difficulty (and there are many factors affecting the choice that change over time). Second, it can handle censored data, and thus it can exploit in a more efficient way the information included in the long panel datasets. The "lifetime budget constraint" approach (Burtless 1986) is one of the first empirically feasible long-horizon retirement models. In its formulation, the standard consumption/leisure budget constraint is adapted to retirement choices: hours of work are replaced by years and annual wages by cumulative compensation.[2]

Its author underlines how it is more forward-looking than the hazard model, but also admits the importance of dynamic capabilities. The option value model and the dynamic programming, in the second evolutionary phase, will for the first time bring these two features – incorporating forward-looking behaviour and dynamic capabilities – together.

A lifetime retirement problem was already solved in Boskin (1977) and Reimers (1977). Its general version, in the case of continuous time, can be written as:

$$\max U = \int_0^{\Omega} U(L_t, C_t) e^{-\beta t} dt \tag{1a}$$

$$s.t \int_0^{\Omega} C_t e^{-\beta t} dt = \int_0^{R} Y_t e^{-rt} dt + \int_R^{\Omega} B_t (R)^{-rt} dt \tag{1b}$$

[2] Burtless and Hausman (1978) and Hausman and Wise (1980) previously applied this model to other fields of economics.

where Ω is the maximum age of the individual, β is the discount factor, Y is the labour income, $B(R)$ is the pension (or/and social security) benefit if retirement occurs at the date R, and r is the market interest rate (borrowing and lending is allowed). Retirement is the date R such that $L_t = 1$, $\forall t \geq R$.

Mitchell and Fields (1984) and Gustman and Steinmeier (1986) provide two of the first and most relevant empirical implementations of this general framework, modelling in detail the lifetime income pattern. The former highlights how both earnings and pension benefits depend on the retirement date, and takes an indirect utility function approach. The latter separately models full and partial retirement. Individuals face a highly kinked budget constraint because part-time wage can be lower than a full-time one and because social security benefits are earnings-tested. Gustman and Steinmeier's is the first model that is able to explain the spikes of exits at ages 62 and 65 in the US, and it is the most advanced and empirically feasible model of this period.

At the end of the first phase therefore, life-cycle and dynamic approaches had already been introduced and the basis for a structural analysis of retirement already posed. Empirical applications still consisted mainly of reduced form models or of other simplified models, however. The next question economists posed was how to introduce uncertainty on future outcomes into the analysis. Dynamic programming was the method that allowed for relevant improvements in this direction.

2.2 Stochastic dynamic programming

The stochastic dynamic programming model (DP) is based on the recursive representation of the value function. At time t, the individual can either decide to retire and derive utility from present and future pension (and/or social security) benefits, or to continue to work and derive utility from the current wage plus keeping the option to re-evaluate the problem the next time. The value function at time t is given by:

$$V_t = \max[E_t[U_w(Y_t) + \upsilon_t + \beta V_{t+1}], E_t[\sum_{s=t}^{\Omega} \beta^{s-t}(U_R(B_s(t)) + \omega_s]] \quad (2)$$

where:

$$V_{t+1} = [\max E_{t+1}[U_w(Y_{t+1}) + \upsilon_{t+1} + \beta V_{t+2}],$$
$$E_{t+1}[\sum_{s=t+1}^{\Omega} \beta^{s-t-1}(U_R(B_s(t+1) + \omega_s)]] \quad (3)$$

etc.

$U_w(.)$ and $U_R(.)$ are the utility functions for a worker and for a retiree respectively, and υ and ω are the correspondent error terms. From this general framework, both the utility functional forms and the structure of the error terms have to be specified in order to define the retirement model. A dynamic programming model therefore does not exist, but there are several distinct models characterised by their *ad hoc* assumptions. For example, assuming that υ_t and ω_t are *i.i.d.* (so that $E_t[\upsilon_{t+s}] = 0$ and $E_t[\omega_{t+s}] = 0, \forall s = 0$), and taking into account of the probability to be alive in *s* conditional on being alive in *t* (2) becomes:

$$V_t = \max[V_t^1 + \upsilon_t, V_t^2 + \omega_t] \quad (4)$$

with:

$$V_t^1 = U_w(Y_t) + \beta\pi(t+1|t)E_t[V_{t+1}] \quad (5a)$$

$$V_t^1 = \sum_{s=t}^{\Omega} \beta^{s-t}\pi(s|t)U_R(B_s(t)) \quad (5b)$$

from which $\Pr(R = t) = \Pr(V_t^1 + \upsilon_t < V_t^2 + \omega_t)$. The solution is obtained by recursive optimisation, imposing the final condition $V_{t_{\max}}^1 = V_{t_{\max}}^2$ (where $t_{\max}$ is the mandatory retirement age).[3]

It requires computing multiple integrals, whose dimension depends on both the number of periods between *t* and $t_{\max}$ and on the error structure.

In order to find a tractable version of (2), the first applications imposed particularly strong assumptions on the error structure. This is the case of Rust (1989) – based on Rust (1987) – who assumes *i.i.d.* errors drawn from a normal distribution.[4] Daula and Moffitt (1989), who build a DP model for retention in the US military, make the same simplifying assumptions.

Gradually relaxing the *i.i.d.* hypothesis, dynamic programming evolved toward more complex error structures. Stock and Wise (1990) assume a Markov process for the error terms, at the cost of ‘approximating’ dynamic programming with the option value model. Lumsdaine, Stock and Wise (1992) in order to compare the predictive validity of DP and option value, modify the models of Daula and Moffitt (1989) and Berkovec and Stern (1991) introducing individual unobserved heterogeneity.[5] Daula and Moffitt (1995) propose a model with a similar error structure of the Lumsdaine, Stock and Wise’s version of Daula and Moffitt (1989).[6] They

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[3] See R. Bellman (1957).

[4] In Rust’s model, the individual maximises his utility with respect to both his working state (choosing between part-time, full-time and retirement) and his level of consumption jointly. Although the extension to multiple choices is an important innovation of the model, in its empirical application consumption is approximated by income. Nevertheless, the Rust’s model represented the reference retirement model for a long time.

[5] In the modified version of Daula and Moffitt’s model, individual effects enter additively into the utility functions. In the revised version of the Berkovec and Stern’s model – which assumes an extreme value distribution and has a closer form solution for the retirement probability – they instead enter multiplicatively.

[6] They quantify the effects of US military compensation of retirement rates, and show that the choice between a military and civilian career is a simple linear function of current and future difference between civilian and military wages.

compare the feasibility of their model with the complexity in Gotz and McCall (1984), who analyse a similar problem but impose restrictions to many parameters and do not compute most of the standard errors.

Berkovec and Stern (1991) innovate in applying the method of simulated moments to ensure empirical tractability to their model. In this method, the distribution of the error terms is simulated drawing from an assumed distribution. They include an additive individual and job specific random effect.[7]

Finally, Rust and Phelan (1997) represents the borderline of the second phase. The model they propose is advanced in several directions, especially in the treatment of uncertainty. Future health status, expenditure, employment, income and even marital status are stochastic. Empirical tractability is guaranteed by restricting the unobserved state variables to follow an *i.i.d.* extreme value distribution, so that all the correlations are incorporated into the observables.[8] Saving and borrowing are allowed, but in practice it is assumed that – due to data limitations and relying on the empirical evidence in the US – consumption is equal to income in every period.

At the end of the second phase, individual heterogeneity is commonly implemented in the error structure of DP models. The most advanced incorporate uncertainty about future outcomes such as health, income and wealth. Saving and borrowing are allowed, but empirical applications still either rely on simplifying assumptions like imperfect credit markets, or assume they are equal to zero (relying on empirical experience or data limitations). The goals are now to model multiple decisions and to allow for consumption smoothing, relaxing the assumptions on the credit markets, and to incorporate complex error structures in multidimensional stochastic frameworks.

2.3 Multiple-decisions and joint retirement models

Models belonging to the previous evolutionary phases incorporate extreme assumptions on credit markets characteristics. For example, Stock and Wise (1990) and Rust and Phelan (1997) assume imperfect credit markets, and do not allow for consumption smoothing. Under this assumption, in each period the level of consumption and the income earned coincide, and the decision of whether to retire defines the optimal level of consumption. In dynamic programming models, given that past choices do not affect future ones, it simplifies the labour supply problem to repetitive one-period optimisations. On the other hand, the lifetime budget constraint model of Burtless (1986) assumes perfect markets and complete consumption smoothing.

More recent models relax these assumptions and take intermediate and more realistic perspectives. New statistical tools, in particular the method of simulated moments, allow dynamic programming to identify the model parameters, also in these circumstances. French (2005) presents a model of labour supply, saving and retirement behaviour in which future health status and wages are uncertain. Individuals can save to insure themselves against health and wage shocks (and for their old age) but cannot borrow from social security, pensions and future wages, in response to an adverse shock. As a consequence, individuals are forced to continue to work until they are eligible for social security and pension benefits, but they may

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[7] As in Rust (1989), their study looks at the transitions between full-time work, part time and retirement. The focus is however on the demographic determinant of the choice, like education, race and health status, while the role of social security and pension in the choice is not considered.

[8] Rust and Phelan (1997) study the effect on labour supply of US Social Security and Medicate in the presence of incomplete markets for loans, annuities and health insurance. Coherently, they restrict the analysis on poorer workers with restricted access to these markets and without pension coverage.

leave afterwards, start dissaving and, for example, smooth-out an increase in the early retirement age. Van der Klaauw and Wolpin (2005) find similar results, but under different assumptions on credit markets. In their model borrowing is allowed as well as saving, but poorer individuals are forced to work until early retirement age because they have lower wages and (optimally) little accumulated wealth.[9]

Health insurance market assumptions have the same relevance of the assumptions on credit markets. A hotly debated issue has always been the effect of Medicare and, to a lesser extent, of the employer-provided health insurance on retirement choices.[10] Gustman and Steinmeier (1994) assume no uncertainty on future health status. Given that the worker evaluates health insurance at the cost paid by his employer and that there is no risk of unexpected expenses, they find a limited effect of health insurance on retirement. Rust and Phelan (1997) assume uncertainty and imperfect markets. Given that the worker takes into account the risk of future health shocks and cannot insure against them, they find a very strong effect. The recent work of French and Jones (2004) highlights the importance of both realistic assumptions on market imperfections and of incorporating uncertainty into the models. In their model, in fact, workers take into account volatility in health expenditures but can also self-insure against future shocks. They find intermediate results, and reconcile previous opposite evidence.

A number of interesting questions were raised in the late 90s in the US as a result of the growing proportion of married women approaching old age with considerable working histories. A first, to which empirical studies gave qualitatively an almost uniform answer, was how frequent the phenomenon of 'joint retirement' is, i.e. spouses retiring approximately at the same time regardless of their individual ages. If in the classical 'male-breadwinning model', retirement is seen as an individual choice, especially taken by males, retirement in the family context requires adapting both the budget constraint and the preferences to the household's environment. Work choices of a member of the family can in fact affect both the financial reward of work and non-work of the other and his/her relative preference for leisure and work.

A pioneering group of studies, dating back to the first half of the 90's or even earlier, documented correlations between spouses in labour force *status* (see Clark, Jonson and MdDermed 1980, Hurd 1990 and McCarty 1990). A different issue, which is first tackled in Blau 1998, is how the labour force status of one member of the family affects the labour force *transition* of the others. Blau's model answers this question by maximising a household utility function in a complex framework, characterised by a correlation between the unobserved component of the utility functions and by lagged endogenous variables that allow past status to

[9] Economists have always looked for a way to solve the age-62 and age-65 'puzzles', i.e. spikes of exits that occur in correspondence to these two ages in the US. Many of them, starting from Gustman and Steinmeier (1986), find a plausible solution in the credit and health insurance market imperfections. French (2005) represents one of the most notable recent examples of this kind. Other studies, like Gustman and Steinmeier (2005) believe that retirement peaks can be attributed to social security rules and to a wide heterogeneity in time preferences. Individuals with high discount rates have few assets and give a high value to the reduction in benefits after age 62. Therefore, ignoring the later increase in benefits, they retire at age 62. Those with low discount rates have more assets and give a high value to the declining actuarial adjustment after age 65. Therefore they are induced to retire at age 65.

[10] Medicare covers the health expenses of the whole American population starting from age 65, independently of working status. Most of the younger workers are covered by an employer-provided insurance that is tied to their job. There exists therefore a potential incentive to continue to work until 65.

affect current decisions.[11] The results show strong associations between the retirement choices of the couple, motivated largely by a preference for shared leisure.

These results are also found in Gustman and Steinmeier (2000), which confirms that joint retirement is due to preferences and not to the budget sets. Moreover, preferences for joint leisure can be asymmetric. Gustman and Steinmeier (2004) provide strong evidence – and confirm the finding of the companion paper Gustman and Steinmeier (2000) – that the husband's decision is actually more strongly influenced by the wife's than vice versa.

Coile (2004) focuses instead on the adaptation of the budget constraint to the family's framework. Husbands and wives' retirement behaviour, according to him, is affected by 'spillover effects' which come from the spouse's financial incentives as provided by pensions and social security. He estimates a reduced form model where the retirement probability depends, among other variables, on the labour force status of the spouse and on the head of household and spouse's financial incentives. Both Blau (1998) and Coile (2004) highlight how not accounting for either spillover effects or shared preferences can lead to a mismeasurement of the effects of policy reforms. For example, a policy intervention that increases the age of retirement by acting on financial incentives, in the case of shared leisure brings about an additional effect that occurs through the spouse's behavioural change.

3. The option value model in the retirement literature

The immediate motivation for the study of Stock and Wise (1990) is the evidence of a little attention dedicated to the effects of pension plans on the retirement of American workers. Economists had instead focused on social security provision which, with few exceptions, was shown to have a very small impact on their choices (see e.g. Burtless and Moffitt 1984, Burtless 1986 and Gustman and Steinmeier 1986). *A priori*, pension funds could have a stronger effect than social security because their design – characterised by a complicated system of incentives and disincentives – was thought to 'drive' the worker's choice to specific retirement ages.

To this aim, Stock and Wise propose a structural model of retirement and estimate it on a pension plan firm dataset. In this section we first provide an introductory description of the model and then we compare it with previously existing models and with the dynamic programming rule. Afterwards we describe its developments and give an overview of the reduced form applications derived from the structural version of the model.

3.1 A description of the model

In the option value model, a worker evaluates the following value function:

$$V_t(r) = \sum_{s=t}^{r-1} \beta^{s-t} U_w(Y_s) + \sum_{s=r}^{\Omega} \beta^{s-t} U_R(B_s(r)) \tag{6}$$

where $U_w(.)$ represents his utility while he is working, which is a function of the wage Y_s he earns at age *s* up to the retirement age *r*, and $U_R(.)$ represents his utility while he is retired,

[11] Blau's model has been recently extended in Mastrogiacomo, Alessie and Lindeboom (2004) to the analysis of differences in retirement behaviour between married couples and singles.

function of the pension $B_s(r)$ he receives at age *s* (where $s \geq r$) if he retires in *r*. β is the subjective time-preference discount factor, and Ω the maximum age he can survive. Therefore, his value function depends on the retirement age *r*. Retirement is seen as an absorbing state, i.e. a condition from which return to work is not allowed.

In a sort of a two-stage comparison, the worker determines first what is the future retirement year that gives him the maximum expected utility, and then he compares that utility ($E_t V_t(r^*)$) with the expected utility of retiring immediately ($E_t V_t(t)$). If we define the difference between the two as the expected gain from postponing retirement, $G_t(r^*) = E_t V_t(r^*) - E_t V_t(t)$, then the worker retires if $G_t(r^*) < 0$, while he continues to work otherwise.

The instantaneous utilities have the following constant relative risk aversion form:

$$U_w(Y_s) = Y_s^{\gamma} + \upsilon_s \tag{7a}$$

$$U_R(B_s) = (kB_s(r))^{\gamma} + \omega_s \tag{7b}$$

where *k* represents the value of income in the status of worker relative to its value in the status of retired, and γ is the degree of risk aversion with respect to income uncertainty. υ_s and ω_s are time-and-individual specific random effects, assumed to be independent over income and age. They capture unobserved determinants of retirement, such as private wealth and health conditions. Given that they are usually persistent over time for the same individual, random effects are assumed to follow a Markovian process as:

$$\upsilon_s = \rho \upsilon_{s-1} + \varepsilon_{\upsilon s} \qquad E_{s-1}(\varepsilon_{\upsilon s}) = 0 \tag{8a}$$

$$\omega_s = \rho \omega_{s-1} + \varepsilon_{\omega s} \qquad E_{s-1}(\varepsilon_{\omega s}) = 0 \tag{8b}$$

$$\mathrm{cov}(\upsilon_s, \omega_s) = 0 \qquad s = t+1 \ldots \Omega \tag{8c}$$

Two versions of the option value model are estimated. The first is called *single year probability* version, and is estimated on a cross-section. The second is the *multiple years probability* version, and requires a longitudinal dataset together with additional assumptions on the error structure. The utility functions parameters k, γ, β, ρ and the variance of the residuals σ_{υ}^2 are obtained by maximum likelihood estimation.

3.2 A comparison with other models

3.2.1 Option value and previous models

According to Stock and Wise, the option value model has been an important improvement in the retirement literature because it unified the advantages of the two most prevalent modelling techniques for that time, i.e. the hazard model and the lifetime budget constraint approach. Like the latter (and contrary to the former) the option value model is in fact suitable to capturing a forward-looking behaviour of an individual who compares the value of retiring today with the value of doing it some years ahead. We provide the following example to illustrate this point. Suppose that a worker has to decide whether to retire at age *t*. Suppose the pension system penalises him if he retires in $t+1, \ldots, t+k-1$, while it gives him a significant premium if he retires at age $t+k$. If he is short-sighted and he compares only the values of retiring in *t* with the value of retiring in $t+1$, then it is optimal for him to retire in *t*. If he is more forward-looking and he compares the utility of retiring in *t* with the utility of retiring in $t+k$, then it is optimal for him to retire in $t+k$. The option value model predicts the correct choice. A retirement model that assumes a more short-sighted behaviour, such as a model based on the accrual (Coile and Gruber 2000), would instead fail. Note how this feature leads to a fit improvement only if financial incentives are non-linear and provide bonus and penalisations at certain ages or seniorities, as in the example above (back-loaded private pensions). In several instances this is not the case and comparing the present with the next alternative is sufficient to capture an optimising forward-looking behaviour. In a limit case – when each individual in the sample chooses $t+1$ as optimal in the first of the two-phases comparison described in the previous section – this feature does not increase the fit at all with respect to a two-year comparison decision rule.

Like the hazard model (and contrary to the lifetime budget constraint), the option value model is dynamic because the information on which the worker's expectations are based change over time. If the worker does not retire, his information set becomes wider and more precise expectations on future wages can be made. It should however be noted how this feature belongs to the multiple-year probability version of the model, where the same individual is followed over time, but does not belong to the – much more adopted – single year version of it.

The hazard model has the advantage that several forms of monetary compensation, such as present, past and future wages as well as social security and pension wealth, can enter simply into the model specification and without increasing its computational complexity. The option value, being a structural model, is on the contrary much less flexible and does not easily accommodate modifications. Moreover, the hazard model is commonly thought not to have an interpretation in terms of utility, but Stock and Wise (1988) show that this is not actually true. They show that it is a special case of the multiple-year probability version of the option value model, and in theory it can replace it. They also stress however that in practice the restrictions that are needed to make an option value and hazard model identical are very strong and an actual substitution of the former with the latter is almost never possible.[12]

3.2.2 Option value and dynamic programming: theory

Dynamic programming and option value share many characteristics, above all the idea that workers decide whether to retire according to an evaluation of the opportunity-cost of the choice in terms of utility. The absorbing state assumption, crucial for the computational feasibility of both of them, is also common.

However they differ widely in the way uncertainty is treated: the option value rule compares the utility of retiring now with the *maximum value of expected* future utilities, while the dynamic programming compares the *expected value of the maximum* of current versus future retirement options. Consider the following example. Define Ω as the worker's maximum life span. Assume, for simplicity, that it is permitted to retire up to the last year of life, i.e. up to age Ω.

[12] The proportional hazard model is a special case of the option value model if some restrictions are imposed on the random effects and on the deterministic part of the expected gain of postponing retirement. In particular, the former must be time-invariant and have a unit exponential distribution while the latter must be non-increasing over time. See Stock and Wise (1988) for further details.

Assume that β in (6) and that *k* and γ in (7a – 7b) are set to one. Consider first his decision of whether retiring at age Ω – 1, i.e. when his time-horizon is one period. According to both option value and dynamic programming, he continues to work if $E_{\Omega-1}V_{\Omega-1} > E_{\Omega-1}V_{\Omega-1}(\Omega-1) \equiv E_{\Omega-1}[Y_{\Omega} + \upsilon_{\Omega}] > E_{\Omega-1}[B_{\Omega}(\Omega) + \omega_{\Omega}]$. The two decision rules thus the same result in this case.

Consider then his decision to retire at age Ω – 2, when his time-horizon is two periods. According to the option value rule, he continues to work if:

$$\max[E_{\Omega-2}V_{\Omega-2}(\Omega-1), E_{\Omega-2}V_{\Omega-2}(\Omega)] > E_{\Omega-2}V_{\Omega-2}(\Omega-2) \equiv$$
$$E_{\Omega-2}(Y_{\Omega-2} + \upsilon_{\Omega-2}) + \max[E_{\Omega-2}[B_{\Omega-1}(\Omega-1) + \omega_{\Omega-1}], E_{\Omega-2}[Y_{\Omega-1} + \upsilon_{\Omega-1}]] >$$
$$E_{\Omega-2}[B_{\Omega-2}(\Omega-2) + \omega_{\Omega-2}] + E_{\Omega-2}[B_{\Omega-1}(\Omega-2) + \omega_{\Omega-1}]$$

while, according to the dynamic programming rule, he does it if:

$$E_{\Omega-2}[Y_{\Omega-2} + \upsilon_{\Omega-2}] + E_{\Omega-2}\max[V_{\Omega-1}(\Omega-1), V_{\Omega-1}(\Omega)] > E_{\Omega-2}V_{\Omega-2}(\Omega-2) \equiv$$
$$E_{\Omega-2}[Y_{\Omega-2} + \upsilon_{\Omega-2}] + E_{\Omega-2}\max[B_{\Omega-1}(\Omega-1) + \omega_{\Omega-1}, Y_{\Omega-1} + \upsilon_{\Omega-1}] >$$
$$E_{\Omega-2}[B_{\Omega-2}(\Omega-2) + \omega_{\Omega-2}] + E_{\Omega-2}[B_{\Omega-1}(\Omega-2) + \omega_{\Omega-1}]$$

To the extent that the maximum between the expected values of two random variables is lower than the expected value of the maximum between them, the option value rule underestimates the value of postponing retirement and consequently overestimates retirement probabilities.

The option value is simpler to estimate than the dynamic programming. Thanks to the absorbing state and Markov assumptions, the value function (6) can be divided into a deterministic and a stochastic part, which drastically simplifies its computation (see Stock and Wise 1990). The dynamic programming, by contrast, does not allow for this simplification, and implies computing multiple integrals.

3.2.3 Option value and dynamic programming: practice

The same theoretical background of option value and dynamic programming, together with the simpler implementation of the option value model, soon attracted the economists' attention on the possible trade-off between computational complexity and predictive validity in retirement modelling. The debate was, from one side, focused on the comparison between structural models and reduced forms and, from the other – within the category of structural model – between option value and dynamic programming.

The first comparison between option value and other models is provided in Lumsdaine, Stock and Wise (1992). Exploiting an exit window in the middle of the period covered by their dataset, the authors compare the predictive validity of the option value model with that of two different versions of dynamic programming and with a probit model. The models developed in Berkovec and Stern (1991) and in Daula and Moffitt (1989) are modified for the comparison purpose.[13] To the same aim, the probit formulation includes a specification with the expected gain from postponing retirement as the sole explanatory variable.

Other comparisons are provided in Ausink and Wise (1993), in Daula and Moffit (1995) and in Burkhauser, Butler and Gumus (2003). In these studies the option value model is applied to study permanent transitions from work to a different status, not necessarily retirement (i.e. problems of optimal stopping). Ausink and Wise (1993) study the effect of the compensation on the departure rates of American military pilots toward both civilian airlines and the military pension. They compare the option value model with both the DP model proposed by Daula and Moffitt (1989) as modified in Lumsdaine, Stock and Wise (1992) and the ACOL model (see note in the next section). Daula and Moffit (1995) propose a similar comparison (although they rename the option value applied in the military as the 'TCOL' model) in order to study military reenlistments. Burkhauser, Butler and Gumus (2003) explain how health conditions and policy variables determine Social Security Disability Insurance application timing in the US.

All of these studies agree on two main findings. The first one, as expected, is that reduced form models – and the ACOL model – have a much lower predictive validity than structural models. The second, more relevant, is that the option value has a predictive validity in line with the dynamic programming models, both in-sample and out-of-sample.[14] These works therefore provided evidence that the trade-off between computational complexity and predictive validity did not exist, and that the option value model was at the same time more computationally feasible and more powerful than dynamic programming in approximating actual retirement.

3.3 Further developments and reduced forms

The above mentioned studies, other than comparing the option value model with DP, modify and develop the original Stock and Wise's model. Ausink and Wise (1993) adapt the instantaneous utility function for 'leavers' (equation 7b) to handle two possible destinations: military pension and civilian career. Burkhauser, Butler and Gumus (2003) make changes in the empirical specification of the expected gain from postponing retirement. They follow Daula and Moffit (1995) and add a vector of observable variables to the utility function for 'non-applicants' (equation 7a). In this way, they incorporate into the model the heterogeneity across socio-demographic groups concerning the relative preference towards leisure versus consumption. They also extend to 'applicants' (leavers) the Taylor approximation that Stock and Wise apply only to workers (stayers). They therefore allow for the variance of expected Social Security Disability Insurance (SSDI) benefits to be different from zero.[15] An extended version of the Stock and Wise's model is proposed in Hurd, Loughran, and Panis (2003). They develop an option value model where the worker can choose between two exit routes –

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[13] The model in Daula and Moffitt (1989) – modified to incorporate an individual random effect – is closer to the option value model than the model in Berkovec and Stern (1991). Both Daula and Moffitt (1989) and Stock and Wise (1990) assume in fact a normal distribution of the residuals and non-zero covariances, although the similarity in the covariance structure comes from very different assumptions.

[14] Daula and Moffit (1995) is in contrast with this result and finds that, although the option value has a comparable in-sample predictive validity, it is not as able as the more complex models to predict out-of-sample.

[15] The length of the period exploited in their estimation – 16 periods (years) instead of the 3 exploited by Stock and Wise (1990) and by Lumsdaine, Stock and Wise (1992b) – also represents a considerable improvement and requires remarkable computational capabilities.

retirement and application to SSDI – according to the maximum between the expected utilities under the two alternatives.[16]

Although applications of the Stock and Wise's model are numerous, most of them do not actually provide estimates of the utility functions parameters. Rather, the expected gain from postponing retirement is simply used as a regressor in reduced form models to explain the retirement probability. In other words, in the structural model the maximum likelihood method *estimates* a specific value function – defining its utility functions parameters – which better approximates observed behaviour. In the reduced form (probit-type) models instead, the retirement probability depends, among other variables, on the expected gain of postponing retirement *computed* exogenously assuming specific parameters of the utility functions.[17]

These reduced form applications of the option value model have multiplied in the literature, because their implementation is relatively easy and because their results are more easily readable and comparable across models. The most recent ones are collected in Gruber and Wise (2004), which present applications for twelve developed countries. For each country a probit model is estimated and, between the various specifications, there is one that includes the "option value" among the right-hand side variables.[18] A peculiar method is used in the German case (Börsch-Supan, Schnabel, Kohnz, and Mastrobuoni 2004), where the option value is partly estimated by grid search (in particular the parameter *k*) and partly exogenously assumed.[19] Beyond those collected in this volume, other significant reduced form applications of the option value model are Samwick (1998) and Blundell, Meghir, and Smith (2002).[20]

An innovative application of the option value model is finally provided in Piekkola and Leijola (2004). They extend it to incorporate the value of unpaid household work (upkeep of the household and providing for its members). In the computations they assume risk neutrality (γ = 1) and a relative value of leisure versus work (κ) equal to 1 (i.e. what they propose is a reduced form application of the option value model). The instantaneous utilities then become:

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[16] They also modify the functional forms of the utility functions, because they could not estimate all the parameters of the original version. Identification problems in estimating the option value model are also found in Harris (2001) and Spataro (2000b).

[17] A very simplified version of the option value model is the average cost of leaving (ACOL) model. It consists in a simple probit model where the probability to retire depends on the expected gain from postponing retirement, specified assuming $\gamma = k = 1$. The ACOL model Warner (1979) is actually prior to the Stock and Wise's model and was extensively used to study retention in the military personnel. According to Ausink and Wise(1993), the ACOL model was used frequently enough by the Air Force Personnel Analysis Center to have been incorporated in an interacted computer programme called the "Compensation Model" for determining the effects of various changes in compensation policies (see Norris 1987).

[18] Results show a strong relationship between levels of social security incentives and retirement behaviour in each country. Simulations show surprisingly uniform policy effects in countries characterised by very different labour markets, cultural and social characteristics. These results confirm and strengthen those found in the previous version of this volume (Gruber and Wise 1999).

[19] The estimates found in this paper were used for other policy simulations first in Berkel and Börsch-Supan (2004) and later in Berkel and Börsch-Supan (2005).

[20] Using a rich dataset, with very detailed information on both pensions and social security benefits, the former study allowed for two strands of the retirement literature to be tied together. It in fact demonstrates that the impact of social security incentives on retirement can be shown to be either very high or very low, depending on whether pensions are kept in or left out of the analysis. The past studies (e.g. Hurd and Boskin 1981), which assume no impact of pensions on retirement and which show a limited impact of social security on it, could be thus reconciled with the more recent ones, which instead show a strong impact of pensions. The latter study is similar to the former but it is applied to the UK instead of the US.

$$U_w(Y_s) = Y_s + D + \upsilon_s$$

$$U_R(B_s) = B_s(r) + D_{ret} + \omega_s$$

where D and D_{ret} represent the domestic work when working and retired respectively. The economic value of one hour devoted to household work is measured with the wage rate of an household-help worker (or minimum wages). Computations are performed for a group of EU countries. The main result is that the inclusion of domestic work in incentive calculations makes retirement much more attractive (replacement rates become even greater than 100% in some cases), and the results correlate with the actual retirement ages in Europe.

4. Conclusions

The economic literature on retirement behaviour has progressed constantly since the early days. The first one-period leisure/consumption model, in which retirement was treated as a standard labour supply choice, made clear its peculiarities and called for an *ad hoc* framework of analysis. Gradually, models incorporated forward-looking behaviour and the life-cycle approach replaced the short-sighted one. Reduced form models were initially the only available analytical framework; OLS regressions, hazard models and other simplified techniques were the econometric tools. When the dynamic programming rule came onto the scene, the development of structural models was slowed down by its computational complexity. Strong simplifying assumptions on the error terms had to be imposed in order to make them tractable.

The option value model was considered as a less complex rule than the dynamic programming one, and no worse at approximating actual behaviour. Afterwards, economic, econometrics and technological advances, together with the availability of longitudinal datasets, allowed for increasingly complex models. Modern specifications relax many simplifying assumptions and include modelling multiple simultaneous decisions and alternative exit routes. They explain much more than the first dynamic programming applications, to which the option value was compared. The most known example is given by the spikes of exit at ages 62 and 65 in the US, which had been a puzzle for a long time. Recently, several explanations of this puzzle have been tested and confirmed in structural models, ranging from heterogeneous subjective discount factors, to limited borrowing and to interactions between Social Security and Medicare institutions.

A comparison between option value and more recent models however depends on the specific context of the analysis. Even if in many cases, as occurred for the US puzzle, it is likely that more complex models better approximate reality, there can be situations in which rules governing actual behaviour are simpler and suitable to be modelled within the option value framework. At the same time, the option value itself can to some extent be modified and adapted to given circumstances.

Between the possible directions taken by the literature on retirement in the coming years, two seem particularly promising. The first is the development of analytical frameworks where supply and demand side aspects of retirement are jointly modelled. While the study of the demand has been so far limited by scarce information on labour inputs and outputs, the new availability of matched employer-employees datasets can favour the development of unified approaches. This can be potentially helpful in understanding much of the unexplained retirement behaviour. The second consists of modelling *continuous* transitions to retirement. Recent evidence highlights various patterns of exit from the labour force and frequent nonsmooth transitions from full-time contracts to old-age pension. Assuming retirement as a zero-one choice – or as an absorbing state – should therefore be reconsidered.

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About AIM (Adequacy & Sustainability of Old-Age Income Maintenance)

The AIM project aims at providing a strengthened conceptual and scientific basis for assessing the capacity of European pension systems to deliver adequate old age income maintenance in a context of low fertility and steadily increasing life expectancy. The main focus is on the capacity of social security systems to contribute to preventing poverty among the old and elderly and more generally to enable persons to take all appropriate measures to ensure stable or “desired” distribution of income over the full life cycle. In addition it will explore and examine the capacity of pension systems to attain broad social objectives with respect to inter- and intra generational solidarity.

Furthermore it will examine the capacity of pension systems to allow workers to change job or to move temporarily out of the labour market and to adapt career patterns without losing vesting of pensions rights. The project will also address the specific challenges with respect to providing appropriate old age income for women.

A general objective of the research project is to clearly identify and analyse the potential trade-offs between certain social policy objectives and overall stability of public debt.

AIM is financed under the 6th EU Research Framework Programme. It started in May 2005 and includes partners from both the old and new EU member states.

Participating institutes

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- Federal Planning Bureau, FPB, Belgium
- Deutsches Institut für Wirtschafsforschung (German Institute for Economic Research), DIW, Germany
- Elinkeinoelämän tutkimuslaitos, (Research Institute of the Finnish Economy), ETLA, Finland
- Fundación de Estudios de Economía Aplicada , FEDEA, Spain
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- Instituto di Studi e Analisi Economica (Institute for Studies and Economic Analysis), ISAE, Italy
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- Centrum Analiz Spolleczno-Ekonomicznych (Center for Social and Economic Research), CASE, Poland
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IER	Institute for Economic Research, Ljubljana, Slovenia
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