Long-Run Economic Perspectives of an Ageing Society: Final Publishable Summary Report

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Executive Summary

The Lepas project integrated into modern economics a biologically founded process of individual aging, i.e. aging understood as the gradual deterioration of the functioning of body and mind. Using the novel life cycle approach we have investigated how aging affects health and productivity with a special focus on health inequality across the EU member states.

We have applied the model in a setup of endogenous economic growth in order to investigate the effects of aging on education, life-time labor supply, long-run economic growth, and welfare. With multi-country models we have analyzed how aging influences human capital formation and migration flows in Europe. We have applied the framework to investigate the interaction between aging, retirement, and health in old age. We have applied the model to explain the observed education gradient, i.e. the inequality of health and life-expectancy across educational groups. We have investigated how aging interacts with health demand and supply and how this feeds back to the macro-economy. We tried to assess whether the EU's market economies and public sectors provide too much or too little health care.

We have discussed our approach and results not only with experts from demography and economics but also with experts from the natural sciences, most importantly with the leaders in the fields of reliability theory and frailty accumulation, i.e. the methods that the Lepas project made accessible for economists. These discussions encouraged us in our endeavor to establish our approach as the new thinking about aging in the social sciences.

Summary Description of Project Context and Objectives

Nearly 25 percent of people in the European Union in 2030 will be above age 65, up from about 17 percent in 2005. Europe's old-age dependency ratio (the number of people age 65 and older compared with the number of working age people ages 15-64) will be more than double by 2050, from one in every four to less than one in every two. This is an unprecedented phenomenon with potentially very important implications on society that are far from being well understood.

Researchers with public finance background frequently deliver gloom predictions of the impact of ageing. However, we believe that in order to fully understand the effect of ageing on the economy, it is necessary to develop an economic theory of ageing that takes into account the endogenous evolution of human frailty and disability. Only if we understand both the biological and economic forces behind the changes in the functional status of human beings during their lives, we will be able to analyse the economic determinants of successful aging. Moreover, a solid modeling of aging is required to study its feedback effects on economic growth, innovation, health expenditure and supply, retirement decisions and intergenerational solidarity.

The core objective of the LEPAS project was thus to integrate a conception of human senescence into macroeconomics that is founded in the life sciences. The milestone of the project was the development of a new theoretical framework based on economic and biological foundations in which we were able to analyze the endogenous evolution of morbidity along the life cycle, and its impact on education, savings, health demand, productivity, and growth.

The core element (WP4), which delivered the new theory was preceded by two "background" work packages. WP 2 provided a survey article about the treatment of senescence in the natural sciences with special focus on approaches that are potentially useful for economists. WP 3 integrated applied econometrics with methods from biology, in particular allometry. The goal was to obtain a quantitative assessment of the relative contribution from biological drivers of morbidity and mortality vs. man-made (technological) drivers, in accounting for the observed increase in life expectancy over the last 100 – 150 years.

We then had our first joint workshop with leading researchers in the life sciences in order to further assess the common ground and the possibility of collaboration (16-18 June 2010, Vienna). For that purpose we have managed to get Professor James Carey from UC Davis, one of the world-wide leading figures in senescence research, as external advisor for our project. The gained knowledge was disseminated by a conference volume.

After having managed to integrate a biological foundation of ageing into the macroeconomic toolbox and to develop an economic life-cycle model we moved further ahead with several applications on EU relevant issues. We mainly addressed our work to analyzing the optimal age of retirement from the individual's and from society's viewpoints (WP5), evaluating the impact of migration on overall productivity and its implications for human capital formation (in a broad sense, including education and health) in an ageing society, and for the design of immigration management policies (WP6), searching for the impact of the aging society on technical change and log-run growth (WP7) and quantifying whether too much or too little is spent on health investment (WP8).

During the third year of the project we had a second workshop with leading researchers in the life sciences as well as in economics in order to discuss our approach and its first applications (15-18 June 2011, Alicante). We compiled the presented work in another conference volume.

The results of the LEPAS project were documented in several academic papers and disseminated to the general public through conference participation, policy briefs, and scientific reports. We built a project specific web page (WP9) that contains all this material and further information about the LEPAS project (`http://www.lepas-fp7.`

de/publications.php).

Description of the Main Results

WP 2: Aging and Frailty: What can be learned from the Natural Sciences?

Objectives: This WP provides an overview over recent developments on the modelling of the aging process in physics, biology, gerontology, and bio-demography with a special focus on the question of which ideas can be fruitfully borrowed for an implementation of ageing in economic models.

The tasks of the work package were tackled as a joint effort between all four partners with each partner contributing to the same question from a different viewpoint. At LUH the focus was on measurement of aging and the explanations offered for the most striking regularities (Gompertz law and the Strehler-Mildvan correlation) in the natural science literature. From the theoretical side, reliability theory was identified as the most promising approach for integration into economic modeling.

The implication of the theory has been tested with the so called frailty index developed in medical literature. The frailty index counts the proportion of the total potential deficits that an individual has, at a given age. The list of potential deficits ranges from mild ones like impaired vision to severe ones like dementia. The frailty index has been developed by Mitnitski and Rockwood and several coauthors in a series of articles (2002a, 2002b, 2005, 2006, 2007). Mitnitski and Rockwood estimate with an R^2 around 95 percent the rate μ at which health deficits are accumulated. On average, adults in developed countries accumulate 3-4% more deficits from one birthday to the next. At the individual level, however, the frailty index reveals marked differences in health status, in particular with respect to education.

LEPAS Researchers in joint work with researchers form the Harvard School of Public Health used the SHARE (2011) data base to compute the frailty index – which was so far only available for the US, Canada and Australia – for a number of European countries. Table 1 shows the result for societies stratified by education. In all 15 European countries for which data was available there exists a strong negative association between education and health deficits. On average, those with tertiary education have accumulated about 50 percent less health deficits than those with only primary education. The Table displays also the well-known fact that citizens of economically more developed countries are on average healthier. There exists thus a double socio-economic gradient across countries and within countries.

Table 1: The Frailty Index by Education across Europe

2007		Austria	Germany	Sweden	Nether-lands	Spain	Italy	France	Denmark	Greece	Switzer-land	Belgium	Czechia	Poland
By educational level														
Primary	Mean	0.25	0.25	0.2	0.19	0.25	0.23	0.22	0.22	0.19	0.18	0.24	0.22	0.31
	SD	*0.13*	*0.14*	*0.12*	*0.12*	*0.14*	*0.13*	*0.13*	*0.12*	*0.12*	*0.1*	*0.14*	*0.12*	*0.15*
Secondary	Mean	0.2	0.18	0.17	0.15	0.16	0.16	0.19	0.18	0.15	0.14	0.19	0.19	0.24
	SD	*0.12*	*0.12*	*0.1*	*0.09*	*0.09*	*0.1*	*0.1*	*0.11*	*0.1*	*0.08*	*0.11*	*0.11*	*0.13*
Higher	Mean	0.14	0.16	0.14	0.17	0.17	0.15	0.17	0.15	0.12	0.14	0.17	0.17	0.22
	SD	*0.08*	*0.11*	*0.07*	*0.1*	*0.1*	*0.1*	*0.09*	*0.09*	*0.07*	*0.08*	*0.11*	*0.1*	*0.12*

At UCPH the focus was on metabolic theories of aging and the connection between allometric measures and aging. In particular, two theories were inspected and evaluated: the free radical theory which considers that oxidative stress leads to cellular damage and thereby organism senescence; and the telomere theory which considers that cell division and oxidative stress lead to cell senescence and thereby aging of the organism. It was assessed in how far these theories may be helpful in shedding light on why longevity varies across societies. At VID the focus was on the evolutionary theories of ageing and in particular on the close links between the processes of fertility and ageing. For that purpose life history analysis was studied, which offers a rigorous explanation for the evolutionary forces behind the ageing process. Key elements of ageing are the value of transfers, opportunity concepts of growth, and quality-quantity trade off in soma. First investigations if and how these theories can be integrated into the economic models have been conducted. At UA the literature was analyzed from a human capital perspective, i.e. aging understood as the decay of human capital. Different approaches to human capital accumulation have been reviewed, with a focus on what the available literature on human capital in economics is missing by disregarding the biological determinants of depreciation of human capital.

WP 3: Accounting for Increasing Life-Expectancy

This work package aimed to elucidate the sources of recent increases in life expectancy. Three major papers on this topic have been made available during the project life:

- Optimal Aging and Death: Understanding the Preston Curve
- Eye Disease and Development
- Long-Run Trends of Human Aging and Longevity

The papers are available from the project web site: http://www.lepas-fp7.de/index.php.

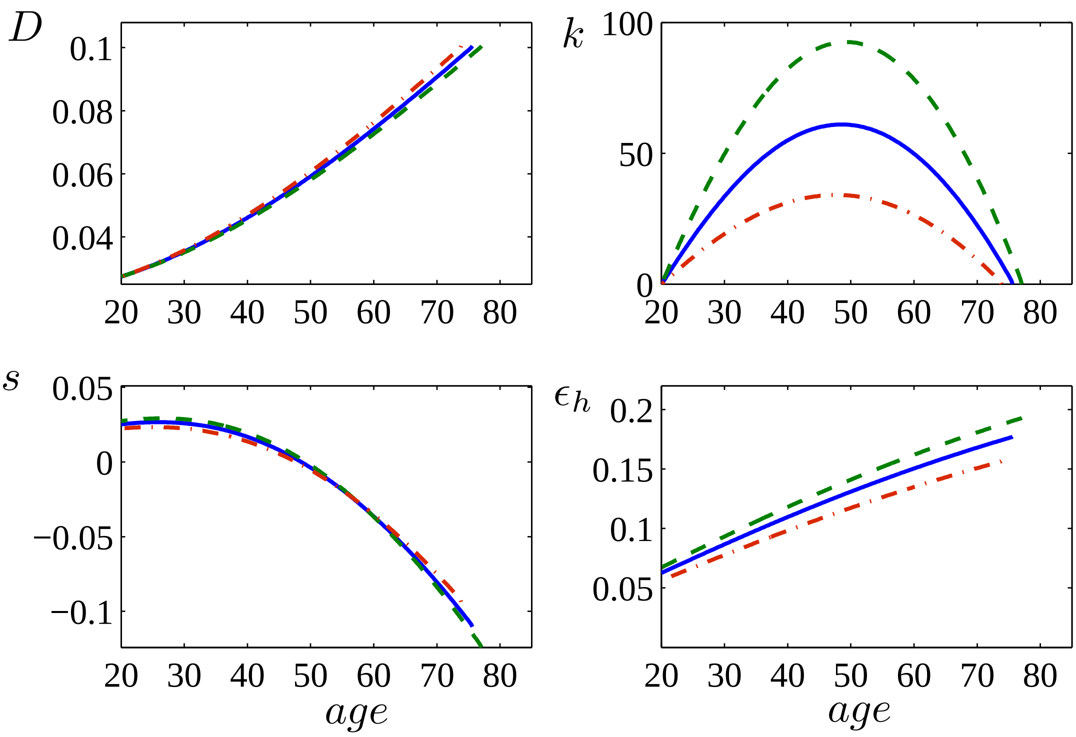
Optimal Aging and Death: Understanding the Preston Curve

The key innovation of this working paper is to integrate a natural science founded approach to aging into an otherwise fairly standard economic model of consumption/savings choice by a representative household. Broadly speaking, the representative households find investments in health attractive as these expenditures serve to slow down the aging process (at the individual level), allowing for greater life span and thus higher welfare. At the same time, households value other things that do not prolong life. These expenditures naturally constitute the alternative costs of health spending. Within this setting the first key question is how households would optimally want to allocate their income over the life cycle. Once this choice has been made, the model predicts the (optimal) ageing and timing of household death.

Figure 1 shows how the average male US American is predicted to react if his income is perturbed. The blue line shows life-trajectories for for frailty (health deficit accumulation) D (top left panel), capital accumulation k (top right panel), the savings rate s (bottom left), and the health expenditure share ϵ_h (bottom right) from the age of 20 to death. The green (dashed) line is associated with an increase of labor income by 1/3, the red (dashed-dotted) line depicts the reaction to a reduction of w by 1/3 (in all the experiments below, "green" is associated with increases, and "red" with reductions in the parameter of interest). As can be seen from the figure, the consequence of higher income is an increase in longevity, peak wealth, and the share of health spending.

Figure 1: Health and Wealth over the Life Cycle

Variation of Labor Income



Green (dashed): wage income increases by 1/3. $\Delta T = 1.47$, implied elasticity 0.07). Red (dotted): wage income decreases by 1/3 ($\Delta T = -1.78$, implied elasticity -0.09).

The intuition for why higher income leads to longer life is found in the desire to smooth consumption. With increasing income, health spending rises more than regular consumption. This occurs as the incentive to smooth the latter is relatively stronger due to diminishing per period marginal utility. Higher income therefore leads to a larger adjustment in the level of health spending compared to non-health consumption. The end result is a slower speed of ageing, and a longer life.

The issue of main interest, however, is the quantitative impact on longevity. As seen from the top left hand side corner of the figure, the impact is modest though not inconsequential. An increase of income of 1/3 (achievable in a generation with an income growth rate of about 1% per year) translates into an increase in longevity of 1.7 years; the reduction involves a fall in longevity of 1.6 years. If we convert the impact into an elasticity - the elasticity of longevity with respect to income - we find it to be around 0.08, implying that a 100 percent increase of income would result in an 8 percent increase of life-expectancy.

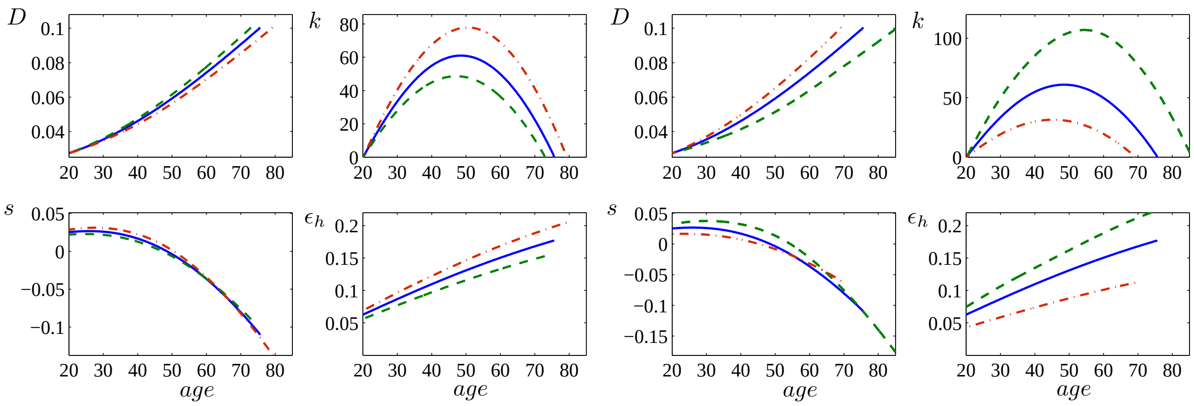
The next experiment concerns health costs; a doubling of the relative price of health goods. Rising relative health prices is a realistic scenario since the price index of medical care has risen faster than the price index of GDP. As is clear from Panel A of Figure 2, when the relative price of health increases, individuals substitute towards regular consumption. As a result, the health share declines. With less health investments, savings (s) decline as well. The end result of a doubling of the relative health price for longevity is a reduction by 2.5 years. This amounts to a longevity-price elasticity of 0.09. While this elasticity is of roughly the same numerical size as the income elasticity it is well to bear in mind that the potential for variation is far smaller; income levels vary across the world easily by a factor of 30 or more, far towering any cross-country variation in price levels.

In Figure 2, panel B, we depict the impact of increasing health productivity, i.e. general medical effectiveness by 33%; an increase by the same factor as that which we analyzed in terms of income. If health productivity rises by 33% the consequence is an increase in longevity of nearly a decade. The implied elasticity is about 1/2. This is a

Figure 2: Health costs and Medical effectiveness

A: Variation of Health Costs

B: Variation of General Medical Effectiveness (A)



Green (dashed):doubling p, $\Delta T = -2.7$, implied elasticity -0.09). Red (dotted): halving p ($\Delta T = 3.6$, implied elasticity 0.13).

Green (dashed): 33 percent increase of A ($\Delta T = 9.8$, implied elasticity 0.53). Red (dotted): 33 percent decrease of A ($\Delta T = -6.4$, implied elasticity -0.35).

very large effect, suggesting that the impact from improvements in health productivity easily may have towered that of rising income. It also suggests that improvements in health efficiency have a large potential to improve life expectancy.

The model does remarkably well in accounting for the "income gradient" in the data (the so-called Preston curve). A first key result is that prevailing differences in average income across countries (and thus in implied, optimal, health investments) can account for difference in life expectancy at age 20 of about a decade. Income therefore matters a great deal. However, a second key result of the analysis is that technological change (increases in health efficiency) has a much greater impact on longevity, quantitatively; the impact from technology is also much larger than that of changes in health services. From a policy perspective this suggests that improvements in health efficiency (which might involve institutional reform of the health sector) will likely have a much bigger impact on health of the populations than policies geared towards subsidizing health spending by individuals.

In the report "Understanding the Differences in Longevity across the EU Member

States" we applied the model to explain variation of life-expectancy in a sample of European countries. The main conclusions summarized in this report are:

- Convergence of income per capita (labor productivity) across the EU member states can be expected to close a considerable fraction the life expectancy gap. But productivity advances are not the most powerful determinant of longevity.

- The most powerful determinant of increases in longevity is improvement in health efficiency (medical technological progress). Health efficiency should be the main policy target.

- Targeting prices (subsidies on wages or prices in the health sector) is a relatively ineffective way of increasing longevity.

Eye Disease and Development

This paper tries to come to grips with the question: How important is health to development outcomes? This is a particularly difficult question to address, as health both impacts on growth, and is the result of income growth. In order to isolate the impact from health empirically one needs to disentangle these two effects. This working paper attacks this difficult separation problem by examining a particular condition (associated with aging): loss of vision from cataract. The key ideas, facilitating us to disentangle impact from loss of vision on growth, is to look at cross-country differences in cataract prevalence which is ascribed to climatic conditions, and not income per se. Building on a large natural science literature the paper employs UVB radiation in this regard.

By studying the impact from the part of cataract incidence across countries which is a consequence of climate variation, we can isolate the impact from cataract, as this variation (in the data) cannot be ascribed to the influence from income. The empirical results are very strong. Loss of vision is a strong determinant of current human capital levels and income per capita differences. More broadly, the results provide new evidence that health is a major determinant of economic growth.

Long-Run Trends of Human Aging and Longevity

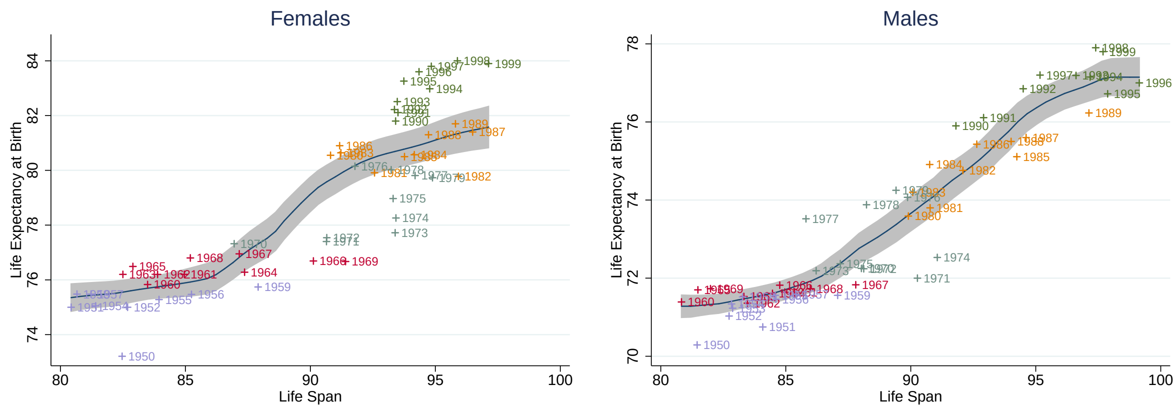
Over the last 200 years humans experienced a huge increase of life expectancy. These advances were largely driven by extrinsic improvements of their environment (for example, the available diet, disease prevalence, vaccination, and the state of hygiene and sanitation). In this paper we ask whether future improvements of life-expectancy will be bounded from above by human life-span. Life-span, in contrast to life-expectancy, is conceptualized as a biological measure of longevity driven by the intrinsic rate of bodily deterioration.

In order to pursue our question we first present a modern theory of aging and show that immutable life-span would put an upper limit on life-expectancy. We then show for a sample of developed countries that human life-span thus defined was indeed constant until the mid 20th century but increased since then by about eight years. In other words, we find evidence for manufactured life-span.

Figure 3 compares for a sample of 26 countries the estimated life-span with "frontier life-expectancy" calculated by Oeppen and Vaupel (2002). Until the 1970s life span and frontier life-expectancy are virtually uncorrelated, which further corroborates the idea of improving life-expectancy through lower background mortality or through better health and nutrition in line with an invariant compensation effect. Then, from about the 1970's onwards we observe a strong positive correlation between the two variables, indicating that recent improvements in life-expectancy were indeed driven at least partly by expanding human life-span.

The notion of an expanding human life-span is helpful to rationalize why other researchers have not (yet) observed any convergence of increasing life-expectancy. Predictions of a certain limit to life-expectancy – for example, that it should not exceed 35

Figure 3: Life Span and ”Frontier” Life Expectancy



Abscissa: life span T_t. Ordinate: frontier life-expectancy taken from Oeppen and Vaupel (2002). The solid line is a fitted spline with a 95 percent confidence interval around it (shaded in gray).

years at age of 50 – are presumably made under the wrong perception of an invariant human life-span, in which case they would have been indeed fully justified. Unlike other species, however, humans seem to be able to modify life-span such that there is no limit of life-expectancy visible in the data.

WP 4: An Economic Life-Cycle Model of Aging and Senescence

In WP 2 we have reviewed different approaches to human capital accumulation that make evident the lack of attention that economists have given to the determinants of its depreciation. We have looked at evidence that clearly points out that the decay of human skills and health is influenced by the environment, usage, and maintenance practices. Our main conclusion has been that the evolution of human capital during the life cycle is badly described by existent theories that treat depreciation or, for our purposes, aging as purely exogenous. We have been able to finalize our model based on the theory of human capital acquisition put forward by Bils and Klenow (2000, American Economic Review) but extended it to incorporate elements from Biology, and in particular, frailty theory.

Another line of "attack" consists of extending the natural science founded model of aging (WP 3) to the study of optimal labor supply. In the greater context of understanding the impact of aging on growth, it is useful to understand how physiological aging impacts on individuals in planning their lifetime labor supply, including the timing of retirement. The end results of this research effort was a fully articulated framework which allowed for a deeper understanding of how aging influences life cycle consumption and savings as well as time of retirement and human capital investments (schooling). The following contains a brief description of the major results compiled in the paper "Health and Education: Understanding the Gradient".

This study presents a novel view on education and health behavior of individuals constrained by aging bodies. The aging process, i.e. the accumulation of health deficits over time, is built on recent insights from gerontology. The loss of body functionality, which eventually leads to death, can be accelerated by unhealthy behavior and delayed through health expenditure. The proposed theory rationalizes why better educated people optimally choose a healthier lifestyle, that is why they spend more on health and indulge less in unhealthy behavior. The model is calibrated for the average male US citizen. In the benchmark case a difference of the return to education that motivates one year more of education motivates also about 8 percent less unhealthy behavior and 5 percent more health expenditure and thus explains half a year gain of longevity. Progress in medical technology explains why the education gradient gets larger over time.

The optimal behavior of individuals over the life-cycle is characterized by several trade-offs. As for the simple model (WP 3) it is assumed that income can be spent on consumption, health expenditure, and saving. In addition this paper considers now that consumption is divided up into health neutral consumption and explicitly unhealthy consumption like e.g. smoking, alcohol consumption, or the intake of other drugs. While, as before, health expenditure reduces the speed of ageing and postpones the time of death, unhealthy consumption, speeds up ageing and prepones death. Furthermore we assume an exogenous age of retirement and – in line with conventional labor economics – a wage per unit of human capital which is increasing at the rate of aggregate productivity growth.

Given the model's extension, individuals face now an allocation decision for unhealthy consumption additional to the optimal allocation of health expenditure over time (WP 3). Quite intuitively, the life cycle optimization produces behavior according to which expenditure on health and on unhealthy goods are negatively correlated, over time as well as across individuals. This means that persons who spend more on health are predicted to indulge less in health-damaging consumption. Demand of unhealthy goods is lower at higher prices and there exists a preemptive price which deters unhealthy consumption. This means that for unhealthy consumption to occur at all, the unhealthy good has to be sufficiently appreciated by the consumer and its price has to be sufficiently low. Optimal behavior furthermore prescribes that expenditure for unhealthy consumption should decrease with age.

Optimal schooling behavior requires that the marginal loss from postponing entry in the labor market equals the marginal gain from extending education. For the special case in which health does not matter for human capital it was shown that optimal education is independent from longevity and coincides with the solution predicted by the conventional model in labor economics. When ageing matters for human capital, however, education and longevity are interdependent through the rate of health deficit accumulation. It is thus a priori unclear how individuals would optimally like to allocate their life-time on schooling and working and their life-time income on unhealthy and health-neutral consumption, savings, and health investments now and in the future. In order to understand what exactly determines how long a person wants to live, facing the force of ageing and the constraints on education and the household budget we calibrated the model to US data.

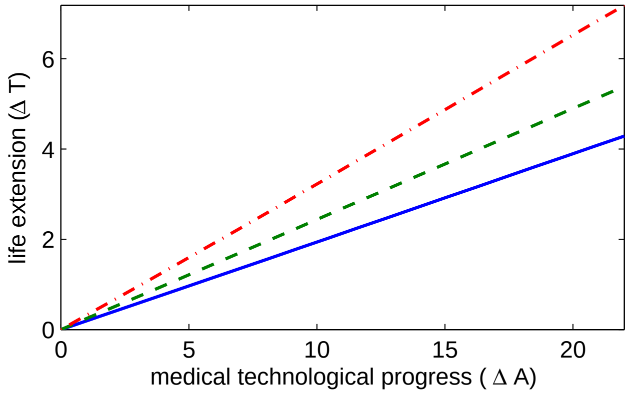
Our benchmark experiment is to increase the return on education such that the reference American is motivated to do one more year of education. Ceteris paribus, he educates a year longer when the return on education rises from 0.100 to 0.104. This motivates him to reduce unhealthy consumption by 8.8 percent and increase health expenditure by 4.4 percent. As a consequence of the behavioral changes, the better educated person lives half a year longer. The result accords well with the empirical observation that education is positively associated with health through behavior as well as through income and that both channels are about equally important (Cutler and Lleras-Muney, 2010).

The model helps to identify causality, a problem, which has tormented the related empirical literature. The mechanism goes as follows. Higher cognitive skills make education more worthwhile. Better educated persons are endowed with more "precious" human capital, which they care more to protect by indulging less in unhealthy consumption and by spending more on health. Consequently they live longer.

The effect of education on life-length is non-linear. The more people educate the larger is the return in terms of longevity. Eight years of education on top of the 13.5 from the basic run, that is basically a PhD degree, is predicted to result in a about eight more years of life. This result fits nicely with Meara et al.'s (2008) observation that in 1990 a college graduate could expect to live 8 years longer than a high school dropout of the same age.

The education gradient responses relatively strongly to medical technological progress. Technological progress is predicted to lead to a steeper education gradient, that is, ceteris paribus, to a more unequal society with respect to health status. The reason is that better educated persons demand more health services in order to protect or repair their human capital.

Figure 4: Medical Technological Progress and the Health Gradient



The figure shows the gain in longevity for alternative progress of medical technology (ΔA). Blue (solid): benchmark run (13.5 years of education, $\theta = 0.1$). Green (dashed): 4 years more of education ($\theta = 0.12$). Red (dash-dotted): 7.2 years more of education ($\theta = 0.14$) The longevity gain is measured relative to the own initial life-span for both types.

Figure 4 shows the longevity gains resulting from alternative increases of the power of medical technology A to reduce health deficits; ΔA is measured in percent of the benchmark run. If medical technology advances at an annual rate of 1 percent (3 percent) the level of A is 20 percent higher after about 18 years (6 years). The solid line shows the predicted longevity for the Reference American (endowed with a return to education of $\theta = 0.1$). The dashed line shows the prediction for a person with $\theta = 0.12$, which educates for 4 years longer and the dash-dotted line reflects longevity of a person with $\theta = 0.14$ and 7.2 more years of education. Although everybody experiences an increase in longevity, the predicted gain of the better educated persons is higher. When A advances by 20 percent the longevity gap between a high school graduate (solid) and a college graduate (dashed) has widened by about 2 years.

WP 5: Aging and Retirement

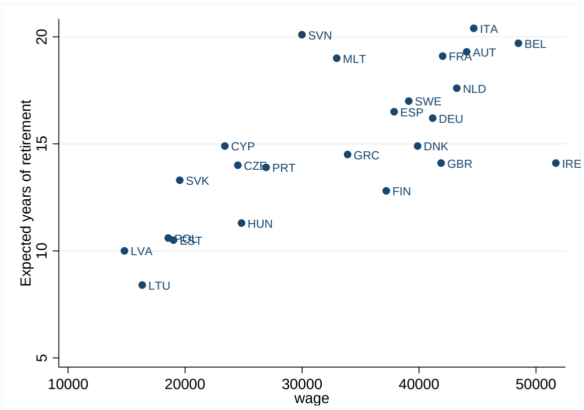
In this WP we applied our model in order to understand the historical evolution of retirement age and retirement duration. In the following we sketch results available in the paper "The Genesis of the Golden Age: Accounting for a Century of Rising Leisure and Health". In contrast to the basic model (WP 3) the wage rate is allowed to change across the life cycle taking into account the overall tendency for wages to rise during life as a consequence of learning-on-the-job as well as the deleterious impact from ageing on work effort. The resulting path of wages, across the life cycle, is hump shaped in keeping with what is known about life time wage income. This empirically meaningful description of wages is one reason why individuals prefer to start life working, and retire late in life; foregone earnings (from not supplying labor) will be greater early in life compared to late in life.

The individuals' income can either be spent on non-health consumption, it can be saved for future purposes, or it can be invested in health, which serves to reduce the speed of ageing and thus delays the time of death. In addition, at each point in time the individual has one unit of time available, which she decides on whether to supply to the labor market or not. Early in life the benefits from supplying labor will exceed its utility costs, as explained below. However, eventually the individual will find it optimal to stop supplying labor in the market; this is the point of retirement. Another important extension is that we now allow individuals to experience disutility from supplying labor, and that the level of disutility is increasing in the accumulated health deficits. This assumption captures the idea that labor supply is more strenuous, and thus welfare reducing for people in poor health. It provides another reason why people supply labor early in life, only to retire later in life: early in life the utility costs from working are considered to be smaller than late in life.

Individuals face a trade-off between consuming more today or making health investments, which allow for greater consumption in the future. In addition, however, we now put individuals in front of another trade-off; namely that between working or retirement (leisure). Hence, the solution to the optimization problem provides a program for optimal consumption and health investments over the life cycle, along an optimal timing of retirement. Given optimal health investments the path of bodily deficits over the life-cycle and thus, eventually, the time of death, are determined. As a result, the model delivers optimal years spent in retirement as well.

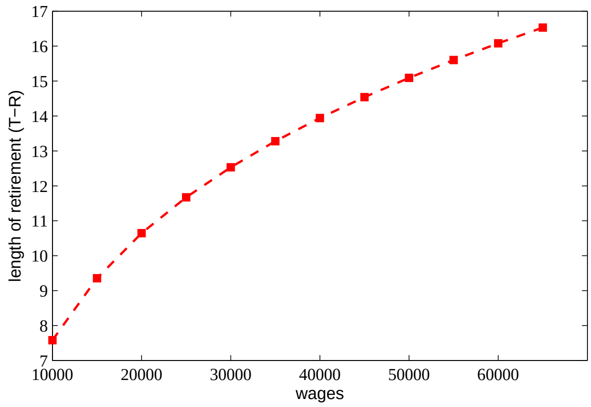
Figure 5: Retirement Years in the EU and in the Model

A: Years of Retirement vs Wages: EU



The figure shows the difference between (male) life expectancy and expected age of retirement, versus the wage rate.

B: Years of Retirement vs Wages: Model



The figure shows link between (male) years of retirement and wages, as implied by the calibrated version of the model developed in Dalgaard and Strulik (2012).

In order to answer the question how the age of retirement (as well as longevity and thus years of retirement) will change, if income rises we again calibrated the model for the average US male citizen and predicted years of retirement for a sample of European countries. Figure 5 depicts the empirically observed link between wage income and years of retirement (Panel A), as well as the model's implications (Panel B). From visual inspection it seems clear that the model matches the data to a reasonable extent, in that it captures broadly the "position" of the apparent years-of-retirement/income gradient. It does slightly underestimate years of retirement at the high income portion of the sample. But since retirement is unquestionably also influenced by institutional features that the model abstracts from, some deviations from actual experiences would be expected. At the same time, since the model does a rather decent job at mimicking the data, this exercise leaves a clue that observed retirement patters probably are not grossly suboptimal.

Table 1: Projecting Age of Retirement and Years of Retirement

Projections by:	Carone (2005)	Model		
		g=0.01	g=0.02	g=0.03
Mean age of exit, 2050	62,9	61,9	62,1	62,4
Mean years of retirement , 2050	22,1	19	24,8	34,2

Notes: (i) g refers to the assumed annual growth rate in wages in the context of the model. The calculations in column 2-4 are made based on the calibrated models' predictions regarding relevant elasticities; see text for details. (ii) The projections for column 1 are from Carone (2005), Table 4, p. 31, and refer to EU average.

A unique feature of our framework is that both longevity and age of retirement are endogenous to wages. Accordingly, provided one can come up with reasonable projections for income growth, we can predict years of retirement. Expected wage growth until 2050 is obviously also an uncertain proposition. Still, using past experiences a plausible projection would be two percent per annum, plus/minus a percentage point. Given these assumptions about future growth, we can use the model's predicted elasticities for age of retirement and years of retirement, respectively. Table 1 reports the results, and those of Carone (2005); they all refer to averages for the EU 25.

The predictions by our model and those of Carone are rather comparable when it comes to age of retirement, though Carone's projections suggest a slightly higher age of retirement compared to our model's predictions. If we assume a growth rate of three percent, however, we project a significantly longer retirement than Carone. It is furthermore worth noting that these calculations do not take into account that health efficiency (be that in terms of medical technology or institutions) may improve in the years to come, which may well work to increase years of retirement via its positive impact on longevity. We thus conclude that reasonable growth in wages, in the absence of reforms, can be expected to increase years of retirement considerably in the years to come.

Another line of research in WP 5 investigated part time work as an alternative to retirement. Part time work can facilitate participation in the labor market and smooth the transition to retirement. Part-time employment, however, represents for the most part an involuntary choice. The aim of this research was to conduct an empirical investigation of the determinants of part-time work. Using Spanish labor market data, we found that part-time work becomes a more desired employment alternative as people age, and that education and children's age have opposite effects on women and men's probabilities of voluntary part-time employment. Interestingly, most part-time work among women occurs in low-skill occupations, whereas part-time work among men is mainly concentrated in high-skill jobs.

WP 6: The Effect of Immigration on the European Aging Society

In this WP we were evaluating the impact of migration on overall productivity and its implications for human capital formation (in a broad sense, including education and heath) in an ageing society, and for the design of immigration management policies. Migration is sometimes seen as a panacea to circumvent the financial problems associated to ageing societies. Other authors, however, see it as a burden, because the arrival of migrant workers can depress the wage of non-educated natives and reduce the economy's average productivity. In this LEPAS paper "Immigration, evolution of skills, and social security" we provide results of a study that analyzed the effect of migration on workers' productivity and the wage gap. For that purpose we constructed a life-cycle model with endogenous educational choices and health investment. Our results point out that, when human capital investment over the life cycle is possible, migration does not universally increase the wage gap, this depends on the economy's initial conditions.

WP 7: Endogenous R&D-driven Growth in an Ageing Society

In this WP we integrated key mechanism from the individual life cycle model into the framework of endogenous long-run economic growth and investigated the impact of increasing longevity on future growth prospects.

Over the course of human history we observe a strong positive correlation between income and life expectancy as well as between income and education. These aggregates showed no visible trend for millennia and then, in most developed countries, began to rise jointly and permanently roughly at the same time, for example around the year 1800 in England. The observed positive *correlation* is thus undisputed, constituting basically a stylized fact of successful human development. Yet there exists a lively debate about the interpretation of the correlation.

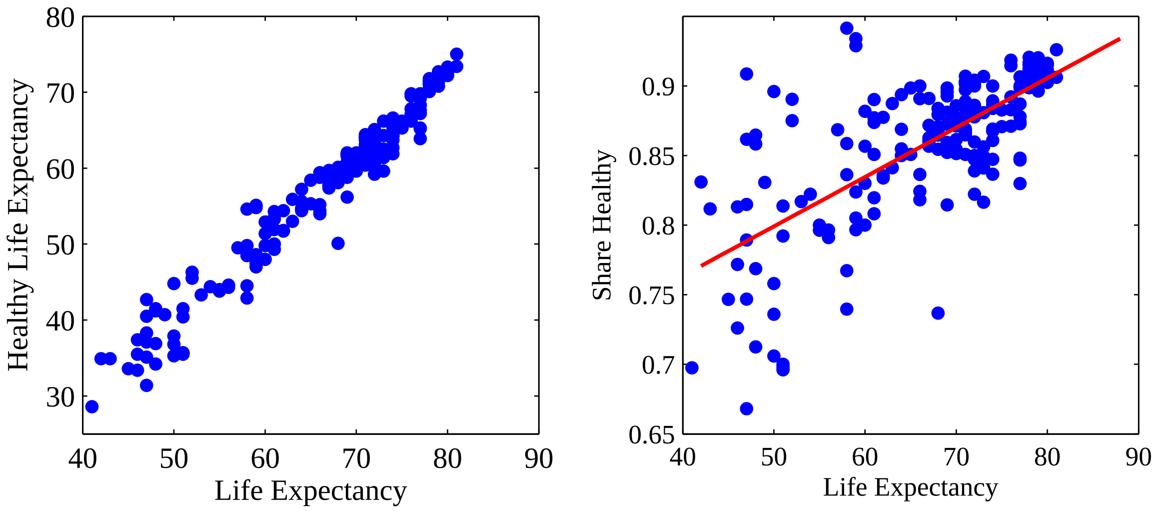
One popular hypothesis, built upon human capital theory and the life cycle of earnings (Ben-Porath, 1967), argues that increasing life expectancy leads to more education and thereby to faster income growth. In simple words the Ben-Porath mechanism implies that the expectation of a longer life leads to more education because it provides a longer working-period during which people can harvest the fruits of their education in form of higher wages. A longer working life makes the opportunity cost of education, stemming from a later entry into the workforce, worthwhile. This line of reasoning seems to suggest that higher education should be associated with more life-time labor supply and, indeed, Hazan (2009) showed, based on a simplified version of the Ben-Porath model, that increasing longevity has a non-negative effect on life-time labor supply. Hazan then continued to show that for male U.S. citizens increasing education was associated with *decreasing* life-time labor supply since the early 19th century; that is, basically since the onset of modern economic growth. Higher life expectancy seemingly cannot have caused education levels to rise through the Ben-Porath mechanism. Consequently, increasing life expectancy – through this channel – could not have caused economic growth.

The key idea of our theory is that there exists a distinct period at the end of human life, in which the body is too frail for labor supply to be worthwhile. The response of labor supply to increasing life expectancy then crucially depends on which period of the life cycle is expected to get longer. If people expect to stay longer in the inactive and potentially frail state, they work harder during the active period of life. If, in contrast, people expect to stay longer in an active and healthy state, they prefer to reduce labor supply per time increment (i.e. per month or week) in the active period and enjoy more leisure.

The left hand side of Figure 6 shows that life expectancy and healthy life expectancy are strongly correlated across countries. As life expectancy improves, healthy life expectancy improves "in sync". But what looks like a linear correlation to the naked eye is actually mildly non-linear. This fact is revealed in the right panel of Figure 6. As life expectancy increases, the share of healthy years increases as well, by about 0.35 percent for every year of life expectancy. With improving longevity we get more healthy as well as more unhealthy years but we get more healthy than unhealthy years. That is, healthy or active life expectancy improves relatively to longevity. This is the stylized fact upon which we built our theory.

With respect to education, increasing longevity has a positive impact no matter where in the life cycle it occurs. Because people derive utility from consumption in every period of their life, a longer life generally induces more education, since higher education provides more income and thus more utility from consumption per time increment during the active and inactive period. The theory thus predicts unambiguously more eduction and less labor supply per time increment if people expect a longer active period of life. With respect to *total* labor supply over the life-time the prediction is generally ambiguous because the negative effect of less labor supply on the intensive

Figure 6: Life Expectancy vs. Healthy Life Expectancy Across Countries



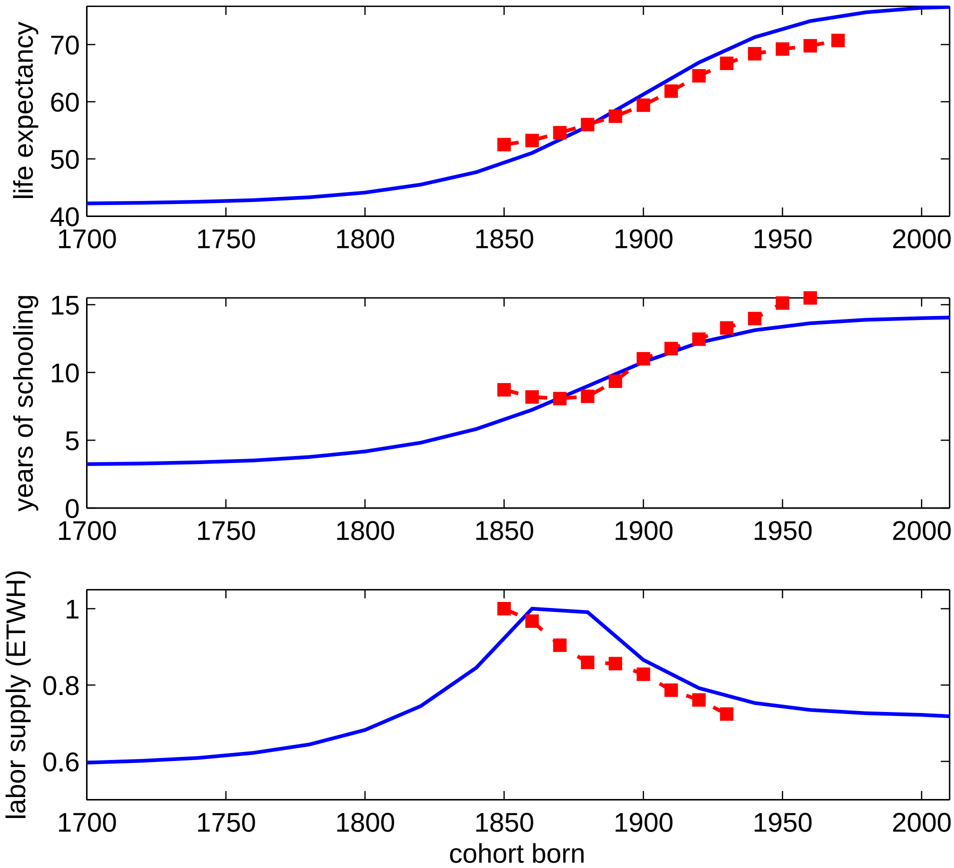
Data for 191 countries from WHO (2012). Life expectancy at 5 from year 2000, healthy life expectancy at 5 from year 2002. Share Healthy (SH) is healthy life expectancy divided by life expectancy (LE). Regression line: SH = 0.61+0.0035 LE; 95% confidence interval for coefficient: $[0.0030, 0.0041]$.

margin could be offset by a longer active life. But it can be that the negative effect dominates if the labor supply elasticity is sufficiently large. In that case the theory predicts that increasing life expectancy causes more education and less life-time labor supply.

We calibrate the model with data for male US citizens and show that the life cycle model explains the historical evolution of life expectancy, education, and labor supply as presented in Hazan's (2009) study quite well. We then develop a unified growth model in which education is the driver of technological progress and show that the life cycle model explains the historical evolution of technological change and GDP growth quite well. We thus re-establish increasing life expectancy as an engine of long-run economic development.

Figure 7 presents the predicted adjustment dynamics for the most interesting epoch from 1700 to today. Solid lines show the predicted trajectories for life expectancy, education, and labor supply. Dashed lines show the historical data from Hazan (2009).

Figure 7: Long Run Evolution of Longevity, Education, and Labor Supply



Solid lines: model prediction, dashed lines: historical data. Labor supply is normalized such that the historical peak is at unity.

Increasing life expectancy causes years of schooling to rise and aggregate labor supply (expected total working hours, ETWH) first to rise and then to fall. The initial rise of ETWH results solely from increasing active life expectancy because, according to the model, labor supply is at the corner before 1850 and a longer healthy life thus translates one to one into more aggregate labor supply. After 1850, individuals increasingly enjoy leisure time and ETWH declines.

Another line of research in this WP, summarized in the paper "A model of health investment, medicine consumption, and income" reassessed our results from the viewpoint of public economics. The rising number of older adults generates an unprecedented demand on the public health system. In a growth framework of health prevention investment and medical technology consumption the use of medical techniques and diseases endogenously determine the levels of income and health. In the model, there are two forms of medical technology: one is embodied in medicines that try to cure sick individuals, whereas the other is disembodied knowledge that tries to prevent health deterioration. We find that larger saving rates are not only a consequence of a larger productivity of the consumption-goods technology; more productive pharmaceutical products and higher levels of preventive-health knowledge also increase the incentive to saving, and allow the economy to achieve larger levels of income, mitigating the adverse effects of ageing.

WP 8: Health, Survival and Consumption over the Life Cycle

In this WP we tried to quantify whether too much or too little is spent on health investment. Results in this research are available in three LEPAS papers

- The Reproductive Value as Part of the Shadow Price of Population
- Externalities in a Life-Cycle Model with Endogenous Survival
- Optimal Choice of Health and Retirement in a Life-Cycle Model

The Reproductive Value as Part of the Shadow Price of Population

The reproductive value arises as part of the shadow price of the population in a large class of age-structured optimal control models. We mentioned that the generalized reproductive value can have a negative sign. As an example, consider a model minimizing the impact of a population of a pest on a valuable supply of a resource. If the pest population (destroying the resource) is modeled, the corresponding shadow price will be negative. This implies that also the generalized reproductive value (i.e. the impact of yet to be born pest individuals on the future stock of the resource) is negative. For another application, consider an age-specific predator/prey model, embracing cattle and wolves, for example, as presented in Wrzaczek et al. (2010). Also in this example the reproductive term can be negative depending on the type of objective function (e.g. the reproductive value of the predator, if in contrast to the prey, it has no direct economic value in and of itself). A further epidemiological application involving the interaction of infected and susceptible individuals is presented in Wrzaczek et al. (2010). Finally, we want to emphasize that the concept of the reproductive value is not only applicable to humans and animals, but also to self-renewing machines or even capital.

Externalities in a Life-Cycle Model with Endogenous Survival

In this paper we study socially vs individually optimal life cycle allocations of consumption and health, when individual health care curbs own mortality but also has a spillover effect on other persons' survival. Such spillovers arise, for instance, when health care activity at aggregate level triggers improvements in treatment through learning-by-doing (positive externality) or a deterioration in the quality of care through congestion (negative externality). We combine an age-structured optimal control model at population level with a conventional life cycle model to derive the social and private value of life. We then examine how individual incentives deviate from social incentives and how they can be aligned by way of a transfer scheme.

The age-patterns of socially and individually optimal health expenditures and the transfer rate are derived both for a steady state and for the transitional period. In the numerical analysis the model has been applied to real data. The transfer scheme turns out to be hump shaped subsidies (with respect to age) for positive and a U-shaped tax for negative spillovers. The shape is driven by the differences in the social and the private value of life. Comparing the transfers in both cases, it turns out to be higher for negative spillovers. This is due to the fact that for negative spillovers taxes intend to reverse private incentives, whereas in the case of positive spillovers subsidies are complements. Furthermore we are able to express the loss of the second best solution (compared to the first best one) in terms of life-expectancy of the individuals.

Optimal Choice of Health and Retirement in a Life-Cycle Model

We examine within a life-cycle set-up the simultaneous choice of health care and retirement (together with consumption), when health care contributes to both a reduction in mortality and in morbidity. Health tends to impact on retirement via morbidity, determining the disutility of work, and through longevity, determining the need to accumulate retirement wealth. In contrast, the age of retirement drives health through changes in the value of survival and the value of morbidity reductions. We apply our model to analyse the effects of moral hazard in the annuity market: While moral hazard always induces excessive health investments and an excessive duration of working life it also triggers an excessive level of consumption if the impact of health on the disutility of work is sufficiently large. We examine a transfer scheme and mandatory retirement as policies to curtail moral hazard.

Our results suggest that while moral hazard and its negative consequences could be eliminated by appropriate taxation of health care, the implementation is likely to prove difficult. As it turns out health care would have to be taxed at rates in the order of 25 per cent during the life years with peak spending. Even if the proceeds of such a tax are rebated to consumers, such a policy is exposing consumers to a high risk of being exposed to high co-payments for health care (when it is most needed). It is therefore unlikely to garner political support. In contrast, our model lends some (limited) support for early retirement policies: even if they are distorting in many other ways, they may have a role in contributing towards a reduction in health-related moral hazard. Conversely, pressures for an extension of the working life, while being justified on the grounds of sustainability of pension systems, should take into consideration the negative side-effect on health-related moral hazard.

Socio-economic Impact and Dissemination Activities

The aging European population is bound to have important effects on economic outcomes. In particular, it has long been recognized that the major demographic changes on the horizon will strongly impact on public budgets. Specifically, one can envision rising expenditures on health care and social security, accompanied by decimated tax revenues due to a receding work force and, possibly, a labor productivity slowdown. As a result, the Welfare State will be put under pressure, spawning the need for policy intervention. The process of a rising mean age of the European populations is largely caused by declining fertility rates, which automatically shifts the age distribution of the population. However, the above challenges are also affected in a major way by the gradual prolonging of life-spans and by the incidence of morbidity during life. Senescence affects the expenditure side (for health care in particular), as well as the revenue side (through productivity). The LEPAS project provides a framework for analysing the economic consequences of aging based on solid natural science foundations. As a result, it creates a far better basis for economic analysis of aging, and thus provides a much firmer foundation for the development of policy advice geared towards providing a steady stream of public goods to the European population.

We presented and discussed our results at local and international scholarly meetings - conferences, seminars, workshops. The first LEPAS workshop and conference took place on 17-18 June 2010 in Vienna, involving the consortium, the advisory board and external guests. As WP leader, VID coordinated the organization of the meeting and the preparation of the conference volume. This first LEPAS conference aimed to discuss our work during the first year of the project. For this purpose we invited Jim Carey (member of the scientific board) and key researchers in the field of economic growth and longevity in addition to all members of the LEPAS project. The aim was to discuss our work as well as to learn more about alternative approaches from the external participants. Topics included the bio-demographic approach to ageing (keynote by Jim Carey); empirical regularities between survival and frailty across different populations; the relationship between longevity, savings, labour supply and economic growth; the modelling of individual behaviour directed towards health and survival; and the effects of eye-sight (as an age-related measure of health) on economic productivity. To document our presentations and papers we have set up a conference volume at the LEPAS homepage (http://www.lepas-fp7.de/publications.php). The second LEPAS workshop and conference took place on 15-18th June 2011 in Alicante, involving the consortium, the advisory board and external guests. Researchers from Spain, Germany, Austria, Denmark, Switzerland, United States, and Canada attended it. The papers presented were included in the Conference Volume (http://www.lepas-fp7.de/publications.php). Topics included (a) measuring aging in individuals and populations, (b) explaining health inequalities around the world and (c) the impact of health on schooling and retirement decisions. Moreover, the consortium attempted a broad interdisciplinary discussion. Therefore, the three key note lectures were held of a biologist, a medical scientist and a demographer, all working on this field of research.

Through our series of policy briefs we aimed to summarize key findings of our project and introduce them to the public and interested stakeholders. These are brief statements in an accessible, non-scientific language that will help to highlight our relevant findings. In the first policy review (http://www.lepas-fp7.de/p-brief-2009-09-02.pdf) we lay out the main objectives of the project in order to advertise the research agenda. In the second policy brief (http://www.lepas-fp7.de/p-brief-2010-04-19.pdf) we lay out our approach to modelling ageing arguing that we need to incorporate a more realistic process of senescence into our economic models. In our third policy brief (http://www.lepas-fp7.de/p-brief-2010-10-31.pdf) we discuss the role of income for explaining differences of life expectancy across countries. In the fourth policy review (http://www.lepas-fp7.de/p-brief-2011-04-26.pdf) we showed that cross-country differences in prosperity can explain differences in longevity (at age 20) of up to a decade. The fifth policy brief (http://www.lepas-fp7.de/p-brief-2012-04-01.pdf) described the ageing population as a global phenomenon. All partners contributed to the policy briefs and have also helped in their wide distribution among both researchers and the public. We have also published three scientific reports which provide a more detailed summary of our research and should be still accessible by non-expert readers and policy-makers. In this reports we also provide some first application of our model and methods for a sample of European countries.

The LEPAS webpage was launched in Month 1 of the project and acts as our main communication portal for the scientific community as well as the public. Through the webpage we announced the objectives of the LEPAS project, post our work in form of LEPAS-working papers and reports on ongoing and upcoming activities such as project workshops. All working papers, conference volumes, policy briefs, and research reports are publically available on the website via the following links: http://www.lepas-fp7.de/publications.php; http://www.lepas-fp7.de/policy-briefs.php. The overall LEPAS research was compiled in a scientific book "Long-Run Economic Perspectives of an Ageing Society" which we distributed among prominent economists working on aging related problems and several natural scientists who got interested in our work during the LEPAS workshops, as well as among policymakers.

Project Website and Contact Details

Project Website: http://www.lepas-fp7.de

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