The Marriage Gap: Optimal Aging and Death in Partnerships [*]

Johannes Schünemann[†], Holger Strulik[‡] and Timo Trimborn[§]

May 2018.

Abstract. Married people live longer than singles but how much of the longevity gap is causal and what the particular mechanisms are is not fully understood. In this paper we propose a new approach, based on counterfactual computational experiments, in order to asses how much of the marriage gap can be explained by income pooling and public-goods sharing as well as joint utility maximization of partners with different preferences and biology. For that purpose we integrate the joint decision making of couples into a biologically founded life-cycle model of health deficit accumulation and endogenous longevity. We calibrate the model with U.S. data and perform the counterfactual experiment of preventing the partnership. We elaborate four economic channels and find that, as singles, men live 8.5 months shorter and women 6 months longer. We conclude that about 25% of the marriage gain in longevity of men can be motivated by economic calculus while the marriage gain for women observed in the data is attributed to selection or other (non-standard economic) motives.

Keywords: health, aging, longevity, marriage-gap, gender-specific preferences, unhealthy behavior.

JEL: D91, J17, J26, I12.

---

[*] We would like to thank David Bardey, Francesca Barigozzi, David de la Croix, Carl-Johan Dalgaard, Oddvar Kaarboe, Mathias Kifmann, Michael Kuhn, and Alexia Prskawetz for discussion and helpful comments.

[†] University of Goettingen, Department of Economics, Platz der Goettinger Sieben 3, 37073 Goettingen, Germany; Visiting Graduate Student, Harvard T.H. Chan School of Public Health; email: jschune@hsph.harvard.edu.

[‡] University of Goettingen, Department of Economics, Platz der Goettinger Sieben 3, 37073 Goettingen, Germany; email: holger.strulik@wiwi.uni-goettingen.de.

[§] Vienna University of Technology, Institute of Statistics and Mathematical Methods in Economics, Wiedner Hauptstraße 8 / 105-3, 1040 Vienna, Austria; email: timo.trimborn@tuwien.ac.at.

1. Introduction

On average, married individuals, in particular men, live longer than singles (Waite and Gallagher, 2002). This stylized fact, which we will refer to as the marriage gap in longevity, is so well established that it is regarded as one of the most robust relationships in social sciences (Liu, 2012). Whether and to what extent being married *causes* better health and higher longevity is less well known. One potential threat to econometric identification is selection into marriage, since wealthier and healthier individuals are more likely to get (and stay) married. The marriage gap declines substantially but does not vanish when socioeconomic status and initial health (as measures of selection into marriage) are taken into account (Dupre et al., 2009; Rendall et al., 2011). Many, but not all studies, also find a significantly higher gain from marriage for men and that in particular married men behave less unhealthy than single men (Dupre et al., 2009; Rendall et al., 2011). Moreover, the marriage gain seems to be increasing over time (Murphy et al., 2007).

Most studies assess the marriage gap by estimating hazard ratios for mortality of married vs. unmarried individuals (see Manzoli et al., 2007, for a survey and a meta study). While technically convenient, the hazard rate approach is not very intuitive. More interesting would it be to asses how marriage affects the longevity of men and women. Such estimates were recently provided by Pijoan-Mas and Rios-Rull (2014) for 50 years old white U.S. Americans. Their study takes behavioral changes into account and measures the life expectancy of hypothetical cohorts with given characteristics. It estimates for the year 2008 a marriage gain of 2.7 years for men and 1.5 years for women. In 1992, the gain was 1.5 years for men and 0.6 years for women.

Several mechanisms through which marriage could have a protective effect have been suggested but their specific role and quantitative importance is less well researched. For example, marriage could provide psychological and social benefits, which lead to improved health outcomes (Waite, 1995), or monitoring and encouragement through the spouse may induce health-promoting behavior (Umberson, 1992; Ross, 1995). Aside from the emotional channels emphasized in the medical and social sciences, marriage provides also significant economic gains from sharing of household public goods (e.g. Manser and Brown, 1980; Lam, 1988; Salcedo et al., 2012).

Acknowledging the potential socio-emotional benefits of marriage, we propose here a new method, based on counterfactual computational experiments, in order to assess whether and if yes how the marriage gap can be explained by "cold-hearted" economic calculus. For that purpose, we integrate the joint decision making of couples into the health deficit model (Dalgaard and Strulik, 2014). We then calibrate the model such that it fits the health behavior, health outcomes, and life expectancy at the age of entry in marriage for the average U.S. American man and woman in the year 2010. The counterfactual experiment is that we prevent marriage and let men and women solve their life-cycle problem as singles. The model predicts that marriage provides a gain in life expectancy of 8.5 months for men, i.e. about 26% of the observed marriage gap, and a loss of 6 months for women. This is an interesting and non-obvious result because women benefit from income pooling and public-goods sharing in marriage. It suggests that the marriage gain in longevity of women observed in the data cannot be motivated by standard economic channels. The marriage gain is thus either motivated by non-standard economic channels like informal health care or the socio-emotional channels mentioned above. Another plausible explanation is that the data show selection rather than causality, i.e. healthier and wealthier women are just more likely to get and stay married.[1]

The counterfactual method allows us to causally examine four economic channels through which living as a couple (in marriage or cohabitation) may affect health and longevity. The first and perhaps most obvious channel is income pooling. Given gender income differences in favor of men, income pooling in marriage benefits the wife at the expense of the husband. This should lead ceteris paribus to greater longevity for the wife and a shorter life for the husband compared to longevity when single. The second channel is given by public-goods sharing. Sharing public goods leads to a (quasi-) increase of income since more resources are available for private goods consumption. Since individuals face decreasing marginal returns from instantaneous consumption, increasing income induces a higher propensity to smooth consumption over a longer lifetime and thus the incentive to spend more on health and to reduce unhealthy goods consumption. The income channel is the core mechanism in the health deficit model of Dalgaard and Strulik (2014), which addressed the socio-economic gradient of health and longevity at the individual level.

The other two channels are based on joint utility maximization in partnerships and they tend to benefit only men. The biological channel takes into account that at any age, men accumulate health deficits at a higher speed (e.g. Mitnitski et al., 2002a, 2002b). This means

[1] The feature that women lose in marriage in terms of health and life expectancy does not imply that women lose in marriage in terms of welfare. In fact, according to our calibration, both men and women gain in marriage in terms of lifetime utility.

that in partnerships, at a given age of the couple, investments in the health of men provide a higher marginal return in terms of health deficits avoided and thus in terms of life extension and the value of life. Compared to individual utility maximization, it is thus optimal for couples to allocate health investments away from the woman and towards the man.

The preference channel takes into account that men tend to be less risk averse and value good health less than women (Sindelar, 1982; Waldron, 1985; Wardle et al., 2004; Croson and Gneezy, 2009), a stylized fact that we replicate in the estimation of our calibrated model. A lower degree of risk-aversion (i.e. less curvature of the utility function) means that men, as individuals, tend to like instantaneous consumption more than women and invest less in their health and longevity. As singles, at a given age, men thus experience more utility and less marginal utility from consumption than women. In partnerships, however, allocative efficiency requires that marginal utility from consumption is equalized between men and women. This means that the couple puts less emphasis on the instantaneous gratification of men and more on their health, now and later in life. Obviously, the opposite holds true for women.

In order to keep the analysis tractable we do not endogenize the marriage market in which the selection process takes place. Such a procedure would be necessary if one seeks to completely explain the marriage gap observed in the data. Here, we assume that the marriage decision has been already made, and aim to analyze the causal contribution of four different channels to the longevity gain (or loss) from marriage. The construction of our counterfactual experiment shuts down reverse causality with respect to these four channels. The reason is that we compare longevity of a married and a single individual, holding constant health, preference, and environmental parameters. As a consequence, the resulting longevity differential can only originate from the economic channels considered in this paper. Although we do not take into account the process of selection, we are able to model the impact of selection in reduced form once the marriage decision has been made. With the help of this experiment, we derive an upper bound on the selection effect.

Summarizing, the model predicts that partnerships are conducive to a longer life of women through income pooling (at the expense of men) and beneficial for both men and women through the public-goods channel, while only men gain (at the expense of women) through the biological channel and the preference channel. The model thus explains why the marriage gain is larger for men than for women. Surprisingly, our quantitative analysis finds that the biological and preference channel outweigh the positive effect of income pooling and public-goods sharing on longevity for women. It thus predicts that differences in economic behavior between single and married women lead to a marriage loss in longevity for wives. We use the term "marriage gain" for linguistic ease. The same results hold true under joint utility maximization of cohabiting couples. In this respect it is interesting that a recent study by Kohn and Averett (2014) finds that, controlling for selection, cohabitation is better than marriage for the health of men and women. While their results could be viewed as challenging for the earlier literature emphasizing the socio-economic benefits from marriage as an institution (Waite and Gallagher, 2002) it is broadly supportive of the public-goods channel emphasized by our theory.[2]

The related health economics literature provides relatively little theory-based discussion of the marriage gap of mortality. One reason is certainly that the literature was dominated for several decades by the health capital model (Grossman, 1972, 2000). Health capital is problematic because it is a latent variable, which is exclusively used by economists and which is alien to the medical and biological sciences. The fact that health capital is unobservable makes it hard if not impossible to calibrate any theory of health behavior with data (for difficulties estimating the health capital model see e.g. Wagstaff, 1986). Health deficits, in contrast, can be reported not only by doctors and scientists but actually by everyone in society. The frailty index provides a straightforward metric for health deficits and its relation to age and mortality can be estimated with high precision. Moreover, since the health capital model counterfactually assumes that healthy people age faster than unhealthy people of the same age, it involves some undesired predictions which makes it hard to fit actual life-cycle trajectories (for a critique, see e.g. Zweifel and Breyer, 1997; Case and Deaton, 2005; Almond and Currie, 2011; Dalgaard and Strulik, 2015).

Our study is related to the work of Jacobson and coauthors who introduce into the health capital framework the idea that, in a family, one could also invest into the health of the partner. This interaction is then investigated for the unitary household (Jacobson, 2000), under Nash-bargaining (Bolin et al., 2001) and for non-cooperative partners (Bolin et al., 2002). In each study the solution is only obtained up to the first-order conditions. Since there are infinitely many trajectories in the phase space fulfilling the first-order conditions, this means that the

[2]It should be noted that our four channels do not exhaust all potential economic channels. For example, there may be extra gains from altruism (the "warm glow" of love) and, particularly for men, from health services provided by the spouse. By comparing childless couples and singles we also do not take into account potential health damage from being a single mother (or single father).

earlier literature did not fully identify how marriage affects health outcomes and longevity. For that purpose one needs to inspect the boundary conditions and the transversality condition (that holds when the first partner dies) since these conditions identify the unique optimal lifetime trajectory and the lifespan of men and women. The Jacobsen approach has been refined by Felder (2006). By simplifying the model, Felder manages to show, by relying only on the first-order conditions, that a longevity differential between sexes exists under certain assumptions and that it is smaller in marriage than for singles. In terms of our model, Felder focusses (in reduced form) on the income channel as well as the biological channel and ignores the public-goods channel and the preference channel. Here, in contrast, we investigate the role of all four economic channels for health behavior and health outcomes and identify their quantitative importance for the marriage gap by calibrating the model with actual data.

Conceptually, this paper builds on our earlier study of the gender differential in longevity among singles (Schünemann et al., 2017b) and it relates more broadly to a strand of recent studies that utilize the health deficit approach to (re-)investigate the Preston curve (Dalgaard and Strulik, 2014), the education gradient (Strulik, 2018), the historical evolution of retirement (Dalgaard and Strulik, 2017), the role of adaptation for health behavior and health outcomes (Schünemann et al., 2017a), and the optimal design of social welfare systems (Grossmann and Strulik, 2017). Conceptually, the task of this paper is much more challenging, both theoretically and in its numerical implementation, because it requires to solve simultaneously two free terminal time problems of optimal control, one at the interior when the first partner dies and one at the boundary when the widow passes away.

The paper is organized as follows. In the next section we propose a life-cycle model of health behavior, health outcomes, and longevity of couples. In Section 3 we calibrate the model with U.S. data and in Section 4 we discuss the implied life-cycle trajectories for married men and women. In Section 5 we perform the counterfactual exercise of preventing marriage and predict the life course of the calibrated couple as singles. We work out four channels through which men and women gain or lose in marriage and discuss their quantitative importance. In Section 6 we provide sensitivity analyses with respect to non-calibrated assumptions and income effects on the marriage gain. We also discuss the impact of the age at marriage. Section 7 concludes.

2. A Life-Cycle Model of Health Behavior and Longevity of Couples

Consider a couple that derives utility from consumption and being in good health. The state of health is measured by the accumulated health deficits D_i and D_j with $i, j = \{F, M\}$ where F and M denote the female and male spouse, respectively. Both spouses are subject to gender-specific biological aging. We follow the approach of Dalgaard and Strulik (2014) and assume that deficits accumulate according to

$$\dot{D}_i = \mu_i(D_i - I_i(h_i) - a) \tag{1}$$

where μ_i denotes the "natural" force of aging. Health deficit accumulation can be slowed down by deliberate health investments h_i. The health production function $I_i(\cdot)$ is assumed to be strictly concave and fulfills the Inada conditions. The parameter a controls environmental influences beyond individual control. The individual dies when $\bar{D}_i$ health deficits have been accumulated. Since the model is formally quite involved (as we demonstrate below), we assume for simplicity a deterministic setup. In related work we took into account that death is a stochastic event and showed that this adds more realism but causes little change of results (Strulik, 2015; Schünemann et al., 2017a).

Gender-specific utility depends on private consumption c_i, commonly consumed goods z, and on accumulated deficits and is given by $u_i(c_i, z, D_i)$. We impose the (standard) assumptions $\frac{\partial u_i(c_i,z,D_i)}{\partial c_i} > 0$, $\frac{\partial^2 u_i(c_i,z,D_i)}{\partial c_i^2} < 0$, $\frac{\partial u_i(c,z,D_i)}{\partial z} > 0$, $\frac{\partial^2 u_i(c_i,z,D_i)}{\partial z^2} < 0$, and $\frac{\partial u_i(c_i,z,D_i)}{\partial D_i} < 0$. Life-time utility of the couple with spouse i and j is then given by

$$V = (1-\theta)\int_0^{T_i} e^{-\rho_i t} u_i(c_i, z, D_i)dt + \theta \int_0^{T_j} e^{-\rho_j t} u_j(c_j, z, D_j)dt. \tag{2}$$

The parameters ρ_i and ρ_j represent the discount rate of future utility while T_i and T_j denote the age of death of spouse i and j, respectively. We model welfare of the household as a weighted sum of the individuals' private utility functions (see e.g. Borella et al., 2017). This way of modeling implements a collective model in which intra-household decision-making leads to pareto-efficient outcomes (Chiappori, 1988, 1992; Browning and Chiappori, 1998). Since the dynamic optimization problem is highly involved, we assume the pareto weight θ to be constant which effectively provides a unitary model of household behavior (see Browning et al. (2006) for a review). Other approaches to household behavior like, for example, non-cooperative bargaining, would lead in our context to differential games between spouses for which we could not obtain a (time-consistent) solution.

Through their health expenditure plan individuals control their speed of deficit accumulation and thus their age of death. The couple receives labor income w, which can be spent on buying health services and private and common consumption goods, as well as on savings. The relative prices of health and public consumption goods are exogenous and given by p and q, respectively. We suppose that the couple has access to financial markets and can save or borrow at net interest rate r. We divide the couple's life cycle into two regimes. In the first one, both spouses are alive ($t \leq T_i, T_j$) while in the second one only one spouse is alive ($T_i < t \leq T_j$). Couple wealth then evolves according to [3]

$$\dot{k} = \begin{cases} w + rk - c_j - ph_j - c_i - ph_i - qz & \text{if } t \leq T_i \\ w + rk - c_j - ph_j - qz & \text{if } t > T_i. \end{cases} \tag{3}$$

Summarizing, the couple maximizes (2) subject to (1) and (3), the initial conditions $k(0) = k_0$, $D_i(0) = D_i^0$, $D_j(0) = D_j^0$, and $D_i(T_i) = \bar{D}_i$, $D_j(T_j) = \bar{D}_j$, $k(max\{T_i, T_j\}) = 0$.

2.1. **Regime I:** $t \leq T_i, T_j$**.** The Hamiltonian when both spouses are alive reads

$$\mathcal{H} = (1-\theta)e^{-\rho_i t}u_i(c_i, z, D_i) + \theta e^{-\rho_j t}u_j(c_j, z, D_j) + \lambda_k \dot{k} + \lambda_i \dot{D}_i + \lambda_j \dot{D}_j \tag{4}$$

where λ_i, λ_j, and λ_k are the co-state variables (shadow prices) of i's deficits, j's deficits and capital, respectively. The necessary conditions are given by

$$\begin{aligned} (1-\theta)e^{-\rho_i t}\frac{\partial u_i(c_i, z, D_i)}{\partial c_i} &= \theta e^{-\rho_j t}\frac{\partial u_j(c_j, z, D_j)}{\partial c_j} \\ &= \frac{1}{q}\left\{(1-\theta)e^{-\rho_i t}\frac{\partial u_i(c_i, z, D_i)}{\partial z} + \theta e^{-\rho_j t}\frac{\partial u_j(c_j, z, D_j)}{\partial z}\right\} \end{aligned} \tag{5a}$$

$$\lambda_i \mu_i \frac{\partial I_i(h_i)}{\partial h_i} = \lambda_j \mu_j \frac{\partial I_j(h_j)}{\partial h_j} \tag{5b}$$

$$\dot{\lambda}_i = -\lambda_i \mu_i - \frac{\partial u_i(c_i, z, D_i)}{\partial D_i} \tag{5c}$$

$$\dot{\lambda}_j = -\lambda_j \mu_j - \frac{\partial u_j(c_j, z, D_j)}{\partial D_j} \tag{5d}$$

$$\dot{\lambda}_k = -\lambda_k r. \tag{5e}$$

[3]Note that the solution would not change in case of an exogenous age of retirement or a widow's/widower's pension as long as the calibrated present value of lifetime income remains unchanged.

Condition (5a) equates marginal utilities from wife's private consumption, husband's private consumption and the common consumption good (adjusted by the relative weight parameter θ and the relative price of the common consumption good q). Equation (5b) implies that the marginal benefit in "utils" of another unit of health expenditure is the same for both spouses. Equations (5c) and (5d) state that the shadow prices of deficits change according to the contribution of an additional unit of deficits to the objective function while equation (5e) requires that λ_k declines at rate r.

2.2. **Regime II: $T_i < t \leq T_j$.** In the second regime only spouse j is alive. The Hamiltonian is now defined by

$$\mathcal{H} = \theta e^{-\rho_j t} u_j(c_j, z, D_j) + \lambda_k \dot{k} + \lambda_j \dot{D}_j. \tag{6}$$

We thus impose the plausible assumption that $\lambda_i = 0$ for $t > T_i$ implying that the accumulation of spouse i's health deficits does not affect the objective function anymore once spouse i has died. The necessary conditions for the second regime read

$$e^{-\rho_j t} \frac{\partial u_j(c, z, D_j)}{\partial c} = e^{-\rho_j t} \frac{\partial u_j(c_j, z, D_j)}{\partial z} \tag{7a}$$

$$\lambda_j = -\frac{p\lambda_k}{\mu_j \frac{\partial I_j(h_j)}{\partial h_j}} \tag{7b}$$

$$\dot{\lambda}_j = -\lambda_j \mu_j - \frac{\partial u_j(c_j, z, D_j)}{\partial D_j} \tag{7c}$$

$$\dot{\lambda}_k = -\lambda_k r \tag{7d}$$

where equation (7a) implies that marginal utilities from private consumption and public consumption have to be equal in optimum.

2.3. **Interior Boundary Conditions.** So far we have stated necessary optimality conditions that hold piecewise in the two regimes. Yet we are missing necessary conditions that apply at the switching point between the different stages. Following Bryson and Ho (1975, pp. 101-104) we introduce an interior boundary condition on T_i, the age of death of spouse i, by

$$\phi(D_i(T_i), T_i) = D_i(T_i) - \bar{D}_i = 0. \tag{8}$$

Equation (8) implies the following necessary conditions at the switching point T_i:

$$\lambda_j(T_i-) = \lambda_j(T_i+), \quad \lambda_i(T_i-) = \lambda_i(T_i+) + \nu, \quad \lambda_k(T_i-) = \lambda_k(T_i+), \quad \mathcal{H}(T_i-) = \mathcal{H}(T_i+) \quad (9)$$

where T_i- signifies the moment just before T_i and T_i+ signifies the moment just after T_i and where ν denotes a constant Lagrange multiplier determined so that the interior boundary condition (8) is matched. From system (9) we can deduce some interesting implications for the control variables of the surviving spouse at the switching point T_i,

$$\frac{\partial I_j(h_j(T_i-))}{\partial h_j} = \frac{\partial I_j(h_j(T_i+))}{\partial h_j} \quad (10a)$$

$$\frac{\partial u_j(c_j(T_i+), z(T_i+), D_j(T_i+))}{\partial c_j} = \frac{\partial u_j(c_j(T_i-), z(T_i-), D_j(T_i-))}{\partial c_j} \quad (10b)$$

$$e^{-\rho_i T_i}\frac{\partial u_i(c(T_i-), z(T_i-), D_i(T_i-))}{\partial z} = e^{-\rho_j T_i}\Big[\frac{\partial u_j(c_j(T_i+), z(T_i+), D_j(T_i+))}{\partial z} - \frac{\partial u_j(c_j(T_i-), z(T_i+), D_j(T_i-))}{\partial z}\Big] \quad (10c)$$

$$\Delta(\lambda_i \dot{D}_i) + \Delta(\lambda_k \dot{k}) = -[e^{-\rho_i T_i}\Delta u_i(c_i, z, D_i) + e^{-\rho_j T_i}\Delta u_j(c_j, z, D_j)] \quad (10d)$$

where $\Delta u_i(c_i, z, D_i) = u_i(c_i(T_i+), z(T_i+), D_i(T_i+)) - u_i(c_i(T_i-), z(T_i-), D_i(T_i-))$ etc. Equation (10a) implies that health investments of the surviving spouse are continuous at the time of death of the partner. Equations (10b) and (10c) show how private and public consumption behave at the switching point. In order to interpret these optimality conditions properly we would actually need to know more about the properties of the utility function. Suppose, for example, that private and public consumption are additively separable. In this case the two conditions imply that private consumption of the surviving spouse is smoothed over the switching point while the public component of consumption jumps downwards. To see the latter result, note that utility is strictly concave in z. Intuitively, the widow or widower reduces public consumption on impact, e.g. by renting a smaller apartment or spending less on holidays.

Finally, equation (10d) determines the optimal time of death T_i which requires the Hamiltonian to be continuous at that point. Economically stated, T_i is chosen optimally when "benefits" equal the (absolute value of) "costs" in terms of utility of expiring at this particular point in time.

2.4. **Transversality Condition (TVC).** The transversality condition associated with the optimal control problem is given by

$$\mathcal{H}(T_j) = 0. \tag{11}$$

The economic intuition is the same as described above for spouse i's optimal age of death. Spouse j chooses their age of death optimally when at T_j the benefits and cost of surviving in terms of "utils" coincide.

3. Calibration

We solve the model numerically using the shooting procedure.[4] To this end, we calibrate the model for the U.S. in the year 2010. With respect to the biological parameters there are no degrees of freedom as they have been estimated with high precision. We take the gender-specific estimates $\mu_F = 0.031$ and $\mu_M = 0.043$ from Mitnitski et al. (2002a). These estimates imply that aging women develop 3.1 percent more health deficits per year while men develop 4.3 percent more deficits in the same time period. Initial and final deficits can be computed from Mitnitski et al.'s regression results. We obtain $D_F^0 = 0.0381$ and $D_M^0 = 0.0305$ as the relevant initial values for a 26.1 years old women and a 28.2 years old men, i.e. for the women's and men's median age at first marriage in 2010. Final values are calculated to fit average life-expectancy of women at 26 years (55.9 years, death at 81.9 years) and men at 28 years (49.6 years, death at 77.6 years) in 2010, giving the estimates $\bar{D}_F = 0.1436$ and $\bar{D}_M = 0.1078$; data on marriage age is from USCB and on life-expectancy from NVSS (2014). The fact that $\bar{D}_F$ exceeds $\bar{D}_M$ captures in reduced form that on average women tend to accumulate more but less fatal deficits than men at any age. Related to the frailty index that we employ in our study this fact is supported by another contribution by Mitnitski et al. (2002b). The authors show that sex-specific mortality rates can be estimated with great precision as a power law (log-log association) of the frailty index ($R^2 > 0.95$) and that, for any given number of health deficits, men are more likely to die than women. Thus any attempt to analyze gender-specific aging and longevity must take into account that men are initially healthier but age faster while women, at any age, have accumulated more health deficits but die later. This inverse association between health and longevity is known as the morbidity-mortality paradox (Verbrugge, 1988; Case and Paxson, 2005; Kulminsky et al., 2008) and is properly replicated by our model (see Figure 1 below)[5]. Following Dalgaard and Strulik (2014) we parameterize the health production function as

[4]Technical information on the solution method is provided in Appendix A.
[5]See Schünemann et al. (2017b) for a detailed discussion on gender-specific deficit accumulation.

$$I_i(h_i) = A_i h_i^{\gamma} \tag{12}$$

with $i = \{F, M\}$. The parameters A (scale) and γ (curvature) capture the health technology where $0 < \gamma < 1$. We have reliable estimates for the environmental constant from Dalgaard and Strulik (2014), $a = 0.013$, and the curvature parameter of the health technology is set to $\gamma = 0.2$ in line with the estimate by Dalgaard and Strulik (2014) and the average value in Hall and Jones' (2007) study.

We normalize the relative price of health goods $p = 1$, and set $w = 54,840$, corresponding to average labor income of a two-person married household (BLS, 2011). Following Jones and Williams (2000) and Jorda et al. (2017), we set $r = 0.07$. In order to guarantee that the savings motive is confined to that of health and consumption spending, we set $k_0 = 0$ and $k(max(T_F, T_M)) = 0$. Following Finkelstein et al. (2013) we assume that bad health negatively affects both utility and marginal utility from consumption. Specifically instantaneous utility is given by

$$u_i(c_i, z, D_i) = \left(\frac{D_i^0}{D_i}\right)^{\alpha_i} \cdot \tilde{u}_i(c_i, z), \qquad \text{with } \tilde{u}_i(c_i, z) = \begin{cases} \beta_i \frac{c_i^{1-\sigma_i}-1}{1-\sigma_i} + \frac{z^{1-\sigma_i}-1}{1-\sigma_i} & \text{for } \sigma_i \neq 1 \\ \beta_i \log(c_i) + \log(z) & \text{for } \sigma_i = 1. \end{cases} \tag{13}$$

The parameter α controls the extent to which health affects utility. The intertemporal elasticity of substitution is captured by the inverse of the parameter σ while β governs the relative preference for private consumption. For the moment, we assume that men and women have the same preference for private consumption, i.e. $\beta_F = \beta_M = \beta$. We check sensitivity to this assumption later. We estimate the "free" parameters ρ_F and ρ_M, σ_F and σ_M, α_F and α_M, A_F and A_M, β and θ such that our model provides the best fit of the following ten data points: 1) per-capita total personal health care spending by gender at age 30, 50, and 70 according to MEPS (2010), 2) an observed expenditure share on public good consumption of 0.59,[6] 3) a wife-to-husband expenditure ratio of 2/3 as estimated by Lise and Seitz (2011), and 4) gender-specific longevity ($T_F = 81.9$ and $T_M = 77.6$).[7] According to this strategy, we obtain the estimates summarized in Table 1.

[6]From the Consumer Expenditure Survey (BLS, 2011), we calculate the share of average annual expenditure of a two-person married household that is spent on common consumption goods. We treat the following categories as common consumption goods: housing, transportation, entertainment, and cash contributions.
[7]Technical information on the calibration procedure is provided in Appendix B.

Table 1: Calibration Results

ρ_F	ρ_M	σ_F	σ_M	α_F	α_M	$\beta_F = \beta_M$	A_F	A_M	θ
0.05	0.07	1.27	1.14	0.24	0.01	1.03	0.00126	0.00132	0.49

Calibration results for the basic model. Assumptions: $\beta_F = \beta_M$, $p = q = 1$.

The results for the discount rate fit well with the notion that women tend to be more patient than men and therefore discount future utility less (e.g. Read and Read, 2004)). The estimates for σ are consistent with the well-known fact that women are more risk-averse than men in the vast majority of economic tasks. Croson and Gneezy (2009), for example, conclude in their review that women are more risk averse in real and hypothetical gambles. These observations are not only obtained in experiments but also when analyzing behavior of actual market participants (see, for example, Cohen and Einav (2007) on auto insurance contracts and Sunden (1998) on pension contribution plans). Mazzocco (2008) provides gender-specific estimates of the intertemporal elasticity of substitution using data from the Consumer Expenditure Survey and finds it to be significantly higher for men than for women. The size of our estimates for σ is in line with recent studies suggesting that the "true" value is probably close to one (Chetty, 2006), or slightly above one, around 1.2 (Layard et al., 2008). The higher estimate of α for women corresponds with the notion that women care more for their health than men. Women consume healthier food and utilize more health services, even when controlling for gender-specific health conditions. In particular, women demand more vitamin supplements, engage in routine screening more frequently and use more prescription- and over-the-counter medicine (Waldron, 1985; Wardle et al., 2004). The technology parameter is estimated to be slightly higher for men than women.[8] The estimates for β suggest that spouses like private and public consumption (almost) equally. Finally, the estimate of θ implies that men have (slightly) higher weight in household utility.

4. The Life-Cycle of a Couple

The results for the predicted life-cycle trajectories can be seen in Figure 1. Red (dashed) lines refer to women, blue (solid) lines refer to men. Data points are indicated by dots. The upper panels show life-cycle health investments of the husband and wife. Our model matches observed health investments reasonably well. In particular, unlike the Grossman (1972) model, it predicts

[8] For a more detailed discussion on these gender-specific parameter estimates, see Schünemann et al. (2017b).

that health investments increase with age at all ages. As the data suggests, health expenditures for the wife are higher than for the husband at (almost) any ages. We can also see how the wife smooths health investments when her husband dies, as implied by equation (10a).

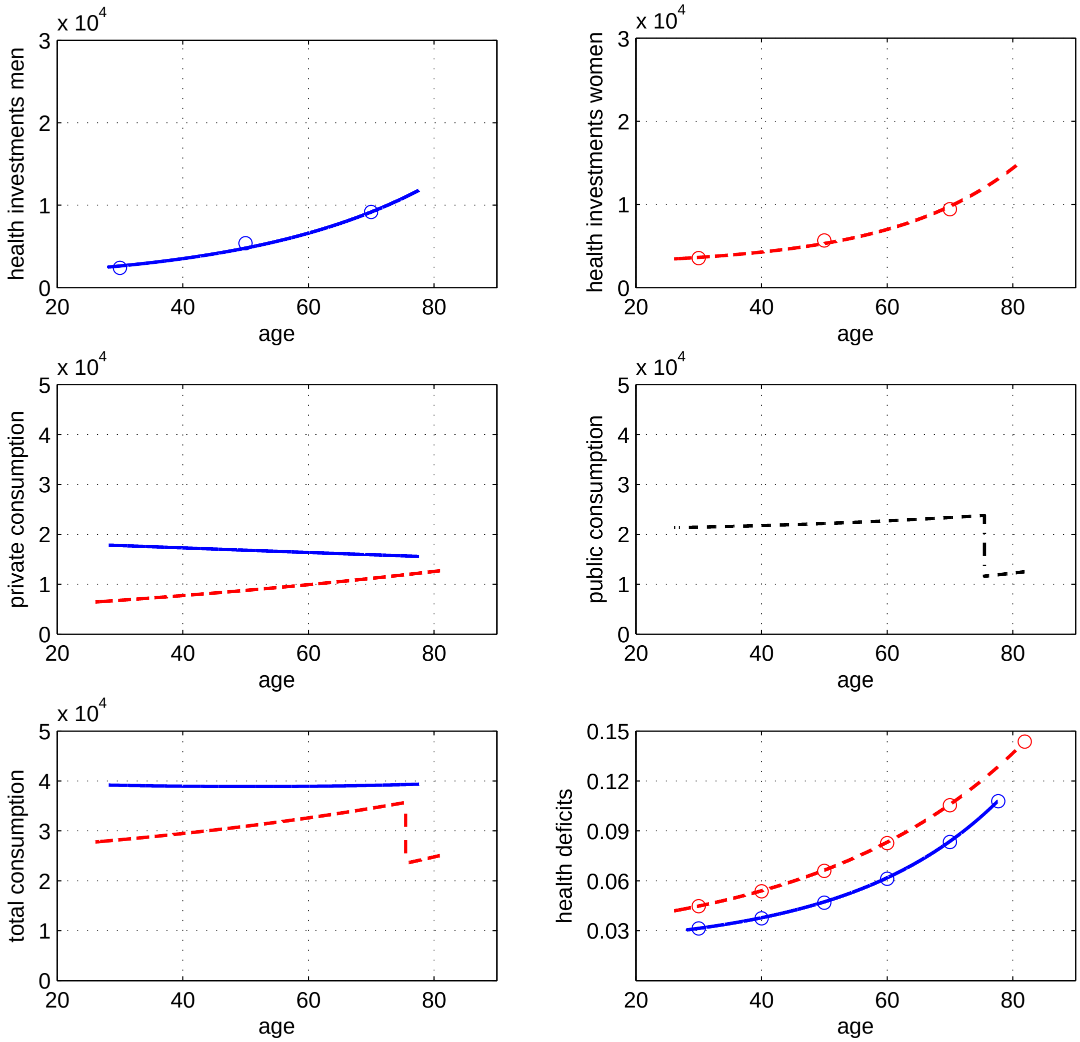
The third panel shows the age profile for private consumption. By construction, wife's private consumption is on average lower than private consumption of the husband. Since private and public consumption enter utility separably, private consumption of the wife is smooth when the husband dies, as required by equation (10b). Interestingly, intra-household allocation of private consumption does not require any (large) differences in the relative weight parameter θ. The unequal allocation is predominantly triggered by differences in relative risk aversion. To see this, note that from (5a), marginal utility of private consumption is equal between spouses, i.e.

$$(1-\theta)e^{-\rho_M t}\beta c_M^{-\sigma_M}\left(\frac{D_M^0}{D_M}\right)^{\alpha_M} = \theta e^{-\rho_F t}\beta c_F^{-\sigma_F}\left(\frac{D_F^0}{D_F}\right)^{\alpha_F}. \tag{14}$$

The calibrated features that $\alpha_F > \alpha_M$ and $\rho_F < \rho_M$, taken for themselves, would induce wives to consume more of the private good than husbands. The calibrated feature that $\sigma_F > \sigma_M$, however, offsets these effects and induces the husband to consume more at any age. A lower σ-value for men implies that men value a smooth consumption profile over a long life less highly than women such that they put more weight on current consumption.

The fourth panel illustrates how public consumption behaves over the life cycle. Equation (10c) implies a jump in the widows consumption of the public good when the husband dies. As can be also seen in the figure, the wife reduces public consumption on impact. This is intuitively plausible. When her husband dies, the wife consumes less of the public good, for example, by moving into a smaller flat or spending less on holidays. The fifth panel shows life-cycle trajectories for total consumption. While consumption of the man is rather constant, consumption of the woman slightly increases with age. This is due to the fact that our calibration suggests higher patience for women compared to men. Therefore women tend to substitute away from present to future consumption. The lower panel on the right-hand side illustrates that our model matches observed health deficits of men and women reasonably well. Women display more health deficits at any age but die later, a stylized fact of gender-specific health outcomes that we discuss in detail in Schünemann et al. (2017b).

Figure 1: Optimal Aging and Death of a Couple: Life Trajectories



Blue (solid) lines: husband, red (dashed) lines: wife, black (dash-dotted): public good consumption. Dots: data (deficits from Mitnitski et al. 2002a; health expenditure from MEPS, 2010). See main text for details.

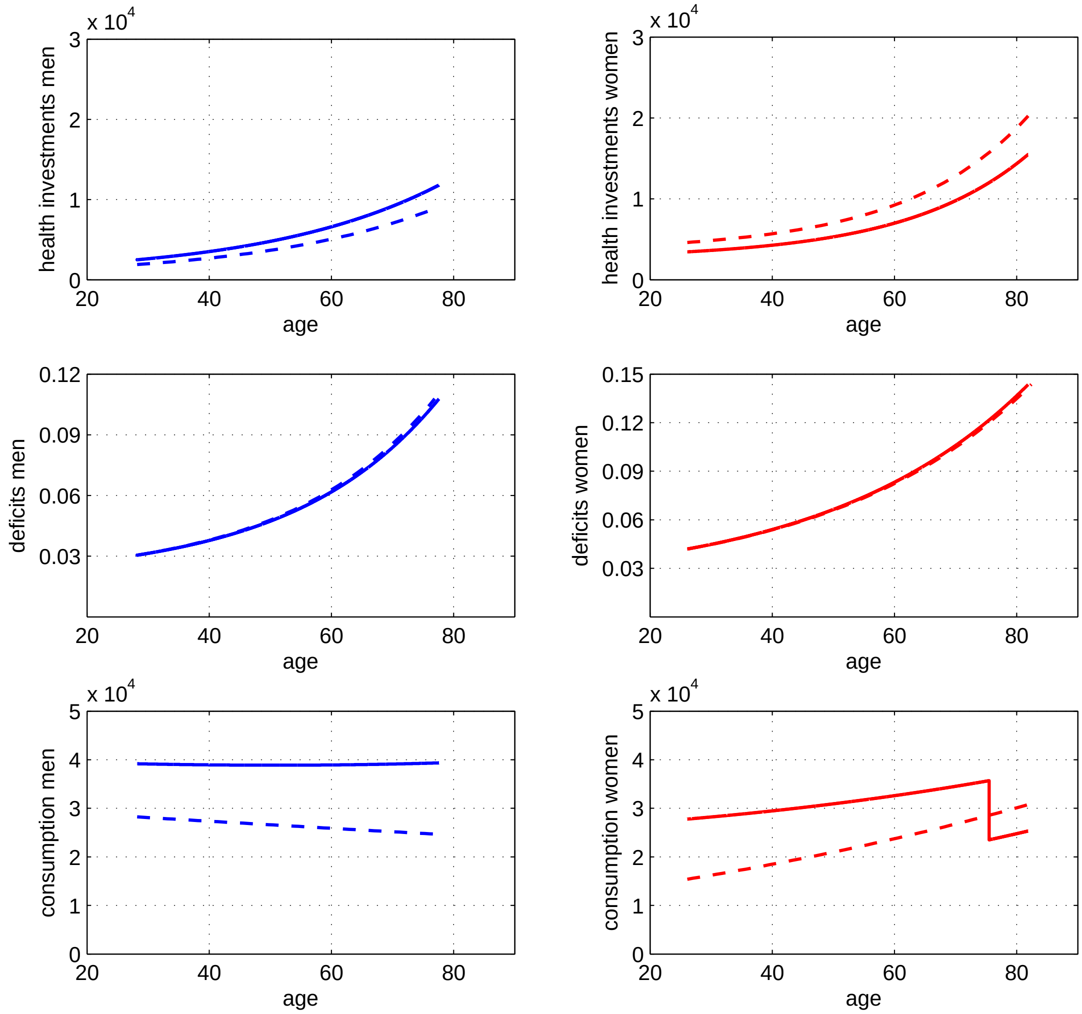
5. The Marriage Gap in Longevity

We next come to our counterfactual experiment which aims to compare life-cycle behavior of married to unmarried individuals. For this purpose, we endow "singles" with the parameters calibrated for the spouses and analyze how this affects health investments and thus longevity. In other words, we solve the model separately for men and women, as in Schünemann et al. (2017b), using the parameters estimated above[9]. In order to account for gender-specific differences in labor income, we divide the couple's labor income according to the gender gap in labor income, defined as the difference between median labor income of males and females. The OECD (2016)

[9]We provide the maximization problem for our counterfactual experiment in the appendix.

estimates for the U.S. that females earn on average 18.8 percent less compared to males in 2010, which provides $w_F = 24,574\$$ for single women and $w_M = 30,266\$$ for single men.

Figure 2: Counterfactual: If Spouses were Singles



Blue (solid) lines: husband benchmark run, blue (dashed) lines: single men, red (solid) lines: wife benchmark run, red (dashed) lines: single women.

The counterfactual experiment implies a marriage gain in longevity for men of about 0.70 years or 8.5 months (from 76.9 to 77.6 years) and a marriage loss in longevity for women of about 0.51 years or 6 months (from 82.4 to 81.9 years). In other words, the gender differential in longevity increases from 4.3 years for married individuals to 5.5 years for singles. Figure 2 shows why and compares life-cycle behavior of married and unmarried individuals. Dashed lines show results for the counterfactual experiment and solid lines reiterate the benchmark run for husband and wife. The upper panels illustrate health expenditure for men and women. At any age, single men spend less on their health than their married counterparts while the opposite is true for women. As can be seen in the next two panels, this translates into faster (slower) accumulation of health deficits for men (women) when single.

That women are predicted to live shorter in marriage is an interesting and non-obvious outcome because the positive quasi-income effect of public-goods sharing and the fact that women gain through income sharing in marriage both suggest that they should gain also in terms of health and longevity. The opposite result originates because of two reasons, biology and preferences. Focussing first on the biology channel, we note that joint utility maximization requires that the marginal benefits of health expenditure in terms of "utils" are equal for husband and wife. This optimality condition is inferred from equation (5b). We can write it as

$$\left(\frac{h_M}{h_F}\right)^{1-\gamma} = \frac{\lambda_M}{\lambda_F}\frac{\mu_M}{\mu_F}\frac{A_M}{A_F}, \tag{15}$$

i.e. we can express the ratio of health investments of men to woman by means of the man to woman ratios of deficit shadow prices, aging parameters, and health technology. From the calibrations above and the medical literature, we know that men age at a higher rate than do women ($\mu_M > \mu_F$) and that health technology is (slightly) more efficient for men ($A_M > A_F$). Hence the marginal benefit of health investments in terms of deficits avoided is higher for men than for women. The couple thus tends to allocate health expenditure away from the woman to the men compared to individual utility maximization where the above optimality condition is missing. However, the wife still invests more in her health at (almost) any age than her husband since $|\lambda_F| > |\lambda_M|$. To see this note that the adjoint variable measures the first-order approximate change in the value function (2) due to a unit increase in the state variable. As the wife cares much more about her health than her husband, the effect of accumulating another unit of D_F is more detrimental to the value function in (2) than another unit of D_M. Summarizing the biological channel suggests that the gender difference in life-cycle health expenditure and thus the gender differential in longevity is smaller among spouses than singles since differences in male and female biology make it more beneficial for the couple to shift health resources away from the wife to the husband. The biology-channel has been suggested previously by Posner (1995) and it has been investigated formally by Felder (2006).

The second channel works through differences in preference parameters between men and women. In particular, the utility function of men exhibits less curvature (lower σ) and thus implies higher marginal utility from consumption for given c than for women. Therefore, when single, the lower degree of risk aversion induces men to spend more on instantaneous consumption and less on their health than women. Consequently single men experience more instantaneous utility and less marginal utility from consumption at given age. As a couple, however, equation (5a) implies that allocative efficiency requires the marginal utility from private consumption to be equal for husband and wife (recall equation (14)). In other words, the couple as a whole tends to put less emphasis on instantaneous satisfaction of men through consumption and more on promoting their health while the opposite is true for women.

Pijoan-Mas and Rios-Rull (2014) estimate the marriage gain in longevity to be 2.7 years for men and 1.5 years for women. Our quantitative results suggest that about 26% of the observed marriage gain in longevity of men can be motivated by economic behavior. Surprisingly, economic behavior of wives is adverse for longevity compared to their single counterparts. In case of men, the positive effects of public-goods sharing, the biological and the preference channel outweigh the negative effect of income sharing on longevity in marriage. For women, the positive effects of income and public-good sharing are quantitatively not sufficient to compensate the negative effects operating through the biological channel and the preference channel. Summarizing, these results suggest that the longevity gain of married women observed in the data cannot be motivated by the standard economic channels discussed in this paper. The marriage gain is thus either motivated by (not modeled) socio-emotional benefits of marriage or indicates selection rather than causality, meaning that healthier women are more likely to get and stay married.

We can derive our results also by considering selection explicitly, i.e. by fitting the observed marriage gap perfectly. In order to take into account that on average healthier people find a partner, we reduce initial deficits of husband and wife such that the observed marriage gap in longevity is explained completely by the model. This approach captures two observed patterns in the marriage market. First, it takes into account that healthier individuals select into marriage. Second, since both husband and wife enjoy a better initial state of health, it also accounts for the concept of assortative mating by health status. Guner et al. (2014) find a strong association between a measure of innate permanent health of husband and wife (correlation coefficient of 0.4 as compared to, e.g., 0.5 for education). In order to match the observed marriage gap in longevity of 2.7 years for men and 1.5 years for women, we reduce initial deficits of husband and wife by 3% (from 0.0305 to 0.0296 for men and from 0.0419 to 0.0406 for women). This yields life expectancies for husband and wife of 79.6 and 83.9 years as compared to 76.9 years for men and 82.4 years for women of our benchmark average singles from above. We find, similarly to our previous identification strategy, that 0.75 (-0.53) years of the observed marriage gap can be attributed to economic behavior, while 1.95 (2.03) years are motivated by selection for men (women). We get to this result as follows. We run the counterfactual experiment and solve for the life cycle choices separately for husband and wife and compare longevity to that of the average benchmark singles from above. This experiment implies a difference in longevity of 1.95 years for men and 2.03 years for women. We thus derived an upper bound of the selection effect stemming from the fact that husband and wife are on average simply healthier than their single counterparts at the time of marriage. The remaining difference between those results and the observed marriage gain can then be identified as the change in life expectancy which is triggered by the four presented mechanisms and amounts to 0.75 years for men and -0.53 years for women, confirming our previous results.

Having described the different channels that lead to the marriage gap in longevity, we now investigate the quantitative importance of each channel. We first examine the marriage gap for the husband. The idea is to vary the parameters of the husband's partner and to check how longevity of the husband changes. The upper part of Table 2 illustrates the results for this experiment. The first row re-states the longevity of a single man as calculated in our

Table 2: Quantifying Channels

channel	T_M	Δ
single	76.90	–
public goods	77.17	0.27
income	76.83	-0.34
preferences	77.09	0.24
biology	77.60	0.51

	T_F	Δ
single	82.40	–
public goods	82.55	0.15
income	82.84	0.39
preferences	82.00	-0.75
biology	81.90	-0.10

counterfactual experiment. The second row shows longevity of the husband in a same-sex marriage. Since income, preferences, and biology do not differ between the two spouses, this experiment identifies the public-goods channel. According to our estimates, the public-goods channel, here determined by the longevity difference of a single man and a husband in a same-sex partnership, accounts for a longevity gain of 0.27 years. In the next row, we open up the income channel and introduce the income a mixed-sex couple is endowed with, i.e. we assume that the male partner of the husband contributes the female labor income to total labor income in the partnership. Since income is pooled in marriage, this reduces the husband's age of death by 0.34 years. In the next step, we add differences in preferences between the partners. To this end, we endow the partner of the husband with the preferences (ρ, σ, and α) of women. Note that in this step, we also account for gender-specific weight in household utility. Since these differences are estimated to be only marginal (0.49 compared to 0.51), this has only an insignificant impact. The resulting increase in the husband's longevity suggests that the preference channel amounts to 0.24 years . In the last case, we additionally open up the biological channel by also accounting for differences in biology (D^0, $\bar{D}$, μ, and A). Therefore, we now consider the benchmark couple which we have modeled and calibrated above. As a consequence, longevity of the husband rises to 77.6 years, implying that 0.51 years can be attributed to the biological channel.

The bottom part of Table 2 shows the same experiment for the wife. Again, we start by quantifying the public-goods channel by means of a same-sex partnership. Longevity of the wife when married to an identical woman increases by 0.15 years compared to when single. Opening up the income channel increases the wife's age of death by 0.39 years since her partner now contributes the male labor income to total labor income of the couple. Next, we endow the partner with preferences of men, resulting in a longevity reduction of the wife of 0.75 years. Finally, we consider the benchmark couple after accounting for differences in biology and find that the biological channel decreases longevity of the wife by another 0.1 years.

6. Sensitivity Analysis

6.1. **Does it Matter that Men and Women Share the Same Preferences for Public Goods?** We next check sensitivity of our results to the assumption $\beta_F = \beta_M$. For this purpose we consider one setting in which we let β_M exceed β_F by 20% (i.e. $\beta_M = 1.2 \cdot \beta_F$) and another setting in which we let β_F exceed β_M by 20% (i.e. $\beta_F = 1.2 \cdot \beta_M$). The remaining parameters are then estimated as before. The calibration results are shown in Table 3.

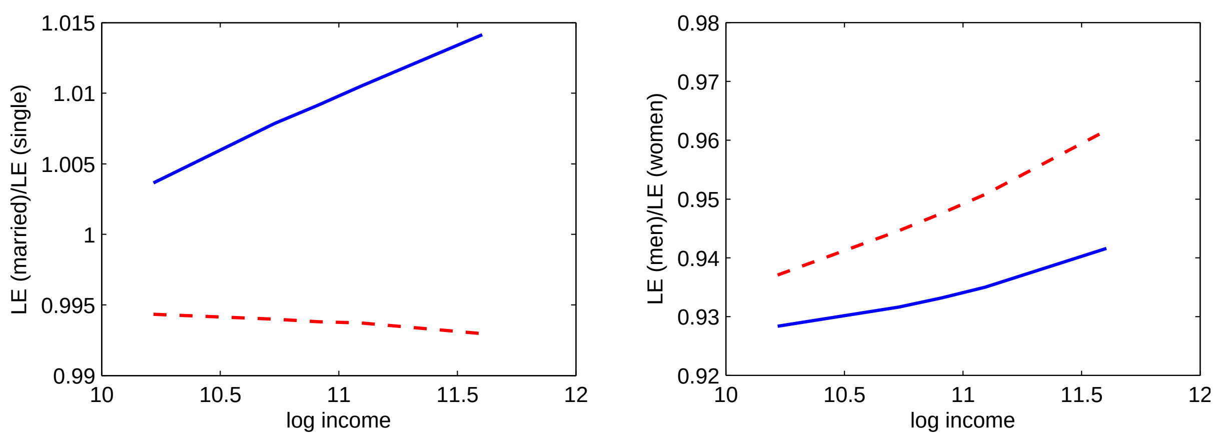
Table 3: Sensitivity Analysis

case	ρ_F	ρ_M	σ_F	σ_M	α_F	α_M	β_F	β_M	A_F	A_M	θ	female gap	male gap
1) $\beta_M > \beta_F$	0.05	0.07	1.24	1.15	0.28	0.01	0.93	1.12	0.00126	0.00132	0.44	-0.46	0.67
2) $\beta_M < \beta_F$	0.05	0.07	1.27	1.12	0.24	0.01	1.19	0.99	0.00126	0.00132	0.49	-0.61	0.76

The parameter estimates differ only mildly from the benchmark run. The last two columns of the table show the marriage gain in longevity. The different specifications of the model presented here imply only small changes in the predicted marriage gain taking into account the considerable difference in the β's. Recall that the marriage gain in the benchmark model was 0.70 years for men and -0.51 years for women.

6.2. **Income and the Marriage Gap.** We next investigate how the marriage gap in longevity reacts to changes in income. This computational experiment can also be seen as a device to predict the future evolution of the marriage gap that is motivated by the channels presented above. For that purpose we analyze how the marriage gap behaves if labor income of couples and singles is successively reduced up to factor 2 and successively increased by the same factor. The results are shown in Figure 3.

FIGURE 3: INCOME AND THE MARRIAGE GAP



Left Panel: Blue (solid) line: marriage gap men, red (dashed) line: marriage gap women. Right Panel: Blue (solid) line: gender differential singles, red (dashed) line: gender differential couple. The log of benchmark income is 10.91.

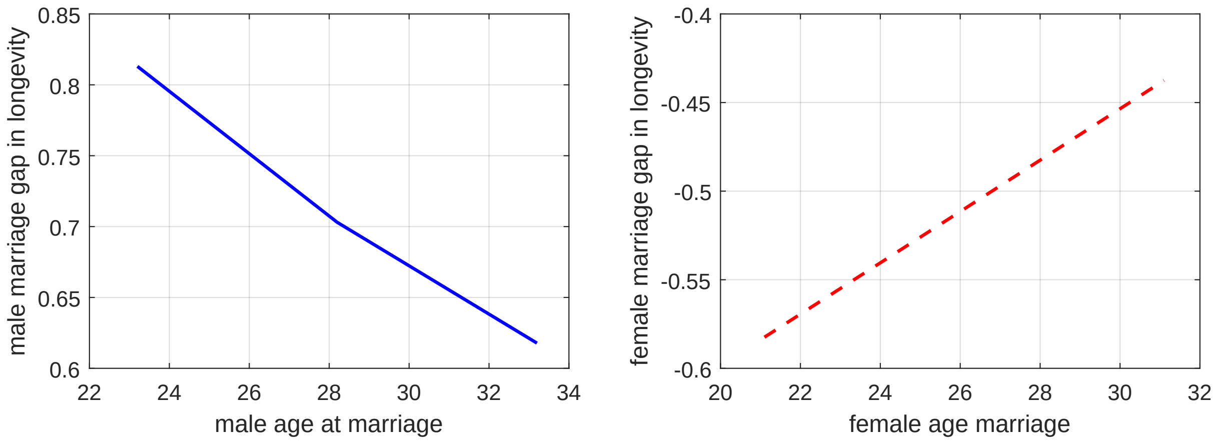
The abscissa measures the log of labor income. In the left panel, the ordinate reflects the marriage gap in longevity. Notice that we have changed the measurement of the marriage gap in order to compare our findings to previous studies. The figure shows that both the marriage gain of men and the marriage loss of women increase with rising income. This finding is particularly interesting when considering the results by Schünemann et al. (2017b). In that paper we replicate the empirically observed fact found by Cullen et al. (2015) that the gender differential in longevity closes with rising income. Intuitively, gender-specific differences in preference parameters (risk aversion, utility weight on health) do matter less with higher income since the slopes of the utility functions $U(c)$ become more similar between men and women (in the limit, utility approaches infinity irrespective of gender). Our modeling of a couple suggests that the gender differential in longevity closes even faster with rising income when men and women are married. To see this, note that an increase of the male marriage gain and an increase of the female marriage loss both contribute to a lower gender differential in marriages compared to singles. This can be seen in the right panel of Figure 3 in which the ordinate measures the gender differential in longevity. The red (dashed) line representing the gender differential in couples rises faster with increasing income than the blue (solid) line reflecting the gender differential for singles. The reason is that the impact of increasing income on the gender differential as identified in our earlier study (Schünemann et al., 2017b) sets in faster through the additional (quasi-) income increase resulting from public-goods sharing.

6.3. **Age at Marriage and the Marriage Gap.** We next want to investigate how the marriage gap in longevity is associated to the marriage age of the spouses. So far we have analyzed the life cycle for a representative couple in which both spouses marry at the observed median age at first marriage. Since we find a longevity effect of marriage, the spousal age at marriage and thus the duration of marriage should magnify this effect. To this end, we vary the age at marriage for both spouses and examine how the marriage gap in longevity is affected. Figure 4 shows the results for this experiment.

The left panel shows the male marriage gap after varying the marriage age of the husband by five years in each direction, i.e. from 23.2 to 33.2 years, while keeping the marriage age of the wife constant. Therefore, we also include the case in which the husband is younger than the wife. The abscissa measures the male age at marriage. As the figure illustrates, the longevity gain of the husband decreases with his marriage age. The reason behind this result is that the beneficial longevity effect from marriage of the husband that we have identified above is reduced because the duration of marriage decreases.

Varying the age at marriage of the wife by five years in each direction, i.e. from 21.1 years to 31.1 years, shows a positive association between marriage age and the marriage gap in longevity as illustrated in the right panel of Figure 4. The explanation works again through the duration

Figure 4: Age at Marriage and the Marriage Gap



Left Panel: Blue (solid) line: marriage gap men. Right Panel: Red (dashed) line: marriage gap women.

of marriage. Since women experience a longevity loss from marriage, marrying later and thus decreasing the duration of marriage reduces the life years lost due to marriage.

7. Conclusion

In this study we proposed a life-cycle model of health behavior and health outcomes of couples with endogenous longevity. We calibrated the model with data on average American couples and used it to identify the longevity gain from marriage for men and women. The model motivates four mechanisms through which marriage effects health outcomes: income pooling, public-goods sharing, the biological channel (accounting for distinct morbidity and mortality of men and women), and the preference channel (accounting for gender-specific time-, risk- and health preferences). We showed that men only lose through income pooling while women lose through the biological channel and the preference channel. According to the benchmark model men gain about 8.5 extra months of life through marriage while women lose 6 months. Pure economic calculus thus motivates about 25 percent of the marriage gain of men and fails to motivate a marriage gain (in terms of life expectancy) for women.

To the best of our knowledge, this study is the first attempt to formally discuss the marriage gap of mortality in a quantifiable life-cycle model. The four channels discussed are thus perhaps the most obvious ones economists can think of. Other effects of marriage on health are conceivable. Some implications of marriage would likely increase the excess gain of men from marriage. For example, we did not take into account that in marriage informal health care can be provided by the spouses and that the bereavement and stress felt after the loss of a spouse may deteriorate health of the surviving partner. Since women, on average, survive their husbands both neglected effects are likely to increase the loss through marriage for women while the informal care channel may further increase the marriage gain of men.

Our study suggests that, if women gain health and longevity through marriage, then the mechanism would likely originate from non-standard (behavioral) economics. Therefore it would be interesting to integrate into our theory a meaningful concept of altruism and other socio-emotional channels, like the spousal support in getting rid of addiction or solving other self-control problems (like nudging the partner to see a doctor). Studying the effect of introducing children into the model is another challenging task for future research.

8. Appendix A: Solution Method

We start by deriving a dynamic system for regime 1 and 2, respectively, using the functional forms introduced in the calibration section. We assume that spouse i lives from 0 to time T_i, and spouse j survives i and lives until $T_j > T_i$. The system for the first regime reads

$$\dot{D}_i = \mu_i(D_i - A_i h_i^\gamma - a) \tag{16a}$$

$$\dot{D}_j = \mu_j(D_j - A_j h_j^\gamma - a) \tag{16b}$$

$$\dot{k} = w + rk - c_i - c_j - ph_i - ph_j - qz \tag{16c}$$

$$\dot{\lambda}_i = -\lambda_i\mu_i + e^{-\rho_i t}(1-\theta)\alpha_i \frac{u_i(c_i, z, D_i)}{D_i} \tag{16d}$$

$$\dot{\lambda}_j = -\lambda_j\mu_j + e^{-\rho_j t}\theta\alpha_j \frac{u_j(c_j, z, D_j)}{D_j} \tag{16e}$$

$$\dot{\lambda}_k = -\lambda_k r \tag{16f}$$

$$\begin{aligned}\dot{z} =& z\left(q\lambda_k r - e^{-\rho_i t}(1-\theta)z^{-\sigma_i}\left(\frac{D_i^0}{D_i}\right)^{\alpha_i}(\alpha_i\frac{\dot{D}_i}{D_i} + \rho_i) - e^{-\rho_j t}\theta z^{-\sigma_j}\left(\frac{D_j^0}{D_j}\right)^{\alpha_j}(\alpha_j\frac{\dot{D}_j}{D_j} + \rho_j)\right) \\ &\cdot\left(\left(\frac{D_i^0}{D_i}\right)^{\alpha_i}\sigma_i z^{-\sigma_i}(1-\theta)e^{-\rho_i t} + \left(\frac{D_j^0}{D_j}\right)^{\alpha_j}\sigma_j z^{-\sigma_{Fj}}\theta e^{-\rho_j t}\right)^{-1},\end{aligned} \tag{16g}$$

and applies for $[0, T_i]$, while the system for the second regime reads

$$\dot{D}_j = \mu_j(D_j - A_j h_j^\gamma - a) \tag{17a}$$

$$\dot{k} = w + rk - c_j - ph_j - qz \tag{17b}$$

$$\dot{\lambda}_j = -\lambda_j \mu_j + e^{-\rho_j t} \theta \alpha_j \frac{u_j(c_j, z, D_j)}{D_j} \tag{17c}$$

$$\dot{\lambda}_k = -\lambda_k r \tag{17d}$$

$$\dot{z} = \frac{z}{\sigma_j} \left(r - \rho_j - \alpha_j \frac{\dot{D}_j}{D_j} \right) , \tag{17e}$$

and applies for $(T_i, T_j]$. Both regimes are connected by the requirement that λ_i, λ_k, and the associated Hamiltonian $\mathcal{H}$ (see equations (4) and (6)) are continuous at the time of the regime switch T_i. The state variables D_j and k are continuous at that point by assumption. Moreover, the point of time of the regime switch is determined by the death of one of the spouses, i.e. $D_i(T_i) = \bar{D}_i$. Boundary conditions for the end of the second regime are $\mathcal{H}(T_j) = 0$, $D_j(T_j) = \bar{D}_j$, and $k(T_j) = 0$.

To solve for the optimal life cycle trajectories we apply a shooting algorithm. This type of algorithm is frequently used to solve differential equations for which only some of the initial conditions are given and additionally a set of final boundary conditions has to be satisfied, i.e. the problem is a two-point boundary value problem. The general idea of shooting is to guess the unknown initial values of the variables and calculate a trial solution by integrating the dynamic system for a given time span. Then, the initial values are updated in an iteration process until the final boundary conditions are met as well. We have to adapt the standard shooting to our setting for two reasons. First the time interval of integration is divided into two regimes which are connected by interior boundary conditions, and second the length of both regimes is unknown and also determined by a boundary condition.

For guessing the initial values of integration we have to take into account equation (5a), which determines the optimal level of public good consumption at the beginning of the first regime. Given the functional forms chosen in the calibration section this equation is given by

$$\lambda_k = \frac{1}{q} \left((1-\theta) \left(\frac{D_i^0}{D_i} \right)^{\alpha_i} e^{-\rho_i t} z^{-\sigma_i} + \theta \left(\frac{D_j^0}{D_j} \right)^{\alpha_j} e^{-\rho_j t} z^{-\sigma_j} \right) . \tag{18}$$

Noticing that the initial values for the state variables D_i, D_j, and k are given, we have three degrees of freedom for choosing initial conditions. We provide initial guesses for λ_i, λ_j, and z. In conjunction with equation (18) the full set of initial conditions is given. We then solve system (16) with the standard Matlab routine for initial value problems (`ode45.m`) until one of the spouses dies and therefore $D_i(T_i) = \bar{D}_i$ holds.

For the second regime, initial conditions of the variables are given by the final values of the first regime

$$D_j(T_j-) = D_j(T_j+) \quad k(T_j-) = k(T_j+) \quad \lambda_j(T_j-) = \lambda_j(T_j+) \quad \lambda_k(T_j-) = \lambda_k(T_j+)$$

and the initial value for z is given by equation (7a). We then integrate system (17) until the second spouse dies $D_j(T_j) = \bar{D}_j$.

Summarizing, we guess three initial values and solve for both regimes considering interior boundary conditions for λ_j and λ_k. There are, however, three conditions that the trial solution does not satisfy: The continuity condition of the Hamiltonian at T_i, $\mathcal{H}(T_i-) = \mathcal{H}(T_i+)$, the transversality condition $\mathcal{H}(T_j) = 0$, and the final boundary condition $k(T_j) = 0$. We then adjust the initial conditions until these three additional conditions are met by using a Newton-Raphson algorithm.

9. Appendix B: Calibration Method

We briefly explain our calibration method for estimating the remaining parameters ρ_F and ρ_M, σ_F and σ_M, α_F and α_M, A_F and A_M, β and θ. We estimate these parameters to fit the model to the following data points: 1) total personal health care per-capita spending by gender at age 30, 50, and 70, 2) an observed expenditure share on public good consumption of 0.59, 3) a wife-to-husband expenditure ratio of 2/3, and 4) gender-specific longevity ($T_F = 81.9$ and $T_M = 77.6$).[10]

Since we cannot determine the relation between the free parameters and the data points analytically, we have to rely on a numerical estimation strategy. The main idea of our estimation strategy is adapted from the Method of Simulated Moments as used in the econometric literature (see McFadden, 1989). Analogous to the MSM, our estimation strategy is to determine parameter values that yield the best fit between the numerically calculated model's response and the data points.

In detail we proceed as follows. We start with a prior for each of the parameters we have to determine. Using the priors, we calculate the optimal lifetime trajectories numerically, and the deviation between the calibration targets (as retrieved from the lifetime trajectories) and the data points. We use a standard Matlab routine (`fminsearch.m`) to minimize the sum of squares

[10]References for these data points are given in Section 3.

of the residuum. In each iteration the algorithm modifies the parameter values in order to improve the model's fit to the data points. It terminates reporting that a parameter set is found which minimizes the deviation between calibration targets and the data points. We observe that the fit is almost perfect indicating that the data points contain sufficient information to determine the parameter values.

10. Appendix C: Counterfactual Experiment

We perform the counterfactual experiment by solving the maximization problem separately for men and women. The maximization problem reads

$$V = \int_0^{T_i} e^{-\rho_i t} u_i(c_i, z_i, D_i) dt$$

with

$$u_i(c_i, z_i, D_i) = \left(\frac{D_i^0}{D_i}\right)^{\alpha_i} \cdot \tilde{u}_i(c_i, z_i), \qquad \text{with } \tilde{u}_i(c_i, z_i) = \begin{cases} \beta_i \frac{c_i^{1-\sigma_i}-1}{1-\sigma_i} + \frac{z_i^{1-\sigma_i}-1}{1-\sigma_i} & \text{for } \sigma_i \neq 1 \\ \beta_i \log(c_i) + \log(z_i) & \text{for } \sigma_i = 1. \end{cases}$$

subject to

$$\begin{aligned} \dot{D}_i &= \mu_i(D_i - A_i h_i^{\gamma} - a) \\ \dot{k}_i &= w_i + r k_i - c_i - p h_i - q z_i \\ \mathcal{H}_i(T_i) &= 0 \end{aligned}$$

where $i = \{F, M\}$. We solve the maximization problem numerically using the gender-specific parameters which we have estimated above. The difference in longevity between the spouses and their single counterparts constitutes the marriage gap in longevity.

References

Almond, D., and Currie, J. (2011). Killing me softly: The fetal origins hypothesis. *Journal of Economic Perspectives* 25(3), 153-72.

Borella, M., De Nardi, M., and Yang, F. (2017). Marriage-Related Policies in an Estimated Life-Cycle Model of Households' Labor Supply and Savings for Two Cohorts. *NBER Working Papers 23972*.

BLS (2011). Consumer Expenditure Survey. U.S. Bureau of Labor Statistics, September 2011 (`http://www.bls.gov/cex/2010/Standard/cucomp.pdf`).

Bolin, K., Jacobson, L., and Lindgren, B. (2001). The family as the health producer–when spouses are Nash-bargainers. *Journal of Health Economics* 20(3), 349-362.

Bolin, K., Jacobson, L., and Lindgren, B. (2002). The family as the health producer–when spouses act strategically. *Journal of Health Economics* 21(3), 475-495.

Browning, Martin and Chiappori, Pierre-André (1998). Efficient intra-household allocation: a characterisation and tests. *Econometrica* 66(6), 1241-78.

Browning, Martin and Chiappori, Pierre-André, and Valérie Lechene (2006). Collective and unitary models: a clarification. *Review of Economics of the Household* 4(1), 5-14.

Bryson, A. E., and Ho, Y. C. (1975). Applied optimal control: optimization, estimation, and control [M]. *Washington, DC: Hemisphere.*

Case, A., and Deaton, A.S. (2005). Broken down by work and sex: How our health declines. In: *Analyses in the Economics of Aging*, University of Chicago Press, 185-212.

Chetty, R. (2006). A new method of estimating risk aversion. *American Economic Review* 96, 1821-1834.

Chiappori, Pierre-André (1988). Rational household labor supply. *Econometrica* 56(1), 63-90.

Chiappori, Pierre-André (1992). Collective labor supply and welfare. *Journal of Political Economy* 100(3), 437-67.

Cohen, A. and Einav, L. (2007). Estimating risk preferences from deductible choice. *American Economic Review* 97(3), 745-788.

Croson, R. and Gneezy, U. (2009). Gender differences in preferences. *Journal of Economic Literature* 47(2), 448-74.

Cullen, M.R., Baiocchi, M., Eggleston, K., Loftus, P., and Fuchs, V. (2015). The Weaker Sex? Vulnerable Men, Resilient Women, and Variations in Sex Differences in Mortality since 1900. NBER Working Paper No. w21114.

Dalgaard, C-J. and Strulik, H. (2014). Optimal aging and death: Understanding the Preston Curve, *Journal of the European Economic Association* 12, 672-701.

Dalgard, C.-J., Strulik, H. (2015). The Economics of Health Demand and Human Aging: Health Capital vs. Health Deficits, Discussion Paper, University of Goettingen.

Dalgaard, C-J. and Strulik, H. (2017).The genesis of the golden age: Accounting for the rise in health and leisure. *Review of Economic Dynamics*, 24, 32-151.

Dupre, M.E., Beck, A.N., and Meadows, S.O. (2009). Marital trajectories and mortality among US adults. *American Journal of Epidemiology* 170(5), 546-555.

Felder, S. (2006). The gender longevity gap: explaining the difference between singles and couples. *Journal of Population Economics* 19(3), 543-557.

Finkelstein, A., Luttmer, E.F., and Notowidigdo, M.J. (2013). What good is wealth without health? The effect of health on the marginal utility of consumption. *Journal of the European Economic Association* 11(1), 221-258.

Grossman, M. (1972). On the concept of health capital and the demand for health. *Journal of Political Economy* 80, 223-255.

Grossman, M. (2000). The human capital model. *Handbook of Health Economics*, Vol. 1, 347-408.

Grossmann, V. and Strulik, H. (2017). Optimal Social Insurance and Health Inequality, Cege Discussion Paper 302, University of Goettingen.

Guner, N., Kulikova, Y., and Llull, J. (2014). Does Marriage Make You Healthier?. Discussion Paper.

Hall, R.E. and Jones, C.I. (2007). The value of life and the rise in health spending. *Quarterly Journal of Economics* 122, 39–72.

Hogg, R.S., Strathdee, S.A., Craib, K.J., O'Shaughnessy, M.V., Montaner, J.S., and Schechter, M.T. (1997). Modelling the impact of HIV disease on mortality in gay and bisexual men. *International Journal of Epidemiology* 26(3), 657-661.

Jacobson, L. (2000). The family as producer of health–an extended Grossman model. *Journal of Health Economics* 19(5), 611-637.

Jones, C.I., and Williams, J.C. (2000). Too much of a good thing? The economics of investment in R&D. *Journal of Economic Growth* 5(1), 65-85.

Jorda, O., Knoll, K., Kuvshinov, D., Schularick, M., and Taylor, A.M. (2017). The Rate of Return on Everything, 18702015. National Bureau of Economic Research Working Paper w24112

Kohn, J.L., and Averett, S.L. (2014). The effect of relationship status on health with dynamic health and persistent relationships. *Journal of Health Economics* 36, 69-83.

Kulminski, A. M., Culminskaya, I. V., Ukraintseva, S. V., Arbeev, K. G., Land, K. C., and Yashin, A. I. (2008). Sex-specific health deterioration and mortality: The morbidity-mortality paradox over age and time. *Experimental gerontology* 43(12), 1052-1057.

Lam, D. (1988). Marriage markets and assortative mating with household public goods: Theoretical results and empirical implications. *Journal of Human Resources* 23(4), 462-487.

Layard, R., Mayraz, G., and Nickell, S. (2008). The marginal utility of income. *Journal of Public Economics* 92, 1846-1857.

Lise, J., and Seitz, S. (2011). Consumption inequality and intra-household allocations. *Review of Economic Studies* 78(1), 328-355.

Liu, H. (2012). Marital dissolution and self-rated health: Age trajectories and birth cohort variations. *Social Science & Medicine* 74(7), 1107-1116.

McFadden, D. (1989). A Method of Simulated Moments for Estimation of Discrete Response Models without Numerical Integration. *Econometrica* 57(5), 995-1026

Manser, M., and Brown, M. (1980). Marriage and Household Decision-Making: A Bargaining Analysis. *International Economic Review* 21(1), 31-44.

Manzoli, L., Villari, P., Pirone, G.M., and Boccia, A. (2007). Marital status and mortality in the elderly: a systematic review and meta-analysis. *Social Science & Medicine* 64(1), 77-94.

Mazzocco, M. (2008). Individual rather than household Euler equations: Identification and estimation of individual preferences using household data. Discussion Paper, available at SSRN 695285 .

MEPS (2010), U.S. Department of Health & Human Services. Center for Financing, Access and Cost Trends, Agency for Healthcare Research and Quality: Medical Expenditure Panel Survey, 2010 (`https://meps.ahrq.gov/mepsweb/data_stats/quick_tables_results.jsp?component=1&subcomponent=0&year=-1&tableSeries=1&searchText=&searchMethod=1&Action=Search`)

Mitnitski, A.B., Mogilner, A.J., MacKnight, C., and Rockwood, K. (2002a). The accumulation of deficits with age and possible invariants of aging. *Scientific World* 2, 1816-1822.

Mitnitski, A.B., Mogilner, A.J., MacKnight, C., and Rockwood, K. (2002b). The mortality rate as a function of accumulated deficits in a frailty index. *Mechanisms of ageing and development* 123, 1457-1460.

Murphy, M., Grundy, E., and Kalogirou, S. (2007). The increase in marital status differences in mortality up to the oldest age in seven European countries, 199099. *Population Studies* 6 1(3), 287-298.

NVSS (2014). US department of health and human services, national vital statistics system. National Vital Statistics Report 63(7).

OECD (2016), Gender wage gap (indicator). doi: 10.1787/7cee77aa-en (Accessed on 14 October 2016) (`https://data.oecd.org/earnwage/gender-wage-gap.htm`)

Pijoan-Mas, J., and Rios-Rull, J.V. (2014). Heterogeneity in expected longevities. *Demography* 51(6), 2075-2102.

Posner, R. A. (1995). *Aging and Old Age.* University of Chicago Press, Chicago.

Read, D., and Read, N.L. (2004). Time discounting over the lifespan. *Organizational Behavior and Human Decision Processes* 94(1), 22-23.

Rendall, M.S., Weden, M.M., Favreault, M.M., and Waldron, H. (2011). The protective effect of marriage for survival: a review and update. *Demography* 48(2), 481-506.

Ross, C.E. (1995). Reconceptualizing marital status as a continuum of social attachment. *Journal of Marriage and the Family* 57, 129-140.

Salcedo, A., Schoellman, T., and Tertilt, M. (2012). Families as roommates: Changes in US household size from 1850 to 2000. *Quantitative Economics* 3(1), 133-175.

Sindelar, J.L. (1982). Differential Use of Medical Care by Sex. *Journal of Political Economy* 90(5), 1003-19.

Schünemann, J., Strulik, H., Trimborn, T. (2017a). Going from bad to worse: Adaptation to poor health, health spending, longevity, and the value of life. *Journal of Economic Behavior and Organization*, 140, 130-146.

Schünemann, J., Strulik, H., Trimborn, T. (2017b). The gender gap in mortality: How much is explained by behavior? *Journal of Health Economics*, 54, 79-90.

Strulik, H. (2015). Frailty, mortality, and the demand for medical care, *Journal of the Economics of Ageing* 6, 5-12.

Strulik, H. (2018). The return to education in terms of wealth and health, *Journal of the Economics of Ageing* 12, 1-14.

Sunden, A. E. and Surette, B.J. (1998). Gender differences in the allocation of assets in retirement savings plans. *The American Economic Review* 88(2), 207211.

Verbrugge, L.M. (1988). A life and death paradox. *American Demographics* 11, 34-37.

Umberson, D. (1992). Gender, marital status and the social control of health behavior. *Social Science & Medicine* 34(8), 907-917.

USCB. United States Census Bureau. Families and Living Arrangements (`http://www.census.gov/hhes/families/data/marital.html`, accessed May 17th, 2016)

Wagstaff, A. (1986). The demand for health: some new empirical evidence. *Journal of Health Economics* 5 195-233.

Waite, L. J. (1995). Does marriage matter?. *Demography* 32(4), 483-507.

Waite, L., and Gallagher, M. (2002). *The case for marriage: Why married people are happier, healthier and better off financially.* Broadway Books.

Waldron, I. (1993). Recent trends in sex mortality ratios for adults in developed countries. *Social Science & Medicine* 36(4), 451-462.

Wardle, J., Haase, A.M., Steptoe, A., Nillapun, M., Jonwutiwes, K., and Bellisie, F. (2004). Gender differences in food choice: the contribution of health beliefs and dieting. *Annals of Behavioral Medicine* 27(2), 107-116.

Zweifel, P. and Breyer, F. (1997). *Health Economics*, Oxford University Press, Oxford.