The Effect of Unexpected Longevity on Intergenerational Policies and Fertility

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Abstract

Longevity is increasing in developed countries, but there is substantial variation in its pace. When the pace is rapid, individuals who had saved anticipating some lifespan may find themselves under-prepared upon retirement for their actual, extended lifespan. This paper argues that unexpected longevity gains can depress fertility further than expected longevity gains, because the former generate such under-prepared old agents who need to be supported by young agents. In an overlapping-generations model with public pensions, we show that although young agents reduce fertility to save more for their old age in both expected and unexpected cases ("life-cycle effect"), they also need to pay taxes to support old agents who become poor in the unexpected case ("policy effect"). Empirical evidence using a panel data of OECD countries are consistent with this argument: unexpected increase in life expectancy at 65 lowers total fertility rate and public family spending growth while raising public old-age spending growth.

JEL Codes: J11, H23

Keywords: population aging, longevity, fertility, intergenerational policy

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1 Introduction

With many countries undergoing a demographic transition towards an aged society, there is a large literature studying the effect of longevity on economic variables. As individuals try to smooth their consumption over a longer lifetime, an increase in longevity is shown to increase the savings rate (Bloom et al., 2003, 2007; Li et al., 2007). Gains in life expectancy may also reduce the fertility rate while raising human capital investment in children, and thus have a positive effect on economic growth (Ehrlich and Lui, 1991; Yakita, 2001; Zhang et al., 2001; Soares, 2005). Most of these studies implicitly assume that individuals are able to expect future longevity and take it into account when making their optimal decisions.

It is not obvious, however, that individuals are able to correctly anticipate their lifespan. In addition to uncertainty at the individual level, changes in medical technology or environmental factors such as pollution impose uncertainty even at the aggregate level. As Figure 1 illustrates, the trend in life expectancy at 65 is not linear and depicts substantial variation across countries and time. Discrepancies between expected and actual lifetime may well arise, particularly in societies experiencing rapid improvements in elderly health, resulting in agents with insufficient assets upon retirement.

*** Figure 1 here ***

This paper studies the effect of unexpected longevity gains on intergenerational policies and fertility. With gradual, and hence expected longevity, individuals can allocate their income during working days to post-retirement periods by increasing savings. Steep rises in longevity are difficult to anticipate beforehand, however, and may limit individuals' ability to make such adjustments. Unexpected longevity gains can thus generate poor old agents who become targeted policy recipients. The increase in government spending impose a heavier burden on the young generation who are primary tax payers, and discourage them from having more children. We explore these mechanisms with a formal model and a cross-country panel analysis.

We build a simple overlapping-generations model where individuals endogenously choose offspring size and make consumption-savings decisions. The model also features a pay-as-you-go public pension system, which turns on when old agents are poorer than some threshold level and is funded by taxing young agents. We compare two economies which are identical except that longevity is expected in one and unexpected in the other. There are two channels through which longevity can affect fertility. First, young agents need to reduce their offspring size and save more for their own old-age consumption because lifetime increased ("life-cycle effect"). Second, young agents' offspring size choice is affected by changes in taxes which finance pensions ("policy effect"). Within a certain range of survival probability, we show that only unexpected longevity gains generate under-prepared old agents who require pensions, and thus lowers young agents' after-tax income and also their fertility.

On the other hand, the pay-as-you-go pension scheme can induce moral hazard behavior of young agents for very large increases in longevity. That is, young agents may have incentive to depend on pensions later rather than lowering their current consumption and offspring size substantially. Although the model is flexible enough to generate such positive policy effects, we believe that this case is unlikely to arise in practice. It is difficult to consider young agents in the aggregate intentionally under-preparing for their old age in order to rely on pensions, which guarantee only minimum standard of living.

Using a panel data of OECD countries, we provide empirical evidence for the model's predictions. We construct a measure of longevity shock for each country and year by calculating the forecast errors between actual life expectancy at 65 and predicted life expectancy at 65 estimated *à la* Lee and Carter (1992). Regression results indicate that larger forecast errors lower the total fertility rate and public family spending growth while raising public old-age spending growth. The findings are robust to controlling for the level of life expectancy at 65, old dependency ratio, and country and year fixed effects, indicating that they are beyond what can be explained from a longer lifespan or larger elderly population *per se*.

We contribute to the literature in several ways. First and foremost, we emphasize the importance of the speed, or unexpectedness, of increasing life expectancy in addition to its level through transition dynamics. Most existing research on longevity utilize the level of life expectancy as the key variable (e.g., Bloom et al., 2003, 2007; Li et al., 2007) and do not study transition dynamics from high to low mortality.[1] Instead, they compare two different steady states with high and low mortality respectively, by which these papers implicitly assume that agents are perfectly able to expect their lifespan. Some papers such as Lee et al. (2000a) include transition dynamics with simulations of the model with various longevity levels but only with an explicit assumption about agents' perfect expectation of lifespan. This paper shows that the dynamic effects of an unexpected increase in longevity can be distinct from an expected one.

Second, the paper introduces a new way in which longevity can affect fertility choices via intergenerational policy. There are two branches of related literature, one on the effect of intergenerational policy on fertility and another on the effect of longevity on fertility.

[1] An exception is Cocco and Gomes (2012), which study the welfare analysis from adopting longevity bond with unexpected longevity risk in aggregate level. They argue that large increases in life expectancy which some advanced countries experienced is, to a large extent, unexpected and measure the risk by allowing the expectation of survival probabilities to evolve following the specification in Renshaw and Haberman (2006) which is a generalized method of Lee and Carter (1992).

The former is mostly about how social security can lower fertility. Cigno and Rosati (1992, 1996), Ehrlich and Kim (2007) and Boldrin et al. (2015) focus on the role of social security as a substitute to family as a source of old-age support, and hence the system lessens the importance of having children. Meanwhile, Van Groezen et al. (2003) argue that child allowances are needed to internalize the positive externality of children when the government redistributes from the young to the old. Ehrlich and Lui (1998) argue that pay-as-you-go social security can decrease at least one in three variables: fertility, savings, and human capital investment, whereas Zhang and Zhang (2004) argue that it reduces fertility and increases human capital investment.

Research on the effect of longevity on fertility focus on the need to save more for old age. For example, Zhang and Zhang (2005) consider children as a kind of young generation's consumption, and thus extended lifetime increases savings while reducing fertility. Zhang et al. (2001) and Yakita (2001) add policy into this framework, but they do not distinguish between expected and unexpected gains in life expectancy. We show how unexpected longevity gains can depress fertility further through the policy effect along with the usual life-cycle effect, and also provide empirical evidence using international data.

Lastly, the paper addresses generational equity. Unexpected longevity can create a generation whose burden is doubled; they support their own retirement as well as their parents'. Despite some positive implications of longevity on economic growth (Ehrlich and Lui, 1991; Galor and Weil, 1999; Zhang et al., 2001; Soares, 2005; Acemoglu and Restrepo, 2017), the cost of population aging may be disproportionately borne by the young generation in transitional periods via lower consumption and fertility. The unequal generational burden-sharing through policies might lead young agents to exhibit political behavior as in Song et al. (2012).

The remainder of the paper is organized as follows. Section 2 provides background on the determinants of longevity. Section 3 introduces the overlapping generations model and its simulation results. Section 4 describes the data and empirical specification. Section 5 presents the findings from cross-country panel data. Section 6 concludes.

2 Background

There are reasons to believe that individuals can expect their lifespan before retirement, and thus take it into account when making optimal consumption and savings decisions. Individuals may refer to their family's history, population health statistics, or their own investment in health to form expectations about their longevity.

The correlations between individual characteristics and health are well-documented. Richer and more educated individuals live longer for various reasons including healthier lifestyle and better information about health-seeking activities (e.g., Kenkel, 1991; Grossman and Kaestner, 1997; Fuchs, 2004; Cutler and Lleras-Muney, 2010). Smoking, alcohol consumption, unhealthy diet, physical inactivity, and long work hours, on the other hand, all have negative associations with life expectancy (see Cawley and Ruhm, 2011 and Kivimäki et al., 2015 for a review). Individuals do seem to understand to some degree these relationships between risk factors and longevity. In studies using the Health and Retirement Survey, for example, respondents with higher socioeconomic status report higher survival probabilities and those who smoke respond lower survival probabilities (Hurd and McGarry, 1995; Khwaja et al., 2007).

There is, however, also a dimension of longevity that is very difficult for individuals to expect beforehand. Most importantly, advances in medical technology is a major driver of life expectancy increase at old ages. These include medical and surgical procedures (angioplasty, joint replacements, organ transplants), diagnostic tests (laboratory tests, biopsies, imaging), drugs (biologic agents, pharmaceuticals, vaccines), medical devices (implantable defibrillators, stents, prosthetics), and new support systems (electronic medical records and telemedicine).[2] Mortality from heart disease, stroke, and cancer—the leading causes of death in many developed countries—has continued to decline in recent years due in large part to improved access to screening, increased early detection, and better treatment and care.[3] Cholesterol levels have also been dropping, particularly for the oldest adults, from increased use of drug therapy.[4] Deaths from infectious diseases have decreased as a result of vaccination and other prevention initiatives.[5]

These breakthroughs in medical technology are very difficult for an individual or a government to foresee, and their potential effects on longevity are further complicated by differences across countries in health care, health-related behaviors, and the prevalence of various diseases. For example, even if a new treatment of a certain illness becomes available worldwide, its impact on health would vary depending on whether or not it is fully covered by health insurance, how the medical staff actually practice the new treatment, and how many people

[2]Refer to National Center for Health Statistics (2010), Cutler et al. (2006), and OECD (2017a) for more details.

[3]From 1950 to 2006, the age-adjusted death rate for heart disease in the US has declined by 66 percent and stroke by 76 percent (National Center for Health Statistics, 2010). In seven European states (Germany, Greece, UK, Spain, France, Finland, and Sweden), there has been a 40 percent reduction of death rates due to heart failure from 1987 to 2008 (Laribi et al., 2012).

[4]From 1988–1994 to 2003–2006, the use of statin drugs by adults age 45 and over increased almost 10-fold in the US, from 2 percent to 22 percent (National Center for Health Statistics, 2010).

[5]Between 1989 and 1997, influenza vaccine coverage in the US tripled for adults age 50–64 and approximately doubled for those age 65 and over. Between 1989 and 2007, the percentage of adults age 65 and over who reported ever having received a pneumococcal vaccination increased from 14 percent to 58 percent (National Center for Health Statistics, 2010).

were initially at risk of getting that illness.[6]

Another exogenous factor of longevity is the environment, particularly air pollution, which has now become the biggest environmental cause of premature death.[7] Air quality in the US and many European countries has improved over the past few decades and has contributed to the increase in life expectancy.[8] But in fast-growing economies like China and India, emissions of air pollutants are continuing to rise and premature deaths from outdoor air pollution are projected to increase significantly (OECD, 2016). Predicting the effect of pollution on one's longevity is difficult because air quality is affected by policies and economic growth of not only one's own country but those nearby as fine particulate matter travel by winds across regions.

A component of longevity gains can thus be perceived as a "shock" to individuals and the society. It is noteworthy that aggregate-level uncertainty imposes a different, and greater, burden on the society than individual-level longevity risk. The risk of some agents living longer or shorter than a given average lifespan can be hedged within a cohort, and therefore has limited effects on the government's budget or intergenerational policies. When the average lifespan itself increases, however, the economic consequences of longer life can no longer be contained within a cohort. At that point, the old generation can only turn to the young generation for support.[9] In the past (and still in most developing countries) intergenerational transfers occurred within a household from adult children to aged parents. In developed countries today, these transfers occur at the society level through intergenerational policies such as pensions.[10]

[6]Mathers et al. (2015) describe how causes of increases in older age life expectancy vary across high-income countries.

[7]According to the World Health Organization, outdoor air pollution was estimated to cause more than 4 million premature deaths worldwide in 2016, overtaking the number of deaths from poor sanitation and a lack of clean drinking water.

[8]Using data on 51 metropolitan areas in the US, Pope III et al. (2009) find that reductions in air pollution accounted for as much as 15 percent of the overall increase in life expectancy. According to European Environment Agency (2018), risks of premature deaths due to air pollution has at least halved since 1990 in Europe.

[9]Another possible solution is to work for longer years. In practice, however, the labor supply response at old ages to longevity is small. Using the Health and Retirement Survey, Bloom et al., 2006 find that increased subjective probabilities have no effect on the length of working life. Hazan (2009) also shows that there seems to be no causal relationship between increased life expectancy and increase in lifetime labor supply using US and Western Europe data.

[10]In OECD countries, public transfers (58 percent) provides the bulk of income in old age, followed by work (24 percent), capital (10 percent), and occupational transfers (8 percent) (OECD, 2017b).

3 The model

We study an endowment economy populated by two overlapping generations: young and old. Agents in the same generation are identical. Let $t \in 1, 2, ...$ denote time. Lifetime is uncertain. Young agents at time $t-1$ become old agents at t with probability p_t. We assume that p_t can be time-varying and individuals have an expectation about the next period's survival probability, which is denoted as $E_t[p_{t+1}]$. This separation between expectations and realized values of survival probability enables us to distinguish between *expected* and *unexpected* longevity gains.

Young agents receive income w in each period. They pay taxes when it is positive and allocate the after-tax income between their own consumption c_t^y, consumption for their offspring n_t, and savings s_t, taking into account their expectations about survival probability. Old agents' consumption $c_t^o + 1$ comes from their savings and public pension η, which the government pays if they are eligible. The return on savings consists of interest rate r and survivor's premium, representing an actuarially fair annuity.

Preferences are represented by

$$U_t(c_t^y, n_t, c_{t+1}^o) = \log(c_t^y) + \gamma \log(n_t) + \beta E_t[p_{t+1} \log(c_{t+1}^o)], \tag{1}$$

where β is discount rate and γ represents the utility weight on offspring. This functional form is similar with those used in Yakita (2001) and Van Groezen et al. (2003), which also study fertility as an endogenous choice in the model.

At time $t+1$, old individuals maximize their utility subject to the following budget constraint given the realization of p_{t+1}

$$c_{t+1}^o \leq \frac{1+r}{p_{t+1}} s_t + \eta_{t+1}, \tag{2}$$

where η_{t+1} represents public pension payment. Dividing the returns of savings with p reflects survival premium as is common in the literature (Yakita, 2001; Zhang et al., 2001; Storesletten et al., 2004; Zhang and Zhang, 2005; Bloom et al., 2007). As survival probability increases, the returns from savings fall. The premium generates the feature that more savings is needed as lifetime extends, without increasing the number of generations in the model.

The pension system is assumed to be mandatory and is designed to ensure that old agents achieve some minimum standard of living.[11] The program pays the fixed amount $\bar{\eta}$ if the

[11]All OECD countries have safety nets provided by the public sector, which are designed to ensure pensioners achieve some absolute, minimum standard of living (OECD, 2017a).

wealth of old agents is less than θ and zero otherwise.

$$\eta_{t+1} = \begin{cases} \bar{\eta} & \text{if } \frac{1+r}{p_{t+1}} s_t \leq \theta, \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

Note that the only unknown at period t regarding the expected pension payment is p_{t+1}. The optimal old-age consumption at $t+1$ can thus be obtained at t with the characterization of $E_t[p_{t+1}]$.

The government operates on a balanced budget each period, and collects taxes from the young to finance possible pension payments to the old. Required tax revenue thus depends on the wealth of old agents; young agents do not have to pay taxes if old agents are not poorer than θ as to require pensions. The tax τ_t levied on the young is

$$\tau_t = \begin{cases} \frac{\bar{\eta} p_t}{n_{t-1}} & \text{if } \frac{1+r}{p_t} s_{t-1} \leq \theta, \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

Considering this tax scheme, the budget constraint of the young generation is given as

$$c_t^y \leq w - \tau_t - f n_t - s_t, \tag{5}$$

where f is the associated cost per unit of offspring and w is endowed income. We abstract from modelling the production side of the economy, because the focus of the paper is the difference in fertility and policy response to expected and unexpected longevity.

3.1 Characteristics of optimal choices

The equilibrium consists of each generation's optimal consumption function, offspring size function, and government policy functions regarding public pensions and the corresponding tax. The optimal consumption function and offspring size function of the young generation are obtained from maximizing equation (1) given constraint (5). Optimal consumption of the old generation can be derived from equating the budget constraint, equation (2). Government policies are represented by equations (3) and (4). Because the budget set is not compact, it is difficult to characterize the full dynamic equilibrium analytically. We therefore present complementary simulation results later in the section.

The relationship between the young's current consumption and size of offspring comes from the same natural logarithmic function. The optimal condition between the two variables is

$$\frac{\gamma}{fn_t^*} = \frac{1}{c_t^{y*}}. \tag{6}$$

The intertemporal consumption choice, on the other hand, depends on whether the pension system switches on following an increase in survival probability. If public pension remains inactive from t to $t+1$ despite an increase in $E_t[p_{t+1}]$, the standard Euler condition can describe the optimal consumption-savings decision,

$$c_t^y = \frac{w}{1+\gamma+\beta E_t[p_{t+1}]}. \tag{7}$$

An expectation of higher survival probability increases the weight young agents place on their utility from old-age consumption, thereby increasing (decreasing) savings (consumption). The result is consistent with the standard life-cycle model and findings from prior studies such as Zhang et al. (2003), Bloom et al. (2007), and Li et al. (2007), which show that higher life expectancy increases savings.

Public pension may activate, however, if old agents' savings fall short of threshold θ. There are two ways in which agents end up with insufficient savings at old age. One is when an expected increase in survival probability induces young agents to intentionally save less in order to become eligible for public pensions the next period. Another is when an unexpected increases in survival probability reduces the rate of return to savings at old age.

Let us first consider the possibility of young agents saving less when there is an *expected* increases in survival probability. Denote $\bar{c}_t^y$ as the cutoff level such that a larger consumption than $\bar{c}_t^y$ activates public pension the next period. Given $E_t[p_{t+1}]$ and a positive θ, the cutoff level is determined by the equality between the total returns from the savings and the pension eligibility threshold,

$$\frac{1+r}{E_t[p_{t+1}]}(w-\tau_t-\bar{c}_t^y) = \theta. \tag{8}$$

The utility maximization problem of young agents can thus be described as a choice between two alternatives: consume less than $\bar{c}_t^y$ (save enough) and not receive pensions when old or consume more than $\bar{c}_t^y$ (save not enough) and receive pensions when old,

$$\max[\max_{c_t<\bar{c}_t^y} U_t(c_t^y, n_t, c_{t+1}^o|\eta_{t+1}=0), \max_{c_t\geq\bar{c}_t^y} U_t(c_t^y, n_t, c_{t+1}^o|\eta_{t+1}=\bar{\eta})]. \tag{9}$$

When expected survival probability increases moderately, young agents save more for their old age as in a standard life-cycle model. The utility gap between the two alternatives in equation (9) shrinks as the expected survival probability rises, however. When expected survival probability increases substantially, young agents no longer find it optimal to undergo a huge drop in their current consumption but rather choose to rely mostly on pensions. That is, moral hazard may occur in order to become eligible for pensions at old age. Given current τ_t, if we denote $p_e(\tau_t)$ as the threshold expected survival probability which activates public pensions at $t+1$, we then have the following proposition:

Proposition 1 *If $E_t[p_{t+1}] \geq p_e(\tau_t)$, young agents consume more than $\bar{c}_t^y$.*

Tax τ_t is not fixed in the model, as it is determined to balance the government's budget. When tax is high, young agents have low after-tax income and find it difficult to save for old age. The incentive to resort to pensions thus becomes stronger when tax is higher. In other words, the required increase in survival probability $p_e(\tau_t)$ that may induce moral hazard of the young and activates the pension system is lower when tax is higher:

Proposition 2 *$p_e(\tau_t)$ is decreasing in τ_t.*

The other way in which the pension system switches on is when an *unexpected* increase in survival probability reduces the current old agents' rate of return to savings. Even if these agents had saved enough so as not to require pensions under the previous survival rate (i.e., no moral hazard), a sudden increase in p_t would make them poorer due to the decrease in survival premium (equation (2)). Let p_u be the threshold survival probability which activates public policy at the current period. We then have the following proposition:

Proposition 3 *An unexpected increase in survival probability p_t larger than p_u makes the old generation at t become eligible for public pensions.*

In sum, when an increase in survival probability is *expected*, young agents lower their consumption to prepare for old age, and pensions need not activate when they retire. An exception is when the expected increase in survival probability is "too large" (higher than $p_e(\tau_t)$) such that it becomes optimal for young agents to depend mostly on pensions at old age than to lower their current consumption substantially. When there is a large *unexpected* increase in survival probability (higher than p_u), on the other hand, old agents may end up receiving pensions even when they had "saved enough" because the effective returns on their savings suddenly fell.

3.2 Dynamic effects of unexpected longevity

To study the dynamic effects of expected and unexpected longevity gains, we compare two identical economies which are hit by an increase in survival rate of the same size once and for all from $\underline{p}$ to $\bar{p}$, where $\underline{p} < \bar{p}$. We assume that the economies were initially at a steady state with $p_1 = \underline{p}$ and that there is an increase in the probability of survival at $t = 5$ in both economies such that $p_5 = \bar{p}$. That is,

$$p_1 = p_2 = p_3 = p_4 = \underline{p} < \bar{p} = p_5 = p_6 = ...$$

In the case of expected longevity, information about this change is available one period in advance at $t = 4$, i.e. $E_4[p_5] = \bar{p}$. In the unexpected case, agents do not know this in advance and update their expectations once the shock is realized at $t = 5$.

$$\begin{cases} \text{Expected longevity: } E_1[p_2] = E_2[p_3] = E_3[p_4] = \underline{p} < \bar{p} = E_4[p_5] = E_5[p_6] = ... \\ \text{Unexpected longevity: } E_1[p_2] = E_2[p_3] = E_3[p_4] = E_4[p_5] = \underline{p} < \bar{p} = E_5[p_6] = ... \end{cases}$$

We simulate the model under the following assumptions. First, we assume that the parameters are set to generate the optimal consumption c_t^{y*} to be an inner solution in interval $(0, \bar{c}_t^y)$ given $\underline{p}$. This means that the public pension system is inactive before the longevity shock. Second, we assume that $p_u < p_e(\bar{\tau})$, where $\bar{\tau} = \frac{\bar{\eta}\bar{p}}{\underline{n}}$ is the tax needed to finance pensions if old agents become eligible for them under $\bar{p}$ and $\underline{n}$ represents the steady state offspring size under $\underline{p}$. The values of p_u and $p_e(\bar{\tau})$ depend on parameters including the size of pension payment $\bar{\eta}$ and the threshold wealth level θ. By assuming $p_u < p_e(\bar{\tau})$, the public pension system activates to support the unintended poor prior to the poor with potential moral hazard motivation.

The dynamic results can be classified into three cases depending on the value of $\bar{p}$. As presented in Figure 2, $\bar{p}$ can be lower than p_u, in between p_u and $p_e(\bar{\tau})$, or higher than $p_e(\bar{\tau})$. Note that in all three cases, agents' response to expected longevity would appear one period earlier than that of unexpected longevity due to the difference in timing of the information arrival.

*** Figure 2 here ***

Case I (low $\bar{p}$)

If $\bar{p} < p_u$, pension system remains inactive. The new survival probability is not high enough to generate a meaningful reduction in the returns on savings of old agents or to induce strategic behavior of young agents. The usual Euler equation holds with $\eta_t = \tau_t = 0$ and as the two economies share the same optimal consumption function for the young (equation (7)), there is no substantial difference in the resulting dynamics between the two economies in terms of the young generation's consumption-savings choice. When survival rate rises from $\underline{p}$ to $\bar{p}$, equations (6) and (7) imply that young agents' consumption and the corresponding size of offspring will decrease in both the expected and unexpected economy as they save more. We label the effect of longevity on fertility via this channel "life-cycle effect" as it follows standard life-cycle considerations discussed in the literature.

*** Figure 3 here ***

Figure 3 indicates that there are subtle differences between the expected (solid line) and unexpected (starred line) economy in timing, however. When an increase in survival probability is expected, agents can prepare in advance for their old age by reducing their consumption and fertility at $t = 4$, a period before the shock (Figure 3a). Because agents increase their savings before the arrival of the shock, their wealth falls only slightly when the shock hits at $t = 5$ (Figure 3b). In the unexpected economy, on the other hand, young agents can change their consumption and fertility behaviors only when the shock is realized at $t = 5$. Agents who are already old at the time of the shock thus experience a sharp drop in their wealth, because they have saved according to $\underline{p}$ and not $\bar{p}$ when young. The drop is not so large as to require pensions, however (above θ, dotted line). From $t = 6$ onwards, the two economies become equivalent again.

Case II (intermediate $\bar{p}$)

If $p_u \leq \bar{p} < p_e(\bar{\tau})$, the dynamics from expected longevity is the same as in Case I above. Young agents correctly anticipate the upcoming decline in effective returns on savings, and prepare for their old age by saving more from $t = 4$. They save enough so that their accumulated wealth when they become old at $t = 5$ is above the pension threshold θ, and hence the pension system remains inactive.

The dynamics from unexpected longevity departs from Case I, however, because $\bar{p}$ is now high enough to lower the total value of savings significantly ($\bar{p} \geq p_u$). The elderly's wealth drops below the pension threshold at $t = 5$ and the government now needs to support the old via pension payment $\bar{\eta}$ (Proposition 3). The young generation at $t = 5$ thus face two separate burden when there is an unexpected longevity shock. First, they need to save more for their own old-age consumption given the lower effective rate of return on savings (life-cycle effect). Second, they need to support their parental generation who suddenly became poor by paying taxes to finance the public pension system. We label this effect on offspring size via public pensions as “policy effect.” Unlike the life-cycle effect, the policy effect kicks in only when the longevity gain is unexpected because the government does not need to levy taxes when it is expected.

*** Figure 4 here ***

Figure 4 shows the simulation results. Although the young reduce their offspring size in both economies, the model produces larger negative effects in the unexpected case due to the policy effect in addition to the life-cycle effect (Figure 4a). The wealth of old agents falls sharply below the pension threshold θ at $t = 5$ (Figure 4b), and hence the pension system switches on with $\tau > 0$ (Figure 4c) in the unexpected economy.

After the shock at $t = 5$, agents in both economies save according to the new survival probability $\bar{p}$ and accumulate enough wealth to not require pensions because $\bar{p} < p_e(\bar{\tau})$ (Proposition 1). No agent is thus entitled to pensions from $t = 6$ onwards and τ returns to 0 as the policy is switched off again (Figure 4c). Note that the two economies are still not equivalent at $t = 6$, however, because the wealth of old agents is lower in the unexpected case (Figure 4b). This is because the cohort was taxed when they were young at $t = 5$, and hence could not accumulate as much savings. This “sandwich” generation pays the costs of the pay-as-you-go system without receiving pensions themselves, and have lower consumption and fewer children than future generations subject to the same $\bar{p}$.

Case III (high $\bar{p}$)

If $\bar{p} \geq p_e(\bar{\tau})$, the new survival probability is so high that young agents may find it optimal to rely on pensions instead of reducing their consumption substantially today. However, the condition which invokes public pension system depends on the value of τ_t, and hence we distinguish between the case in which $\tau_t = 0$ and $\tau_t > 0$.

Consider $p_e(\bar{\tau}) \leq \bar{p} < p_e(0)$. When such $\bar{p}$ is expected, young agents do not choose to depend on pensions given $\tau_t = 0$ because $\bar{p} < p_e(0)$. The dynamics in the expected economy thus resemble those in Cases I and II except for the magnitude; young agents reduce their consumption and offspring size more here because survival probability is higher (Figure 5a). When $\bar{p}$ is unexpected, on the other hand, old agents at $t = 5$ suddenly become poor and the pension system is switched on because $\bar{p} \geq p_u$ as in Case II (Figure 5b). To finance the system, taxes are levied on young agents with rate equal to $\bar{\tau}$. The difference with Case II is that young agents exhibit moral hazard behavior and decide to rely on pensions given $\bar{p} \geq p_e(\bar{\tau})$ (Proposition 1). The policy effect allows young agents to choose larger offspring size than what the life-cycle effect suggests, because it alleviates the burden of privately preparing for old-age consumption.

Figure 5 shows the response when $p_e(\bar{\tau}) \leq \bar{p} < p_e(0)$. In this numerical exercise, young agents save just enough to make the total return equal to the pension threshold θ, the pension system remains active, and the dependency continues after the unexpected longevity shock (Figure 5b). It can be confirmed in the figure that offspring size is larger than what the life-cycle effect suggests (dotted line in Figure 5a).

*** Figure 5 here ***

Lastly, consider $\bar{p} \geq p_e(0)$. Young agents choose to rely on pensions at old age even when they are currently not being taxed ($\tau_t = 0$). When such $\bar{p}$ is expected, young agents decrease consumption at $t = 4$ as in cases above, but not as much as they would without pensions. Now that their old-age consumption is going to be partly supported by pensions, they consume more and have more children than suggested by the life-cycle effect (dotted line in Figure 6a). At $t = 5$, the pension system switches on and young agents pay taxes to support their parents' pensions in addition to saving for their own old age. Fertility thus falls compared to $t = 4$ when there was no tax, but again, it is still higher than what would have been without the policy effect. The rationale is similar when $\bar{p} \geq p_e(0)$ is unexpected, except that both the life-cycle effect and the policy effect kick in at $t = 5$. This creates a steeper one-time decline in young agents' consumption and offspring size compared with the expected case in which the decline occurs across two periods.

Figure 6 presents the simulation results. Note that the level of offspring size at $t = 5$ is slightly higher than the expected case. This is because young agents reduce their offspring size in advance at $t = 4$ in the expected economy and the resulting smaller cohort imposes a larger tax burden on the young generation at $t = 5$.

*** Figure 6 here ***

Summary

In the model, longevity affects fertility through two channels: the life-cycle effect and the policy effect. The life-cycle effect decreases fertility by the same amount in both expected and unexpected economies. The policy effect, on the other hand, depends on whether or not the increase in survival probability is expected and whether or not the increase is large. If the improvement in lifespan is small, the policy effect is absent and agents simply save more for their old age (Case I). If the improvement is intermediate, then the policy effect kicks in only in the unexpected economy where old agents suddenly find themselves in need of financial assistance. As the pension system is activated, lower after-tax income depresses fertility rates of the young (Case II). When the improvement is sufficiently large, the policy effect on fertility may even become positive as young agents decide to rely on pensions instead of consuming less and having fewer children today (Case III).

Although the policy effect on fertility can either be negative or positive in theory depending on the size of longevity gain, we believe it is reasonable to consider the first two cases (Case I and Case II) in practice. Only the last case (Case III) with a very large jump in survival probability implies moral hazard behavior of the young generation, who become eligible for public pensions by intentionally becoming poorer than the pension threshold. The pension system in the model captures the spirit of public programs which help the elderly maintain some absolute, minimum standard of living. It is therefore difficult to consider the last case using aggregate data of advanced countries, where most people do not rely on pensions for their living.

A number of challenges remain when taking the model to actual data. First, survival probability does not actually increase once but increases continuously in varying increments over time. In the empirical analysis, we therefore regard the longevity "shock" as a continuous variable. The model predicts that the fertility and policy response would be larger for larger values of the shock.

Second, the distinction between expected and unexpected increase in longevity differs by the time period considered. If the unit of time is defined finely, for example a year, then there is virtually no difference between expected and unexpected increase in old-age survival for a 30-year-old saving for his retirement because it is still a couple of decades away. A 60-year-old, on the other hand, would find it much more difficult to smooth his consumption when there is an unexpected longevity gain because he only has a few years of working life left. If the unit of time is defined coarsely, for example 30 years, this implies that individuals make their consumption-savings and fertility decisions only about once throughout their working life. We therefore take caution when choosing time horizons in the next section.

Third, the model abstracts from other factors which may also affect the fertility decision in a developed country context, such as female labor supply, quantity-quality trade-off, childcare substitutability, gender norms, and institutions. There is a rich literature that discuss the potential effect of these variables (see for e.g., Becker, 1991, Feyrer et al., 2008 for an overview). We therefore emphasize that the model does not intend to provide *the* explanation for lower fertility rates in some developed countries, but offers a new perspective by focusing on the effect of unexpected longevity. In our empirical analysis, we include additional controls and use country and year fixed effects to address this issue.

4 Empirical framework

4.1 Data and variable construction

To test the predictions of the model using cross-country panel data, we first need to construct a measure of unexpected longevity. As discussed in Section 2, longevity is affected by various factors both at the individual and aggregate level. Uncertainty about one's lifetime at the individual level has been documented using survey data on subjective survival forecasts.[12] Uncertainty about longevity at the aggregate level, on the other hand, has been much less studied.

To construct a measure of unexpected longevity across countries and years, we therefore estimate the model in Lee and Carter (1992) on age-specific mortality rate data. The Lee-Carter model is the most widely used mortality forecasting technique in the world today, used not only in studies on longevity (e.g., Cocco and Gomes, 2012 and Lee et al., 2000b) but also by institutions such as the United Nations and the United States Social Security Administration and Census Bureau. The model extrapolates historical trends and forecasts probability distributions of age-specific death rates using standard time-series procedures.

To briefly outline the model, mortality rate at age x in period t ($m_{x,t}$) are given by

$$\ln(m_{x,t}) = a_x + b_x \times k_t + \epsilon^m_{x,t}, \tag{10}$$

where k_t is a time-varying index which captures the evolution of mortality over periods, and a_x and b_x are age-specific parameters. Coefficient a_x describes the general shape across age of the mortality schedule and b_x describes which rates decline more or less rapidly in response to changes in k. To estimate (10) for a given matrix of rates $m_{x,t}$, the Single Value Decomposition (SVD) is used because there are no given regressors.

It is known that a random walk with drift describes k well. The evolution of k_t can thus be expressed as

$$k_t = \mu^k + k_{t-1} + \epsilon^k_t, \tag{11}$$

where μ^k is the drift parameter which captures the average annual change in k and drives the forecasts of long-run changes in mortality.

[12] The literature on survival expectations beginning with Hamermesh (1985) provides micro-level evidence of differences between subjective survival forecasts and objective forecasts drawn from life tables. Studies such as Elder (2013), Wu et al. (2015), and O'Dea and Sturrock (2018), for example, use survey data and find that individuals are in general pessimistic about life expectancy and underestimate their likelihood of surviving to their 70s.

In this paper, we define unexpected longevity as the difference between actual life expectancy at 65 and the predicted life expectancy at 65 obtained using the Lee-Carter model. Specifically, we use each country's past 30 years of age-specific mortality rate data from the Human Mortality Database (HMD) to estimate the parameters in equations (10) and (11). Using these estimates, we are able to produce forecasts of age-specific mortality rates, and hence calculate life expectancies at any age. We choose life expectancy at 65 because we are interested in capturing unexpected gains in longevity for individuals who have already reached retirement. Note that life expectancy at younger ages (life expectancy at birth, for instance) usually differ from life expectancy at old ages because they are affected by infant mortality rates.

For example, we use data on 1969–1999 age-specific mortality rates in the US to obtain forecasts of age-specific mortality rates in the US in 2000. Because we have data on *actual* age-specific mortality rates in the US in 2000 as well, we are able to calculate the US life expectancy at 65 in 2000 from actual mortality rates ($m_{x,t}$) as well as from the forecasted mortality rates ($\widehat{m}_{x,t}$). The difference between these two measures would be the forecast error of life expectancy at 65 in the US in 2000.

The horizon of 30 years of data is chosen to balance the trade-off between data availability and stability of forecasts. If the horizon is set too long, there will not be enough observations for analysis. If the horizon is set too short, we will no longer be able to distinguish temporary fluctuations from long-run trends. According to Lee and Carter (1992), the fitted models and forecasts exhibit some instability when the base period is reduced to 10 or 20 years. Besides, the length of time should be consistent with the spirit of our model. It is unlikely that individuals consider the past 50 years of mortality rates to predict their lifetime. At the same time, it is difficult for individuals to adjust their plans for old-age consumption with updated mortality rates on a yearly basis.

Figure 7 depicts the forecast errors of life expectancy at 65 in OECD countries. HMD provides data for 40 countries, 31 OECD and 9 non-OECD. We restrict our estimation sample to OECD members because the paper addresses developed countries facing low fertility and population aging problems and also because of data availability issues for the policy variables used in our analysis. Forecast errors are positive, negative, or close to zero depending on whether the actual life expectancy at 65 in year t is above, below, or close to, the forecasts using long-run trends in age-specific mortality rates. It is noteworthy that the forecast errors fluctuate in different ways across countries and time. For example, although Japan and South Korea both have very high life expectancy at 65, the forecast errors show opposite trends: they are decreasing towards zero in Japan, whereas increasing to positive values in South Korea. This pattern is consistent with Figure 1 panel (b), where we find that most of the improvement in life expectancy at 65 occurred in earlier decades for Japan and in more recent decades for South Korea.

*** Figure 7 here ***

The sources and summary statistics of variables used in the empirical analysis are listed in Table 1. Data exist for 31 OECD countries starting from 1950 for demographic variables and from 1980 for policy variables. Exp65 shock refers to the forecast errors found above.

*** Table 1 here ***

Data on longevity and population structure come from the HMD and the World Bank. As depicted in Figure 1, there is an overall increase in life expectancy. From 1950 to 2016, the mean of life expectancy at 65 (at birth) in the sample has risen from 68 (14) to 82 (21) years. The old dependency ratio refers to the ratio of the elderly (age 65 and above) to the working-age (age 15–64) population, and has a mean of 20.5 and a standard deviation of 4.45. The mean total fertility rate is only 1.86, as it decreased from 2.91 in 1960 to 1.69 in 2016. GDP is taken from the Penn World Table and measures expenditure-side real GDP at chained PPPs, in million 2011 US dollars.

Intergenerational policy variables include public old-age spending and public family spending. They are both taken from the OECD Social Expenditure database (OECD SOCX), which provides information on social expenditures for OECD countries from 1980 to 2015.[13] The database reports mandatory private and voluntary private social expenditures as well, but we focus on public social expenditures because we are interested in the allocation of resources by the government. Public expenditures are grouped into nine categories: old-age, survivors, incapacity-related, health, family, active labor market programs, unemployment, housing, and other social policy areas. We use old-age and family public spending in our analysis, because the benefits are directed to a generation. We report the variables in terms of percent of GDP in order to compare across countries and time.

Public old-age spending comprises on average 6.6 percent of GDP. Its largest component is undoubtedly pension (85.7 percent).[14] Other components include early retirement pension (6.6 percent) and in-kind benefits such as residential care and home-help services (7.3 percent). Family social expenditures, on the other hand, take up on average 2 percent of GDP. The largest item within this category is family cash allowances (46 percent), followed by in-kind benefits toward early childhood education and care (24 percent), and paid maternity and parental leave (14 percent).

[13]For most countries, the series go back to 1980, but for countries that joined in the 1990s and 2000s data may only be available for shorter periods.

[14]This is calculated by taking the average of each component's share of public old-age spending across OECD countries.

4.2 Empirical specification

Our regression specification is a linear model with country fixed effects:

$$\Delta \ln y_{i,t} = \beta exp65shock_{i,t} + \gamma exp65_{i,t-5} + \theta X_{i,t-5} + \eta_i + \delta_t + \varepsilon_{i,t}. \tag{12}$$

where i index country and t index time. Each variable is averaged over five years for consecutive beginning years, and the difference operator is $\Delta z_{i,t} = z_{i,t} - z_{i,t-5}$.[15] The dependent variable is hence the growth in the five-year average of y, the total fertility rate or public spending, in country i period t. Growth rates are used instead of levels because we are interested in studying the difference between expected and unexpected longevity gains in terms of their dynamics and not the steady states. As illustrated in the simulation results, fertility and policies at the steady state may be the same after an expected and unexpected increase in survival probability; the distinction arises during the transition.

The key regressor is the unexpected change in longevity ($exp65shock$) defined as the difference between actual and predicted life expectancy at 65 following the Lee-Carter model aforementioned. Equation (12) thus tests the causal effect of an unexpected increase in life expectancy at 65 on the total fertility rate or public spending growth in country i period t. It is worth noting again that the Lee-Carter forecast of life expectancy at 65 takes into account the previous 30 years of mortality rate data in each country, including recent trends until $t-1$. The variable $exp65shock$ can thus be considered as a conservative measure of longevity shock because consumption-savings decisions are actually made throughout one's working life, including periods much before the mortality rates of $t-1$ are realized.

Other controls include lagged values of life expectancy at 65 ($exp65$) and a vector of other characteristics (X) such as life expectancy at birth, the log of GDP per capita, and the old dependency ratio. We use lagged values to address the possibility of reverse causality. For instance, policies may affect life expectancy at 65 by improving the elderly's living standards. Country dummies (η_i) are included to control for unobservable country effects such as differences in family formation or health behaviors due to institutional or cultural factors. It also alleviates the concern about comparability across countries in how public spending is classified. Time dummies (δ_t) are included to control for unobservable period effects such as business cycles.

In comparison to prior studies, a distinctive feature of the specification is that we consider the explicit role of the unexpected component of life expectancy at 65 in addition to its level. This allows us to distinguish between the case with and without unexpected increase in life expectancy at 65, conditional on the same life expectancy at 65 in the previous period.

[15] We interpolate for missing values when taking the average.

We also control for the old dependency ratio so that our estimate of β is not confounded by cohort size effects. When the elderly vote share becomes larger, for instance, policies towards the elderly may become more generous to win elections. The aim of our analysis is to investigate whether policies change in response to longevity shocks, conditional on the elderly share of the population. The framework thus differs from Razin et al. (2002) or Shelton (2008), which focus on the relationship between the dependency ratio and policy variables.

Because we include five-year lags and there are some countries missing data for earlier years, there are on average 40 observations per country for the fertility regression and 24 observations per country for the policy regressions. Although taking averages reduces sample size, an advantage is that it lessens the short-term cyclical influence on macroeconomic variables. In our context, it also helps to address the fact that fertility and policy decisions are not made within a one-year time frame.

5 Empirical findings

Table 2 reports the results of regressing the TFR growth on unexpected longevity, using equation (12). The average TFR growth rate is about -5 percent per period, indicating an overall decline in fertility among OECD countries. The coefficient on $exp65shock$ is negative and highly significant in all four columns with country and time fixed effects. Consistent with our model, an unexpected increase in longevity further reduces a country's TFR from its declining trend. The level of life expectancy at 65 also has a negative effect as in prior studies on fertility (e.g., Zhang and Zhang, 2004; Zhang and Zhang, 2005), although statistically insignificant.[16] Lagged values of the log of GDP per capita and the old dependency ratio have statistically insignificant effects on TFR growth.

*** Table 2 here ***

To test whether intergenerational policies is a potential link between unexpected longevity and fertility, we conduct analyses using policy measures as dependent variables. Table 3 columns 1–3 report the regression results for public old-age spending as a percentage of GDP from the OECD SOCX. On average, it has grown by on average 5 percent per period. Even with country and time fixed effects and other controls, $exp65shock$ has a positive and statistically significant effect on public old-age spending growth. The increase in government expenditures toward the elderly becomes larger when there is an unexpected increase in

[16]Using life expectancy at birth instead of life expectancy at 65 does not change results.

life expectancy at 65. The result remains robust to the inclusion of both last period's life expectancy at 65 and the old dependency ratio, and thus cannot be explained by a mechanical increase in pension payments due to a larger elderly share of the population. Previous period's log of GDP per capita also has a positive and statistically significant effect on public old-age spending growth.

*** Table 3 here ***

Next, we examine the effect of the life expectancy 65 shock on public spending towards the young generation. Of course, benefits to the young generation need not fall despite an increase in public old-age spending. The government may increase overall spending by raising taxes or debt. In practice, however, it is difficult to raise social expenditures indefinitely and there is competition for public resources. Public family spending is thus one way to measure intergenerational redistribution given the lack of cross-country panel data on effective labor tax rates.[17]

Table 3 columns 4–6 report the results on public family spending growth as a percentage of GDP. Government expenditure in this area has grown by on average 9 percent per period. The relatively high growth rate reflects the expansion of support for families with children during the past several decades, such as public childcare services. Unexpected gains in life expectancy at 65, however, is shown to significantly lower the growth in public family spending within a country. The level of life expectancy at 65 and the old dependency ratio do not have significant effects in addition to $exp65shock$. Log of GDP per capita again has a statistically significant positive effect on public family spending growth.

*** Table 4 here ***

To establish robustness of our findings, we conduct several sensitivity tests with alternative specification or sample used in related empirical studies. Table 4 presents the estimates of the key regressor, $exp65shock$, from separate regressions with TFR growth (column 1), public old-age spending growth (column 2), and public family spending growth (column 3) as the dependent variable. Fixed effects and other controls are included although not reported in the table.

First, in panel A, we additionally control for female labor force participation (LFP) rate. Female labor supply is endogenous to decisions regarding fertility and public family spending, so we include its lag to lessen the possibility of reverse causality. The sample size reduces slightly due to missing observations of female LFP in earlier years for some OECD

[17] OECD *Taxing Wages* calculates average effective tax rate on labor but is only available from 2000.

countries, but the effect of unexpected longevity remains robust and highly significant in all three columns. In panel B, we use 10-year lags instead of 5-year lags as controls. The sample size becomes smaller due to the further lag needed, but the same pattern is observed for $exp65shock$ as in Tables 2 and 3. Unexpected gains in life expectancy at 65 raises TFR growth and public old-age spending growth while dampening family spending growth.

In order to address the concern regarding institutional differences in public programs across countries, panel C includes mandatory private social expenditures in the policy measures (columns 2 and 3). The OECD SOCX provides information on expenditures on the basis of whoever controls the relevant financial flows; public institutions or private bodies. The analysis in Table 3 uses public spending only, i.e., those managed by the general government. The classification is not always clear-cut, however, as public and private sectors may sometimes serve similar roles. For example, pensions paid to former civil servants through autonomous funds are recorded as private spending items in the SOCX. We therefore test the effect of unexpected longevity on a broader definition of social expenditures, by summing the public and mandatory private spending in each category.[18] The results remain unchanged for both old-age and family spending.

In panel D, we use the difference in each dependent variable instead of its growth from last period. The unit of the dependent variable is therefore different here, with the change in TFR from the previous period -0.1, and the change in public old-age spending 0.4 percent of GDP, and the change in public family spending 0.1 percent of GDP. The findings on unexpected longevity remain qualitatively unchanged, however.

*** Table 5 here ***

As a final check, we run a series of placebo tests using policies which are *not* directed to a certain generation. If unexpected increase in life expectancy at 65 is systematically correlated with other aspects of the society such as economic development or political shifts toward a bigger or smaller government, we may observe significant effects of $exp65shock$ on other social expenditures as well. We therefore replicate our main analysis on all remaining public expenditure categories in the OECD SOCX: survivors, incapacity-related benefits, health, active labor market programs, unemployment, and housing.[19] Note that the eligibility of

[18]Mandatory private social expenditure is social support stipulated by legislation but operated through the private sector. Voluntary private social expenditure are benefits accruing form privately operated programs that involve redistribution of resources across households. (See Adema et al. (2011) for more details.)

[19]Expenditure on survivors include widow's pension and funeral expenses. Incapacity-related benefits comprise disability pensions, pensions due to occupational injury and diseases, paid sick leave, and rehabilitation services. Expenditure in health encompasses expenditure on in-patient care, ambulatory medical services, and pharmaceutical goods. Active labor market programs includes spending on public employment services and administration, training, job rotation and sharing, supported employment and rehabilitation,

receiving benefits in these areas are tied to an individual's economic or health status rather than an individual's cohort. Table 5 confirms that none of these items are affected by unexpected longevity, in contrast to our findings on public old-age and family spending.

In sum, the regression results using cross-country panel data support our model's predictions. Longer life lowers fertility rates because individuals need to save more for their old age. *Unexpected* longer life lowers fertility rates even further, because the young generation now needs to also support the elderly who suddenly find themselves under-prepared for their extended lifetime. The findings suggest that this negative policy effect triggered by unexpected longevity can be one of the reasons for declining fertility rates in countries with rapid improvements in old-age survival.

6 Conclusions

Life expectancy at 65 depicts an increasing trend across developed countries but there is much variation in its pace. Due to factors including medical technology advancements and changes in the environment, there is thus uncertainty about lifetime even at the aggregate level. Particularly in countries experiencing a rapid decline in old-age mortality, the gap between expected and actual lifetime may widen and generate dynamic effects on fertility and policies unlike those in countries where the gap is small.

This paper shows that an unexpected longevity gain can depress fertility further than an expected longevity gain due to its effect on intergenerational policies. When there is an unexpected increase in longevity, retirees find themselves with insufficient savings for old age and require support from the government, i.e., the young generation. The burden of supporting the poor elderly through taxes in addition to the burden of saving for one's own longer lifetime results in the young generation reducing offspring size. In a simple overlapping generations model with public pensions, we show how the two channels—the life-cycle effect and the policy effect—operate when the increase in survival probability is expected and unexpected. Simulations of the model illustrate that under reasonable assumptions, a negative policy effect on fertility exists only when the longevity gain is unexpected.

Regression results using a panel data of OECD countries corroborate our theoretical predictions. We construct a measure of longevity shock by calculating the forecast errors between actual life expectancy at 65 and predicted life expectancy at 65 following the Lee and Carter (1992). We show that larger forecast errors in life expectancy at 65 generate lower

direct job creation, and start-up incentives. The category unemployment includes all cash expenditures to persons to compensate for unemployment. Rent subsidies and other cash benefits to the individual to help with housing costs are grouped under housing. Other social policy areas include other income maintenance and social assistance programs. Refer to OECD (1996) for more details.

total fertility rate and public family spending growth but higher public old-age spending growth, controlling for the level of life expectancy at 65, GDP per capita, old dependency ratio, as well as country and year fixed effects.

Findings imply that the speed of longevity gains, and hence how well agents are able to expect their lifespan, is important as much as the length of lifespan itself. It provides an explanation for why old-age related policies and fertility rates can evolve differently in developed countries with similar levels of life expectancy and elderly share of the population. Particularly, countries with rapid improvements in longevity would experience rapid population aging not only because of the direct increase in the number of old agents but also because of the ensuing decline in young agents' fertility rate.

References

Acemoglu, Daron and Pascual Restrepo, "Secular stagnation? The effect of aging on economic growth in the age of automation," *American Economic Review*, 2017, *107* (5), 174–79.

Adema, Willem, Pauline Fron, and Maxime Ladaique, "Is the European welfare state really more expensive?," 2011.

Becker, Gary S., *A Treatise on the Family: Expanded Edition*, Cambridge: Harvard University Press, 1991.

Bloom, David E, David Canning, and Bryan Graham, "Longevity and life-cycle savings," *Scandinavian Journal of Economics*, 2003, *105* (3), 319–338.

_ , _ , Michael Moore, and Younghwan Song, "The effect of subjective survival probabilities on retirement and wealth in the United States," Technical Report, National Bureau of Economic Research 2006.

_ , _ , Richard K Mansfield, and Michael Moore, "Demographic change, social security systems, and savings," *Journal of Monetary Economics*, 2007, *54* (1), 92–114.

Boldrin, Michele, Mariacristina De Nardi, and Larry E Jones, "Fertility and social security," *Journal of Demographic Economics*, 2015, *81* (3), 261–299.

Cawley, John and Christopher J Ruhm, "The economics of risky health behaviors," in "Handbook of health economics," Vol. 2, Elsevier, 2011, pp. 95–199.

Cigno, Alessandro and Furio C Rosati, "The effects of financial markets and social security on saving and fertility behaviour in Italy," *Journal of Population Economics*, 1992, *5* (4), 319–341.

_ and _ , "Jointly determined saving and fertility behaviour: Theory, and estimates for Germany, Italy, UK and USA," *European Economic Review*, 1996, *40* (8), 1561–1589.

Cocco, Joao F and Francisco J Gomes, "Longevity risk, retirement savings, and financial innovation," *Journal of Financial Economics*, 2012, *103* (3), 507–529.

Cutler, David, Angus Deaton, and Adriana Lleras-Muney, "The determinants of mortality," *Journal of Economic Perspectives*, 2006, *20* (3), 97–120.

Cutler, David M and Adriana Lleras-Muney, "Understanding differences in health behaviors by education," *Journal of health economics*, 2010, *29* (1), 1–28.

Ehrlich, Isaac and Francis T Lui, "Intergenerational trade, longevity, and economic growth," *Journal of Political Economy*, 1991, *99* (5), 1029–1059.

_ and _ , "Social security, the family, and economic growth," *Economic Inquiry*, 1998, *36* (3), 390–409.

— **and Jinyoung Kim**, "Social security and demographic trends: Theory and evidence from the international experience," *Review of Economic Dynamics*, 2007, *10* (1), 55–77.

Elder, Todd E, "The predictive validity of subjective mortality expectations: Evidence from the health and retirement study," *Demography*, 2013, *50* (2), 569–589.

European Environment Agency, "Air quality in Europe: 2018 Report," 2018.

Feyrer, James, Bruce Sacerdote, and Ariel Dora Stern, "Will the stork return to Europe and Japan? Understanding fertility within developed nations," *Journal of Economic Perspectives*, 2008, *22* (3), 3.

Fuchs, Victor R, "Reflections on the socio-economic correlates of health," *Journal of health economics*, 2004, *23* (4), 653–661.

Galor, Oded and David N Weil, "From Malthusian stagnation to modern growth," *American Economic Review*, 1999, *89* (2), 150–154.

Groezen, Bas Van, Theo Leers, and Lex Meijdam, "Social security and endogenous fertility: Pensions and child allowances as Siamese twins," *Journal of Public Economics*, 2003, *87* (2), 233–251.

Grossman, Michael and Robert Kaestner, "Effects of education on health," *The social benefits of education*, 1997, *12*, 69.

Hamermesh, Daniel S, "Expectations, life expectancy, and economic behavior," *The Quarterly Journal of Economics*, 1985, *100* (2), 389–408.

Hazan, Moshe, "Longevity and lifetime labor supply: Evidence and implications," *Econometrica*, 2009, *77* (6), 1829–1863.

Hurd, Michael D and Kathleen McGarry, "Evaluation of the subjective probabilities of survival in the health and retirement study," *Journal of Human resources*, 1995, pp. 268–292.

III, C Arden Pope, Majid Ezzati, and Douglas W Dockery, "Fine-particulate air pollution and life expectancy in the United States," *New England Journal of Medicine*, 2009, *360* (4), 376–386.

Kenkel, Donald S, "Health behavior, health knowledge, and schooling," *Journal of Political Economy*, 1991, *99* (2), 287–305.

Khwaja, Ahmed, Frank Sloan, and Sukyung Chung, "The relationship between individual expectations and behaviors: Mortality expectations and smoking decisions," *Journal of Risk and Uncertainty*, 2007, *35* (2), 179–201.

Kivimäki, Mika, Markus Jokela, Solja T Nyberg, Archana Singh-Manoux, Eleonor I Fransson, Lars Alfredsson, Jakob B Bjorner, Marianne Borritz, Hermann Burr, Annalisa Casini et al., "Long working hours and risk of coronary heart disease and stroke: a systematic review and meta-analysis of published and unpublished data for 603 838 individuals," *The Lancet*, 2015, *386* (10005), 1739–1746.

Laribi, Said, Albertine Aouba, Maria Nikolaou, Johan Lassus, Alain Cohen-Solal, Patrick Plaisance, Gérard Pavillon, Preeti Jois, Gregg C Fonarow, Eric Jougla et al., "Trends in death attributed to heart failure over the past two decades in Europe," *European journal of heart failure*, 2012, *14* (3), 234–239.

Lee, Ronald, Andrew Mason, and Timothy Miller, "Life cycle saving and the demographic transition: The case of Taiwan," *Population and Development Review*, 2000, *26*, 194–219.

_ , _ , and _ , "Life Cycle Saving and the Demographic Transition: The Case of Taiwan," *Population and Development Review (Supplement)*, 2000, *26*, 194–219.

Lee, Ronald D and Lawrence R Carter, "Modeling and forecasting US mortality," *Journal of the American statistical association*, 1992, *87* (419), 659–671.

Li, Hongbin, Jie Zhang, and Junsen Zhang, "Effects of longevity and dependency rates on saving and growth: Evidence from a panel of cross countries," *Journal of Development Economics*, 2007, *84* (1), 138–154.

Mathers, Colin D, Gretchen A Stevens, Ties Boerma, Richard A White, and Martin I Tobias, "Causes of international increases in older age life expectancy," *The Lancet*, 2015, *385* (9967), 540–548.

National Center for Health Statistics, "Health, United States, 2009: With special feature on medical technology," 2010.

O'Dea, Cormac and David Sturrock, "Subjective expectations of survival and economic behaviour," *Institute for Fiscal Studies Working Paper W18/14*, 2018.

OECD, "Social Expenditure Statistics of OECD Member Countries, Provisional Version," *Labour Market and Social Policy Occasional Papers*, 1996.

_ , *Economic Consequences of Outdoor Air Pollution*, Organisation for Economic Co-operation and Development, 2016.

_ , "Health at a glance 2017: OECD indicators," 2017.

OECD, "Pensions at a Glance 2017: OECD and G20 Indicators," 2017.

Razin, Assaf, Efraim Sadka, and Phillip Swagel, "The aging population and the size of the welfare state," *Journal of Political Economy*, 2002, *110* (4), 900–918.

Renshaw, Arthur E and Steven Haberman, "A cohort-based extension to the Lee–Carter model for mortality reduction factors," *Insurance: Mathematics and economics*, 2006, *38* (3), 556–570.

Shelton, Cameron A, "The aging population and the size of the welfare state: Is there a puzzle?," *Journal of Public Economics*, 2008, *92* (3), 647–651.

Soares, Rodrigo R, "Mortality reductions, educational attainment, and fertility choice," *American Economic Review*, 2005, *95* (3), 580–601.

Song, Zheng, Kjetil Storesletten, and Fabrizio Zilibotti, "Rotten parents and disciplined children: A politico-economic theory of public expenditure and debt," *Econometrica*, 2012, *80* (6), 2785–2803.

Storesletten, Kjetil, Christopher I Telmer, and Amir Yaron, "Consumption and risk sharing over the life cycle," *Journal of monetary Economics*, 2004, *51* (3), 609–633.

Wu, Shang, Ralph Stevens, and Susan Thorp, "Cohort and target age effects on subjective survival probabilities: Implications for models of the retirement phase," *Journal of Economic Dynamics and Control*, 2015, *55*, 39–56.

Yakita, Akira, "Uncertain lifetime, fertility and social security," *Journal of Population Economics*, 2001, *14* (4), 635–640.

Zhang, Jie and Junsen Zhang, "How does social security affect economic growth? Evidence from cross-country data," *Journal of Population Economics*, 2004, *17* (3), 473–500.

_ **and** _ , "The effect of life expectancy on fertility, saving, schooling and economic growth: theory and evidence," *Scandinavian Journal of Economics*, 2005, *107* (1), 45–66.

_ **,** _ **, and Ronald Lee**, "Rising longevity, education, savings, and growth," *Journal of Development Economics*, 2003, *70* (1), 83–101.

Zhang, Junsen, Jie Zhang, and Ronald Lee, "Mortality decline and long-run economic growth," *Journal of Public Economics*, 2001, *80* (3), 485–507.

Table 1: Descriptive Statistics

Variable	Source	Mean	SD	N	n (countries)	t (years)
Exp65 shock	Human Mortality Database	0.25	0.37	1401	31	1950-2016
Exp65	Human Mortality Database	16.81	2.28	1401	31	1950–2016
Exp0	Human Mortality Database	75.53	4.15	1401	31	1950-2016
Ln(GDPpc)	Penn World Table	9.99	0.54	1356	31	1950-2014
Old dependency ratio	World Bank	20.50	4.45	1265	31	1960-2016
Total Fertility Rate	World Bank	1.86	0.49	1265	31	1960-2016
Public old-age spending (% of GDP)	OECD	6.60	2.47	853	31	1980-2015
Public family spending (% of GDP)	OECD	2.03	1.02	853	31	1980-2015

Table 2: Effect of Unexpected Longevity on Fertility

Dependent variable:	**Total fertility rate growth**			
	(1)	(2)	(3)	(4)
Exp65 shock	-7.80**	-11.89***	-11.17***	-12.00**
	(3.45)	(4.04)	(3.94)	(4.41)
L.Exp65		-1.55	-1.37	-0.99
		(1.58)	(1.53)	(1.46)
L.ln(GDPpc)			6.31	6.47
			(6.38)	(5.83)
L.Old dependency ratio				-0.40
				(0.39)
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Dep var mean	-5.42	-4.90	-4.64	-4.64
N	1,074	1,006	984	984

Notes. The sample is OECD countries from 1960 to 2016. All variables are averaged over five-year periods. L. denotes five-year lags. See Table 1 for variable definitions and data sources. Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Effect of Unexpected Longevity on Public Spending

Dependent variables:	**Public spending (% of GDP) growth**					
	Old-age			**Family**		
	(1)	(2)	(3)	(4)	(5)	(6)
Exp65 shock	13.05**	11.83**	12.13**	-22.28***	-23.21***	-18.26**
	(6.06)	(4.76)	(5.41)	(7.37)	(7.24)	(8.63)
L.Exp65	6.67	5.43	5.33	-5.24	-6.19	-7.79
	(6.66)	(4.73)	(4.97)	(7.01)	(6.69)	(6.58)
L.ln(GDPpc)		50.97***	51.27***		38.78**	43.51***
		(12.51)	(13.20)		(14.22)	(15.27)
L.Old dependency ratio			0.10			1.57
			(0.87)			(1.16)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Dep var mean	5.32	5.32	5.32	9.19	9.19	9.19
N	608	608	608	608	608	608

Notes. The sample is OECD countries from 1980 to 2015. All variables are averaged over five-year periods. L. denotes five-year lags. See Table 1 for variable definitions and data sources. Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Additional Sensitivity Tests

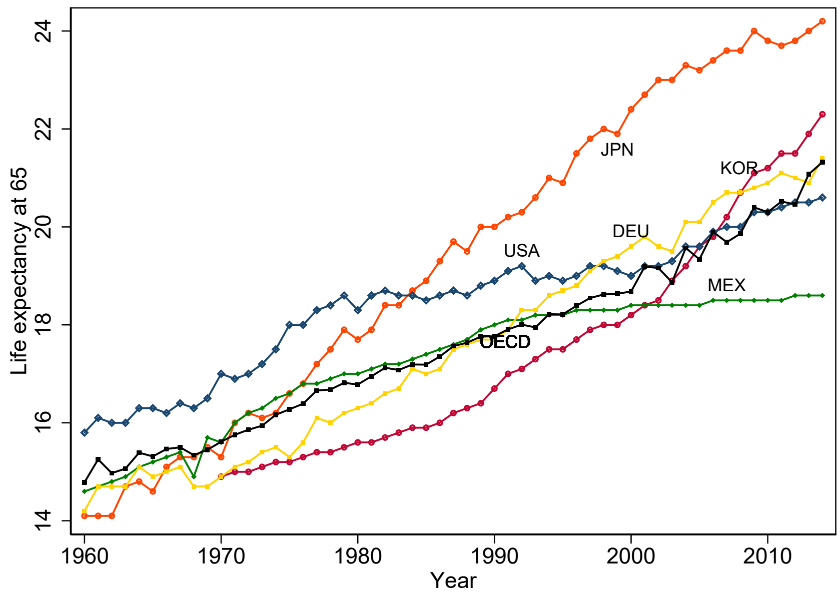
Dependent variables:	**TFR growth**	**Public spending growth**	
		Old-age	**Family**
	(1)	(2)	(3)
A. Controlling for female LFP			
Exp65 shock	-8.27**	12.39*	-20.93**
	(3.22)	(6.29)	(8.34)
Dep var mean	-2.33	5.85	10.08
N	715	556	556
B. Using 10-year lags			
Exp65 shock	-10.48**	14.45**	-17.30
	(4.19)	(5.29)	(11.38)
Dep var mean	-3.23	5.25	8.81
N	844	578	578
C. Including mandatory private spending			
Exp65 shock	-12.00**	13.75**	-17.23*
	(4.41)	(5.50)	(8.66)
Dep var mean	-4.64	6.56	9.10
N	984	608	608
D. Using difference of dep var			
Exp65 shock	-0.22**	0.77**	-0.23
	(0.09)	(0.36)	(0.16)
Dep var mean	-0.10	0.37	0.14
N	984	608	608

Notes. This table shows estimates $Exp65shock$ based on the fixed-effects specification with full controls as in Tables 2 and 3. Estimates of all other controls are suppressed. Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

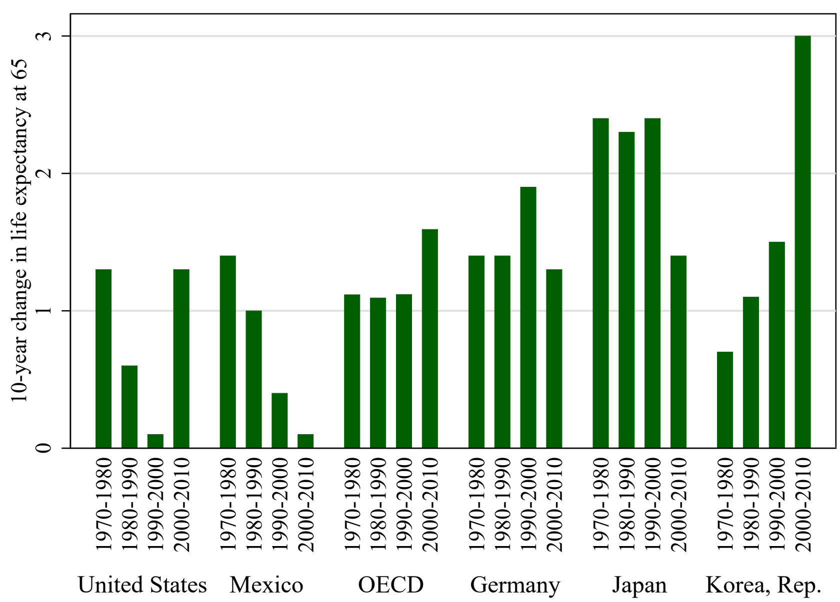
Table 5: Placebo Tests using Other Public Spending

Dependent variables:	**Public spending (% of GDP) growth**					
	Survivor	**Incapacity**	**Health**	**Labor**	**Unempl**	**Housing**
	(1)	(2)	(3)	(4)	(5)	(6)
Exp65 shock	-1.84	-5.48	6.40	-18.93	14.30	50.89
	(13.64)	(8.32)	(6.86)	(14.67)	(23.23)	(31.74)
L.Exp65	-15.15	-4.94	7.86	-2.05	-9.44	36.14*
	(16.28)	(7.99)	(6.35)	(11.62)	(19.44)	(20.88)
L.ln(GDPpc)	16.93	48.38	20.45	34.32	138.58**	6.79
	(28.50)	(29.57)	(20.85)	(36.60)	(51.77)	(55.57)
L.Old dependency ratio	2.05	1.54	-0.27	-1.45	3.41	2.52
	(1.65)	(1.38)	(1.81)	(3.30)	(3.62)	(3.04)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Dep var mean	-6.27	0.88	7.95	8.21	-1.63	15.78
N	608	608	626	531	581	575

Notes. The sample is OECD countries from 1980 to 2015. *Survivor* includes widow's pension and funeral expenses. *Incapacity* comprise disability pensions, pensions due to occupational injury and diseases, paid sick leave, and rehabilitation services. *Health* encompasses expenditure on in-patient care, ambulatory medical services, and pharmaceutical goods. *Labor* refers to active labor market programs, including public employment services and administration, training, job rotation and sharing, supported employment and rehabilitation, direct job creation, and start-up incentives. *Unempl* includes unemployment compensation and severance pay. *Housing* includes rent subsidies. All variables are averaged over five-year periods. L. denotes five-year lags. See Table 1 for variable definitions and data sources. Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$



(a) Life Expectancy at 65



(b) Decadal Changes in Life Expectancy at 65

Figure 1: Trends in Life Expectancy at 65, Selected OECD Countries

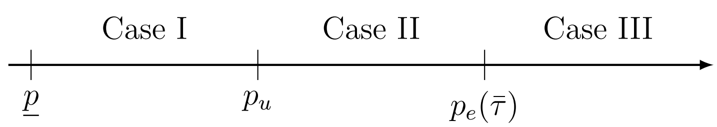
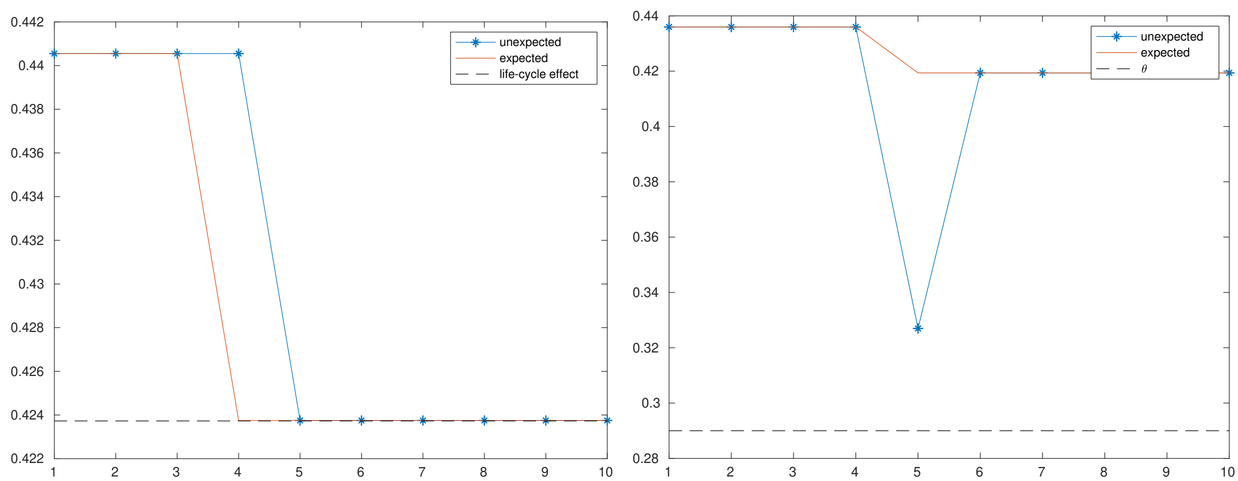
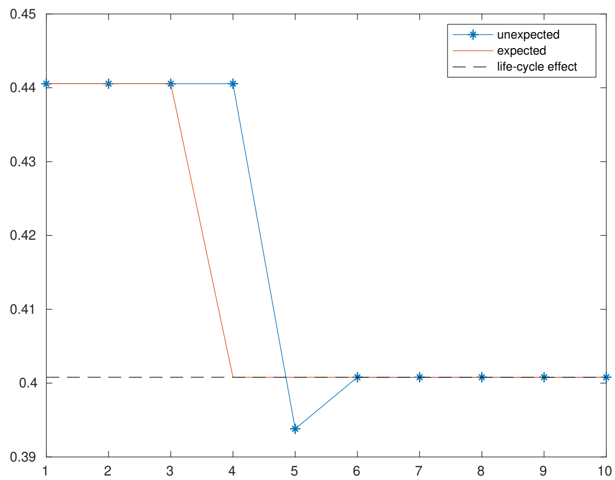


Figure 2: Three Cases by the Value of $\bar{p}$

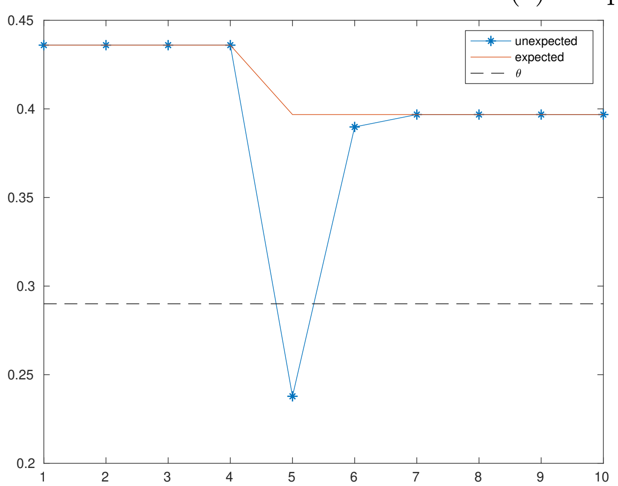


(a) Offspring Size (b) Wealth of Old Agents

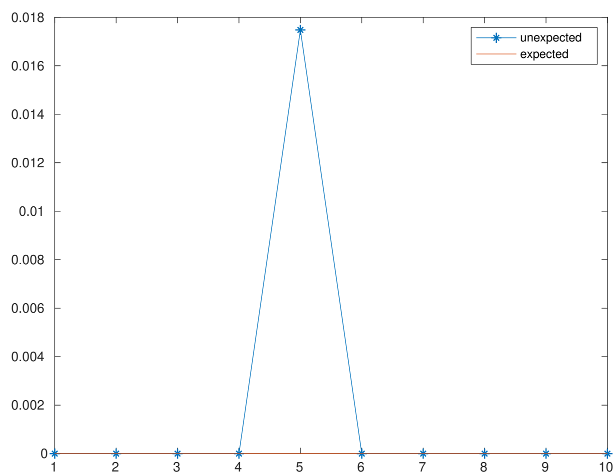
Figure 3: Response to Longevity Shock in Case I, $\bar{p} < p_u$



(a) Offspring Size

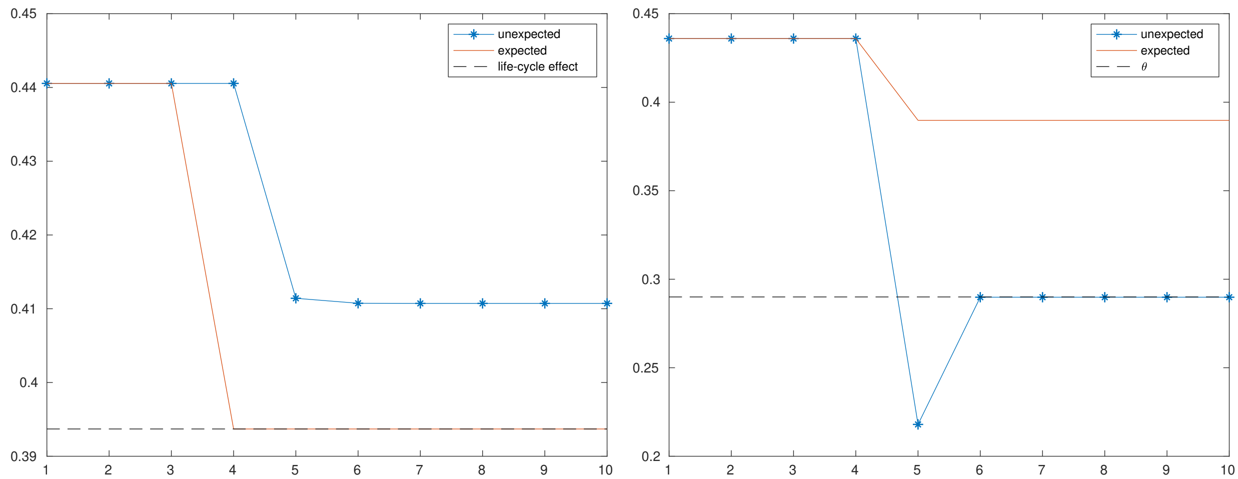


(b) Wealth of Old Agents



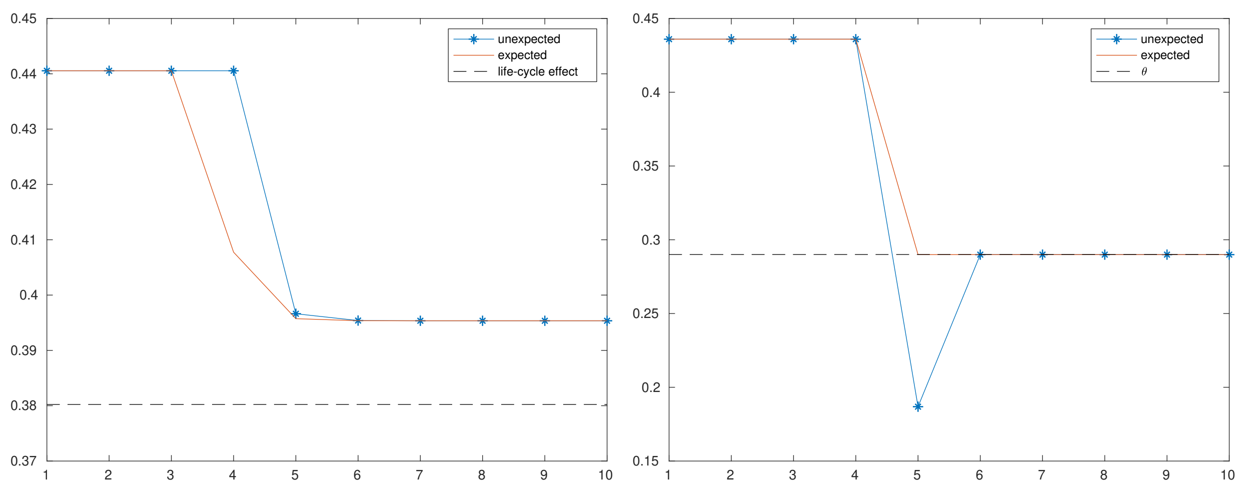
(c) τ

Figure 4: Response to Longevity Shock in Case II, $p_u \leq \bar{p} < p_e(\bar{\tau})$



(a) Offspring Size (b) Wealth of Old Agents

Figure 5: Response to Longevity Shock in Case III, $p_e(\bar{\tau}) \leq \bar{p} < p_e(0)$



(a) Offspring Size (b) Wealth of Old Agents

Figure 6: Response to Longevity Shock in Case III, $\bar{p} \geq p_e(0)$

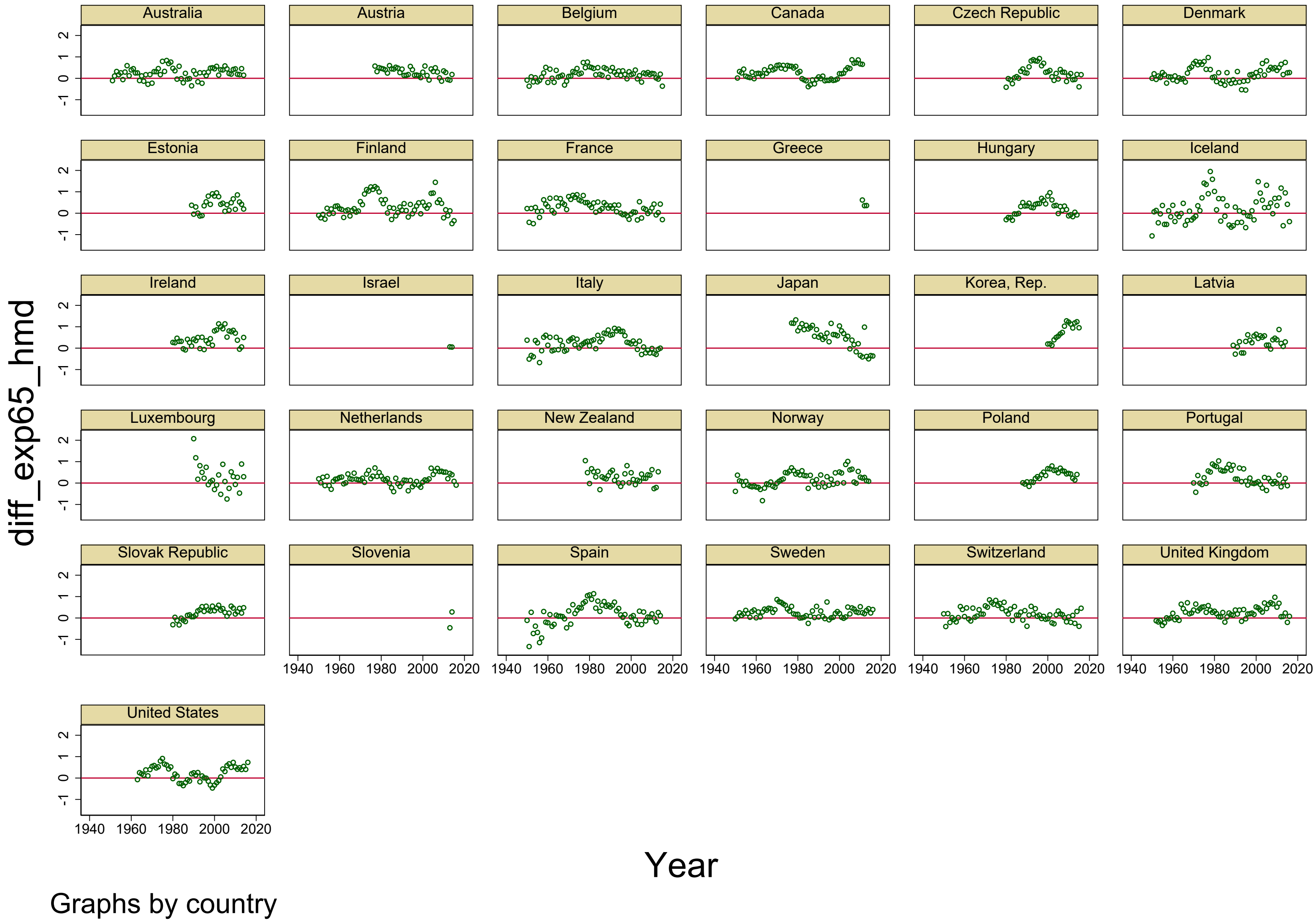


Figure 7: Forecast Errors of Life Expectancy at 65, OECD Countries