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Edouard Debonneuil, Stéphane Loisel, Frédéric Planchet. CONDITIONS OF INTEREST OF A LONGEVITY MEGAFUND FOR PENSION FUNDS. 2017. hal-01571937v1

HAL Id: hal-01571937

<https://hal.science/hal-01571937v1>

Preprint submitted on 4 Aug 2017 (v1), last revised 10 Dec 2017 (v3)

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CONDITIONS OF INTEREST OF A LONGEVITY MEGAFUND FOR PENSION FUNDS

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Version 1.2 du 01/08/2017

ABSTRACT

Pension funds that handle retirement risk need to invest assets in a diversified manner, on long durations and if possible while facing interest rate and longevity risk. In the recent years, a new class of investment called a longevity megafund was described, that invests in clinical trials for solutions against age-related diseases. Using simple models, we here study the financial interest for pension funds of investing in a longevity megafund.

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1. INTRODUCTION

1.1. ANTI-AGING SOLUTIONS: HOPE FOR PHARMACEUTICAL COMPANIES AND FEAR FOR RETIREMENT SYSTEMS

In the 19th and 20th centuries, infant mortality rates and young adult mortality rates have dropped so that the future of life expectancy is now to a large extent a matter of solutions to old age conditions (Vallin 2010).

In this beginning of the 21st century, a series of biomedical discoveries suggest that mortality rates may drop at old age as well. The lifespan of laboratory nematodes was extended circa ten times with one single gene change (Ayyadevara, 2008). The lifespan of laboratory mice was extended by 70% through a combination of gene change and diet (Bartke, 2008). Among numerous biomedical innovations for healthy longevity (Moskalev 2017), that include a list of potential treatments (Barardo 2017), one may cite the well-known bioprinting of new organs (Ravnic 2017, Mir 2017) or the less-known but potentially sooner deployed ability to have organs regrow themselves, new and young, within the body (Fahy 2003, Ocampo 2016, Mosteiro 2016, Mendelsohn 2017): science is on its way to slow down human aging but also to restore youthful characteristics to the body once old. This means better health at old ages, which in turn means lower mortality rates and longer lives.

When will old-age solutions come? That is a key question for the pharmaceutical industry. The pharmaceutical industry currently suffers from a lack of profitability of investments in research and development due to very low success rates in clinical trials (Scannel 2012), in part due to the attempt to gradually adapt the methods for single, acute diseases to multiple, chronic diseases (Thiem 2011, Roman 2017) instead of targeting the underlying aging and regenerative processes as described above. As many biotech companies now carry that latter approach, various investors reports, books and conferences consider that current retired persons may be the first populations to benefit in large from such advances (Mellon 2017, Pratt 2016, Casquillas 2016). When essentially focusing on hair and skin aging, which were the main industry drivers until recently, estimated sizes of the anti-aging market are USD 122 billion in 2013, 140 in 2015, 192 in 2019 and 217 in 2021 (Zion Market Research 2017, Transparency Market Research 2016).

When will old-age solutions come? That is a key question for retirement systems also: they face the "longevity risk" that retirements must be paid longer than financially planned. Current retirement systems essentially stem from the middle of the XXth century, when most young workers were not expected to reach retirement age, and they depend on various mortality tables that are regularly updated but that empirically underestimate historical life expectancy trends (Antolin 2014, Debonneuil 2017). In the USA only, if deaths caused by cardiovascular diseases and cancer were eliminated, the fiscal imbalance of Social Security and Medicare programs may be as high as USD 87 trillion in present value (Zhavoronkov 2012). May such imbalances be offset by investing retirement contributions in the burgeoning anti-aging market?

1.2. LONGEVITY MEGAFUND: A POTENTIAL SOLUTION?

The concept of "cancer megafund" was developed to face the current pharmaceutical industry crisis that particularly affects cancer research and development: instead of having investors bet high amounts on one risky drug development, the megafund is a financial structure that pools a large number of diversified drug developments and structures investments into debt and equity with low returns but sufficiently low risk (due to the strong diversification) to make investments attractive (Fernandez 2012). The debt part is useful to attract larger investments and to finance long term projects, which is needed for many biomedical developments. The concept has then been and is being studied for various health applications, from rare diseases to biomedical innovation in large, in London, the USA, Australia or Sweden (Swedish Agency for Growth Policy Analysis 2017) and even for non-health-related applications (Hull 2016). In parallel, several remarks have proposed the need for strong contextual attention to properly implement the megafund concept (Boissel 2013, Marko 2013, Tenenbaum 2013, Fagnan 2014, Fagnan 2015, Lo 2014, Lo 2015, Yang 2016).

One of the applications of the megafund concept is the "longevity megafund" (MacMinn 2017, Kahn 2015, Stein 2016). Such a megafund tracks the biomedical innovations that are likely to increase lifespan, as much as possible, and invests in the corresponding developments to become a sort of longevity risk tracker. Such has diverse benefits. By investing in a range of innovations that is wider than cancer therapies, a better diversification of risk is provided which is an essential feature of the megafund concept to make investments attractive. By tracking potential solutions to age-related conditions, that correlate with longevity risk, it can attract large investments for the equity part of the megafund: annuity insurance providers and pension funds can invest to hedge their longevity risk. Some first simulations on life settlements indicate that it is a better hedge than existing longevity hedges with respect to longevity shocks and basis risk (MacMinn 2017). One may notice that having the income from therapeutical developments come before the treated persons actually live longer is also an interesting feature to possibly adjust retirement benefits in advance. Also, by targeting a large number of diseases the longevity megafund can attract health providers to hedge the risk of reimbursing new, expensive drugs (Stein 2016).

1.3. IN WHAT CONDITIONS IS A LONGEVITY MEGAFUND INTERESTING TO HEDGE LONGEVITY RISK?

We note that, despite so many theoretical advantages, the literature contains little studies about the conditions in which the longevity megafund is interesting to hedge longevity risk. This article aims at investigating such conditions at a deeper level.

2. FEASIBILITY OF HEDGING LONGEVITY RISK WITH A MEGAFUND

2.1. WHAT TYPE OF RETIREMENT SYSTEMS COULD BENEFIT FROM INVESTING IN A LONGEVITY MEGAFUND?

Retirement systems are mainly composed of defined benefits plans, defined contributions plans, pay-as-you-go plans, and insurance retirement contracts. So far, to our knowledge the literature suggests that longevity megafunds may hedge longevity risk, without investigating what type of plans would best benefit from investing in a longevity megafund.

2.1.1. Defined benefit plans

"Defined benefits" means that the pension fund is entitled to pay benefits until the ends of pensioner lives. The benefits are defined as a percentage of the pensionable salary, for example 20% of the average salary over the last three years of work. The capital to pay retirement is typically obtained by collecting a portion of salaries throughout life ("contributions"), for example 10% of salaries, and investing it.

Investing in a longevity megafund could be a way for defined benefit pension funds to hedge their longevity risk: in case of strong longevity improvements, investment returns are greater so the accumulated capital can pay benefits longer.

2.1.2. Defined contribution plans

In defined contribution plans, contributions are collected and invested and the capital serves to pay retirement, but the longevity risk stays at the level of the pensioners: if a pensioner uses the whole capital during retirement the pension plan does not need to pay anything more to the pensioner. In recent decades, a shift has occurred from defined benefit plans to defined contribution plans in order to avoid longevity risk.

Since they do not directly carry longevity risk, at first sight defined contribution pension funds have no interest in investing in a longevity megafund. At second sight, they may have an interest as they would then propose a capital that reduces the longevity risk of their pensioners: in case of strong longevity improvements, pensioners would have a greater capital.

2.1.3. Deferred annuities

We make this specific paragraph for whole life deferred annuities, that are often provided by insurance companies and that have an important nuance compared to the above descriptions. Indeed, after contributions are collected and invested (for example like defined contribution plans) regular benefits must be paid (like defined benefit plans) but the benefits are not calculated as a percentage of the pensionable salary. Instead, benefits are calculated as a percentage of accumulated capital (the percentage is given by a mortality table).

The nuance is fundamental because in case of high longevity trends, a larger capital will not cover longer durations of benefits. Instead, it is result is larger benefits. Longer and larger benefits: the longevity risk is doubled!

2.1.4. Pay-as-you-go pension plans

In pay-as-you-go pension plans there is no, or very little, investment: the contributions from workers directly pays the benefits to retired persons. In such a system, that is for example widely spread in France, the lack of investment makes the longevity megafund of no use.

2.1.5. Qualitative conclusions

In conclusion, from a first qualitative perspective a longevity megafund makes sense for defined benefit and possibly defined contribution pension plans, but a priori not for pay-as-you-go schemes nor for providers of deferred annuities.

Our analysis is somewhat schematic as numerous retirement systems exist and risks can be transferred to stakeholders who have distinct characteristics. For example, insurers providing deferred annuities may transfer their longevity risk to reinsurers who might benefit from investing in a longevity megafund. Also, various practical aspects such as counterparty risk, basis risk and megafund returns (of course) may modulate the conclusions.

2.2. NEEDED MEGAFUND RETURNS TO HEDGE LONGEVITY RISKS.

Following that schematic, qualitative analysis we here study the investments returns of a megafund that are needed to hedge longevity risk of a defined benefit pension plan.

2.2.1. High returns are crucial to hedge longevity risk

Given the high megafund returns that may be needed in case of longer lives, we start with a very simple model to clearly indicate the orders of magnitude. We consider a pensioner who pays 1 every year from age 25 (included) to age 65 (excluded). Its contributions are invested in funds that are expected to provide the annual return $i=1.5\%$. At age 65, the expected capital is

$$(1+i)^{65-25} + (1+i)^{65-26} + \dots + 1 + i = \frac{(1+i)^{65-25+1} - (1+i)}{i} \approx 55$$

The annual benefits are contractually defined based on that expected capital, to pay the benefits for 20 years for example: up to an expected pensioners lifespan of 85 years. However, let's consider that strong biomedical interventions take place and that pensioners live to 95-100. Benefits must be paid for 30-35 years instead of 20, which is a circa 50% greater duration!

To pay benefits on a 50% great duration, the capital must be 50% greater. Using the formula with $i=3.3\%$ instead of 1.5% provides the needed 50% greater capital. It means that the defined benefit pension plan would have offset its longevity risk if all contributions had been invested in a longevity megafund that provides annual returns of 3.3%.

However, pension funds would likely not transfer all their assets into a longevity megafund -- a new type of structure -- but rather at most for example 20%. The megafund should therefore provide much higher returns so that, when diluted in 80% of returns at 1.5%, the overall return is 3.3%. $3.3\%=(1-20\%)*1.5\%+20\%*10.5\%$: if pensioners are to live to ages 95-100 on average the megafund should provide 10.5% annual returns! Now, if only 10% of assets were invested in the megafund, it should similarly provide 19.5% annual returns. If 5% of assets were invested in the megafund, it should provide 37.5% annual returns!

Said differently, *if a longevity megafund is not able to generate 10%-20% annual returns in case of material longevity increases, unless pension funds invest surprisingly large percentages of their assets into longevity megafunds, it does not seem to be a viable approach to hedge longevity risk.*

The model was stress tested under the assumption that respectively 10% and 20% of assets are invested in the megafund. It appears that the needed returns are absolutely not sensitive to initially expected pension fund returns (if they are 2.5% instead of than 1.5% the longevity megafund should provide an additional 0.02%, respectively 0.06%).

However, offsetting the longevity risk of currently 45-year-old pensioners rather than 25-year-old pensioners requires respective annual megafund returns of 13.8% and 26.1%!

2.2.2. Asset Liability Management (ALM) perspective

To look more familiar to ALM standards, we consider employees of different age tranches, each with different salaries and different returns as shown in table 1. The table can be read as a demographic picture of a 12 000-employee company that is stable over time, or the follow-up of a typical employee from age 20 to 65. For the sake of simplicity, we use that latter view in our computations, however as we just estimated needed annual megafund returns are about 3%-6% higher in case of strong longevity.

Tab. 1. Age tranches

Age	Number persons	Individual annual contributions	Investment returns
[20-35[4000	3000	i1=5%
[35-50[4000	4500	i2=4%
[50-65[4000	6000	i3=2%

From age 20 to 65, the collected and invested annual contributions lead to a total capital of

$$C = 4000 \left[6000 \frac{(1 + i_3)^{16} - 1 - i_3}{i_3} + 4500 \frac{(1 + i_2)^{16} - 1 - i_2}{i_2} (1 + i_3)^{15} + 3000 \frac{(1 + i_1)^{16} - 1 - i_1}{i_1} (1 + i_2)^{15} (1 + i_3)^{15} \right] \approx 1\,587\,000$$

During retirement, benefits often contractually increase with age. For the sake of simplicity, we here consider that the rate of increase equals the discount rate such that benefit duration equals retirement length: if a person aged 65 lives until age x the duration of benefits is $x-65$. If we consider that the benefits are defined so that the capital exactly pays the benefits and that pensioners all live to age 85 (in practice mortality tables are used) the first annual benefit is then $(1\,587\,000/4000)/(85-65) = 19\,836$ per pensioner.

Now comes longevity risk and longevity hedge. If pensioners live to age x , the longevity loss for the company is $19\,836 * 4000 * (x-85)$. For example, if pensioners live up to age 100 the loss is 1.2 billion for the pension fund. To offset such losses, the pension fund may have invested a percentage of its assets in the longevity megafund.

Let us consider age-tranche specific, percentage of investment in the megafund; for example, $p_1=20\%$, $p_2=15\%$, $p_3=10\%$.

The needed annual returns i of the megafund are then such that the greater needed capital (which is proportional to the duration of benefits, see left part of the following formula) is obtained by partially investing contributions in the megafund (right part of the following formula):

$$C \times \frac{x - 65}{85 - 65} = 4000 \left[6000 \frac{(1 + \tilde{i}_3)^{16} - 1 - \tilde{i}_3}{\tilde{i}_3} + 4500 \frac{(1 + \tilde{i}_2)^{16} - 1 - \tilde{i}_2}{\tilde{i}_2} (1 + \tilde{i}_3)^{15} + 3000 \frac{(1 + \tilde{i}_1)^{16} - 1 - \tilde{i}_1}{\tilde{i}_1} (1 + \tilde{i}_2)^{15} (1 + \tilde{i}_3)^{15} \right]$$

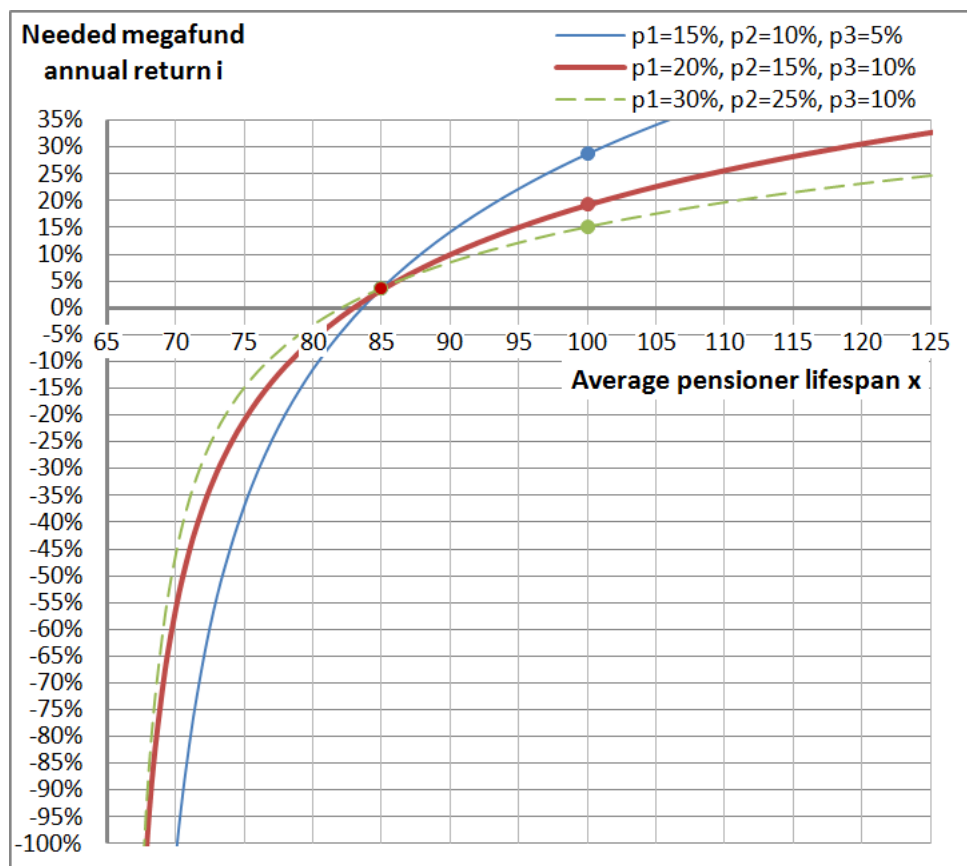
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where $\tilde{i}_1 = p_1 i + (1 - p_1) i_1$, $\tilde{i}_2 = p_2 i + (1 - p_2) i_2$, $\tilde{i}_3 = p_3 i + (1 - p_3) i_3$

The formula links pensioner lifespan x and needed megafund annual return i .

For every value x we extract the corresponding value i using the Microsoft Excel solver; the result is on Figure 1. If pensioners on average live to age 70 or less a full loss of longevity megafund (return of -100%) can be supported by the remaining investments of the pension fund to pay retirements (of course, better returns are always welcome!). If pensioners live to the expected age of 85, the longevity megafund should provide the same average returns as other funds, 3-4% annually. If pensioners live to age 100, 15% or 20% or even 29% annual returns should be provided by the longevity megafund depending on the percentage of investments of the pension fund in the megafund; if pensioners live longer even greater returns are needed. Are such large returns possible?

Fig. 1 - Needed megafund return depending on pensioner lifespan to perfectly hedge longevity risk. Three lines are displayed, they correspond to different percentages of investments in the megafund.



2.3. CAN A MEGAFUND PROVIDE SUCH HIGH LEVELS OF RETURNS?

To analyze the possibility of generating such returns, let us consider the stylized model of the original cancer megafund paper (Fernandez 2012): N independent drug development programs each require an initial investment $C_0 = \$200$ million and generate 10 years later a revenue $Y_{10} = \$12.3$ billion (present value of returns starting after 10 years) with a percentage $p = 5\%$ of successful programs (and no revenue from unsuccessful programs). The expected 10-year return on investment is $\rho = \frac{p \times Y_{10} + (1-p) \times 0}{C_0} \approx 3.1$ and the expected annualized return is:

$$r = \left(\frac{p \times Y_{10} + (1 - p) \times 0}{C_0} \right)^{\frac{1}{10}} - 1 \approx 11.9\%$$

A non-blockbuster numerical example is also provided, i.e. with annual revenues less than \$1 billion starting at year 100, that also leads to $\rho \approx 3.1$ and $r \approx 11.9\%$ ($C_0 = \$100$ million, $Y_{10} = \$3.1$ billion, $p = 10\%$).

But r is not precisely the return that matters to hedge longevity risk. A megafund must be structured into debt and equity (non-debt), because without the debt part it would be difficult to find enough investors to have enough drug development programs financed for the megafund risk to become small compared to returns, and to be financially attractive. And the debt part, composed of "research-backed obligations" (RBOs), provides fixed annual returns, that cannot hedge longevity risk. Therefore i , the annualized return of the equity part of the megafund, that provides gains in excess of RBOs, is the rate that matters to possibly hedge longevity risk:

$$i = \left(\max\left(\frac{p \times Y_{10}}{\alpha C_0} - \beta, 0\right) \right)^{\frac{1}{10}} - 1$$

where α is the percentage of investments of the megafund in equity and β is the gains not given to equity by amount of equity investment. If RBOs provide an annual return of 5% then β can be estimated as using $\beta = \frac{(1-\alpha) C_0 \times 1.05^{10}}{\alpha C_0}$. In the blockbuster and non-blockbuster examples where $\rho = 3.1$, $\alpha = 50\%$ equity leads to $\beta = 1,62$ and $i = 16.4\%$ and $\alpha = 25\%$ and $i = 22.3\%$: as we can see, the equity share can be used as a lever to obtain higher returns if there are enough successful drug development programs at the cost of reducing returns if there are not enough.

11.9% is a high overall return compared to returns obtained in more precise simulations (Fernandez 2012, Fagnan 2014, Yang 2016). However returns can increase with a good validation of projects and a careful structure of megafund (Yang 2016). In addition, cancer drug development is financially less attractive than for other diseases (Fernandez 2012) so for a more general, longevity megafund we keep $\rho = 3.1$ as a estimate that reflects recent pharmaceutical trends.

To conclude, yes, a careful longevity megafund - or rather its equity part - can provide such high returns. However, regarding hedging longevity risk, one needs to look at the link between equity returns and longevity.

2.4. LINK BETWEEN MEGAFUND EQUITY RETURNS AND LONGEVITY.

The link between megafund equity returns and longevity depends on how longevity changes occur. A strong longevity increase would typically arise from a large number of health solutions to age-related conditions that affect a large number of persons.

2.4.1. Linkage 1: drug discovery success rate, i.e. 10-year megafund returns, increase linearly with lifespan

A longevity scenario is that a number n of health solution would each provide for example 5 years of added lifespan to 10% of retired persons: the greater the number n the longer the average lifespan, in a proportional manner. The link between the megafund and longevity is that as the number n of meaningful health solutions increases the

megafund should be able to capture them in its given resources. The link may be proportional: the proportion p of successful drug development programs should approximately increase in a proportional manner (p is the ratio of successful programs over funded programs, it is closer to 0 than to 1) if the megafund managers are sufficiently able to distinguish important programs from less important ones. In that scenario, the 10-year return on investments, for drug development programs, $\rho = \frac{p \times Y_{10}}{C_0}$, should increase linearly with lifespan:

$$\rho_x = 3.1 + \theta_{(\pm)}(x - 85) + \varepsilon \quad (\text{Linkage 1})$$

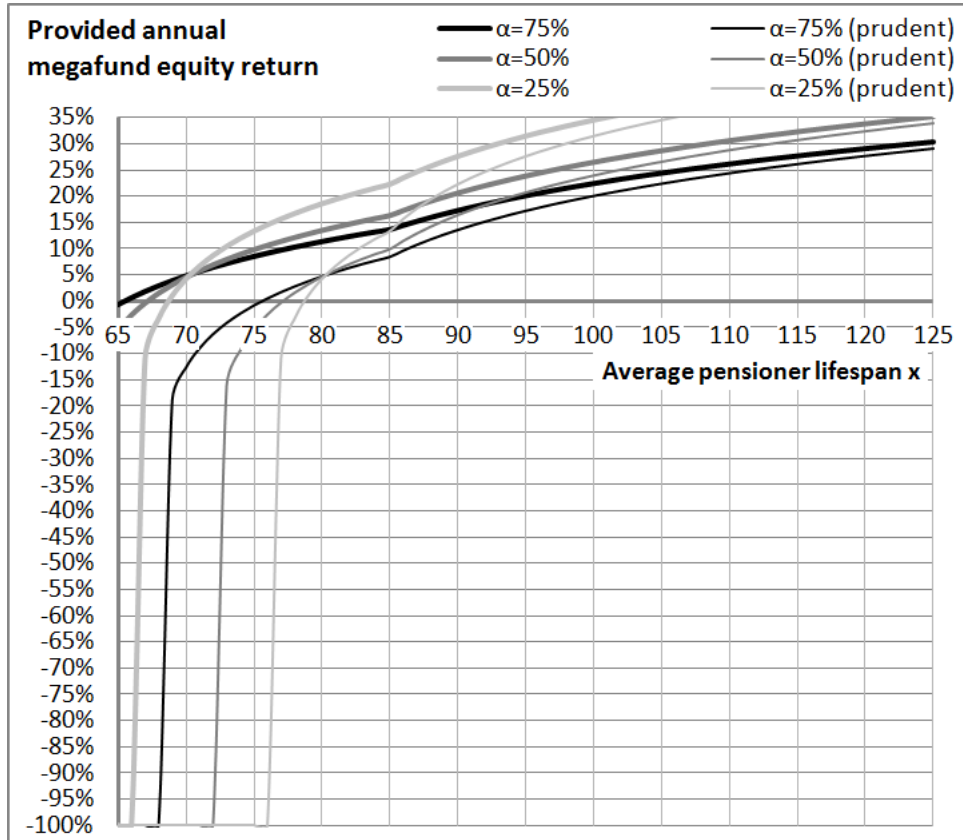
where the coefficient $\theta_{(\pm)}$ and the noise ε remain to be chosen. For increasing lifespan, we take $\theta_+ = 0.2$: if pensioners live to 100 it corresponds to a double of return on investments ($\rho_{100} = 6.1$) and a double of successes in blockbuster and non-blockbuster programs: on the one hand, it is difficult to imagine much higher financial returns so 0.2 may be high, on the other hand it seems that greater successes than 10% of blockbuster programs and 20% non-blockbuster programs may be achieved so 0.2 may be small. For decreasing lifespan, we consider that the biomedical and longevity link is reduced, as a decrease in lifespan would probably largely be driven by pollution, obesity or other aspects that negatively affect health, so we arbitrarily take $\theta_- = 0.1$. We take ε as a uniform random variable between -1 and +1 such that if x is around 85 or lower the link between pharmaceutical results and longevity isn't clear.

Of course, the reader may view those numbers as adequate or not. With the link we established here, equity returns are:

$$i = \left(\max\left(\frac{3.1 + \theta_{(\pm)}(x - 85) + \varepsilon - (1 - \alpha)1.05^{10}}{\alpha}, 0\right) \right)^{\frac{1}{10}} - 1$$

Figure 2 describes the provided returns.

Fig. 2 - Equity returns provided by the longevity megafund, depending on pensioner lifespan, equity share α of megafund investments, and a prudent view on other factors ($\varepsilon = -1$ instead of 0).



2.4.2. Linkage 2: due to breakthroughs, annualized equity returns increase linearly with lifespan

The rate of discoveries is one driver for longevity and it is easy to link it with returns as done just above. However, longevity breakthroughs are to be possibly expected as well, such as tissue regeneration techniques that are currently in labs and that may reach large populations in the forthcoming decades. The link between longevity and returns is less predictable in that scenario because of the novelty of the situation; however, it can be expected to be strong because longevity is then strongly driven by one or a few treatments.

In the previous scenario (linkage 1) the annualized equity return has a concave shape due to the exponent 1/10. In this scenario (linkage 2), for the sake of simplicity we remove that concave shape by considering that the annualized equity returns increase linearly with lifespan:

$$i = \left(\frac{x - x_0}{85 - x_0} \right) i_{85} + \varepsilon \quad (\text{Linkage 2})$$

where $i_{85} = \left(\max\left(\frac{3.1 + \varepsilon - (1 - \alpha)1.05^{10}}{\alpha}, 0\right) \right)^{\frac{1}{10}} - 1$ is the return in expected conditions with respect to longevity: the return showed at age 85 in Figure 2. x_0 is the age at which i would be expected to be zero and ε is a uniform random number. As Linkage 1 is related to the rate of success of moderate health improvements, we can consider it as a scenario for moderate longevity risk so for Linkage 2 we choose coefficients that align Linkage 1

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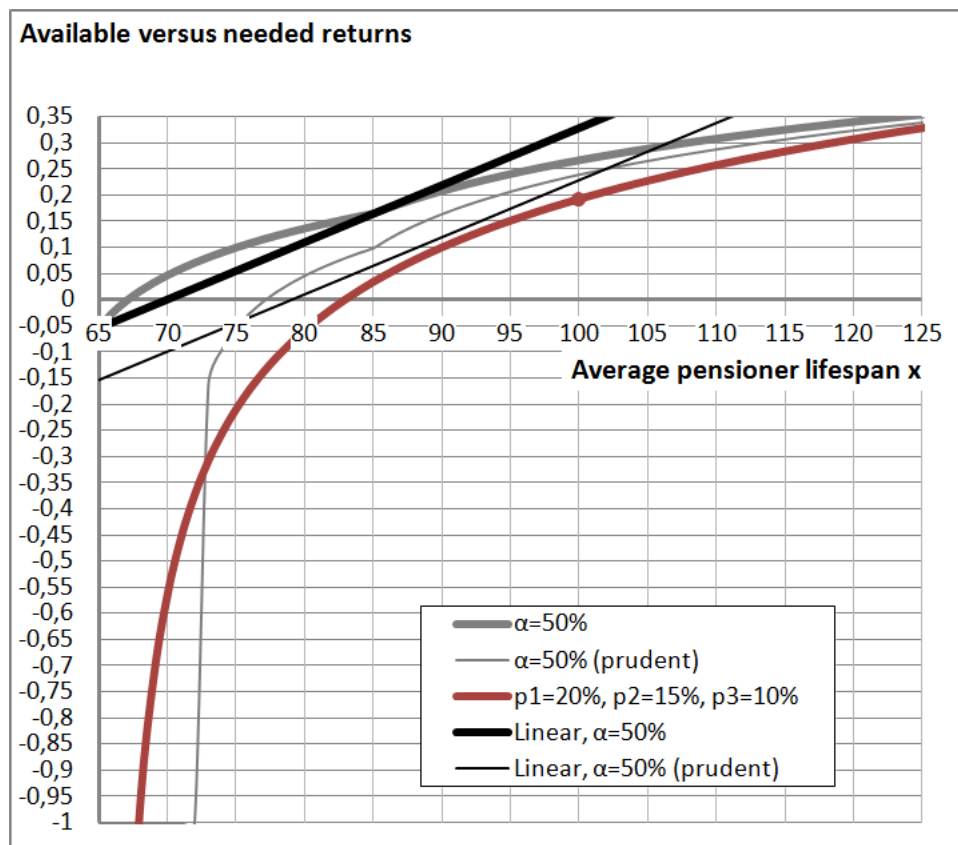
and Linkage 2 around the age of 85: we take $x_0 = 75$ and ε between -20% and +20%. We can see the alignment in Figure 3.

Of note, since longevity may be driven from many discoveries, a small number of key discoveries, and many key discoveries (the combination of both), Linkage 1 is probably prudent.

2.5. CONCLUSION: A POSSIBLE HEDGE

Figure 3 superimposes needed returns for the pension fund in the case of approximately 15% investment in the megafund ($p_1=20\%$, $p_2=15\%$, $p_3=10\%$) and provided equity returns by the pension fund, for both Linkage 1 and Linkage 2, in case it has 50% of investments for RBOs.

Fig. 3 - Available megafund equity returns (black and grey lines , prudent or best estimate) versus needed returns for the pension fund. The straight black lines use the second scenario ("Linear"), the curved grey lines use the first scenario.



The megafund seems to provide enough return, except in the prudent Linkage 1 case when longevity decreases. Such is of course the result of models. Other models or other parameters could lead to provide insufficient returns compared to the needed returns for the pension fund. However, we see that the sufficient return stems from the main assumptions that i) the returns are above 5% under current longevity trends, i.e. that the assumptions published for megafunds so far are not absurd, and ii) that the link between longevity and megafund returns are at least like Linkage 1. So, with that simple analysis, there is a sound possibility of hedging longevity risk by investing in a biomedical megafund.

3. IMPACT OF INVESTING IN A MEGAFUND ON NEEDED OWN FUNDS

The above analysis shows that investing in a longevity megafund can in theory provide adequate returns over the years to hedge longevity risk, when taking a prudent view compared to a central view. This seems good news for a pension fund because it suggests that large increases of longevity can be managed by having invested in a longevity megafund and holding a minimum amount of prudential capital to face risks, instead of requiring very large amounts of capital to face very large risks.

The above analysis was voluntary schematic for the sake of clarity. Longevity was described by the age x at which everyone dies whereas in practice mortality spreads over ages. Also, the analysis stopped at comparing needed versus provided annualized long-term returns, whereas a sufficient prudential capital is needed at all times to avoid bankruptcy.

Therefore, we adjust the previous analysis of a defined benefit pension plan to incorporate such aspects. After defining refined assumptions to model longevity, pension fund and megafund behaviors, we measure what level of prudential capital is needed today to pay retirement until the last death of current employees.

3.1. REFINED ASSUMPTIONS

3.1.1. Mortality

We consider the following model of annual mortality rates, for someone aged x in t years:

$$q_{x,t} = \frac{0.5}{1 + e^{a-b(x-\varphi t)}}$$

As studied by Debonneuil et al. 2017, such a model leads to non-decelerating life expectancy trends. With $a=10.5$ and $b=0.1$ the model has expected behaviors. The current ($t=0$) life expectancy at birth is 84.4 years; it is slightly above the general population life expectancy (the 2015 life expectancy in the UK, France and Japan is respectively 81.2, 82.4 and 83.7) which is desired as it concerns workers and insured persons. With this model also, the current life expectancy at 65 is 22.1 years leading to the average age of 87.1 years, which is expectedly higher than 84.4 years as it doesn't take into account people who died before the age of 65.

With $\varphi=23\%$ the model reproduces current major longevity trends. Life expectancy at birth increases by 23% of year annually, which is the "best practice trend" of long lived countries (Vaupel 2010). Current annual mortality improvements are $\frac{q_{70,0}-q_{70,1}}{q_{70,0}} = 2.1\%$ at age 70. For those currently aged 65, it leads to an remaining expected lifespan of 25.6 years, so an expected lifespan of 90.6; such is higher than 87.1 because improvements are expected during these years. For current newborns, it leads to an expected lifespan of 105.8; one shall note that even for newborns of the general population, if current life expectancy trends continue lifespans of long-lived countries are expected above 100 (Vaupel 2010).

Future longevity trends are however unknown. For the sake of simplicity we suppose that φ is constant over time and lognormally distributed over scenarios of the future, with mean $\log(23\%)$ and standard-deviation of 1. In such conditions, there is as much probability (50%) that probability φ is lower than 23% as greater than 23%. There is also a

7% possibility that $\varphi > 1$. Over long periods of time, the latter corresponds to people enjoying better health and reduced mortality risks as time goes, for example because of the emergence and progressive generalization of tissue regeneration techniques. Some may find this lognormal distribution particularly inadequate and the latter 7% excessively high or excessively low (Debonneuil 2016). That is why we will mainly consider four longevity scenarios: $\varphi=0\%$ (no improvement in the future), $\varphi=23\%$ (best practice trend), $\varphi=46\%$ (double trend) and $\varphi=69\%$ (triple trend). Of note, around 1950 Japan had a trend that was clearly above $\varphi=100\%$, suggesting that high trends are possible when hygiene & biomedical knowledge as well as social contexts are adequate. Similarly, over the last decades, life expectancy has increased by more than $\varphi=50\%$ of year annual in countries like Malaysia, Philippines, Vietnam, Laos and Bangladesh (Carbonnier 2013). Of note also, during approximately 70 years after the microbial communications of Louis Pasteur, φ was around 30% in long-lived countries (Vallin 2010); improving hygiene requires complex cultural, technological and urbanization changes, it may be that using anti-aging therapies once they are available is a faster process.

3.1.2. Population, contributions, investments (without megafund) and benefits

At time $t=0$ we consider 300 persons of age 20, $300(1 - q_{20,0})$ employees of age 21, $300(1 - q_{20,0})(1 - q_{21,0})$ employees of age 22, etc. until age 100. Such provides a distribution of the population across ages that is roughly natural. Every year ($t=1, t=2$, etc.) the persons die according to mortality rates and 300 new persons aged 20 arrive. For the sake of simplicity, we do not model arrivals and departures at other ages.

As in table 1, persons aged 20-34, 35-49 and 50-54 provide respective annual contributions of 3000, 4500 and 6000. Also, by default investments respectively provide $i_1=5\%$, $i_2=4\%$ and $i_3=2\%$ of expected annual returns, corresponding to three different funds that take different degrees of risk. For each of the three funds the volatility σ is given by a Sharpe ratio of 1.5, a risk-free rate of 1% and a 2 by 2 correlation of 50%:

$$\sigma_k = \frac{i_k - 1\%}{1.5} \quad \langle \sigma_k, \sigma_l \rangle_{l>k} = 50\% \quad k, l = 1, 2, 3$$

We consider a 2-by-2 correlation of returns of 50% between the three funds.

Regarding contractual benefits, we consider that they have been defined by generation (generations of people contributing since age 20) so that the accumulated capital at age 65 match the remaining lifespan based on the mortality rates with $\varphi=23\%$. Since most actuarial tables have decelerating trends (Debonneuil 2010) actuaries often declare such benefits as prudent when building retirement products. As done in the above stylized models, for the sake of simplicity we suppose that the benefits increase with age like corresponding investment returns so the duration of benefits is equal to the remaining lifespan at age 65: we do not need to model annual benefits, rather the accumulated capital at age 65 and the remaining lifespan. For the computation of contractual benefits, we also take the simplifying approximations that mortality rates before age 65 at those at time $t=0$ and that investments are exactly 5%, 4% and 2% (without considering volatility). We will see in the results that these approximations have a good accuracy.

3.1.3. Megafund

A percentage of contributions ($p_1=20\%$, $p_2=15\%$, $p_3=10\%$) can be invested in the equity part of the megafund, whose return is correlated with longevity. In line with the previous

approach, as a first possible linkage between megafund returns and longevity, the 10 year return of the whole megafund is linked with longevity as follows:

$$\rho_\varphi = 3.1 + \theta_{(\pm)}(\varphi - 23\%) + \varepsilon \quad (\text{Linkage 1})$$

ε is a random uniform number between -1 and 1 drawn once for each scenario of the future in order to represent that the correlation is not deterministic. In the formula, we replaced (x-85) by $(\varphi - 23\%)$, therefore the coefficient $\theta_{(\pm)}$ must be adjusted to the new scale. We do so using age 40 as a sound actuarial age: $\theta_{(\pm)}$ was previously chosen to express the possibility of living to 100 instead of 85, i.e. 15 additional years brought by biomedical discoveries. When $\varphi = 23\%$, people currently aged 40 are expected to live up to the age of 94.5 on average. When $\varphi = 44.5\%$, people currently aged 40 are expected to live up to the age of 109.5: that is also 15 additional years. Consequently, the previous values of $\theta_{(\pm)}$ are multiplied by $\frac{15}{44.5\% - 23\%}$: $\theta_{(\pm)} = 14$ when $\varphi > 23\%$ and $\theta_{(\pm)} = 7$ when $\varphi < 23\%$.

The annualized return of the megafund equity tranche in scenario 1 is then:

$$i = \left(\max\left(\frac{3.1 + \theta_{(\pm)}(\varphi - 23\%) + \varepsilon - (1 - \alpha)1.05^{10}}{\alpha}, 0\right) \right)^{\frac{1}{10}} - 1$$

By analogy with the previous approach also, a second potential linkage between the megafund and longevity is

$$i = \frac{\varphi}{23\%} \left[\left(\max\left(\frac{3.1 - (1 - \alpha)1.05^{10}}{\alpha}, 0\right) \right)^{\frac{1}{10}} - 1 \right] + \varepsilon \quad (\text{Linkage 2})$$

where ε is uniform between -10% and 10%.

In the two models of linkage we consider that $\alpha = 50\%$ of the megafund is structured in equity.

3.2. SIMULATIONS, PROBABILITY OF RUIN AND PRUDENTIAL CAPITAL

10,000 scenarios of the future were constructed using the software R. The code is in the supplementary materials. Each scenario draws the longevity trend φ , the "luck" of the megafund ε and, for each future year, the annual returns $i_t^k, k = 1,2,3$ of the three funds (depending on the employee age). Other calculations within a scenario do not require drawing random numbers. A Cholesky decomposition of the covariance matrix (σ_k, σ_l) is used to simulate correlated returns.

At $t=0$, the defined benefit pension fund starts with its initial population of persons aged 20-65 and an accumulated wealth based on historical mortality rates (modelled with $t=0$ mortality rates) and exactly 5%, 4% and 2%. The defined benefit pension fund then either invests $p_1 p_2 p_3$ in the megafund or does not invest in the megafund. We then simulate scenarios of the future where the longevity trend (φ), the megafund luck (ε) and the returns of funds (i_t^k) intervene. In order to assess the right amount of prudential capital at $t=0$, we instead suppose no initial additional wealth, we allow wealth to become negative (instead of claiming bankruptcy) and for each scenario of the future we measure wealth after all benefits were paid. That measure is discounted using the investment composition of the scenario to represent the initial additional wealth that would have

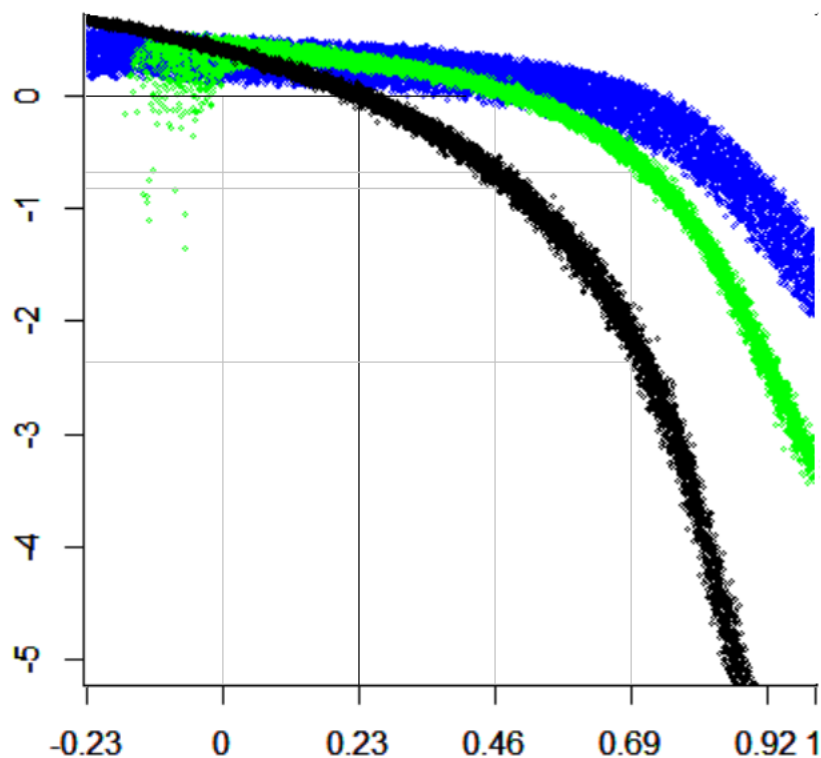
been needed and invested to provide the right amount to pay retirements in the future, without reaching bankruptcy.

The needed prudential capital is then arguably defined as the 5% worst initially needed capital across scenarios of the future. This would mean that there is a 5% risk of not paying retirement benefits, however in case of strong risks the wealth provided by new business may be used to pay the older business to some extent, or other adjustments may be provided meanwhile. So, the risk of not paying retirements is arguably lower than 5% (arguably, as events can be worse than modelled and as reactivity can be questioned with respect to retirement systems).

3.3. RESULT: NEEDED PRUDENTIAL CAPITAL

Figure 4 shows the needed amount of additional initial wealth, expressed as a proportion of the initial wealth, depending on the future longevity trend. The first obvious result is that all curves go down on the right side: with these refined assumptions, under extreme longevity scenarios the hedge is partial when investing about $p_2=15\%$ in the longevity megafund. The second obvious result is that the two linkage models lead to approximately the same need of prudential capital (the same bottom of curve) if the future longevity trend isn't three times the current one. The third results is that under such non-too-extreme longevity scenarios, much less prudential capital is needed when investing in the megafund.

Fig. 4 - Needed additional wealth depending on the future longevity trend - Excess initial wealth (or lack of, when <0) as a proportion of the initial wealth¹



More precisely, the y-axis shows the actualized remaining wealth after paying retirement benefits for current employees, divided by the current wealth of the pension fund: "-1" means that 100% of additional wealth would be needed today, i.e. that the current wealth

¹ Forthcoming longevity trend φ (was 0.23 in last decades).

should be double. Each dot in the graph is the result of a scenario of the future. In black, no investment is performed in the megafund ($p_1=p_2=p_3=0$). In the light color (light green), the pension fund invests in the megafund which behaves like Linkage 1. In the dark color (blue), the pension fund invests in the megafund which behaves like Linkage 2.

Of note, when not investing in the megafund (nor applying some other major longevity hedge mechanism), if the current longevity trend continues ($\varphi = 23\%$) an additional capital of circa 3.5% of the initial wealth may be considered. Such is due to the risk of the funds -- the thickness of the black curve -- and taking the average (the center of the black curve) instead of a VaR at 5% shows a perfectly neutral initial wealth -- 0 -- indicating that the approximations used to compute benefits are accurate, as expressed above.

If the current longevity trend doubles however ($\varphi = 46\%$) then about 70% of additional initial wealth is needed. Such a strong additional need would be eliminated when investing in a longevity megafund, if the models described here hold well. If instead the trend triples ($\varphi = 69\%$) then about 200% of additional initial wealth is needed, which the megafund reduces to about 50% (60% if the megafund behaves like the linkage1 model, 40% if it behaves like the linkage2 model).

However, if longevity trend is negative, a prudential capital is needed due to the fact to invest in the equity part of a megafund, that would not have been needed otherwise. That is a reality if success rates of drug development programs are lower than historical pharmaceutical success. The structuring of the megafund may be optimized to reduce that risk, such as having a third tranche of the megafund that absorbs this risk.

These comments are based on specific longevity trends. In practice however, one does not know the future of longevity so the prudential additional wealth shall cover a wide range of possible longevity trends. Using the lognormal distribution of longevity trends, our simulations suggest that with a 5% probability to have an insufficient initial wealth, the prudential capital would be 8.5 times the initial wealth! Investing in the megafund would reduce it to 4 times under the Linkage 1 behavior, and to 1.7 times under the Linkage 2 behavior. With a 10% VaR, these numbers respectively become 4 and 1.05. One might have expected that longevity risk is handled with a prudential capital of 10% or 30% of the initial wealth, such is not the case here because we consider the type of breakthroughs that were described at the beginning of the article and that are burgeoning.

4. CONCLUSION

The current article studied the conditions in which investing in a longevity megafund can hedge longevity risk. It appeared that the hedge may work for defined benefit pension plans and with some degree if the change of longevity is too radical.

One might hope that in case of a very radical longevity change, retirement systems are thoroughly adjusted. However, adjusting retirement systems is obviously not easy, and that longevity hedge approach may be considered. The risk analysis performed at the end of this article suggests that the short-term prudential capital risk approach that is currently proposed by diverse regulators, such as the Solvency Capital Requirement in insurance, may not lead to the right order of magnitude of prudence.

The results we obtain depend very largely on models, and not on strong empirical evidence. Indeed, the megafund remains at this stage a theoretical concept. If the biomedical discoveries described at the beginning of the article truly extend human

lifespan in a very significant manner, it may be important not to wait too much to develop this longevity megafund solution. It is therefore a good timing to perform more research on the predicted behavior of the megafund depending on its details. For example the current article focused more on the actuarial aspects of the megafund than the pharmaceutical aspects, which are important. Also, a key dimension in the longevity megafund is intellectual property, and research should be performed on that aspect as well.

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