How the variability of demographic events can affect the solvency of pension plans with few participants? ♥♥ ♥♥

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ABSTRACT

In Brazil, the development of public pension programs resulted in different regimes, the Regimes Proprios de Previdencia Social (RPPS) for civil servants, and the Regime Geral da Previdencia Social (RGPS) for workers in the private sector. RPPS are generally small: 60% with less than 500 active workers. Such small number of participants implicates greater variability in the demographic events (mortality and health status and family transitions) and it is more common to observe more variation in relation to the mean. However, even in this scenario, such variability is not considered properly in the decision making process and the calculation of the plan costs and its sustainability. The objective of this paper is to analyze how the variability of demographic events affects the solvency of small public pension programs for civil servants. More specifically, we investigate the relationship between the variability of demographic events and population size and how they impact on the calculation of deficit risks. We also propose a way to measure the demographic risk and how to include that in the operationalization of the programs.

Key words: Social security, microsimulation, population size.

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1 INTRODUCTION

The study of pension sustainability and funding, in demography and actuarial science, focus on the estimation actuarial assumptions (BORGES, 2009; GOMES; FIGOLI; RIBEIRO, 2010; OLIVEIRA et al., 2012; SILVA, FLÁVIA SOMMERLATTE, 2009) or review the adequacy of an estimated mass of participants to actuarial assumptions (PITACCO, 2002; SILVA, FABIANA LOPES DA, 2010; WAEGENAERE; MELENBERG; STEVENS, 2010). In this paper, we assume that the set of estimated functions are appropriate for the population. We, then, investigate how the randomness of these functions may affect the solvency of pension funding, the probability and time to ruin.

This is of particular importance to Brazil, since the pension system is structured in a way that encourages the existence of plans with a small number of participants. In Brazil, the development of public pension programs resulted in different regimes for civil servants and workers in the private sector, the Regimes Próprios de Previdência Social (RPPS) and the Regime Geral de Previdência Social (RGPS), respectively (BRASIL, 1988). Each entity may have a RPPS to their workers, that is the Federal Government has a RPPS, each one of the states has its own RPPS, and each municipality may have its own system (BRASIL, 1988).

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In 2012, there were 1911 RPPS, of those 1883 were from local (city level) governments (NOGUEIRA, 2012). They insured about 2 million civil servants and over 560,000 retirees and pensioners and manage over R$ 49 billion (about 25 billion dollars) in securities and investments. Local RPPS are also the ones with the smaller numbers of participants. Whereas state level RPPS had, on average, more than 178,000 individuals each, including active employees, retirees and pensioners, city level, that are not state capitals, had, on average, only 883 participants, which could generate funding and operational difficulties, as we discuss further in the paper.

Besides being very different in terms of number of participants, the Brazilian pension regimes are also very different in terms of structure. While RGPS and Federal Government RPPS are structured in unfunded system, following a PAYGO structure, the States and city-level operate as funded programs, or are in transition to become a funded program (MINISTÉRIO DA PREVIDÊNCIA SOCIAL, 2008b). In common, both RPPS and the RGPS are Defined Benefit (DB), since the rule for granting benefits is defined in the Constitution (BRASIL, 1988). But only contribution rates for state and local RPPS are defined actuarially (MINISTÉRIO DA PREVIDÊNCIA SOCIAL, 2008a). As they are the smaller programs, in number of participants, they can be affected by variations in demographic functions.

To analyze the risk of deficit in pension plans, Winklevoss (1993) held deterministic and stochastic projections and observed that, at first, the normal contribution rate is sufficient to maintain the solvency of the plans. However, over time and the accumulation of the effects of the variability of actuarial assumptions, the normal contribution ceases to be satisfactory, even when using costing methods assuming that the contribution rate should be constant in time. The probability of ruin or deficit is also analyzed by other authors, for example Bowers et al. (1997), Devolder (2011) and Rodrigues (2008). However, as pointed by Winklevoss (1993) all of these analyzed the effects of variability in the interest rate and the rate of increase in wages, which are economic assumptions, and they do not consider demographic assumptions nor the size of the population in its calculations. Olivieri and Pitacco (2008) and Olivieri and Pitacco (2011) analyzed demographic risk, but only considering mortality, not the others.
demographic functions. In this paper, we also incorporate the impact of health, familial and labour market transitions in the study.

In this paper, we perform stochastic forecast to analyze the solvency of funded pension plans, for civil servants in Brazil, focusing on the randomness of demographic events (mortality and disability, marriage and fertility). The main assumption of this study is that greater variability of demographic events in pension program with small number of participants may result, at some point, in a flow of pension benefits much higher than expected and that the RPPS is unable to afford, causing ruin, even if in the long term (and considering the average estimates of events), there is actuarial balance. If this hypothesis is confirmed, it is necessary to redesign the current pension system and how to calculate the current contribution rates and actuarial reserves.

2 DATA AND METHODS

In this paper, we simulate the impacts of the variability of demographic events in small pension programs from a hypothetical situation of implementing a new RPPS program that is in actuarial balance. We considered only voluntary and compulsory retirement, disability benefits and survival benefits (BRASIL, 1988). The simulations were performed with different initial population sizes to test the impact of population size in addition to variability in demographic functions. As the RPPS is in actuarial balance, it is not necessary to consider the history of past benefits and contributions. This allows us to analyze the effects of variability of demographic functions independent of past benefits, and also eliminates the need to adopt assumptions about the history of these functions.

We also considered that the system is closed to the entry of new participants, since there is no clear rule for the entry of new workers, which is dependent on policy issues. The period of analysis is 75 years, the same period required by the Brazilian Ministry of Social Security for the analysis of the solvency of the plans, so there is consistency in the results of this work within the RPPS guidelines.
Figure 1 shows the basic assumptions defined in simulation model. The observed values of the economic assumptions of interest rate and growth of salary do not depend on the population size, thus we kept the values of these functions constant in the model (WINKLEVOSS, 1993). The demographic assumptions, mortality, disability, age of entry in the labour market, probability of having a spouse, probability of having a child, age of spouse and child's age were considered stochastically. That is, its observed value may vary for each individual randomly around a mean value estimated.

In the situation when exists some statutory limit for actuarial assumptions to actuarial valuation, we adopted the average value of the premise. To estimate the mortality we used the IBGE life table by age and sex, the life table from the official government source elaborated in 2010. To estimate the transition to disability, we used information from the Álvaro Vindas table. We use real wage growth rate of 1% per year and interest rate of 6% per year (MINISTÉRIO DA PREVIDÊNCIA SOCIAL, 2008b).
If the legal limits are not defined in the legislation - in the case for entry age in the labour market, probability of having a spouse, probability of having a child, age of spouse and age of the child – we estimated functions from *Pesquisa Nacional por Amostra de Domicílios* (PNAD) 2011, a survey held annually in Brazil (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2011). For simplicity, we assume that individuals retire as soon as they reach the minimum retirement eligibility age, which are 65 for males and 60 for females and 10 years of contribution if retirement age; or 60 years of age and 35 of contribution for male, and 55 years of age and 30 years of contribution for woman, if retirement contribution time; or 70 years of age if mandatory retirement (BRASIL, 1988). Box 1 presents the assumptions used in the simulation model compared to the legal retirement rules in Brazil that are defined in the Constitution.

**Box 1. Retirement rules used in the simulation.**

<table>
<thead>
<tr>
<th>Type of retirement</th>
<th>Legal rules</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandatory</td>
<td>70 years old</td>
<td>70 years old</td>
</tr>
<tr>
<td>Age</td>
<td>10 years in public service, 5 years in the current position and 65 years of age for males and 60 for females.</td>
<td>10 years of contribution and 65 years of age for males and 60 for females.</td>
</tr>
<tr>
<td>Age and length of contribution</td>
<td>10 years in public service, 5 years in current position. 60 years of age for males and 55 for females. And reduction in 5 years if public school teacher.</td>
<td>10 years of contribution and 60 years of age for males and 55 for females.</td>
</tr>
</tbody>
</table>

We are interested in analyzing the effects of the variability of demographic events in a pension plan. Instead of using a macrosimulation strategy, that would aggregate all individuals and project an average value (VOS; PALLONI, 1989), we used a Monte-Carlo microsimulation approach. In this model, we constructed individual stories, assessing the presence or absence of events randomly each time period for each individual (VOS; PALLONI, 1989; ZHAO, 2006). After each of the individual is exposed to demographic events, we move on to the next simulation period and the process is repeated. The repetitions will be as many as the quantity of desired periods for projection. At the end, the resulting
population equals the projected population with all its features, for instance sex and age composition (MASON, 2010; ZHAO, 2006). As the occurrence or not of events is random, every round of microsimulation might have a different result (MASON, 2010; VOS; PALLONI, 1989; ZHAO, 2006). This methodology allows us to analyze the variability and the probability distribution of events in the population of interest in the end of the simulation, which would not be possible if we use a macrossimulation model (MASON, 2010; VOS; PALLONI, 1989; ZHAO, 2006). We analyze the results of the simulations using the Monte Carlo method (MASON, 2010; VOS; PALLONI, 1989; ZHAO, 2006), which is based on several repetition of the random sampling to estimate the distribution of interest (Hromkovic 2003). We run the simulations using R software (R DEVELOPMENT CORE TEAM, 2013) with the aid of lifecontingencies package (SPEDICATO; KAINHOFER; OWENS, 2014).

Figure 2 depicts, schematically, the simulation model. At the beginning all workers are active, but can change states each year randomly. For each worker, states can be active in the labour market, disabled, retired, deceased with dependent spouse (and children), deceased with dependent children, or deceased without dependents. To check if the worker changed state, the simulation model generates a random number that is compared to the probability of the worker being in every state each year given the previous state. If the worker is active in the labour force, every year (round of simulation) the worker can remain active, become disable, retire or die. Being disable or retired, the worker can continue in this state and continue receiving benefits, or die. In case of death of the worker we evaluate if he has dependents. If so, we evaluate until when the dependents could receive the benefits. The benefits cease when the beneficiary dies or, in the absence of spouse, when the youngest son complete 21 years of age. The obligations of the plan to cease to the worker/participant has no beneficiary.
We run simulation models to workers from the city of Portalegre, in 2012, based on real data from the municipality. There are 335 active workers in that year. Of those 63.3% are women and 46.7% males. The average earnings is R$ 1,617.14. The lowest salary is R$ 853.10 and the highest, R$ 2,986.66. There are no workers receiving above the RGPS contributory ceiling wage, R$ 4,157.05 in 2012 (PORTALEGRE, 2012).

Figure 3 shows the percentage of workers by initial situation for every round of the simulation. They are all active at the beginning because it was considered the hypothetical situation of implementation of a new RPPS. In the initial years, a small amount of workers transits to disability, overtime most retire and then they die out. Over time, few workers left pension only for their children and a greater percentage leaves survival benefits for their spouses. After 35 years, for example, 37% (125) of the workers remain active, 39.4% are retired (132 workers) and 4.8% (16) of them receive disability benefits. We also observed that 18% (60 workers) of initial workers have died, and 11.6% (39 workers) have died without leaving dependents. Among those who left dependents, 95% (20) left spouse and only 0.3% (1 worker) had no spouse but left children under age 21 as beneficiaries. We can also observe that the retirement benefit is the most common type of benefit, and that duration retirement is much shorter than the duration of contribution in our model. Moreover, we observed that by the end of the 75 years of simulation, virtually all workers are dead as well as their beneficiaries.
Figure 4 presents, for each state, time and simulation round, the difference between the number of individuals observed and the average in 100 rounds of simulations. Panel A shows the variation in the number of active workers; Panel B shows the deceased workers without beneficiaries; Panel C gives the number of disabled workers. The following panels show the variation in the number of retirees, children receiving benefits, spouses and beneficiaries, respectively. The number of active workers present the greatest variability in the early years of simulation, but then the variability tends to zero. This is because at the beginning of the simulation period there are large number of active workers, but after some time they all change state and the number of active workers goes to zero. Among the disabled workers (those receiving disability benefits) the variability also decreases in recent years of simulation, but not as intensely. This decrease occurs because at the end of 75 years the majority of individuals are already dead.
Fig. 4. Difference between the numbers of active, disabled, retired, children beneficiaries, spouses beneficiaries and dead workers without dependents relative to the average number of workers in these states over 75 years, 100 simulations, Portalegre.

Also in Figure 4, it is noteworthy that the number of individuals in the first state, active, indicates the number of contributors to the pension plans. The last state, deceased without dependents, is the state in which nobody gets benefits. The state 'deceased without dependents' is one that presents more different values from the average. In one of the simulations we observed a difference of 28 individuals more than the average for whom the pension plan does not have any commitments, the equivalent to more than 8% variation of the mass of 335 initial workers.

In Figure 4, we observe the main source of variation is mortality. The second is the entry age in the job that also affects the retirement status since, by RPPS rules, one can retire by age or by age and length of contribution. The third leading cause of variation is nuptiality. Finally, we have the variation in the amount of disable, then the children. Once you know the status of each individual in relation to the plane it is possible to identify periods in which each
individuals have made contributions to or received benefits from the RPPS. It is assumed that only active individuals make the contributions. They correspond to a percentage of salary at the time of contribution.

By analyzing the state of the worker relative to the pension program it is also possible to identify the time at which the pension plan must pay benefits, since pension benefits are paid to retired or disable worker, or their dependents in the case of death of the worker. It remains, therefore, known the amount of money to be paid by the RPPS in each of these moments. This amount, however, differs from the amount actually received by the worker due to the financial compensation. The financial compensation occurs because we considered the implementation of a new RPPS, but during the time before that workers could be contributing to the RGPS. The financial compensation is the amount transfered from the RGPS to the RPPS because of the time that the worker has contributed to the general program (BRASIL, 1999; RODRIGUES, 2008). The value of financial compensation is equal to the minimum value between the benefit amount calculated under the rules of RGPS ($B_{RGPS}$) and calculated according to the rules of RPPS ($B_{RPPS}$), multiplied by the percentage corresponding to the period of contribution to RGPS ($Tc_{RGPS}$) in the total time of service of public servants ($Tc_{Total}$) (BRASIL, 1999).

Once the contribution wage and future benefits are known, the contribution rate is defined as 38.2%, which is the rate of actuarial balance for this population given the actuarial assumptions. The value of the reserve pension plan was estimated from the calculated contribution rate. It was assumed that the reserve each time $t$, $R_t$, is equal to the reserve at the earlier time $R_{t-1}$ increased interest $i$ plus contributions $C_t$ less benefits $B_t$. Thus, $R_t = R_{t-1}(1+i) + C_t - B_t$.

Figure 5 presents the confidence intervals of 90% and 99% for the value of the mathematical reserve calculated without considering the interest rate of investments (or considering a interest rate equals to zero), and considering the interest rate equals to 6% per year to 500
rounds of simulations for the civil servants of Portoalegre. We find that, depending on the variation of demographic functions, the pension plan can be in deficit or surplus, even if the contribution rate calculated according to the actuarial assumptions set actuarial balance to ensure a return of 6% per year. It is clear, moreover, that the plans had deficit at different points in time, depending on the variation of demographic function observed. The variation of these functions is responsible therefore by the duration of the solvency of small plans. Another conclusion is that the variance of the reserve increases with time since an event occurred at an early time still resonant for many years. This means that the variability has a cumulative effect on pension plans, which justifies the need for constant monitoring of plans. This is important because managers need to the necessary steps as soon as they observed variations from the expected values; to prevent such variation is reflected in the time and cause deficits.

Figure 5 also shows that the reserve initially increases with the contributions, but starts to decrease with the increasing volume of benefits paid. However, the time when the reserve with returns starts decreasing is at later period of time compared to the situation that assumes 0% interest rate. This indicates that an increase in interest rate increases the time that the pension plan has a lower probability of ruin. We also note that the effect of the variability of demographic functions is more evident when one does not consider the interest rate. That is, the return potentiates the effect of the variability of demographic functions in the reserve, increasing the variability of results over time. As return rates have cumulative effect, the effect of population variability in the reserve functions also becomes cumulative and is greater the longer the time period analyzed. These results lead to the conclusion that interest rate increases the risk arising from the variability of demographic functions.
3 RESULTS

The preliminary analysis show results to a single population size and focus on the importance of considering the variability in the demographic variables to a pension program. In this paper, we also want to compare actuarial mathematical reserves for different population sizes. For this purpose we analyzed 3 different population sizes: the population of 335 workers from Portalegre, the double of population, and the triple. This simple exercise allowed us to analyze whether the methodological procedures indicates that the results depend solely on the size of the population, not its composition. We run 500 replications of the simulation model for each population size.

Figure 6 shows the median and the confidence intervals of 90% and 99% for reservation for each population size. The larger the population, the greater the values of reserve and more variation in their values. This is because the value of the reserve plan that has more workers is greater and they need to cover future benefits for a larger population. Likewise, if there is a deficit this will have to be increased, and if there is a surplus this surplus is also increased.
As in Olivieri e Pitacco (2011), in this paper the values of the reserve were standardized dividing their original value by the size of the initial population of workers. Figure 7 shows, without scale effect population size, the higher the initial population of workers, the lower the variance of the worker reservation by over time.

Figure 8 summarizes the same results showing the variance of the standardized reserve every moment of time. The variance of reserve per worker increases over time, but is lower when the initial population is greater. Also there is a large difference between the variances in populations of 335 and 670 workers, but a small difference between the variances in the populations of 670 and 1005 workers. Therefore, in small populations, unless each individual represents a large increase in the variance, one observes small variation. This is different from
what happens in larger populations, as a single individual has less weight to that extent, there is more variation.

**Fig. 8. Variance of reserve divided by the initial population of workers for populations of 335, 670 and 1005 workers, 500 simulations.**

Given the variability of mathematical reserves, in some results the value of the reserve was negative, known as ruin (KAAS et al., 2008). It is important to know both the probability of ruin and the time at which ruin occurs and how it varies for each population size. It is expected that in smaller populations the variability of demographic functions to have greater weight in the observed value of the reserve. On one hand, in a small population it is expected to observe greater probability of ruin in short periods of times. On the other hand, the larger the population the longer the time until ruin. However, average reserve does not assume constant value in time. It varies with time, being lower at the beginning of the pension plan and increased the maturation of the population tended to decrease again with the retirement and benefit payments. Therefore, it is expected that the probability of ruin vary over time and to the ageing of the population.

Figure 9 confirms the intuitive results. The probability of ruin becomes positive in a short time span for smaller populations. Therefore, the smaller the population the lower the time until ruin. Likewise, the smaller the population larger the probability of ruin each time, during the 75 years of simulation.
Fig. 9. Probability of ruin in time for populations of 335, 670 and 1005 workers, 500 simulations.

Figure 10 shows the average size of the failure by worker, in each of the 500 simulation rounds for each population size. The size of the deficit was greater for smaller than for larger populations.

Fig. 10. Average size of ruin by worker for populations of 335, 670 and 1005 workers, 500 simulations.

Taking together the average size of the deficit times the probability of ruin every moment we have the solvency risk in each period of time. Figure 11 shows that in the population of 335 workers has positive probability of ruin in shorter times and very large average ruins. Hence it
can be concluded that the smaller the population the greater solvency risk by demographic changes.

Fig. 11. Risk for populations of 335, 670 and 1005 workers, 500 simulations.

Finally, we propose a rate of demographic risk to compensate for the variability in the demographic events. If there is a risk associated to the variability of demographic functions, then we can prevent the risk of such variation with a rate of demographic risk. To calculate this rate we divided the sum of the present value of the expected deficit at the end of the 75-year period of simulation to the present value of future mass of contribution. Thus the rate of population risk is one that amortizes the expected deficit over time.

The calculated rate reflects the relationship between variability and population size of the reserve. Figure 12 shows, for the population of 335 workers, that a rate of demographic risk of 0.35% would be required, while the population of 670 workers would require a rate of 0.23%, and for a population of 1005 workers, a rate of only 0.20%. Therefore, the larger the population the lower the rate of demographic risk, so this rate tends to zero as population size increases.
5 CONCLUSIONS

This paper investigated the relationship between population size and consequent variation of the observed values of demographic events and solvency of defined benefit capitalized pension plans. More specifically, we analyzed the effect of variation in demographic functions for small RPPS programs, which are pension schemes for public servants in Brazil.

Unlike Olivieri and Pitacco (2008) and Olivieri and Pitacco (2011) that used analytical models, in the analysis, we used microsimulation models based on the implementation of a new RPPS for different population size of workers (civil servants). This methodology allowed the analysis considering 7 demographic random variables simultaneously.

From the results, we observed that there is a relationship between population size and the risk of solvency of pension plans, so that the smaller the population the largest the demographic, as Olivieri and Pitacco (2008) and Olivieri and Pitacco (2011). But we find also that the higher the interest rate is higher demographic risk.

Assuming that the risk is caused by random variation around the average demographics functions, we proposed a rate of demographic risk as a measure to stabilize the contribution rate. This rate of population risk would dilute this risk of ruin over time allowing more time
between actuarial solvency and ruin. However, despite the inherent risk of variability of demographic functions, found that plans with small number of participants are viable, but the constant monitoring of the plan is indicated because it can decrease the risk of ruin, as warned Devolder (2011).

Although this paper has been based on the public pension program for the civil servants, RPPS, the analysis and procedures can be extended to other types of pension plans or even to other types of insurance, since the final conclusion is that random variations can affect the solvency of the plans. Thus, any pension plan that deals with demographic characteristics and demographic variations may be subject also to insolvency given to random variation.

This is a preliminary investigation, which also needs more analysis to reach more conclusive results. Further work could investigate the importance of each demographic variable separately in the risk of overall demographic changes; consider more than one state change throughout the year; and find a mathematical relationship between population size and risk of demographic changes.

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