AN ACTUARIAL BALANCE MODEL FOR DB PAYG PENSION SYSTEMS WITH DISABILITY AND RETIREMENT CONTINGENCIES

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ABSTRACT

In this paper we develop the theoretical basis for drawing up the “Swedish” actuarial balance of a defined benefit pay-as-you-go (DB PAYG) scheme with retirement and disability benefits. Our model enables us to obtain the system's average turnover duration, measure the scheme's solvency and explore the phenomenon identified as “pension reclassification”, an unhealthy practice that masks the system's real status and makes it very difficult to obtain accurate actuarial results by contingency. Additionally, the proposed model has practical implications which could be of interest not only to DB systems but also to notional defined contribution schemes (NDC) and policy-makers.

Keywords: Political risk, Solvency, Sweden, Transparency, United States**.**

JEL: H55; H83; J26; M49.

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1.- Introduction.

Regularly compiling an official actuarial balance (AB) is standard practice in public Social Security Administrations (SSAs) in countries such as the USA (BOT (2010)), Japan (AAD (2009)), Sweden (Pensionsmyndigheten (2011)), Canada (OSFIC (2008)), the UK (GAD (2010)) and Finland (Elo et al (2010)). The AB is becoming an instrument essential to the efficient running of PAYG pension systems because it tends to minimize the traditional difference between the planning horizons of whichever authority is in charge of the system and the system itself. The core idea behind ABs for PAYG pension systems, in line with Barr & Diamond (2010), is that any analysis that looks only at the future liabilities of PAYG pension systems while ignoring explicit or implicit assets is misleading.

For Vidal-Meliá et al (2010), there are compelling reasons why a society should have an AB: stakeholders will have a good idea of how far promises or commitments made to them regarding their pensions are being kept; public interest in how the system is developing is strengthened, making it easier to introduce automatic balance mechanisms (ABMs)[1]; and it should "force" politicians to be much more careful about what they say about the system, thereby reducing populism in pensions and enabling the impact of proposed reforms to be assessed with greater reliability and, where appropriate, accepted with more widespread support.

When it comes to compiling the AB for PAYG systems, there are basically two options to choose from: what are known as the Swedish and US models.

The AB sheet for the NDC pension system[2] has been compiled in Sweden[3] since 2001. It can be described as a financial statement listing the pension system's obligations to contributors and pensioners at a particular date, with the amounts of the various assets (financial and through contributions) which back up these commitments. For Settergren (2009), Swedish reporting on financial status bears greater resemblance to the standard income statement and balance sheet of an insurance company. As we will see later, this balance sheet

[1] An ABM is a set of predetermined measures established by law to be applied immediately as required according to the solvency indicator. Its purpose, through successive application, is to provide what could be called "automatic financial stability", which can be defined as "the capacity of a pension system to adapt to financial, economic and demographic turbulence without legislative intervention". For more details, see the papers by Barr & Diamond (2011), Vidal-Meliá et al (2009), Turner (2008), Börsch-Supan (2007), Penner & Steuerle (2007) and Lindbeck (2006).

[2] A notional defined contribution scheme (NDC) is a pay-as-you-go scheme that deliberately mimics a financial defined contribution (FDC) scheme by paying an income stream whose present value over the person's expected remaining lifetime equals his or her accumulation at retirement, and in doing so has many features of an FDC scheme. See for example the papers by Lindbeck & Persson (2003), Williamson (2004), Holzmann & Palmer (2006) Vidal-Meliá et al. (2006) and Whitehouse (2010).

[3] Papers on the Swedish pension system include those by Palmer (2002), Sunden (2006), Pensionsmyndigheten (2011) and Chłoń-Domińczakel al (2012).

structure is perfectly valid for defined benefit pay-as-you-go systems (DB PAYG) in which the contribution rates for different contingencies are clearly separated.

The AB of the OASDI program[4] has been compiled in US since1941. As Goss (2010) explains, it measures the difference in present value - discounted by the projected yield on trust fund assets - between spending on pensions and income from contributions over the next 75 years as a whole, expressed as a percentage of the present value of the contribution bases for that time horizon, taking into account that the level of financial reserves (trust fund) at the end of the time horizon reaches a magnitude of one year's expenditure.

The two models have very different characteristics and strengths. In the Swedish model the main accounting entries are developed from the principles of double-entry bookkeeping; and can briefly be summed up as showing the actuarial (im)balance in pension systems in understandable language in the shape of assets and liabilities and without needing to use explicit projections[5]. However, it can only be applied to the retirement contingency. The so-called US model, on the other hand, uses explicit projections to highlight future challenges to the financial side deriving basically from ageing, the expected increase in longevity and fluctuations in economic activity.

This paper will deal exclusively with the Swedish-type AB model, and especially the two concepts that make the balance possible: the system's average turnover duration and the contribution asset. These concepts initially appear in connection with NDCs, the general outline of which can be found in papers by Settergren (2001) and (2003), while in the paper by Settergren & Mikula (2005), both concepts are modeled in continuous time, giving theoretical support. The legal definitions and specific formulas applied in the Swedish system can be found in Pensionsmyndigheten (2011), while detailed explanations regarding the evolution of the system's solvency as determined from the balance can be found in the paper by Settergren (2012).

The search for valid expressions to apply to DB PAYG systems began with the paper by Boado-Penas et al (2008), continuing with that by Vidal-Meliá et al (2009), which in addition links it to the concept of the ABM. The paper by Vidal-Meliá & Boado-Penas (2013) obtains the analytical properties of the contribution asset and confirms its soundness as a measure of the assets of a PAYG scheme. However, all the papers cited limit themselves to the retirement

[4] The Old-Age, Survivors, and Disability Insurance (OASDI) program in the United States provides a basic level of monthly income when insured workers become eligible for retirement and in cases of death or disability. The OASDI program consists of two separate parts that pay benefits to workers and their families - Old-Age and Survivors Insurance (OASI) and Disability Insurance (DI). Under OASI, monthly benefits are paid to retired workers and their families and to survivors of deceased workers, while under DI, monthly benefits are paid to disabled workers and their families. See the papers by BOT (2010), DeWitt (2010), Hoskins (2010) and Diamond & Orszag (2005).

[5] See the paper by Boado-Penas & Vidal-Meliá (2012) for an in-depth study of the main differences and similarities.

contingency, which may be appropriate for defined contribution (DC) pension systems in which the contributory contingencies are clearly separated, but in DB PAYG systems there tends to be no clear separation between contingencies as far as contribution rates are concerned, and disability pensioners are often reclassified as retirement pensioners once they reach a certain age. Also, spending on disability pensions is hardly inconsiderable[6].

The aim of this paper is to develop a theoretical basis for applying the Swedish AB to both the retirement and disability contingencies in a DB PAYG system. As mentioned earlier, there is a large gap in the literature which this paper hopes to fill, since so far nobody has looked at the possibility of compiling this type of AB from the integrated perspective of both retirement and disability contingencies, which are closely linked and account for a very high proportion of pension spending in DB systems.

After this brief introduction, in Section 2 we develop a new expression for the system's average turnover duration in which both contingencies are included. In Section 3 the expressions obtained are applied using various reasonable assumptions to a numerical example representative of the system. The results for the system's assets and liabilities per contingency are also shown and special attention is paid to the phenomenon identified as pension reclassification. In Section 4 we list our main conclusions, and the paper ends with two appendixes in which we deduce some of the formulas used earlier.

2.- The contribution asset and the turnover duration in DB PAYG systems with two contingencies.

In this section we develop the concept of the contribution asset (CA)[7] for a case in which the participants' lives last ($w-1-x_e$) periods, where ($w-1$) is the highest age to which it is possible to survive and x_e is the age of entry into the system. In this case, A generations of contributors, ($w-1-(x_e+A)$) generations of retirement pensioners and ($w-2-x_e$) generations of disability pensioners coexist at each moment in time[8].

[6] In Spain at 1-1-2012, spending on contributory retirement pensions accounted for 67.95% of total spending on pensions, while disability pensions accounted for 11.39%, together totaling 79.34% of contributory spending. According to information provided by BOT (2011), spending on retirement pensions in the USA accounted for 63.19% of the total, with disability pensions - which are not subject to reclassification like they are in Spain - accounting for 16.40%, together totaling 79.59%.

[7] Jackson (2004) proposed a financial statement for US Social Security prepared in accordance with the principles of accrual accounting, and based on the so-called “quasi asset”, an amount equal to the present value of excess revenues to be contributed by system participants over the additional benefits that they will accrue over the balance of their working lives. Valdés-Prieto (2005) also suggests using this “quasi asset” (“hidden asset” in his terminology) as a valid asset for drawing up the AB sheet of a DB PAYG scheme.

[8] We adopt the hypothesis that at the earliest age at which one can contribute, x_e years, there are no disability pensioners. However, people become disabled throughout the period and start to receive a pension one year later, i.e. at age x_e+1 años.

The process for obtaining the system's turnover duration (TD)[9], its CA and a description of some of its characteristic features can be separated into 5 steps for the purposes of clarity:

1.-Description of the system and determination of the year in which it reaches a steady state[10] (the contribution rates for both contingencies remaining stable in time and the system's financial equilibrium being maintained).

2.-Obtaining the analytical expressions for the system's liabilities from the actuarial point of view, distinguishing between contributors and pensioners, retirement and disability.

3.-Obtaining the analytical expression for the system's TD in the form of pay-in and pay-out.

4.-Obtaining the expression for the system's TD as the difference in the weighted average ages of pensioners and contributors.

5.-Obtaining the system's TD and CA as weighting for the TDs and CAs for each contingency.

2.1.-Description of the system and determination of the year in which it reaches a "mature" state.

We use the case developed Vidal-Meliá & Boado-Penas (2013) in which the contribution base increases or decreases at an annual real rate of g, i.e. zero inflation is assumed, but with the additional assumptions that the population increases or decreases over time at an annual accumulative rate of γ affecting all groups of contributors equally, which means it must be assumed that real GDP and the wage bill also increase or decrease at rate G $=(1+g)\cdot(1+\gamma)-1$ and that pensions in payment increase or decrease at an annual rate of λ.

The pension system's parameters are considered to be in a steady state. The contributor collective is open, i.e. the system has *guaranteed* a perpetual flow of new entrants. Both the age giving entitlement to retirement pension, "x_e+A", and the formula used for calculating retirement pension are constant, leading to a fixed replacement rate of size □. As regards disability pension, it is supposed that initially the ages that give entitlement are to be found in age interval [x_e, x_e+A-1][11] and that for each age within that interval the calculation formula is a percentage (or adjustment factor) of the wage base. The age interval is later widened to [x_e +1, w-1].

[9] Lee (1994) began the formal development of the TD and described a framework to organize, summarize, and interpret data on transfer systems and the life cycle. Other pioneering papers which arrive at similar frameworks are Arthur & McNicoll (1978) and Willis (1988).

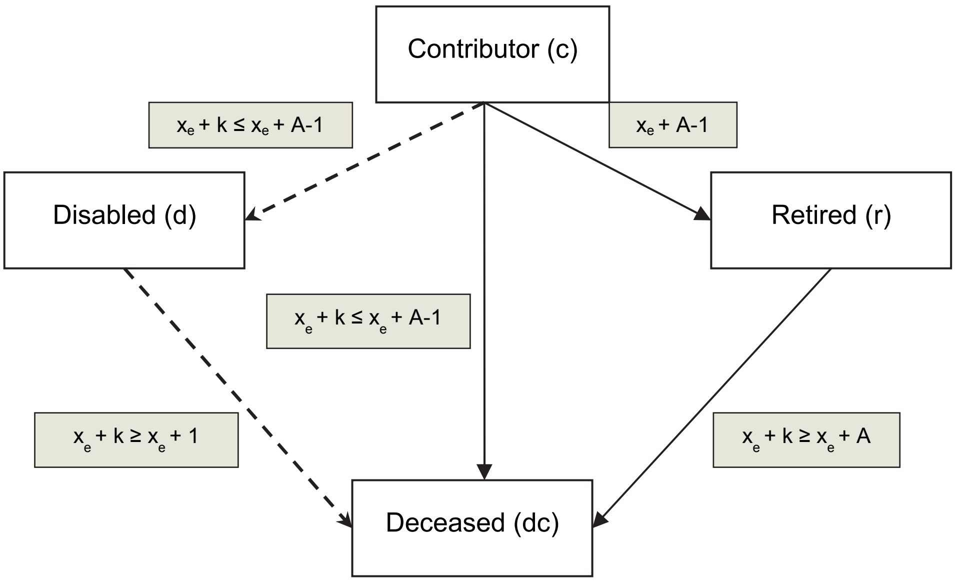
[10] It is usual to replace the qualifying condition "steady state" with the condition "mature".

[11] Indeed a person of x_e years may become disabled after having paid contributions, and therefore starts to receive disability pension at age x_e+1 years. Similarly, a person of x_e+A-1 years may become disabled at that age after contributing and will therefore receive benefit for being disabled at age x_e+A years.

Diagram 1 shows the relationships (transitions) between the various collectives (states) that will be separated in the model:

Diagram 1.

Contribution, disability, retirement and death



The difference between this and the model found in Vidal-Meliá & Boado-Penas (2013) is that a new state - disability - is introduced, along with the new relationships shown in the diagram by dotted lines.

The demographic-financial structure at any moment "t" from the system's inception is given by:

1.-Age:

$$\begin{cases} \overbrace{x_e,\ x_e+1,\ x_e+2, \ldots\ldots, x_e+A-1,}^{\text{Contributors' ages}}\ \underbrace{x_e+A, x_e+A+1, \ldots\ldots w-1}_{\text{Pensioners' ages (retirement)}} \\ \underbrace{x_e+1,\ x_e+2, \ldots\ldots, x_e+A-1, x_e+A, x_e+A+1, \ldots\ldots w-1}_{\text{Pensioners' ages (disability)}} \end{cases} \quad \textbf{[1.]}$$

We adopt the assumption that the contributor cannot contribute and receive pension in the same year. However, if an individual becomes disabled at contribution age $x_e + k \in [x_e, x_e+A-1]$, the corresponding disability pension payable will be $x_e + k+1 \in [x_e+1, x_e+A]$.

2.- Number of contributors by age at time t:

$$\left\{ N_{(x_e,t)},\ N_{(x_e+1,t)}, \ldots\ldots\ldots, N_{(x_e+A-1,t)} \right\} = \left\{ N_{(x_e,0)}(1+\gamma)^t,\ N_{(x_e+1,0)}(1+\gamma)^t, \ldots\ldots\ldots, N_{(x_e+A-1,0)}(1+\gamma)^t \right\} \quad \textbf{[2.]}$$

where $N_{(x_e+k,t)} = N_{(x_e,t)}\ {}_kR_{x_e}$, with ${}_kR_{x_e}$ being the stable-in-time ratio between the number of individuals of age x_e and x_e+k years, which can be increasing or decreasing and can also be expressed by means of probabilities ${}_kp_{x_e}$. Stable ratios or probabilities include the decrements due to death and disability associated with each age, with the possibility of a return to active life not being considered (practical disability model). It is a different matter when it comes to considering decrements or new entries due to migratory movements, these being included in parameter γ.

3.- Average wage (average contribution base) by age at time t:

$$\left\{ y_{(x_e,t)},\ y_{(x_e+1,t)}, \ldots\ldots\ldots, y_{(x_e+A-1,t)} \right\} = \left\{ y_{(x_e,0)}(1+g)^t,\ y_{(x_e+1,0)}(1+g)^t, \ldots\ldots\ldots, y_{(x_e+A-1,0)}(1+g)^t \right\} \quad \textbf{[3.]}$$

4.- Number of disabled in age interval [x_e+1 , x_e+A] at t = 1

$$\begin{aligned}
I_{(x_e+1,1)} &= N_{(x_e,0)} \cdot i_{x_e}, \\
I_{(x_e+2,1)} &= N_{(x_e+1,0)} \cdot i_{x_e+1} = N_{(x_e,0)} \cdot p_{x_e} \cdot i_{x_e+1}, \\
&\ldots\ldots\ldots, \\
I_{(x_e+k,1)} &= N_{(x_e+k-1,0)} \cdot i_{x_e+k-1} = N_{(x_e,0)} \cdot {}_{k-1}p_{x_e} \cdot i_{x_e+k-1}, \\
&\ldots\ldots\ldots, \\
I_{(x_e+A,1)} &= N_{(x_e+A-1,0)} \cdot i_{x_e+A-1} = N_{(x_e,0)} \cdot {}_{A-1}p_{x_e} \cdot i_{x_e+A-1}
\end{aligned} \quad \textbf{[4.]}$$

where i_{x_e+k-1} is the probability that an individual of age x_e+k-1 will suffer permanent disability without being able to return to active life, $I_{(x_e+k,1)}$ is the number of people who become disabled[12] in year t of age x_e+k, and $p^I_{x_e+k-1}$ is the probability of survival of a disabled person at age x_e+k-1, which may be different from that for the active population.

For t ≥ 2 and age interval [x_e+1 , x_e+A], we need to consider two types of disabled

[12] Become disabled as far as the system is concerned, because their disability really began in the previous period [0, 1).

people: those aged x_e+k years who became disabled in the current year, $I^N_{(x_e+k,t)}$, and those whose disability began earlier or survivors aged x_e+k years who continue from previous years, $I^s_{(x_e+k,t)}$, whose evolution will depend on survival probabilities $p^I_{x_e+k-1}$. The structure for the number of people who became disabled during the year in question is always given by:

$$
\begin{aligned}
& I^N_{(x_e+1,t)} = N_{(x_e,t-1)} \cdot i_{x_e} = N_{(x_e,0)} \cdot (1+\gamma)^{t-1} \cdot i_{x_e} = I_{(x_e+1,1)} \cdot (1+\gamma)^{t-1}, \\
& I^N_{(x_e+2,t)} = N_{(x_e+1,t-1)} \cdot i_{x_e+1} = N_{(x_e+1,0)} \cdot (1+\gamma)^{t-1} \cdot i_{x_e+1} = N_{(x_e,0)} \cdot (1+\gamma)^{t-1} \cdot p_{x_e} \cdot i_{x_e+1} \\
& = I_{(x_e+2,1)} \cdot (1+\gamma)^{t-1}, \ldots\ldots\ldots \ldots\ldots\ldots \ldots\ldots\ldots \ldots, \\
& I^N_{(x_e+k,t)} = N_{(x_e+k-1,t-1)} \cdot i_{x_e+k-1} = N_{(x_e+k-1,1)} \cdot (1+\gamma)^{t-1} \cdot i_{x_e+k-1} = N_{(x_e,0)} \cdot (1+\gamma)^{t-1} \cdot {}_{k-1}p_{x_e} \cdot i_{x_e+k-1} \\
& = I_{(x_e+k,1)} \cdot (1+\gamma)^{t-1}, \ldots\ldots\ldots \ldots\ldots\ldots \ldots\ldots\ldots \ldots, \\
& I^N_{(x_e+A,t)} = N_{(x_e+A-1,t-1)} \cdot i_{x_e+A-1} = N_{(x_e+A-1,0)} \cdot (1+\gamma)^{t-1} \cdot i_{x_e+A-1} = N_{(x_e,0)} \cdot (1+\gamma)^{t-1} \cdot {}_{A-1}p_{x_e} \cdot i_{x_e+A-1} \\
& = I_{(x_e+A,1)} \cdot (1+\gamma)^{t-1}
\end{aligned}
$$

[5.]

After x_e+A+1 years all the disabled in the system are by definition considered survivor disabled because, once the state of activity disappears, nobody can become disabled for the purposes of the system. Therefore, and always for t ≥ 2, as far as the continuing disabled are concerned a distinction has to be made between two age intervals, [x_e+2, x_e+A][13] and from x_e+A+1 years onwards. The structure of the survivor disabled in [x_e+2, x_e+A] incorporates all those who became disabled in successive earlier periods and have survived. In general,

$$
\begin{aligned}
& I^S_{(x_e+k,t)} = I_{(x_e+k-1,t-1)} \cdot p^I_{x_e+k-1} = \left(I^N_{(x_e+k-1,t-1)} + I^S_{(x_e+k-1,t-1)}\right) \cdot p^I_{x_e+k-1} = \\
& I_{(x_e+k-1,1)} \cdot (1+\gamma)^{t-2} \cdot p^I_{x_e+k-1} + I_{(x_e+k-2,t-2)} \cdot p^I_{x_e+k-2} \cdot p^I_{x_e+k-1} = \\
& I_{(x_e+k-1,1)} \cdot (1+\gamma)^{t-2} \cdot p^I_{x_e+k-1} + I_{(x_e+k-2,t-2)} \cdot {}_2p^I_{x_e+k-2} = \\
& I_{(x_e+k-1,1)} \cdot (1+\gamma)^{t-2} \cdot p^I_{x_e+k-1} + I_{(x_e+k-2,1)} \cdot (1+\gamma)^{t-3} \cdot {}_2p^I_{x_e+k-2} + I_{(x_e+k-3,t-3)} \cdot {}_3p^I_{x_e+k-3} \\
& = \ldots = \\
& \sum_{s=\text{Máx}\{1,k-t+1\}}^{k-1} I_{(x_e+s,1)} \cdot (1+\gamma)^{t-1-k+s} \cdot {}_{k-s}p^I_{x_e+s}
\end{aligned}
$$

[6.]

The total number of disabled for each age in t can be calculated by:

[13] In k = 1 the disabled are always newly disabled as they come from age x_e in t-1, and therefore I(x_e +1, t) = I^N(x_e +1, t).

$$l_{(x_e+k,\,t)} = \sum_{s=\text{Máx}\{1,k-t+1\}}^{k} l_{(x_e+s,\,1)} \cdot (1+\gamma)^{t-1-k+s} \cdot {}_{k-s}p^{I}_{x_e+s} \qquad \textbf{[7.]}$$

This type of structure is maintained until all the disabled people who began in t = 1 have disappeared, which means that $t = w\text{-}x_e$, and therefore from here onwards in all this disability band we get k < t, and so $\text{Max}\{1, k-t+1\} = 1$.

From x_e+A+1 years onwards no more new disabled people are taken into account, and so for age interval [x_e+A+1, w-1], i.e. k $\in$ {1, w-1- (x_e+A)}, we get:

$$l_{(x_e+A+k,\,t)} = l_{(x_e+A,\,t-k)} \cdot {}_k p^{I}_{x_e+A} = \left(\sum_{s=\text{Máx}\{1,\,A-t+k+1\}}^{A} l_{(x_e+s,\,1)} \cdot (1+\gamma)^{t-k-1-A+s} \cdot {}_{A-s}p^{I}_{x_e+s} \right) \cdot {}_k p^{I}_{x_e+A} \qquad \textbf{[8.]}$$

The demographic framework above implies that the age-wage structure only undergoes proportional changes. The slope of the age-wage structure is constant.

The annual retirement pension is $P^{R}_{(x_e+A,\,1)} = \beta \cdot Y_{C,\,0}$, which is a set percentage, β, of the average contribution bases taking into account all the years (A) contributed, and pensions in payment are indexed at an annual rate of λ. It will also be assumed that contributions and benefits are payable in advance.

If $\forall$k $\in$ [1, A] the initial annual disability pension (in t=1) is $P^{I}_{(x_e+k,\,1)}$, the pension amounts for the newly disabled in t ≥ 2 and $\forall$k $\in$ [1, A] are calculated according to the following formula:

$$P^{I}_{(x_e+k,\,t)} = P^{I}_{(x_e+k,\,1)} \cdot (1+g)^{t-1} = b^{I}_{k} \cdot \bar{y}_{(x_e+k,\,1)} \cdot (1+g)^{t-1} \qquad \textbf{[9.]}$$

because $P^{I}_{(x_e+k,\,1)}$ is considered to be a variable percentage, b^{I}_{k}, of the contribution base of all the wages that contributions had been paid on, k years, at the age of becoming disabled, $\bar{y}_{(x_e+k,\,1)} = \dfrac{\sum_{h=0}^{k-1} y_{(x_e+h,\,-k+h+1)}}{k}$, therefore: $P^{I}_{(x_e+k,\,1)} = b^{I}_{k} \cdot \bar{y}_{(x_e+k,\,1)}$

The amounts of the disability pensions for survivors from previous periods, $P^{S}_{(x_e+k,\,t,\,x_e+s)}$, also in t ≥ 2, $\forall$k $\in$ [1, A] and being x_e+s, with $s \in \{\text{Max}\{1, k-t+1\}, \cdots, k-1\}$, the age at which the disability first began, would be obtained in accordance with this formula:

$$P^S_{(x_e+k,t,x_e+s)} = P^I_{(x_e+s,1)} \cdot (1+g)^{t-k-1+s} \cdot (1+\lambda)^{k-s} = b^I_s \cdot \bar{y}_{(x_e+s,1)} \cdot (1+g)^{t-k-1+s} \cdot (1+\lambda)^{k-s} \quad \textbf{[10.]}$$

It can in fact be seen that for each period t and for each age k there is a vector 1x(k-s) of old pension amounts, i.e. of as many components as the difference between the age used for calculating the benefit, k, and the age at which it first came into payment, s.

The disability pensions for ages [x_e+A+1, w-1-x_e-A) are all for survivors as no newly disabled are considered, but by following them back to age x_e+A they may come from newly disabled at that age or from survivor disabled from previous ages (a vector of 1x2), in such a way that:

$$P^I_{(x_e+A+k,t)} = \left(P^I_{(x_e+A,t-k)}, P^S_{(x_e+A,t-k)}\right) \cdot (1+\lambda)^k \quad \textbf{[11.]}$$

but because, following **[10.]**, $P^S_{(x_e+A,t-k)}$ is going to depend on the age at which the disability originally began, then we get $s \in \{Max\{1, A+1-t+k\}, \cdots, A-1\}$, and once we consider $P^I_{(x_e+A,t-k)}$, the final formula for $s \in \{Max\{1, A+1-t+k\}, \cdots, A\}$ will be:

$$P^I_{(x_e+A+k,t,x_e+s)} = P^I_{(x_e+A,1)} \cdot (1+g)^{t-k-A-1+s} \cdot (1+\lambda)^{A+k-s} = b^I_s \cdot \bar{y}_{(x_e+s,1)} \cdot (1+g)^{t-k-A-1+s} \cdot (1+\lambda)^{A+k-s} \quad \textbf{[12.]}$$

and like what we said for equation **[11.]**, $P^I_{(x_e+A+k,t)}$ is also a row vector, in this case of 1x(A-1-s) with $s \in \{Max\{1, A+1-t+k\}, A\}$.

In this scenario, the stability of the total contribution rate ($\theta^I + \theta^R$) that ensures equality between contribution revenue and pension expenditure depends on the stability of the dependency ratios of both contingencies. For the retirement contingency, the contribution rate from year “w-x_e-A”, counting from the system's inception, can be considered constant from the actuarial point of view because from that moment the dependency ratio (dr) stabilizes.

$$dr_t = \frac{\overbrace{\sum_{k=1}^{A} I_{(x_e+k,\,t)}}^{\text{disabled (working ages) } (D_t^I)} + \overbrace{\sum_{k=1}^{w-x_e-A-1} I_{(x_e+A+k,\,t)}}^{\text{disabled (retirement ages) } (D_t^r)} + \overbrace{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,\,1)} \cdot (1+\gamma)^{t-1-k}}^{\text{retirement pensioners } = R_t}}{\underbrace{(1+\gamma)^{t-1} \cdot \sum_{k=0}^{A-1} N_{(x_e+k,\,1)}}_{\text{contributors } = C_t}}$$

$$= \frac{\sum_{k=1}^{A}\sum_{s=1}^{k} I_{(x_e+s,\,1)} \cdot (1+\gamma)^{-k+s} \cdot {}_{k-s}p^I_{x_e+s} + \sum_{k=1}^{w-x_e-A-1}\left(\sum_{s=1}^{A} I_{(x_e+s,\,1)} \cdot (1+\gamma)^{-A-k+s} \cdot {}_{A+k-s}p^I_{x_e+s}\right)}{\sum_{k=0}^{A-1} N_{(x_e+k,\,1)}} \quad \textbf{[13.]}$$

$$+ \frac{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,\,1)} \cdot (1+\gamma)^{-k}}{\sum_{k=0}^{A-1} N_{(x_e+k,\,1)}} = dr_t = ... = dr = \frac{D+R}{C} = \frac{D}{C} + \frac{R}{C} = dr^D + dr^R$$

The same moment "w -x_e-A" can be considered for disability pensioners from retirement age onwards, but for continuing disability pensioners these pensions end up being dependent on pensions from before retirement age, and so in fact the ratio between contributors and disability pensioners does not stabilize until "w-x_e-1". Given that it is clear that w-x_e-1 > w-x_e-A and it is assumed that t >= w-x_e-1, the contributor/pensioner ratio must be stable because all three collectives evolve (growing or shrinking) at a rate exactly the same as γ.

From that year onwards the system is "mature" and, as can be seen in Appendix 1, the expressions for the contribution rates for both contingencies (retirement/R and disability/D), which can be separated, are:

$$\theta_t^R = \frac{\overbrace{\beta \cdot Y_{C,0} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,\,1)} \cdot (1+G)^{t-k} \cdot (1+\lambda)^k}^{\text{Expenditure on retirement benefits}}}{\underbrace{(1+G)^t \cdot \sum_{k=0}^{A-1} y_{(x_e+k,\,1)} \cdot N_{(x_e+k,\,1)}}_{\text{Aggregate contribution base}}} = \frac{P_{(x_e+A,\,1)} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,\,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^k}{\sum_{k=0}^{A-1} y_{(x_e+k,\,1)} \cdot N_{(x_e+k,\,1)}} = \theta_{t+1}^R = ... = \theta^R$$

[14.]

with $Y_{C,0} = \frac{\sum_{k=0}^{A-1} y_{(x_e+k,\,-A+k+1)}}{A}$, the average contribution base taking into account all the years (A) contributed, and consequently $\beta Y_{C,0} = P_{(x_e+A,\,1)}$, and also in the case of disability:

$$P_{(x_e+A,t)} = P_{(x_e+A,1)} \cdot (1+g)^{t-1} \cdot = \beta \cdot Y_{C,0} \cdot (1+g)^{t-1}; \tag{15.}$$

while the contribution rate for the disability contingency is:

$$\theta_t^D = \frac{\overbrace{\sum_{k=1}^{A}\sum_{s=1}^{k} P^I_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k-s} \cdot {}_{k-s}p^I_{x_e+s}}^{\text{Expenditure on disability benefits (working ages)}} + \overbrace{\sum_{k=1}^{w-x_e-A-1}\left(\sum_{s=1}^{A} P^I_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{A+k-s} \cdot {}_{A+k-s}p^I_{x_e+s}\right)}^{\text{Expenditure on disability benefits (retirement ages)}}}{\underbrace{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}}_{\text{Aggregate contribution base}}} = \ldots = \theta^D \tag{16.}$$

If the system's average disability pension is considered to be:

$$\bar{P}_t^D = \frac{\overbrace{(1+g)^{t-1} \cdot \left(\sum_{k=1}^{A}\left(\sum_{s=1}^{k} P^I_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k-s} \cdot {}_{k-s}p^I_{x_e+s}\right)\right)}^{\text{Expenditure on disability benefits (working ages)}}}{\underbrace{\sum_{k=1}^{A}\sum_{s=1}^{k} I_{(x_e+s,1)} \cdot (1+\gamma)^{-k+s} \cdot {}_{k-s}p^I_{x_e+s} + \sum_{k=1}^{w-x_e-A-1}\left(\sum_{s=1}^{A} I_{(x_e+s,1)} \cdot (1+\gamma)^{-A-k+s} \cdot {}_{A+k-s}p^I_{x_e+s}\right)}_{\text{Disability pensioners}}} + \frac{\overbrace{(1+g)^{t-1} \cdot \left(\sum_{k=1}^{w-x_e-A-1}\left(\sum_{s=1}^{A} P^I_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{A+k-s} {}_{A+k-s}p^I_{x_e+s}\right)\right)}^{\text{Expenditure on disability benefits (retirement ages)}}}{\underbrace{\sum_{k=1}^{A}\sum_{s=1}^{k} I_{(x_e+s,1)} \cdot (1+\gamma)^{-k+s} \cdot {}_{k-s}p^I_{x_e+s} + \sum_{k=1}^{w-x_e-A-1}\left(\sum_{s=1}^{A} I_{(x_e+s,1)} \cdot (1+\gamma)^{-A-k+s} \cdot {}_{A+k-s}p^I_{x_e+s}\right)}_{\text{Disability pensioners}}} \tag{17.}$$

then the system's average retirement pension, taking into account **[15.]**, can be expressed as:

$$\bar{P}_t^R = \frac{\overbrace{\beta \cdot Y_{C,0} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot (1+g)^{t-1-k} \cdot (1+\gamma)^{t-1-k} \cdot (1+\lambda)^{k}}^{\text{Expenditure on retirement pensions}}}{\underbrace{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot (1+\gamma)^{t-1-k}}_{\text{Retirement pensioners}=R_t}} = \frac{P_{(x_e+A,t)} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k}}{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot (1+\gamma)^{-k}} \tag{18.}$$

with the average contribution base being:

$$\overline{W}_t = \frac{\sum_{k=0}^{A-1} y_{(x_e+k,\,t)} \cdot N_{(x_e+k,\,t)}}{\sum_{k=0}^{A-1} N_{(x_e+k,\,t)}} = \frac{\overbrace{(1+G)^{t-1} \cdot \sum_{k=0}^{A-1} y_{(x_e+k,\,1)} \cdot N_{(x_e+k,\,1)}}^{\text{Aggregate contribution base}}}{\underbrace{(1+\gamma)^{t-1} \cdot \sum_{k=0}^{A-1} N_{(x_e+k,\,1)}}_{\text{Contributors}=C_t}} = \frac{(1+g)^{t-1} \cdot \left(\sum_{k=0}^{A-1} y_{(x_e+k,\,1)} \cdot N_{(x_e+k,\,1)} \right)}{\sum_{k=0}^{A-1} N_{(x_e+k,\,1)}}$$

[**19.**]

In the steady state reached, the average pension-average contribution base quotient is already constant for both contingencies due to the fact that the numerator and denominator evolve at the rate of variation in wages:

$$\frac{\overline{P}_t^D}{\overline{W}_t} = \frac{\overline{P}_{t+1}^D}{\overline{W}_{t+1}} = ... = \frac{\overline{P}^D}{\overline{W}} = fr^D, \qquad \frac{\overline{P}_t^R}{\overline{W}_t} = \frac{\overline{P}_{t+1}^R}{\overline{W}_{t+1}} = ... = \frac{\overline{P}^R}{\overline{W}} = fr^R$$ [**20.**]

Therefore the contribution rate that ensures equality between revenue and expenditure is the product of the demographic dependency ratio and the financial ratio:

$$\left\{\theta^D, \theta^R\right\} = \left\{fr^D \cdot dr^D, fr^R \cdot dr^R\right\} = \left\{\frac{\overline{P}^D}{\overline{W}}\frac{D}{C}, \frac{\overline{P}^R}{\overline{W}}\frac{R}{C}\right\}$$ [**21.**]

2.2.-Obtaining the analytical expressions for the system's liabilities from the actuarial point of view.

Once the contribution rate has been determined for both contingencies, the time comes to look at how to calculate the system's permanent liabilities with both contributors and pensioners so as to be able to continue the process of obtaining the system's average turnover duration and contribution asset.

The system's liabilities, V^T, have two components: (i) liabilities to current pensioners, V^r, and (ii) liabilities to current contributors, V^c. A distinction has to be made between the liabilities for both contingencies.

If we take into account formula [**17.**] and carry out some algebraic operations, the first component for the disability contingency is:

$$
{}^{I}V_t^r = \sum_{k=1}^{A}\left(\sum_{s=1}^{k} P^I_{(x_e+s,t)} \cdot I_{(x_e+s,t)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k-s} \cdot {}_{k-s}p^I_{x_e+s}\right) \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k}
$$

$$
+ \qquad \textbf{[22.]}
$$

$$
\sum_{k=1}^{w-x_e-A-1}\left(\sum_{s=1}^{A} P^I_{(x_e+s,t)} \cdot I_{(x_e+s,t)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{A+k-s} \cdot {}_{A+k-s}p^I_{x_e+s}\right) \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+A+k}
$$

with ${}^{I}\ddot{a}^{\lambda}_{x_e+k}$ and ${}^{I}\ddot{a}^{\lambda}_{x_e+A+k}$ respectively being the present value of a lifetime annuity for the disabled of 1 monetary unit per year payable in advance and growing at real rate λ, valued at age "x_e+k" years and age "x_e+A+k" years, with a technical interest rate equal to d=G.

For the retirement contingency, the first component is equal to:

$$
{}^{R}V_t^r = P_{(x_e+A,t)} \cdot \sum_{k=0}^{w-xe-A-1} N_{(x_e+A+k,t)} \cdot \ddot{a}^{\lambda}_{x_e+A+k} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k} \qquad \textbf{[23.]}
$$

with $\ddot{a}^{\lambda}_{x_e+A+k}$ being the present value of a lifetime annuity of 1 monetary unit per year payable in advance and growing at real rate λ, valued at age "x_e+A+k" years, with a technical interest rate equal to d=G.

The second component is the liability to current contributors, whose payments have not yet begun but to whom a commitment has been made by virtue of the contributions already paid. As can be seen in Appendix 2, this second component of disability contingency liabilities is calculated using the prospective method and will be the *difference* between the (actuarial) present value of future pensions and the (actuarial) present value of future contributions:

$$
{}^{D}V_t^c = \overbrace{\sum_{k=1}^{A}\sum_{h=k}^{A} P_{(x_e+h,t)} \cdot I^N_{(x_e+h,t)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+h} \cdot \left[\frac{(1+G)}{(1+d)}\right]^h}^{\text{present value of future disability pensions}} - \underbrace{\theta^D\left(\sum_{k=0}^{A-1}\sum_{h=0}^{k} N_{(x_e+k,t)} \cdot y_{(x_e+k,t)} \cdot \left[\frac{(1+G)}{(1+d)}\right]^h\right)}_{\text{present value of future contributions}} \qquad \textbf{[24.]}
$$

For the retirement contingency, according to Vidal-Meliá & Boado-Penas (2013), the liability to current contributors is equal to:

$$
{}^{R}V_t^c = \overbrace{P_{(xe+A,t)} \cdot N_{(xe+A,t)} \cdot \ddot{a}^{\lambda}_{xe+A} \cdot \sum_{h=1}^{A}\left[\frac{(1+G)}{(1+d)}\right]^h}^{\text{present value of future retirement benefits}} - \underbrace{\theta^R\left(\sum_{k=0}^{A-1}\sum_{h=0}^{k} N_{(xe+k,t)} \cdot y_{(xe+k,t)} \cdot \left[\frac{(1+G)}{(1+d)}\right]^h\right)}_{\text{present value of future contributions}} \qquad \textbf{[25.]}
$$

2.3.-Obtaining the analytical expression for the system's TD in the form of pay-out and pay-in.

To obtain the TD in a financially sustainable PAYG system that includes both contingencies, like in the process described by Settergren & Mikula (2005) and Boado-Penas et al (2008) which only considered the retirement contingency, the total liabilities are divided by the annual contribution flow. Also, in line with Samuelson (1958), Aaron (1966) and Gronchi & Nisticò (2008), the interest rate for discounting future pensions and contributions is taken to be the internal rate of return (IRR), i.e. the wage bill. Therefore, for the disability contigency, the TD_t^D is:

$$TD_t^D = \frac{{}^{D}V_t^T}{C_t^I} = \frac{\overbrace{\sum_{k=1}^{A}\left(\sum_{h=1}^{k} P^I_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{1+\lambda}{1+G}\right]^{k-h}\cdot {}_{k-h}p^I_{x_e+h}\right)\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k}}^{\text{present value of disability pensions (working ages)}}}{\theta^D\cdot\left(\sum_{k=0}^{A-1} y_{(x_e+k,1)}\cdot N_{(x_e+k,1)}\right)}$$

$$+$$

$$\frac{\overbrace{\sum_{k=1}^{w-x_e-A-1}\left(\sum_{h=1}^{A} P^I_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{1+\lambda}{1+G}\right]^{A+k-h}\cdot {}_{A+k-h}p^I_{x_e+h}\right)\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+A+k}}^{\text{present value of disability pensions (retirement ages)}}}{\theta^D\cdot\left(\sum_{k=0}^{A-1} y_{(x_e+k,1)}\cdot N_{(x_e+k,1)}\right)}$$

$$+$$

$$\frac{\overbrace{\sum_{k=1}^{A}\sum_{h=k}^{A} P^I_{(x_e+h,1)}\cdot I^N_{(x_e+h,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+h}\cdot\left[\frac{1+G}{1+d}\right]^{h}}^{\text{present value of future disability pensions}}}{\theta^D\cdot\left(\sum_{k=0}^{A-1} y_{(x_e+k,1)}\cdot N_{(x_e+k,1)}\right)} - \frac{\overbrace{\sum_{k=0}^{A-1}\sum_{h=0}^{k} N_{(x_e+k,1)}\cdot y_{(x_e+k,1)}\cdot\left[\frac{1+G}{1+d}\right]^{h}}^{\text{present value of future contributions}}}{\sum_{k=0}^{A-1} y_{(x_e+k,1)}\cdot N_{(x_e+k,1)}} \qquad \textbf{[26.]}$$

By substituting **[16.]** into **[26.],** the TD_t^D can be expressed as:

$$
\begin{aligned}
TD_t^D = & \overbrace{\frac{\sum_{k=1}^{A} {}^{I}\ddot{a}^{\lambda}_{x_e+k}\cdot\left(\sum_{h=1}^{k} P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h}\cdot {}_{k\text{-}h}p^{I}_{x_e+h}\right)}{\sum_{k=1}^{A}\left(\sum_{h=1}^{k} P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h}\cdot {}_{k\text{-}h}p^{I}_{x_e+h}\right)+\sum_{k=1}^{w\text{-}x_e\text{-}A-1}\left(\sum_{h=1}^{A} P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k\text{-}h}\cdot {}_{A+k\text{-}h}p^{I}_{x_e+h}\right)}}^{1} \\
& + \overbrace{\frac{\sum_{k=1}^{w\text{-}x_e\text{-}A-1} {}^{I}\ddot{a}^{\lambda}_{x_e+A+k}\cdot\left(\sum_{h=1}^{A} P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k\text{-}h}\cdot {}_{A+k\text{-}h}p^{I}_{x_e+h}\right)}{\sum_{k=1}^{A}\left(\sum_{h=1}^{k} P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h}\cdot {}_{k\text{-}h}p^{I}_{x_e+h}\right)+\sum_{k=1}^{w\text{-}x_e\text{-}A-1}\left(\sum_{h=1}^{A} P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k\text{-}h}\cdot {}_{A+k\text{-}h}p^{I}_{x_e+h}\right)}}^{2} \\
& + \overbrace{\frac{\sum_{k=1}^{A} P^{I}_{(x_e+k,1)}\cdot I^{N}_{(x_e+k,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k}\cdot\left(\sum_{h=1}^{k}\left[\frac{1+G}{1+d}\right]^{h}\right)}{\sum_{k=1}^{A}\left(\sum_{h=1}^{k} P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h}\cdot {}_{k\text{-}h}p^{I}_{x_e+h}\right)+\sum_{k=1}^{w\text{-}x_e\text{-}A-1}\left(\sum_{h=1}^{A} P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k\text{-}h}\cdot {}_{A+k\text{-}h}p^{I}_{x_e+h}\right)}}^{3} \\
& - \overbrace{\frac{\sum_{k=0}^{A-1}\sum_{h=0}^{k} N_{(x_e+k,1)}\cdot y_{(x_e+k,1)}\cdot\left[\frac{1+G}{1+d}\right]^{h}}{\sum_{k=0}^{A-1} y_{(x_e+k,1)}\cdot N_{(x_e+k,1)}}}^{4}
\end{aligned}
$$

[27.]

If we assume that $(1+g)\cdot(1+\gamma)-1=d=G$, the numerator of the third term of **[27.]**, after some transformations, is equal to:

$$\sum_{k=1}^{A} P^{I}_{(x_e+k,1)}\cdot I^{N}_{(x_e+k,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k}\left(\sum_{h=1}^{k}\left[\frac{1+G}{1+d}\right]^{h}\right)=\sum_{k=1}^{A} P^{I}_{(x_e+k,1)}\cdot I^{N}_{(x_e+k,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k}\cdot k \qquad \textbf{[28.]}$$

and if we consider that the numerator of the first 3 terms of expression **[27.]**, the present value of disability benefits awarded in year t, is equivalent to the year's disability contributions, i.e. expenditure on disability pensions in year t[14]:

[14] The same result was obtained in the paper by Vidal-Meliá & Boado-Penas (2013) for the case of a system with a retirement contingency. Therefore it can be said that the system's income from contributions is equivalent to the present actuarial value of the pensions awarded in that year (commitments the system takes on with pensioners who have just retired).

$$\sum_{k=1}^{A}\left(\sum_{h=1}^{k}P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h}\cdot{}_{k-h}p^{I}_{x_e+h}\right)+\sum_{k=1}^{w-1-(x_e+A)}\left(\sum_{h=1}^{A}P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k-h}\cdot{}_{A+k-h}p^{I}_{x_e+h}\right)$$

$$=$$

$$\sum_{k=1}^{A}P^{I}_{(x_e+k,1)}\cdot I^{N}_{(x_e+k,1)}\cdot{}^{I}\ddot{a}^{\lambda}_{x_e+k}$$

[29.]

then, after algebraically manipulating the numerator of the fourth term of formula **[27.]**, TD^{D}_{t} works out as:

$$TD^{D}_{t}=$$

$$\left.\begin{array}{c}\overbrace{\frac{\sum_{k=1}^{A}{}^{I}\ddot{a}^{\lambda}_{x_e+k}\cdot\left(\sum_{h=1}^{k}P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h}\cdot{}_{k-h}p^{I}_{x_e+h}\right)}{\sum_{k=1}^{A}P^{I}_{(x_e+k,1)}\cdot I^{N}_{(x_e+k,1)}\cdot{}^{I}\ddot{a}^{\lambda}_{x_e+k}}}^{1=pt^{D1}_{r}}\\+\\\overbrace{\frac{\sum_{k=1}^{w-x_e-A-1}{}^{I}\ddot{a}^{\lambda}_{x_e+A+k}\cdot\left(\sum_{h=1}^{A}P^{I}_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k-h}\cdot{}_{A+k-h}p^{I}_{x_e+h}\right)}{\sum_{k=1}^{A}P^{I}_{(x_e+k,1)}\cdot I^{N}_{(x_e+k,1)}\cdot{}^{I}\ddot{a}^{\lambda}_{x_e+k}}}^{2=pt^{D2}_{r}}\end{array}\right]\text{Pay out duration}=pt^{D}_{r}$$

$$+$$

$$\left.\underbrace{\overbrace{\frac{\sum_{k=1}^{A}P^{I}_{(x_e+k,1)}\cdot I^{N}_{(x_e+k,1)}\cdot{}^{I}\ddot{a}^{\lambda}_{x_e+k}\cdot k}{\sum_{k=1}^{A}P^{I}_{(x_e+k,1)}\cdot I^{N}_{(x_e+k,1)}\cdot{}^{I}\ddot{a}^{\lambda}_{x_e+k}}}^{3}}_{\bar{k}^{I}_{t}}-\overbrace{\frac{\sum_{k=0}^{A-1}N_{(x_c+k,1)}\cdot y_{(x_c+k,1)}\cdot(k+1)}{\sum_{k=0}^{A-1}N_{(x_c+k,1)}\cdot y_{(x_c+k,1)}}}^{4}\right]\text{Pay in duration}=pt^{D}_{c}$$

[30.]

The third addend of the expression is a weighted average of years contributed until entry into the state of disability starting at age x_e +1 for current contributors, $\bar{k}^{I}_{t}\in[1,A]$, and also, as happened in the case of retirement, the average TD is clearly disaggregated into two sub-periods termed pay-in, pt^{D}_{c}, and pay-out, pt^{D}_{r}, which correspond to the time that one monetary unit contributed to the disability contingency forms part of the liabilities to contributors and pensioners respectively. It needs to be pointed out that the pay-out could in turn be broken down into sub-periods, one part deriving from the disability age band in which there are contributors, pt_r^{I1}, and the other part deriving from the disability age band in which there are retirement pensioners, pt_r^{I2}.

According to Vidal-Meliá & Boado-Penas (2013), the TD_t^R for the retirement contingency is:

$$TD_t^R = \frac{\sum_{k=0}^{w-xe-A-1} N_{(x_e+A+k,1)} \cdot \ddot{a}^{\lambda}_{x_e+A+k} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^k}{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^k} + \overbrace{\frac{N_{(x_e+A,1)} \cdot \ddot{a}^{\lambda}_{x_e+A} \cdot \sum_{h=1}^{A}\left[\frac{(1+G)}{(1+d)}\right]^h}{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^k}}^{A} - \frac{\sum_{k=0}^{A-1}\sum_{h=0}^{k} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)} \cdot \left[\frac{(1+G)}{(1+d)}\right]^h}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}} \quad \textbf{[31.]}$$

After some algebraic manipulations and taking into account that the second term of **[31.]** is equal to A, the generations of contributors coexisting at each moment in time, the formula can be expressed as:

$$TD_t^R = \underbrace{\overbrace{\frac{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \ddot{a}^{\lambda}_{x_e+A+k} \cdot \left[\frac{1+\lambda}{1+G}\right]^k}{N_{(x_e+A,1)} \cdot \ddot{a}^{\lambda}_{x_e+A}}}^{\text{Pay out duration}}}_{pt_r^R} + A - \underbrace{\overbrace{\frac{\sum_{k=0}^{A-1} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)} \cdot (k+1)}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}}}^{pt_c^R}}_{\text{Pay in duration}} \quad \textbf{[32.]}$$

2.4.-Obtaining the expression for the TD as the difference in the weighted average ages of the pensioners and contributors.

The expressions obtained so far are the basis for determining the TD according to the ages of the contributor and pensioner collectives, and this will make it possible to calculate representative values for the items forming part of the system's contribution asset, and, by comparing them with the liabilities, obtain solvency indicators.

The weighted average age at which contributions cease to be made to the disability contingency, $\bar{x}_t^D$, would be[15]:

$$\bar{x}_t^D = x_e - 1 + \bar{k}_t^D = \frac{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k} \cdot (x_e + k - 1)}{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k}} \qquad \textbf{[33.]}$$

It is important to bear in mind that for the retirement contingency in this model, determining the average age of entry into retirement needs no further calculation because it is assumed that there is just a single retirement age, x_e+A, and contributions for this contingency cease one year earlier. However, formula **[33.]** is similar if not identical in structure to the formula used by the Swedish authorities for the NDC system which only includes the retirement contingency[16].

If we take the expression for the TD^D_t determined by formula **[30.]** and add to it and subtract from it the weighted average age at which disability contingency contributions cease, $\bar{x}_t^D$, the TD can be expressed as the difference between the weighted average age of the disability pensioners, A_r^D, and the weighted average age of the contributors, $A_c^R = A_c^D$:

[15] The weighted average age for receiving the first disability benefit would be one year later given the hypotheses we considered regarding prepayment of contributions and pensions.
[16] See Pensionsmyndigheten (2011), Appendix B. Mathematical Description of the Balance Ratio, formula 2.0.

$$TD_t^D = x_e + \bar{k}_t^D - 1 + \underbrace{\frac{\sum_{k=1}^{A} {}^I\ddot{a}^{\lambda}_{x_e+k} \left(\sum_{h=1}^{k} P^I_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h} \cdot {}_{k-h}p^I_{x_e+h}\right)}{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k}}}_{pt_r^{D1}}$$

$$+$$

$$\underbrace{\frac{\sum_{k=1}^{w-x_e-A-1} {}^I\ddot{a}^{\lambda}_{x_e+A+k} \cdot \left(\sum_{h=1}^{A} P^I_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k-h} \cdot {}_{A+k-h}p^I_{x_e+h}\right)}{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k}}}_{pt_r^{D2}}$$

$$-$$

$$\underbrace{\left(x_e + \bar{k}_t^D - 1 - \bar{k}_t^D + \underbrace{\frac{\sum_{k=0}^{A-1} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)} \cdot (k+1)}{\sum_{k=0}^{A-1} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)}}}_{-pt_c^D}\right)}_{A_c^D} \qquad [34.]$$

Note that, unlike what happens in the retirement contingency, the pay-in can have a negative value in the disability contingency if the weighted average age at which contributions to the disability contingency cease is lower than the weighted average age of the contributors. In fact it is difficult for this situation to come about, but it could happen if the probabilities of becoming disabled were decreasing with the age of the contributors and the system's structure had a great many more younger contributors than older ones.

If the first term (the weighted average age at which contributions to the disability contingency cease) is added to the second and third addends (pay-out) and it is considered that total spending on disability pensions for beneficiaries aged x_e+k years and x_e+A+k years respectively can be expressed by:

$$PT^I_{(x_e+k,1)} = \sum_{h=1}^{k} P^I_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k-h} \cdot {}_{k-h}p_{x_e+h} \qquad [35.]$$

$$PT^I_{(x_e+A+k,1)} = \sum_{h=1}^{A} P^I_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{A+k-h} \cdot {}_{A+k-h}p_{x_e+h} \qquad [36.]$$

then after a few (tedious) algebraic manipulations we get:

$$pt_t^D =$$

$$\overbrace{\frac{\sum_{k=1}^{A}\left({}^{I}\ddot{a}^{\lambda}_{x_e+k} + x_e + \bar{k}_t^D - 1\right)\cdot\left(PT^I_{(x_e+k,1)}\right)}{\sum_{k=1}^{A} P^I_{(x_e+k,1)}\cdot I^N_{(x_e+k,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k}}}^{1} + \overbrace{\frac{\sum_{k=1}^{w-x_e-A-1}\left({}^{I}\ddot{a}^{\lambda}_{x_e+A+k} + x_e + \bar{k}_t^D - 1\right)\cdot\left(PT^I_{(x_e+A+k,1)}\right)}{\sum_{k=1}^{A} P^I_{(x_e+k,1)}\cdot I^N_{(x_e+k,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k}}}^{2} \qquad \textbf{[37.]}$$

Once it has been developed as necessary, the numerator of the first addend (1) of expression **[37.]** can be expressed as:

$$\sum_{k=1}^{A}\left({}^{I}\ddot{a}^{\lambda}_{x_e+k} + x_e + \bar{k}_t^I - 1\right)\cdot PT^I_{(x_e+k,1)} = \sum_{k=1}^{A} PT^I_{(x_e+k,1)}\cdot\left(x_e + \bar{k}_t^I + k - 1\right) + A\cdot\left(\sum_{k=1}^{w-x_e-A-1} PT^I_{(x_e+A+k,1)}\right) \qquad \textbf{[38.]}$$

Continuing along similar lines with the numerator of the second summand (2) of expression **[37.]**, we get:

$$\sum_{k=1}^{w-x_e-A-1}\left({}^{I}\ddot{a}^{\lambda}_{x_e+A+k} + x_e + \bar{k}_t^I - 1\right)\cdot PT^I_{(x_e+A+k,1)} = \sum_{k=1}^{w-x_e-A-1} PT^I_{(x_e+A+k,1)}\cdot\left(x_e + \bar{k}_t^I + k - 1\right) \qquad \textbf{[39.]}$$

If the results of **[38.]** and **[39.]** are added we get:

$$\sum_{k=1}^{A}\left({}^{I}\ddot{a}^{\lambda}_{x_e+k} + x_e + \bar{k}_t^I - 1\right)\cdot PT^I_{(x_e+k,1)} + \sum_{k=1}^{w-x_e-A-1}\left({}^{I}\ddot{a}^{\lambda}_{x_e+A+k} + x_e + \bar{k}_t^I - 1\right)\cdot PT^I_{(x_e+A+k,1)}$$

$$=$$

$$\sum_{k=1}^{A} PT^I_{(x_e+k,1)}\cdot\left(x_e + \bar{k}_t^I + k - 1\right) + A\cdot\left(\sum_{k=1}^{w-x_e-A-1} PT^I_{(x_e+A+k,1)}\right) + \sum_{k=1}^{w-x_e-A-1} PT^I_{(x_e+A+k,1)}\cdot\left(x_e + \bar{k}_t^I + k - 1\right)$$

$$=$$

$$\overbrace{\sum_{k=1}^{A} PT^I_{(x_e+k,1)}\cdot\left(x_e + \bar{k}_t^I + k - 1\right)}^{1} + \overbrace{\sum_{k=1}^{w-x_e-A-1} PT^I_{(x_e+A+k,1)}\cdot\left(x_e + \bar{k}_t^I + A + k - 1\right)}^{2}$$

$$=$$

$$\overbrace{\sum_{k=1}^{A}\left(x_e + \bar{k}_t^I + k - 1\right)\cdot\left(\sum_{h=1}^{k} P^I_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{1+\lambda}{1+G}\right]^{k-h}\cdot {}_{k-h}p^I_{x_e+h}\right)}^{1}$$

$$+$$

$$\overbrace{\sum_{k=1}^{w-x_e-A-1}\left(x_e + \bar{k}_t^I + A + k - 1\right)\cdot\left(\sum_{h=1}^{k} P^I_{(x_e+h,1)}\cdot I_{(x_e+h,1)}\cdot\left[\frac{1+\lambda}{1+G}\right]^{A+k-h}\cdot {}_{A+k-h}p^I_{x_e+h}\right)}^{2} \qquad \textbf{[40.]}$$

If the values for (1) and (2) in **[40.]** are substituted in **[37.]**, the expression for the TD for disability can be formulated according to the difference between the average ages of those receiving disability benefits, by aggregating the first two addends, and the average age of the contributors:

$$TD_t^D = A_r^D - A_c^D =$$

$$\left.\frac{\left(\begin{array}{c}\sum_{k=1}^{A}\left(x_e + \bar{k}_t^I - 1 + k\right)\cdot\left(\sum_{h=1}^{k} P^I_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h} \cdot {}_{k\text{-}h}p^I_{x_e+h}\right) \\ + \\ \sum_{k=1}^{w-x_e-A-1}\left(x_e + \bar{k}_t^I - 1 + A + k\right)\cdot\left(\sum_{h=1}^{A} P^I_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k-h} \cdot {}_{A+k\text{-}h}p^I_{x_e+h}\right)\end{array}\right)}{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k}}\right\} = A_r^D$$

$$- \qquad \textbf{[41.]}$$

$$\left(\frac{\sum_{k=0}^{A-1} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)} \cdot (x_e + k)}{\sum_{k=0}^{A-1} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)}}\right) = A_c^D$$

The alternative formula is:

$$TD_t^D =$$

$$\left.\left(x_e + \bar{k}_t^D - 1\right) + \frac{\left(\begin{array}{c}\sum_{k=1}^{A} k \cdot\left(\sum_{h=1}^{k} P^I_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^{k-h} \cdot {}_{k\text{-}h}p^I_{x_e+h}\right) \\ + \\ \sum_{k=1}^{w-x_e-A-1}\left(A + k\right)\cdot\left(\sum_{h=1}^{A} P^I_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)}\right]^{A+k-h} \cdot {}_{A+k\text{-}h}p^I_{x_e+h}\right)\end{array}\right)}{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k}}\right\} = A_r^D$$

$$- \qquad \textbf{[42.]}$$

$$\left(\frac{\sum_{k=0}^{A-1} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)} \cdot (x_e + k)}{\sum_{k=0}^{A-1} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)}}\right) = A_c^D$$

The second addend of A^D_r in **[42.]** is just a weighted average of the years that the disabled people in the age bands $[x_e+1, x_e+A]$ and $[x_e+A+1, w-1]$ have been receiving disability benefits.

Vidal-Meliá & Boado-Penas (2013) obtained the equivalent expressions to **[41.]** and **[42.]** for the retirement contingency:

$$TD^R_t = \overbrace{(x_e + A - 1) + pt^R_r}^{\text{weighted average age for the retirement pensioners}} - \underbrace{(x_e + A - 1 - pt^R_c)}_{\text{weighted average age for the retirement contributors}} =$$

$$\overbrace{(x_e + A - 1) + \frac{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \ddot{a}^{\lambda}_{x_e+A+k} \cdot \left[\frac{1+\lambda}{1+G}\right]^k}{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^k}}^{\text{weighted average age for the retirement pensioners}} - \underbrace{\left(x_e + A - 1 - A + \frac{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \cdot (k+1)}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}} \right)}_{\text{weighted average age for the retirement contributors}} =$$

$$\underbrace{\frac{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot (x_e + A + k) \cdot \left[\frac{1+\lambda}{1+G}\right]^k}{\sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^k}}_{A^t_r} - \underbrace{\frac{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \cdot (x_e + k)}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}}}_{A^t_c} = A^R_r - A^R_c$$

[43.]

2.5.- Obtaining the system's TD and CA as weighting for the TDs and CAs for each contingency. Compiling the AB.

Once the TD for each contingency has been determined, it is time to formulate the TD for the system, TD^S_t, which derives from the weighting of the various contingencies the system contains. The starting point for obtaining the expression is the value of the system's commitments with contributors and pensioners for the two contingencies:

$$TD_t^S = \frac{V_t^S}{C_t^S} = \frac{{}^I V_t^T + {}^R V_t^T}{C_t^R + C_t^D} = \frac{{}^D V_t^r + {}^D V_t^c + {}^R V_t^r + {}^R V_t^c}{\theta^D \cdot \left((1+G)^{t-1} \cdot \sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \right) + \theta^R \cdot \left((1+G)^{t-1} \cdot \sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \right)} =$$

$$\underbrace{\frac{\overbrace{{}^D V_t^r + {}^R V_t^r}^{\text{liability to pensioners (both contingencies)}}}{(\theta^D + \theta^R) \cdot \left((1+G)^{t-1} \cdot \sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \right)}}_{pt_r^s} + \underbrace{\frac{\overbrace{{}^D V_t^c + {}^R V_t^c}^{\text{liability to pensioners (both contingencies)}}}{(\theta^D + \theta^R) \cdot \left((1+G)^{t-1} \cdot \sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \right)}}_{pt_c^s}$$

[44.]

If we develop the second term of the previous expression, the pay-in for the whole system, pt_c^s, we get:

$$pt_c^S =$$

$$\left\{ \frac{\overbrace{\sum_{k=1}^{A} \sum_{h=k}^{A} P_{(x_e+h,t)} \cdot {}^I l_{(x_e+h,t)}^N \cdot {}^I \ddot{a}_{x_e+h}^{\lambda} \cdot \left[\frac{(1+G)}{(1+d)} \right]^h + P_{(x_e+A,t)} \cdot N_{(xe+A,t)} \cdot \ddot{a}_{xe+A}^{\lambda} \cdot \sum_{h=1}^{A} \left[\frac{1+G}{1+d} \right]^h}^{\text{present value of future pensions (retirement and disability)}}}{(\theta^D + \theta^R) \cdot \left((1+G)^{t-1} \cdot \sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \right)} \right\} (=1)$$

$$-$$

$$\left\{ \frac{\overbrace{(\theta^D + \theta^R) \cdot \left(\sum_{k=0}^{A-1} \sum_{h=0}^{k} N_{(xe+k,t)} \cdot y_{(xe+k,t)} \cdot \left[\frac{1+G}{1+d} \right]^h \right)}^{\text{present value of future system's contributions}}}{(\theta^D + \theta^R) \cdot \left((1+G)^{t-1} \cdot \sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \right)} \right\} (=2)$$

[45.]

In this expression we can simplify the last two terms that appear, first the system's total future pensions (minuend 1) by substituting $\{\theta^D, \theta^R\}$ by their values in **[13.]** and **[16.]**, and also, given that expressions **[28.]** and

$$P_{(x_e+A,1)} \cdot N_{(xe+A,1)} \cdot \ddot{a}_{xe+A}^{\lambda} \cdot \sum_{k=1}^{A} \left[\frac{1+G}{1+d} \right]^k = P_{(x_e+A,1)} \cdot N_{(xe+A,1)} \cdot \ddot{a}_{xe+A}^{\lambda} \cdot A \quad \textbf{[46.]}$$

can be substituted in the numerator, and given that **[29]** and

$$P_{(x_e+A,1)} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^k = P_{(x_e+A,1)} \cdot N_{(x_e+A,1)} \cdot \ddot{a}^{\lambda}_{x_e+A} \qquad \textbf{[47.]}$$

can be substituted in the denominator, the minuend of expression **[45.]** turns out to be a weighted average of $\bar{k}_t^D$ and of A, with the weightings being the respective present actuarial values of the pensions in payment for each contingency, which is equivalent to pension spending for each contingency. In other words, it is a weighted average of the number of years until entry into the pensioner state beginning from age x_e +1 for current contributors, $\bar{k}_t^S \in [1, A]$:

$$\bar{k}_t^S = \frac{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k} \cdot k + P_{(x_e+A,1)} \cdot N_{(x_e+A,1)} \cdot \ddot{a}^{\lambda}_{x_e+A} \cdot A}{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \, {}^I\ddot{a}^{\lambda}_{x_e+k} + P_{(x_e+A,1)} \cdot N_{(x_e+A,1)} \, \ddot{a}^{\lambda}_{x_e+A}} \qquad \textbf{[48.]}$$

The weighted average age at which contributions cease to be paid for both of the system's contingencies, $\bar{x}_t^S$, is a weighted average of $\bar{x}_t^D$, the weighted average age at which contributions cease to be paid for the disability contingency, and of "x_e+A-1" years, the weighted average age at which contributions cease to be paid for the retirement contingency, for the spending on pensions for each contingency. Its expression is:

$$\bar{x}_t^S = x_e + \bar{k}_t^S - 1 = \frac{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k} \cdot (x_e + k - 1) + P_{(x_e+A,1)} \cdot N_{(x_e+A,1)} \cdot \ddot{a}^{\lambda}_{x_e+A} \cdot (x_e + A - 1)}{\sum_{k=1}^{A} P^I_{(x_e+k,1)} \cdot I^N_{(x_e+k,1)} \cdot {}^I\ddot{a}^{\lambda}_{x_e+k} + P_{(x_e+A,1)} \cdot N_{(x_e+A,1)} \cdot \ddot{a}^{\lambda}_{x_e+A}} \qquad \textbf{[49.]}$$

If we work out the second term, 2, of formula **[45.]**, which expresses total future contributions, then the system's pay-in total, pt_c^S, is notably simplified:

$$pt_c^S = \bar{k}_t^S - \frac{\sum_{k=0}^{A-1} N_{(x_e+k,1)} \cdot y_{(x_e+k,1)} \cdot (k+1)}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}} \qquad \textbf{[50.]}$$

Returning to the first term, the system's total pay-out, pt_r^S, of formula **[45.]**, after substituting $\{\theta^D, \theta^R\}$ by their values in **[13.]** and **[16.]**, we get:

$$pt_r^s = \frac{\sum_{k=1}^{A} {}^{I}\ddot{a}^{\lambda}_{x_e+k} \cdot PT^{I}_{(x_e+k,1)} + \sum_{k=1}^{w-x_e-A-1} {}^{I}\ddot{a}^{\lambda}_{x_e+A+k} \cdot PT^{I}_{(x_e+A+k,1)}}{\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I^{N}_{(x_e+k,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k} + P_{(x_e+A,1)} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k}}$$

$$+ \qquad \textbf{[51.]}$$

$$\frac{P_{(x_e+A,1)} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \ddot{a}^{\lambda}_{x_e+A+k} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k}}{\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I^{N}_{(x_e+k,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k} + P_{(x_e+A,1)} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k}}$$

If we consider the following expressions for simplifying the weighted formulas:

$$PT^{D}_{(x_e+k,1)} = \sum_{h=1}^{k} P^{I}_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k-h} \cdot {}_{k-h}p_{x_e+h} \qquad \textbf{[52.]}$$

$$PT^{D}_{(x_e+A+k,1)} = \sum_{h=1}^{w-x_e-A-1} P^{I}_{(x_e+h,1)} \cdot I_{(x_e+h,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{A+k-h} \cdot {}_{A+k-h}p_{x_e+h} \qquad \textbf{[53.]}$$

$$PT^{D} = \sum_{k=1}^{A} PT^{D}_{(x_e+k,1)} + \sum_{k=1}^{w-x_e-A-1} PT^{D}_{(x_e+A+k,1)} \qquad \textbf{[54.]}$$

$$PT^{R} = P_{(x_e+A,1)} \cdot \sum_{k=0}^{w-x_e-A-1} N_{(x_e+A+k,1)} \cdot \left[\frac{1+\lambda}{1+G}\right]^{k} \qquad \textbf{[55.]}$$

the denominator for the system's TD, its total spending on pensions, can be expressed by:

$$PT_t^S = PT_t^D + PT_t^R \qquad \textbf{[56.]}$$

If the TDs for the disability and retirement contingencies $\left\{TD_t^D, TD_t^R\right\}$ are weighted by their respective total spending on pensions as part of the system's total spending on pensions, and given that the denominators $\left\{TD_t^D, TD_t^R\right\}$ are respectively $\left\{PT^D, PT^R\right\}$, we get:

$$TD_t^S = \frac{PT_t^D \cdot TD_t^D + PT_t^R \cdot TD_t^R}{PT_t^S} = \frac{PT_t^D \cdot \frac{NTD_t^D}{PT_t^I} + PT_t^R \cdot \frac{NTD_T^R}{PT_t^R}}{PT_t^S} = \frac{NTD_t^D + NTD_t^R}{PT_t^S} \qquad \textbf{[57.]}$$

an expression in which the numerator is the sum of the numerators of the TDs for disability and retirement, the same as in **[45.]**,

$$NTD_t^S = NTD_t^D + NTD_t^R \qquad \textbf{[58.]}$$

and the denominator is the system's total spending on pensions, PT_t^S.

Thus, given that the numerator, NTD^S, and the denominator, PT^S, are the same as in **[44.]**, the expression coincides with the definition of the system's TD and we can therefore conclude that it can be calculated as a weighted average of the TDs for both contingencies, the weighting being the spending on pensions by contingency as part of total spending.

Just like what happens with the TDs for the contingencies, the system's total TD can also be calculated according to the difference between the average ages of all the beneficiaries for both contingencies and the average age of the contributors.

$$TD_t^S = \frac{PT_t^D \cdot \left[A_r^D - A_c^D\right] + PT_t^R \cdot \left[A_r^R - A_c^R\right]}{PT_t^S} = \frac{PT_t^D \cdot A_r^D + PT_t^R \cdot A_r^R}{PT_t^S} - \frac{PT_t^S \cdot A_c}{PT_t^S} = \frac{PT_t^D \cdot A_r^D + PT_t^R \cdot A_r^R}{PT_t^S} - A_c \quad \textbf{[59.]}$$

To put it a different way, the TD_t^S can be obtained as the difference between the weighted average of the average ages of disability and retirement, the weightings being the spending on pensions per contingency as part of total spending, and the average age of the contributors.

The system's contribution asset, CA_t^S, can therefore be defined as the maximum level of liabilities that can be financed by the contribution rate determined for the system without extraordinary contributions from the sponsor. The value of the CA is the product of the turnover duration TD_t^S and the value of the contributions made in that period for the retirement and disability contingencies. The TD_t^S is interpreted as the number of years expected to elapse before the committed liabilities with contributors and pensioners for retirement and disability are completely renewed at the current contribution level. As Lee (2006) points out, the TD synthesizes into a single number a great deal of information about the system's rules, the age distribution of the population, the age patterns of labor supply and earnings, survival and, in our model, disability rates too[17]. Analytically the CA_t^S can be expressed as:

$$CA_t^S = CA_t^R + CA_t^D = TD_t^S \cdot C_t^S = (A_r^S - A_c^S) \cdot C_t^S = (pt_r^S + pt_c^S) \cdot C_t^S = TD_t^R \cdot C_t^R + TD_t^D \cdot C_t^D = (pt_r^R + pt_c^R) \cdot C_t^R + (pt_r^D + pt_c^D) \cdot C_t^D = (A_r^R - A_c^R) \cdot C_t^R + (A_r^D - A_c^D) \cdot C_t^D = V_t^S = {}^D V_t^T + {}^R V_t^T$$

[17] For Goss (2010), it is often desirable to express the outcome of a complex process in a single number. Historically, a single summary number, referred to as the US AB, has been used as a measure of the financial status of the OASDI program.

[60.]

The AB sheet of a balanced PAYG system can be expressed as shown in Table 1:

Table 1: AB Sheet of a Balanced PAYG System	
ASSETS	**LIABILITIES**
Contribution Asset for disability= CA_t^D	Liability to pensioners for disability = ${}^{D}V_t^r$
	Liability to contributors for disability = ${}^{D}V_t^c$
Contribution Asset for retirement = CA_t^R	Liability to pensioners for retirement = ${}^{R}V_t^r$
	Liability to contributors for retirement = ${}^{R}V_t^c$
Total Assets = CA_t^S	**Total Liabilities =** V_t^S

The solvency index (ratio), $SI_t^S = \frac{CA_t^S}{V_t^S}$, is equal to one in the case of a balanced pension system. Consequently, at the date of the balance sheet participants have a realistic expectation of receiving the benefits that have been foreseen, without the system's sponsor having to make periodic contributions, as long as the system's rules and the economic and demographic conditions prevailing at the time of valuation remain constant. Solvency is clearly never completely assured in the long term as neither the assets nor the liabilities are known in their entirety.

It is worth highlighting, as Lee (2006) indicated for the case of the retirement contingency, that when using this framework for actual, nonsteady state situations, "we have to imagine stopping time at two intervals and using a comparative static comparison between them". This is the approach developed in practice. In the Swedish case, for example, Pensionsmyndigheten (2011), the balance sheet is compiled every year according to verifiable events and transactions, but it tends to provide a true and fair view because successive changes are included as they are registered in consecutive balance sheets, and consequently the solvency indicator remains reasonably reliable[18].

However, the real situation of the system would in practice be an AB in which other elements would or could appear, such as: financial assets, resulting from an accumulation of treasury surpluses; financial liabilities, resulting from an accumulation of treasury deficits; actuarial deficits, resulting from an accumulation of actuarial losses; or actuarial surpluses, resulting from an accumulation of actuarial profits. The system's actuarial profit or loss, which should not be confused with the treasury surplus or deficit, $C_t^S - PT_t^S$, is determined by

[18] See the papers by Auerbach & Lee (2009a and 2009b).

comparing the system's assets and liabilities in two consecutive periods, and the real solvency index must consider these elements in order to provide a true and fair view.

Last but not least, the model makes it possible to obtain an actuarial income statement by contingency, thereby enriching the information on the sources from which future financial imbalances in the system may originate and making it easier to set the contribution rates that should be applied for each contingency. The results mainly depend on annual financial variations (treasury surpluses or deficits, return on financial assets and costs of liabilities), on the evolution of the economic factors (contributors, contribution bases, the structure of the economic activity that has an impact on disability rates), on demographic factors (longevity of the various collectives) and on the rules of the pension system.

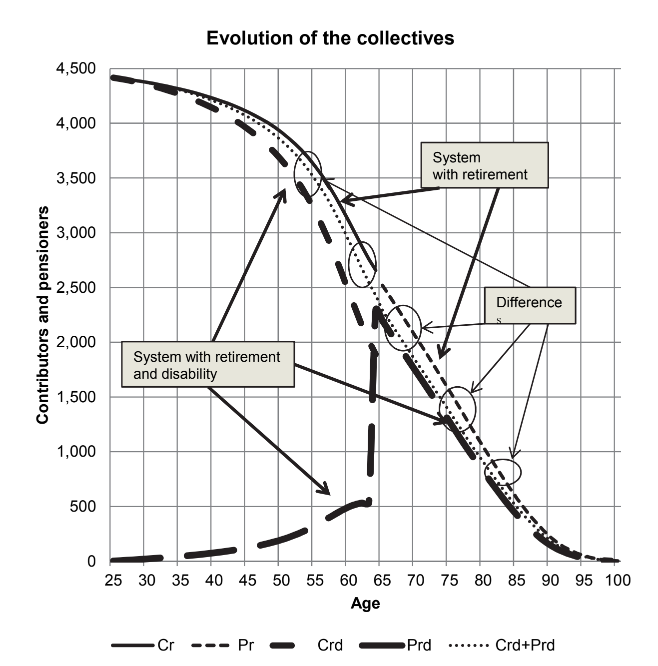
4.-Numerical example.

Our starting point in this section is the numerical example developed by Vidal-Meliá & Boado-Penas (2013). They work with contributors and pensioners by age and contributions (wages) and a “mature” pension structure, 36 years after the system's inception, assuming that g grows at an annual accumulative rate of 1%, the population grows at an annual accumulative rate of 2%, and the pension payable to pensioners at age 65 is 80% of the previous 40 years' contributions and constant in real terms (λ =0%).

With these conditions, see Table 2, the contribution rate for balance is 16.51% and the TD is 27.59 years (weighted average age of pensioners 73.32 years, weighted average age of contributors 45.72 years) distributed over 9.32 years for the pay-out and 18.28 years for the pay-in. The contributor-pensioner ratio is 4.5 and the financial ratio 0.7427. As a result, according to formula **[21.]**, the product is the system's contribution rate.

If from the start we extend this initial system by adding a disability contingency in which a contributor who becomes disabled receives a pension with a variable replacement rate that depends on age and contributions made in such a way that a contributor who becomes disabled at age 64, the last age at which it is possible to contribute, would receive a pension identical to that which would be payable on retirement at 65, in the new steady state, 75 years after the system's inception. The evolution of the pensioner and contributor collectives is shown in Figure 1.

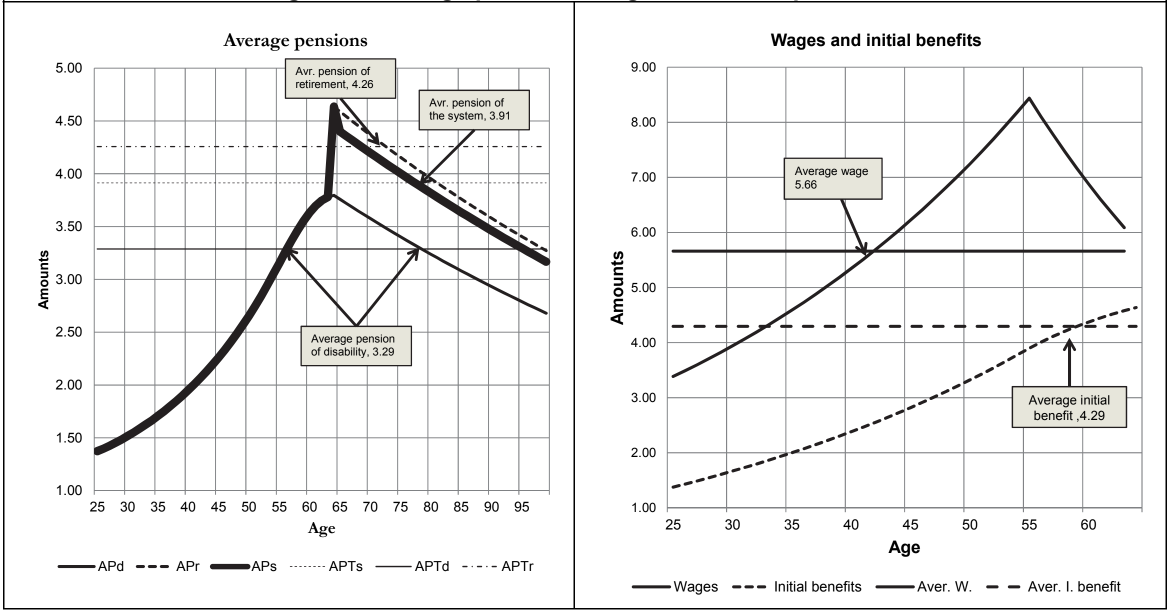
Figure 1: Evolution of the collectives.



The table shows the evolution of contributors and pensioners in both systems, that with base retirement only (Cr, Pr) and that with both contingencies separated (Crd, Prd). The two separate contingencies are also shown combined (Crd +Prd) so that the result can be compared with the base retirement model. It can be seen that in the new system there are two types of beneficiary, disability pensioners and retirement pensioners, and that the collective as a whole is smaller than that of the base system because of two effects: disabled people do not live as long, and population growth does not affect the two systems in the same way, since a large proportion of the disabled group is of survivors and not affected by all the increases in population. Differences by age are shown in the graph by ellipses and reach their maximum at age 65, after which they are decreasing. The two collectives, the system with only retirement and the one with both retirement and disability, would only coincide under the additional supposition of equal longevity for both disabled and non-disabled (active or retired), when zero population growth is assumed. If population growth has a positive value, given the way in which disability is determined, the growth rate of the disabled is lower than that of the contributing population. Therefore, if both collectives are compared, there are always fewer for all ages in the collective (Crd +Prd). The greatest difference comes about at age 65. If there is a decrease in the population the opposite occurs.

Figure 2 shows the evolution of average pensions, wages and initial pensions by age, and also average pensions by contingency, the total for the system, the total average wage and the system's average initial pension. The average disability pension (APd) by age is growing, given that a higher pension is awarded when more contributions have been made, while the average retirement pension (APr) and disability pension (APd) strictly for the retirement period is decreasing because once the pension is awarded it remains constant in real terms.

Figure 2: Average pensions, wages and initial pensions.



The main values making up the new system's equilibrium and their comparison with the previous situation are shown in Table 2.

Table 2: Pension system with two contingencies: some selected values. Comparison with the base scenario obtained by Vidal-Meliá & Boado-Penas (2013).

Items	Base*	Retirement + Disability		
	Retirement	Retirement	Disability	System
θ	0.16511	0.12461	0.05297	0.17758
fr	0.743	0.752	0.581	0.691
dr	0.222	0.166	0.091	0.257
A_r **(years)**	73.316	73.316	64.890	70.802
A_c **(years)**	45.724	44.954	44.954	44.954
TD_t **(years)**	27.592	28.362	19.936	25.849
$\bar{x}_t$ **(years)**	64.000	64.000	54.614	61.200
pt_c **(years)**	18.276	19.046	9.661	16.247
pt_r **(years)**	9.316	9.316	10.276	9.602
Base scenario with G=(1.01)(1.02)-1=0.0302				

Our attention is drawn to two aspects in particular:

1.-The slight increase in the contribution rate for the system as a whole when compared to the base system, despite the fact there is a new contingency. This is mainly due to two reasons. Firstly there is a transfer of beneficiaries who were previously considered retired and who, in the new system, despite being of retirement age, originate in disability. Secondly, as mentioned earlier, disabled people have a lower life expectancy, which lowers the cost of the contingency.

If we were to falsely consider those disabled people who reach retirement age as retirement pensioners, a phenomenon known as “pension reclassification”, the apparent cost of retirement would increase noticeably. Indeed, if it were supposed that those disabled people who reach or pass normal retirement age were reclassified as retirees, the contribution rate assigned to retirement would increase from 0.12461 to 0.15177, while the rate for disability would go down from 0.05297 to 0.02581. The image of the system as a whole would not change from 0.17758, but there would be some not very transparent transfers between contingencies because of the change in the average TD for each contingency.

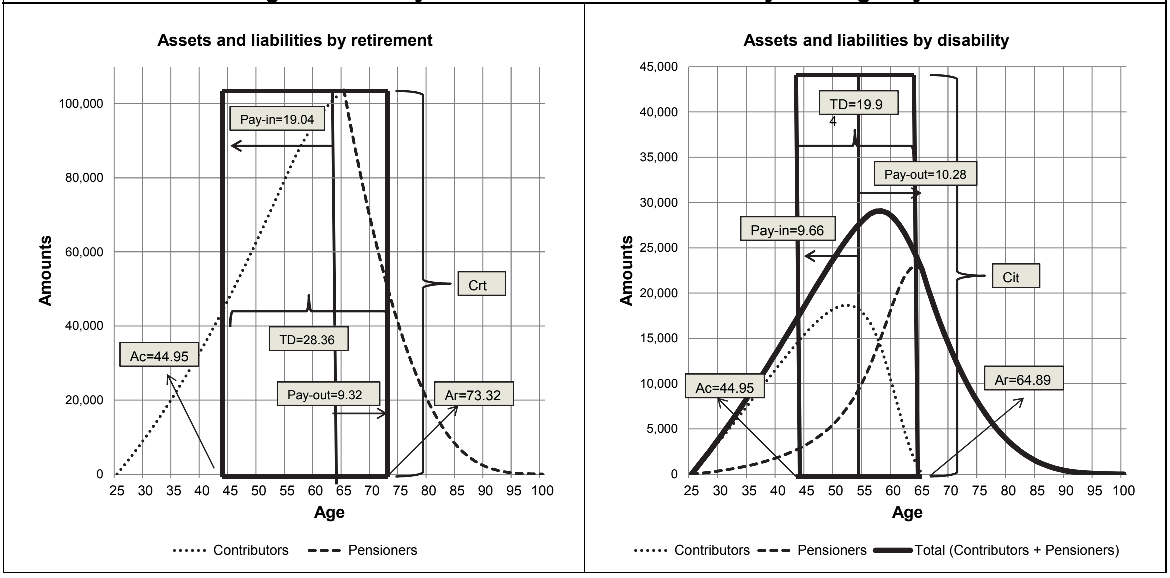
2.-The slight variation in the base system's TD along with that of the retirement contingency in the integrated system, brought about by the slight change in the average age of the contributors after considering decrements through disability. The system's TD does change more noticeably due to the effect of the disability contingency, which makes the weighted average age at which the last contribution is made almost ten years earlier than for the retirement contingency. It can also be shown that the system's TD is a weighted average of the TDs for the contingencies, the weighting element being the contribution rate per contingency. This is due to the fact that the annual income from contributions coincides with the annual spending on pensions and in turn corresponds to the new pensions awarded during the year.

As regards the liabilities that the system takes on with contributors and pensioners for both contingencies and their relationship with the contribution asset, the profiles by age seen from various perspectives are shown in Figures 3 and 4.

The first part of Figure 3, the system's assets and liabilities by contingency, which corresponds to the retirement contingency, shows a profile in line with the initial assumptions that the system's total commitments increase with the age of the contributor, given that contributions accumulate until the age at which one becomes entitled to receive retirement pension, then from that moment on, due to the fact that pensions are decreasing with age because they were awarded in earlier periods and because the number of pensioners is also decreasing, they gradually become smaller. The liabilities for retirement perfectly match the contribution asset for retirement. The liabilities for retirement is the area beneath the curve for contributors and pensioners, while the contribution asset for retirement is the area represented by the base rectangle, the difference between the weighted average ages of pensioners and contributors, and the height is the amount of the contributions made per contingency[19].

[19] This is equivalent to the present value of benefits awarded during the period.

Figure 3: The system's assets and liabilities by contingency



The second part of Figure 3, the system's assets and liabilities by contingency, is for the disability contingency. The system's total commitments for this contingency, in which contributors and pensioners are superimposed, is the result of aggregating the commitments with pensioners and contributors which present a different dynamic. As far as contributors are concerned, and unlike in the case of retirement, the profile for the system's commitments follows an outline typical of risk contingencies, an increase up to a maximum at a particular age, and then a decrease until it disappears. The explanation is obvious. The obligation to contribute comes to an end and the system's commitment with the contributor is extinguished because disability can no longer come about.

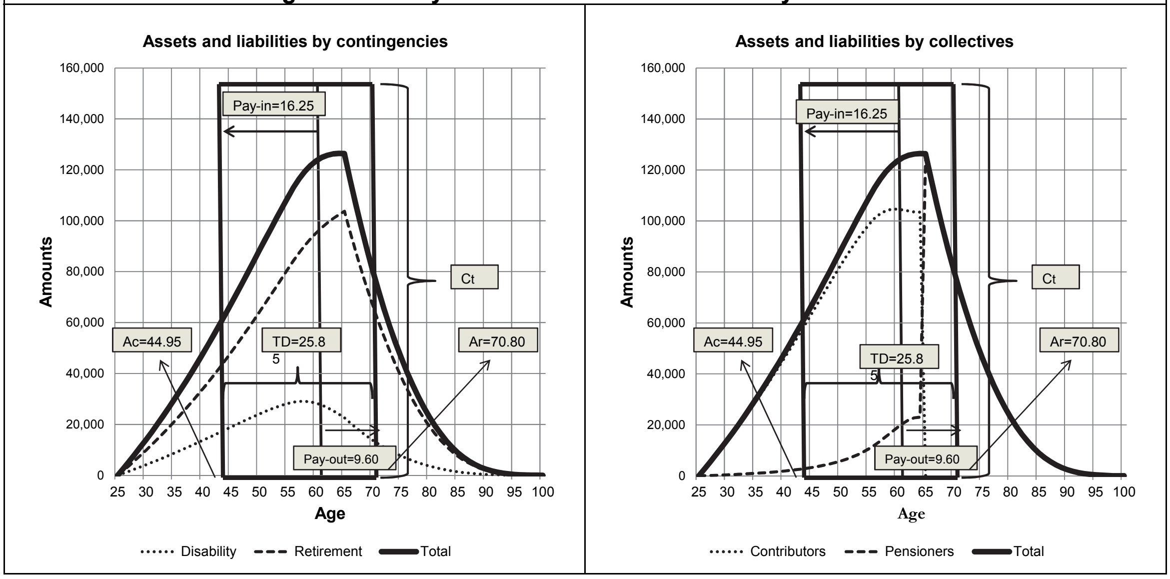
In the case of disability pensioners, the commitments increase with age until they reach a maximum at age 64, from which time no more disability pensions can be awarded. From here on, due to the fact that pensions are decreasing with age, the commitments gradually become smaller because the pensions were awarded in earlier periods and because the number of pensioners is also decreasing.

The total liabilities for disability match perfectly with the contribution asset for disability. The total liability for disability is the area below the total curve. The contribution asset for disability is the area represented by the base rectangle, the difference between the weighted average ages of the disability pensioners and contributors, while the height is the amount of contributions paid for the contingency[20].

[20] Like in the case of the retirement contingency, this is equivalent to the present value of the disability benefits awarded during the period.

Figure 4, the system's (total) assets and liabilities by contingency, shows the perspective from the system's point of view. The system's liabilities is the aggregation of the liabilities by contingency or collective, and the contribution asset derives from the system's turnover duration which is a weighted average of the TDs of each contingency multiplied by the spending on pensions of each contingency. The profile for the system's total liabilities mainly follows the outline for the main contingency

Figure 4: The system's assets and liabilities by collective



Everything shown in Figures 3 and 4 is quantified and included in the AB sheet presented in Table 3, which shows the values for each of the items that make up the balance, and in which it is possible to have a numerical view of the “matching” of the system's different capital amounts that go to determine a solvency indicator equal to the unit.

Table 3: AB sheet of a balanced PAYG system. Numerical example.					
ASSETS			LIABILITIES		
Items	Amount	%	Items	Amount	%
CA_t^D	879,191.64	23.005	${}^{D}V_t^r$	453,158.65	11.858
			${}^{D}V_t^c$	426,032.99	11.148
CA_t^R	2,942,507.93	76.995	${}^{R}V_t^r$	966,488.69	25.289
			${}^{R}V_t^c$	1,976,019.25	51.705
CA_t^S	**3,821,699.57**	**100.000**	V_t^S	**3,821,699.57**	**100.000**
Base scenario with G=(1.01)(1.02)-1=0.0302					

The picture that the same system would provide with pension reclassification, Table 4, would have noticeable effects on the structure of the balance by contingency, although the final outcome as regards assets and liabilities is identical to the system without reclassification. The so-called true and fair view of the system would be distorted.

It can be said that the reclassification of pensions, which is normal practice in some public SSAs, leads to distortions when assigning both assets and liabilities, which, although it has no consequences in overall terms when the system is balanced, may indeed have consequences and very serious ones when a real unbalanced system is studied.

Table 4: AB sheet of a balanced PAYG system. Numerical example with "pension reclassification"					
ASSETS			**LIABILITIES**		
Items	**Amount**	**Items**	**Amount**	**Items**	**Amount**
CA_t^D	250,580.11	6.557	${}^{D}V_t^r$	43,013.95	1.126
			${}^{D}V_t^c$	207,566.16	5.431
CA_t^R	3.571,119.46	93.443	${}^{R}V_t^r$	1,164,380.68	30.468
			${}^{R}V_t^c$	2,406,738.77	62.976
CA_t^S	**3,821,699.57**	**100.000**	V_t^S	**3,821,699.57**	**100.000**
Base scenario with G=(1.01)(1.02)-1=0.0302					

4.- Concluding remarks and future research.

Concern about the financial health of public pension systems in all its various designations (solvency, sustainability, viability, equilibrium) brought about by the ageing of the population, the fall in the rate of economic growth and bad practices in system management, occupies a very prominent place on the agenda of many governments and international organizations such as the World Bank, the OECD and the ILO, and can therefore be said to be a matter of world importance. It is no exaggeration to say that the problems of pension systems are a recurring theme in economic policy and are of permanent topical interest for many citizens in various countries.

A basic element for improving pension system management and bringing the planning horizons of the authority in charge of the system and the contributors and pensioners closer together is full information. As Regúlez-Castillo & Vidal-Meliá (2012) point out, the aim is to show the situation of the pension system by providing an indicator of financial solvency, sustainability or solidity, the most vital goal being to convey to contributors and pensioners the message that their pensions depend on two things: the individual effort deriving from their actions - amounts contributed, contribution history, retirement age - and the collective situation, i.e. the system's ability to fulfil all its acquired obligations.

The instrument from which the overall indicators are derived is the one known as the "AB", the main examples of which are the "Swedish" and "US" models. The biggest drawback of the Swedish model, from the perspective of applying it to defined benefit systems, is that its theoretical base was only developed for the purpose of using it for the retirement contingency.

In this paper we have developed the theoretical base for applying the Swedish-type AB to both retirement and disability contingencies in a DB PAYG system, thereby laying the first stone towards filling the large gap that exists in the literature in this field. Also, this model starts to make it possible to assess the degree of solvency from the integrated perspective of both retirement and disability contingencies, which are linked together and represent a very high proportion of spending on pensions in DB systems.

The basic element that enables the AB to be compiled is what is known as the system's “contribution asset”, which, in the model developed and in line with what the authors already believed intuitively, is a weighted average of the contribution assets of the two contingencies which make up the system and which depend on the economic-demographic structures of the system's collectives, contributors and pensioners, in the so-called “mature” state.

The model makes it possible to obtain an actuarial income statement by contingency, thereby providing richer information about the sources from which future financial imbalances could appear and making it easy to set the contribution rates that should be applied for each contingency.

On the practical side, the numerical example developed enables a debate to be opened regarding the appropriateness of a generalized practice carried out by many public SSAs: pension reclassification. This (bad) practice involves considering as disability pensions those pensions being paid to disabled people who reach the usual age of retirement. This is an unhealthy phenomenon because it masks the system's real solvency situation and makes it very difficult to obtain accurate actuarial results by contingency, and therefore may act as a way of camouflaging early retirements or decrements from the labor market as false disabilities. It also makes it more difficult to make projections of the pensioner collective by “mixing” two collectives (retirement pensioners and disability pensioners of retirement age) with different mortality rates. It should be pointed out that private capitalization pension systems that cover retirement and disability contingencies do not reclassify pensions once they are in payment as this would prevent them from correctly determining the actuarial result by contingency.

The model developed has many other practical implications which could be of interest not only to DB systems but also to notional defined contribution schemes (NDC), social security actuaries, public finance economists and policy-makers. For example, as regards the current pension system in Sweden, the NDC model, which only covers the retirement contingency, this could be extended to cover disability now that the relationship between both contingencies is clear. The AB could be compiled for both contingencies, which would thus notably increase its representativeness as it would include a higher proportion of total spending on pensions, and the legitimacy of applying an ABM would also be strengthened as the action would be based on a more reliable solvency indicator. This would be one of the points where this research could most naturally be extended, by having to integrate one of the peculiarities of the Swedish NDC model: the so-called survivor dividend.

Further work could be carried out on the model developed here, with future research extending into at least four additional areas:

1.-By considering different degrees of disability and/or the possibility of a return to active life. In practice there are usually various degrees of disability recognized and these have a direct effect on the amount of benefit paid and the likelihood or not of returning to active life. The most natural way to do this would be to extend the states in Diagram 1, which would obviously involve a considerable increase in the complexity of the formulas to be obtained.

2.-By extending the model (the AB) with the incorporation of widows' and/or survivor contingencies, which would enable virtually all spending on pensions in DB systems to be included.

3.-By extending the model (the AB) with the incorporation of long-term care as a contributory contingency, as has been offered in the German contributory pension system since the mid-1990s. Given the accelerated ageing process taking place in developed countries, long-term care is an area of considerable interest that needs to be specifically taken into account as a cost with fundamental links to retirement and certain degrees of disability.

4.-By considering a stochastic rather than a determinist actuarial valuation model, either by using an analytical approximation, Iyer (2008), or simulation models, as proposed by Buffin (2007) and OACT (2009) for the US-type AB, and by Melis & Trudda (2012) for Italy. Instead of the traditional determinist actuarial valuation, in other areas of finance and private insurance there is already widespread use of stochastic models, but they have yet to become normal practice when analyzing social security systems, where it is only in the last decade that the beginnings of such work has been seen.

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Appendix 1.- The system's contribution rate in a "mature" state.

To obtain the evolution of contribution rates $\left\{\theta^{I},\theta^{R}\right\}$ over time, the following accounting rule needs to be applied: "income from the system's contributions should be equal to the expenditure on pensions".

Year 1:

$$\overbrace{\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I_{(x_e+k,1)}}^{\text{Expenditure on disability benefits}} + \overbrace{\beta \cdot Y_{C,0} \cdot N_{(x_e+A,1)}}^{\text{Expenditure on retirement benefits}} = \overbrace{\left(\theta^{I}_{1}+\theta^{R}_{1}\right) \cdot \sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}}^{\text{incomes from contributions}} \quad \textbf{[61.]}$$

The contribution rates that exactly achieve financial equilibrium are aggregate benefit expenditure divided by the aggregate contribution base:

$$\left(\theta^{D}_{1}+\theta^{R}_{1}\right)=\frac{\sum_{k=0}^{A-1} b^{I}_{k} \cdot y_{(x_e+k,1)} \cdot N_{(x_e+k,1)} \cdot i_{x_e+k} + \beta \cdot Y_{C,0} \cdot N_{(x_e+A,1)}}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}} \quad \textbf{[62.]}$$

…

Year t:

$$\sum_{k=1}^{A} P^{I}_{(x_e+k,t)} \cdot I^{N}_{(x_e+k,t)} + \underbrace{\sum_{k=2}^{A} P^{S}_{(x_e+k,t)} \cdot I^{S}_{(x_e+k,t)}}_{\text{disability pensions of previous years (working ages)}} +$$

$$+\underbrace{P^{I}_{(x_e+A+1,t)} \cdot I_{(x_e+A+1,t)} + P^{I}_{(x_e+A+2,t)} \cdot I_{(x_e+A+2,t)} + \ldots + P^{I}_{(x_e+A+t-1,t)} \cdot I_{(x_e+A+t-1,t)}}_{\text{disability pensions of previous years (retirement ages)}}$$

$$+\beta \cdot Y_{C,0} \cdot (N_{(x_e+A,1)} \cdot (1+G)^{s-1} + N_{(x_e+A+1,1)} \cdot (1+G)^{s-2} \cdot (1+\lambda) + N_{(x_e+A+2,1)} \cdot (1+G)^{t-3} \cdot (1+\lambda)^{2}$$

$$+ \ldots\ldots + N_{(x_e+A+t-1,1)} \cdot (1+\lambda)^{t-1}) =$$

$$\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I_{(x_e+k,1)} \cdot (1+G)^{t-1} + \sum_{k=2}^{A}\left(\sum_{s=Máx\{1,k-t+1\}}^{k-1} P^{I}_{(x_e+s,1)} \cdot (1+g)^{t-1-k+s} \cdot (1+\lambda)^{k-s} \cdot I_{(x_e+s,1)} \cdot (1+\gamma)^{t-1-k+s} \cdot {}_{k-s}p^{I}_{x_e+s}\right)$$

$$+\sum_{k=1}^{t-1} P^{I}_{(x_e+A+k,t)} \cdot I_{(x_e+A+k,t)} +$$

$$+\beta \cdot Y_{C,0} \cdot (N_{(x_e+A,1)} \cdot (1+G)^{s-1} + N_{(x_e+A+1,1)} \cdot (1+G)^{s-2} \cdot (1+\lambda) + N_{(x_e+A+2,1)} \cdot (1+G)^{t-3} \cdot (1+\lambda)^{2}$$

$$+ \ldots\ldots + N_{(x_e+A+t-1,1)} \cdot (1+\lambda)^{t-1}) =$$

$$\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I_{(x_e+k,1)} \cdot (1+G)^{t-1} + \sum_{k=2}^{A}\left(\sum_{s=Máx\{1,k-t+1\}}^{k-1} P^{I}_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot (1+G)^{t-1-k+s} \cdot (1+\lambda)^{k-s} \cdot {}_{k-s}p^{I}_{x_e+s}\right)$$

$$+\sum_{k=1}^{t-1} P^{I}_{(x_e+A,\ t-k)} \cdot (1+\lambda)^{k} \cdot I_{(x_e+A,t-k)} \cdot {}_{k}p^{I}_{x_e+A} +$$

$$+\beta \cdot Y_{C,0} \cdot (N_{(x_e+A,1)} \cdot (1+G)^{t-1} + N_{(x_e+A+1,1)} \cdot (1+G)^{t-2} \cdot (1+\lambda) + N_{(x_e+A+2,1)} \cdot (1+G)^{t-3} \cdot (1+\lambda)^{2}$$

$$+ \ldots\ldots + N_{(x_e+A+t-1,1)} \cdot (1+\lambda)^{t-1}) =$$

$$\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I_{(x_e+k,1)} \cdot (1+G)^{t-1} + \sum_{k=2}^{A}\left(\sum_{s=Máx\{1,k-t+1\}}^{k-1} P^{I}_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot (1+G)^{t-1-k+s} \cdot (1+\lambda)^{k-s} \cdot {}_{k-s}p^{I}_{x_e+s}\right) +$$

$$+\sum_{k=1}^{t-1}\left(\sum_{s=Máx\{1,A+1-t+k\}}^{A} P^{I}_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot (1+G)^{t-k-A-1+s} \cdot (1+\lambda)^{A+k-s} \cdot {}_{A+k-s}p^{I}_{x_e+s}\right) +$$

$$+\beta \cdot Y_{C,0} \cdot (N_{(x_e+A,1)} \cdot (1+G)^{s-1} + N_{(x_e+A+1,1)} \cdot (1+G)^{s-2} \cdot (1+\lambda) + N_{(x_e+A+2,1)} \cdot (1+G)^{t-3} \cdot (1+\lambda)^{2}$$

$$+ \ldots\ldots + N_{(x_e+A+t-1,1)} \cdot (1+\lambda)^{t-1}) =$$

$$\sum_{k=1}^{A}\left(\sum_{s=Máx\{1,k-t+1\}}^{k} P^{I}_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot (1+G)^{t-1-k+s} \cdot (1+\lambda)^{k-s} \cdot {}_{k-s}p^{I}_{x_e+s}\right) +$$

$$\sum_{k=l}^{t-1}\left(\sum_{s=Máx\{1,A+1-t+k\}}^{A} P^{I}_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot (1+G)^{t-k-A-1+s} \cdot (1+\lambda)^{A+k-s} \cdot {}_{A+k-s}p^{I}_{x_e+s}\right)$$

$$+\beta \cdot Y_{C,0} \cdot \sum_{k=0}^{t-1} N_{(x_e+A+k,1)} \cdot (1+G)^{t-1-k} \cdot (1+\lambda)^{k}$$

[63.]

Then, the contribution rates for year “t” are calculated as:

$$\left(\theta_t^D+\theta_t^R\right)=\frac{\sum_{k=1}^{A}\left(\sum_{s=Máx\{1,\,k-t+1\}}^{k}P^I_{(x_e+s,\,1)}\cdot I_{(x_e+s,\,1)}\cdot(1+G)^{t-1-k+s}\cdot(1+\lambda)^{k-s}\cdot\ {}_{k-s}p^I_{x_e+s}\right)}{(1+G)^{t-1}\cdot\sum_{k=0}^{A-1}y_{(x_e+k,\,1)}\cdot N_{(x_e+k,\,1)}}$$
$$+\frac{\sum_{k=1}^{t-1}\left(\sum_{s=Máx\{1,\,A+1-t+k\}}^{A}P^I_{(x_e+s,\,1)}\cdot I_{(x_e+s,\,1)}\cdot(1+G)^{t-k-A-1+s}\cdot(1+\lambda)^{A+k-s}\cdot\ {}_{A+k-s}p^I_{x_e+s}\right)}{(1+G)^{t-1}\cdot\sum_{k=0}^{A-1}y_{(x_e+k,\,1)}\cdot N_{(x_e+k,\,1)}} \quad \textbf{[64.]}$$
$$+\frac{\beta\cdot Y_{C,0}\cdot\sum_{k=0}^{t-1}N_{(x_e+A+k,\,1)}\cdot(1+G)^{t-1-k}\cdot(1+\lambda)^{k}}{(1+G)^{t-1}\cdot\sum_{k=0}^{A-1}y_{(x_e+k,\,1)}\cdot N_{(x_e+k,\,1)}}$$

Year "w-x_e-A" counted from the system's inception

The highest age for any member of the group, at which point there are no longer any survivors, is defined as "w". Therefore, from date "w-x_e-A" counted from the system's inception, the probability that an individual of age "x_e+A" will reach age "w" is zero. In addition, all survival probabilities from that year onwards are also zero for that cohort.

${}_{w-x_e-A}p_{x_e+A}$: probability that an individual of age "x_e+A" will reach age limit w, verifies

$0={}_{w-x-A}p_{x_e+A}={}_{w-x_e-A+1}p_{x_e+A}={}_{w-x_e-A+2}p_{x_e+A}=\ldots$

Thus when t ≥ w-(x_e +A) we get:

$$\left(\theta_t^D+\theta_t^R\right)=\frac{\sum_{k=1}^{A}\left(\sum_{s=Máx\{1,\,k-t+1\}}^{k}P^I_{(x_e+s,\,1)}\cdot I_{(x_e+s,\,1)}\cdot(1+G)^{t-1-k+s}\cdot(1+\lambda)^{k-s}\cdot\ {}_{k-s}p^I_{x_e+s}\right)}{(1+G)^{t-1}\sum_{k=0}^{A-1}y_{(x_e+k,\,1)}N_{(x_e+k,\,1)}}$$
$$+\frac{\sum_{k=1}^{t-1}\left(\sum_{s=Máx\{1,\,A+1-t+k\}}^{A}P^I_{(x_e+s,\,1)}\cdot I_{(x_e+s,\,1)}\cdot(1+G)^{t-k-A-1+s}\cdot(1+\lambda)^{A+k-s}\cdot\ {}_{A+k-s}p^I_{x_e+s}\right)}{(1+G)^{t-1}\cdot\sum_{k=0}^{A-1}y_{(x_e+k,\,1)}\cdot N_{(x_e+k,\,1)}} \quad \textbf{[65.]}$$
$$+\underbrace{\frac{\beta\cdot Y_{C,0}\cdot\sum_{k=0}^{w-(x_e+A)-1}N_{(x_e+A+k,\,1)}\cdot(1+G)^{t-1-k}\cdot(1+\lambda)^{k}}{(1+G)^{t-1}\cdot\sum_{k=0}^{A-1}y_{(x_e+k,\,1)}\cdot N_{(x_e+k,\,1)}}}_{\text{contingencia de jubilación}=\theta_t^R}$$

The third term of equation **[65.]** does not depend on period "t" and can be simplified. Hence the contribution rate for the retirement contingency is:

$$\theta_t^R = \frac{\beta \cdot Y_{C,0} \cdot \left(\sum_{k=0}^{w-(x_e+A)-1} N_{(x_e+A+k,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)} \right]^k \right)}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}} = \theta \qquad \textbf{[66.]}$$

However, the first two terms of equation **[65.]**, the contribution rate for the disability contingency, still depend on period "t" considered from the system's inception.

Year "w-x_e-1" counted from the system's inception

For the disability contingency, from date "w-x_e-1" counted from the system's inception, the probability that a disabled person of age "x_e+k" with k ∈ {1, …, A} will reach age "w" is zero, and all survival probabilities from that year onwards are also zero for that cohort:

${}_{w-(x_e+k)}p^I_{x_e+k}$: probability that a disabled person of age "x_e+k" will reach age limit w verifies:

$$0 = {}_{w-(x_e+k)}p^I_{x_e+k} = {}_{w-(x_e+k+1)}p^I_{x_e+k} = {}_{w-(x_e+k+2)}p^I_{x_e+k} = \cdots = {}_{w-(x_e+A)}p^I_{x_e+A}$$

In addition, when t ≥ w-x_e-1, it is obvious that ∀k ∈ {1, …, A} verifies k+1 ≤ t, so then $\text{Max}\{1, k-t+1\} = 1$. Likewise ∀k ∈ {1, …, w-1-(x_e+A)} also verifies that A+k+1 ≤ t, so then $\text{Max}\{1, A+k-t+1\} = 1$. As a result, the system's contribution rate can be expressed as:

$$\left(\theta_t^D + \theta_t^R\right) = \underbrace{\frac{\sum_{k=1}^{A} \left(\sum_{s=1}^{k} P^I_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)} \right]^{k-s} \cdot {}_{k-s}p^I_{x_e+s} \right)}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}} + \frac{\sum_{k=1}^{w-1-(x_e+A)} \left(\sum_{s=1}^{A} P^I_{(x_e+s,1)} \cdot I_{(x_e+s,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)} \right]^{A+k-s} \cdot {}_{A+k-s}p^I_{x_e+s} \right)}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}}}_{\left(\theta_t^D = \text{rate of contribution for disability}\right)} + \underbrace{\frac{\beta \cdot Y_{C,0} \cdot \left(\sum_{k=0}^{w-(x_e+A)-1} N_{(x_e+A+k,1)} \cdot \left[\frac{(1+\lambda)}{(1+G)} \right]^k \right)}{\sum_{k=0}^{A-1} y_{(x_e+k,1)} \cdot N_{(x_e+k,1)}}}_{\left(\theta_t^R = \text{rate of contribution for retirement}\right)} \qquad \textbf{[67.]}$$

Appendix 2.-Liabilities to current contributors by disability in year t = w-x_e-1 counted from the system's inception.

Current contributors may not reach retirement age in the labour market for two reasons - death or permanent disability - and therefore both probabilities need to be taken into account.

The present actuarial value of future disability benefits in t= w-x_e-1 years is:

- Contributors aged "x_e+A-1" years:

$$P^{I}_{(x_e+A,\,t+1)}\cdot I^{N}_{(x_e+A,\,t+1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+A}\cdot(1+d)^{-1}= \\ =P^{I}_{(x_e+A,\,1)}\cdot I^{N}_{(x_e+A,\,1)}\cdot(1+G)^{t}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+A}\cdot(1+d)^{-1} \qquad \textbf{[68.]}$$

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- Contributors aged "x_e" years:

$$P^{I}_{(x_e+1,\,t+1)}\cdot I^{N}_{(x_e+1,\,t+1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+1}\cdot(1+d)^{-1}+P^{I}_{(x_e+2,\,t+2)}\cdot I^{N}_{(x_e+2,\,t+2)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+2}\cdot(1+d)^{-2} \\ +P^{I}_{(x_e+3,\,t+3)}\cdot I^{N}_{(x_e+3,\,t+3)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+3}\cdot(1+d)^{-3}+....+P^{I}_{(x_e+A-1,\,t+1+A-2)}I^{N}_{(x_e+A-1,\,t+1+A-2)}\,{}^{I}\ddot{a}^{\lambda}_{x_e+A-1}(1+d)^{-(A-1)} \\ +P^{I}_{(x_e+A,\,t+1+A-1)}I^{N}_{(x_e+A,\,t+1+A-1)}\,{}^{I}\ddot{a}^{\lambda}_{x_e+A}(1+d)^{-A}= \\ =P^{I}_{(x_e+1,\,1)}\cdot I^{N}_{(x_e+1,\,1)}\cdot(1+G)^{t}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+1}\cdot(1+d)^{-1}+P^{I}_{(x_e+2,\,1)}\cdot I^{N}_{(x_e+2,\,1)}\cdot(1+G)^{t+1}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+1}\cdot(1+d)^{-2} \\ +P^{I}_{(x_e+3,\,1)}\cdot I^{N}_{(x_e+3,\,1)}\cdot(1+G)^{t+2}\,{}^{I}\cdot\ddot{a}^{\lambda}_{x_e+2}\cdot(1+d)^{-3}+...+P^{I}_{(x_e+A,\,1)}\cdot I^{N}_{(x_e+A,\,1)}\cdot(1+G)^{t+1+(A-2)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+A}(1+d)^{-A} \\ =\sum_{h=1}^{A}P^{I}_{(x_e+h,\,1)}\cdot I^{N}_{(x_e+h,\,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+h}\cdot(1+G)^{t+1+h-2}\cdot(1+d)^{-h} \qquad \textbf{[69.]}$$

Consequently, if we add from x_e+1 to x_e+A we get:

$$\sum_{k=1}^{A}\sum_{h=k}^{A}P^{I}_{(x_e+h,\,1)}\cdot I^{N}_{(x_e+h,\,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+h}\cdot(1+G)^{t+1+h-2}\cdot(1+d)^{-h} \\ = \\ (1+G)^{t-1}\cdot\sum_{k=1}^{A}\sum_{h=k}^{A}P^{I}_{(x_e+h,\,1)}\cdot I^{N}_{(x_e+h,\,1)}\cdot {}^{I}\ddot{a}^{\lambda}_{x_e+h}\cdot\left[\frac{(1+G)}{(1+d)}\right]^{h} \qquad \textbf{[70.]}$$

but we can add diagonally to obtain the equivalent expression to **[70.]:**

$$\begin{bmatrix} P^{I}_{(x_e+A,1)} \cdot I^{N}_{(x_e+A,1)} \cdot {}^{I}a^{\lambda}_{x_e+A} \sum_{h=1}^{A} (1+G)^{t+1+h-2} \cdot (1+d)^{-h} + \\ P^{I}_{(x_e+A-1,1)} \cdot I^{N}_{(x_e+A-1,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+A-1} \cdot \sum_{h=1}^{A-1} (1+G)^{t+1+h-2} \cdot (1+d)^{-h} \\ P^{I}_{(x_e+A-2,1)} \cdot I^{N}_{(x_e+A-2,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+A-2} \cdot \sum_{h=1}^{A-2} (1+G)^{t+1+h-2} \cdot (1+d)^{-h} + \ldots. \\ \ldots\ldots.. + P^{I}_{(x_e+2,1)} \cdot I^{N}_{(x_e+2,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+2} \cdot \sum_{h=1}^{2} (1+G)^{t+1+h-2} \cdot (1+d)^{-h} + \\ + P^{I}_{(x_e+1,1)} \cdot I^{N}_{(x_e+1,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+1} \cdot (1+G)^{t} \cdot (1+d)^{-1} \end{bmatrix}$$

$$=$$

$$\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I^{N}_{(x_e+k,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k} \left(\sum_{h=1}^{k} (1+G)^{t+1+h-2} \cdot (1+d)^{-h} \right)$$

$$= \qquad \textbf{[71.]}$$

$$(1+G)^{t-1} \left(\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I^{N}_{(x_e+k,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k} \left(\sum_{h=1}^{k} (1+G)^{h} \cdot (1+d)^{-h} \right) \right)$$

$$=$$

$$(1+G)^{t-1} \cdot \left(\sum_{k=1}^{A} P^{I}_{(x_e+k,1)} \cdot I^{N}_{(x_e+k,1)} \cdot {}^{I}\ddot{a}^{\lambda}_{x_e+k} \left(\sum_{h=1}^{k} \left[\frac{(1+G)}{(1+d)} \right]^{h} \right) \right)$$

The present value of future contributions is:

- Contributors aged "x_e+A-1" years:

$$\left(\theta^{D}\right) \cdot \left[N_{(x_e+A-1,1)} \cdot y_{(x_e+A-1,1)} \cdot (1+G)^{t} \right] \qquad \textbf{[72.]}$$

……………………………………………………………………………..

- Contributors aged "x_e" years:

$$\left(\theta^{D}\right) \cdot \begin{bmatrix} N_{(x_e,1)} \cdot y_{(x_e,1)} \cdot (1+G)^{t} + N_{(x_e+1,1)} \cdot y_{(x_e+1,1)} \cdot (1+G)^{t+1} \cdot (1+d)^{-1} + \\ \ldots\ldots\ldots\ldots\ldots\ldots + N_{(x_e+A-1,1)} \cdot y_{(x_e+A-1,1)} \cdot (1+G)^{t-1+A} \cdot (1+d)^{-(A-1)} \end{bmatrix} \qquad \textbf{[73.]}$$

Therefore:

$$
\left(\theta^{D}\right)\cdot\left[\begin{array}{l}
N_{(x_e+A-1,1)}\cdot y_{(x_e+A-1,1)}\cdot\sum_{h=0}^{A-1}(1+G)^{t+h}\cdot(1+d)^{-h}+\\
N_{(x_e+A-2,1)}\cdot y_{(x_e+A-2,1)}\cdot\sum_{h=0}^{A-2}(1+G)^{t+h}\cdot(1+d)^{-h}+\ldots.\\
\ldots\ldots\ldots\ldots\ldots\ldots+N_{(x_e,1)}\cdot y_{(x_e,1)}\cdot(1+G)^{t}
\end{array}\right]
$$

$$
= \qquad \textbf{[74.]}
$$

$$
\left(\theta^{D}\right)\cdot\left(\sum_{k=0}^{A-1}\sum_{h=0}^{k}N_{(x_e+k,1)}\cdot y_{(x_e+k,1)}\cdot(1+G)^{t+h}\cdot(1+d)^{-h}\right)
$$

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