China-USA Business Review, ISSN 1537-1514
June 2012, Vol. 11, No. 6, 836-843

Defined Benefit and Defined Contribution Retirement Plan Simulations

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The focus of this paper is the effect of changes to employer sponsored retirement plans on employee retirement benefits. Today's retirement benefits consist mainly of three types of plans: defined benefit (DB), defined contribution (DC), and "hybrid" plans. Many employers have changed the type of plan they offered in recent years. Specifically, there is a shift from DB plans to DC plans. A retirement benefit comparison is made between a DB plan and a DC plan under different scenarios which depend on years of work, market yield, interest rates, and predicted wage increases. Using simulation modeling, DB and DC benefits are compared over different career lengths for a worker with a starting salary of $50,000. Simulated fluctuations in annual market yield and average national wage increases are used to project DC balances. DB benefits are simulated using random fluctuations in both wage increases and interest rates used for lump sum conversions. The resulting simulated benefits show that DC plans are generally inferior to DB plans. In addition, simulated DC retirement account balances have a much higher standard deviation than the present value of traditional DB plan annuities. However, DB benefits that are converted to lump sums have standard deviations closer to those of DC lump sums due to the variability of interest rates used in the conversion of DB annuities to a lump sum.

Keywords: retirement, benefit projection, retirement simulation, defined contribution (DC), defined benefit (DB)

Introduction/Background

During the past thirty years, employers have transitioned from offering traditional defined benefit (DB) retirement plans to defined contribution (DC) plans. The drawback of DC plans is that the money is typically invested in mutual funds and is subject to market volatility (Coombes, 2009). In addition, the money available to the individual at retirement under a contributory plan is a lump sum. This requires the retiree to then be responsible for turning that money into income during their retirement years, typically purchasing a life annuity with the funds. In contrast, defined benefit plans are not subject to market volatility and are paid out as life annuities.

Another common alternative to DB and DC plans in recent times is to combine the concept of the defined

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benefit and defined contribution plans into a hybrid plan—these plans have a variety of names such as: cash balance (Lowman, 2000), pension equity (Green, 2003), or stable value. These hybrid plans accumulate an employee account balance in a similar fashion to the defined contribution plan, but the income earns fixed interest and is not invested in the stock market. Typically, hybrid plans are less valuable than either DB or DC plans.

Employees across the country are facing changes to their retirement benefits. When such changes occur, employers typically send benefit statements to the employees, projecting how the change may affect future benefits. These projections are simplistic and assume constant yield, project wage increases and interest assumptions. Therefore, it is difficult for employees to understand the future impact of changes on their retirement plans.

Employers sponsoring a DB plan, whether changing the plan provisions or not, are required to send statements to their employees that typically include a benefit projected to age 65. In the case of a DC plan, the employer may send a periodic statement showing a projected benefit amount, otherwise, it is up to the employees to plan for their own retirement by doing a projection. For both DB and DC plans, these projections make constant growth assumptions for wage increases and market yield. In addition, the conversion rates between lump sums and annuities for future benefits are unknown, making a comparison between DB and DC benefits difficult.

Rather than using the typical constant increase method for projecting benefits for both DC and DB plans (Bishop, Schumacher, & Heeder, 2011), simulation techniques allow us to project benefits in a more realistic manner. In addition, it is beneficial to see the variation that occurs over a long period of time.

For example, suppose the employees are 40 years old and their DC benefit statement shows current and projected lump sum benefits. The hypothetical current balance might be $100,000. The projected balance assuming continued employment until age 65 might be $553,462.00 (this is also a hypothetical value). The projection is based on a constant salary increase and constant market yield. Presenting a benefit of 25 years in the future is not realistic. In reality, the amount that the employee is likely to receive at age 65 is a range of values depending on future increases.

Considering the same sample employee receiving a DB benefit statement. In this case, the current benefit earned is a single life annuity benefit that is payable at age 65. A hypothetical amount might be $20,000 per year. The projected benefit assuming continued employment might be $61,240 per year payable starting at age 65. This projected amount is only a guess of what might happen in the future based on future salary increases.

In order to compare the value of the DB plan benefit with the DC plan benefit, one of the benefits must be converted to the same form of payment as the other benefits. At any point in time, a fair conversion rate can be determined based on reasonable interest and mortality assumptions. For example, supposing this factor is 10.0000, then the DB annuity is worth $61,240 × 10.0000 = $612,400. Therefore, the DB plan life annuity is worth more than the DC benefit of $553,462.

The first set of simulations presented within demonstrates the stability of the defined benefit annuity value. These simulations utilize actual national average wage increases over the past 59 years (as used by the social security administration), and market yield data over the same 59 year period. Simulated benefits are also computed over different length careers. In this case, the annuity conversion to lump sum is kept fixed using current interest and mortality assumptions. The resulting simulation produces a more realistic projection, and includes the advantage of displaying a range of possible benefit values.

More recently, DB plans often offer lump sum benefit payments in addition to the life annuity payment option. The conversion rates for determining DB plan lump sum values are defined by the Pension Protection Act of 2006. Additional simulations are presented for the conversion of DB plan annuities to DB plan lump sum benefits using randomized interest rates used for the conversion of the life annuity to a lump sum amount. The interest rates come from the Moody Aaa corporate bond annual rates from 1976 to 2010. These rates are an approximation of rates required for lump sum conversion by the Pension Protection Act of 2006.

The second set of simulations demonstrates that defined benefit lump sums are much more volatile than defined benefit life annuities, but still much less volatile than defined contribution balances.

Simulation Methodology

Defined contribution account balances are projected based on simulated stock market performance using the S&P as the benchmark. The amount contributed to the account each year is a percentage of the employee's pay and so a wage projection is also necessary in order to determine the amount allocated to the account annually. In all cases, we have assumed a starting salary of $50,000.

An excel-based simulation software package, @RISK, was utilized to test the various retirement scenarios. For each projected service period, i.e., 25 years, 35 years, and 45 years, 10,000 simulated projections were performed. A discrete uniform distribution was used to randomly generate wage increases and S&P increases based on equally likely probabilities for all annual increase percentages from years 1950 to 2009.

In order to minimize the variation in results for the comparisons between DB and DC benefits, the random numbers used in both formulas were the same. Therefore, each simulated wage projection is the same for both DB and DC benefits.

For the first set of simulations, the defined benefit calculations only require a wage increase simulation. These benefits do not depend on the market but only depend on a benefit formula based on final salary and length of service. This benefit is expressed as an annual life annuity, therefore, conversion to a single lump sum benefit is required when the comparison with a DC balance is made. The conversion rate used within is the January, 2011 PPA projected spot rate required for conversion of annuities to lump sum benefits. The current conversion factor is 12.265 (i.e., the lump sum is worth 12.265 times an annual life annuity).

The future conversion rate could be anywhere from approximately 8.0 to 14.0 for benefit conversions being performed in the future. These varying conversion rates are simulated in the second set of simulations presented in the results section below.

Both DC and DB retirement plans are simulated based on both a better than average plan formula, and worse than average plan formula. The following assumptions and simulation parameters are summarized below:

- Current salary of $50,000;
- Discrete random selection of national average wage increases from 1950 to 2009;
- Discrete random selection of S&P annual increases from 1950 to 2009;
- Benefit accrual begins on the date of hire (also called service start age);
- Service start ages of 20, 30, and 40;
- DC is made mid-year;
- Semi-annual interest compounding;

- Actuarial conversion factors for various forms and timing of benefit payments are based on current Pension Protection Act assumptions (2010 mortality and yield rates for January 1, 2011) (Hamilton & Burns, 2001).

Research Design

Simulation 1—Comparison of Defined Benefit and Defined Contribution Present Value of Annuity

The simulation results presented within provide a range of likely retirement benefit amounts based on the level of benefit the employer offers. All benefit projections are simulated lump sum values payable at age 65 for both DB and DC retirement plans.

First, consider a typical projected defined contribution plan benefit assuming a 5% of pay employer contribution for an employee aged 40, retiring at age 65. The 5% contribution assumption is based on an approximate average large company DC plan (range is roughly 2%-8%). The resulting range of simulated lump sum retirement values is displayed in Figure 1.

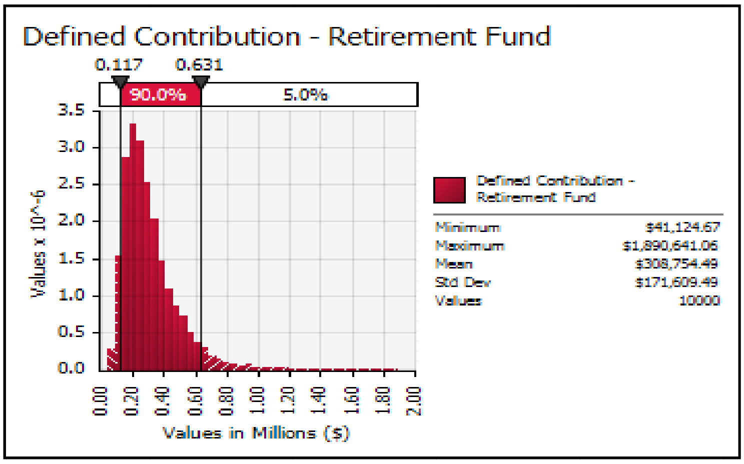

Figure 1. Defined contribution retirement lump sum.

In contrast, a typical DB benefit formula (Hamilton & Burns, 2001), also assuming a 40-year old employee projected to retire at age 65, computed using a typical 1.5% multiplier (1.5% times (years of service) times (final five average annual salaries) times (lump sum conversion factor)) is simulated in Figure 2.

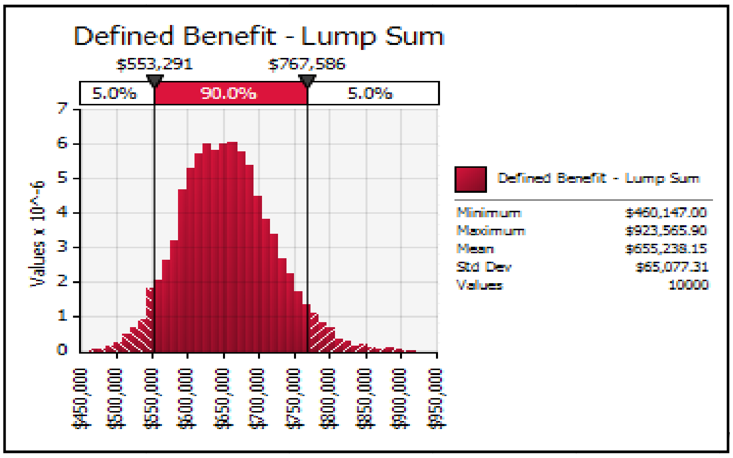

Figure 2. Defined benefit present value of life annuity.

For this example, the DB formula produces a significantly larger benefit value (mean = $644,238, standard deviation = $65,077) than the corresponding DC formula (mean = $308,754, standard deviation = $171,069). However, there is a much larger deviation in the value of the DC benefit and a long upper-end tail to the simulation distribution. Considering that the rates used for the DB plan (1.5%) and DC plan (5%) are in the middle range of what these plans typically offer in private industry, the DB plan produces a far more valuable and stable benefit.

The Tables below summarize the simulations for employees' entering their retirement plans at ages 40, 30, and 20 respectively. All values assume retirement at age 65. The three rate levels chosen for the tables represent high, medium, and low rates for DC and DB plans in private industry.

Table 1 highlights benefit comparison projections for a shorter career. Since the DC plan benefit simulation distribution has a long right tail, the median is a good central measure for comparison with the DB plan. The mid-range DC rate (5%) has a simulated median benefit of $268,524. This is only 41.2% of the benefit that is produced by the mid-range DB median benefit ($652,384).

Table 1

Twenty five Years—Start Contributing Age 40—Retire Age 65

	Defined benefit			Defined contribution		
Contribution rate/Fixed benefit rate	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
8%/2%	$873,651	$869,945	$86,770	$494,007	$429,638	$274,575
5%/1.5%	$655,238	$652,384	$65,078	$380,754	$268,524	$171,609
2%/1%	$436,825	$434,923	$43,385	$123,502	$107,409	$68,644

Table 1 also demonstrates that the DC plan at 8% is comparable to a DB plan with a 1% formula, particularly if the median is the measure considered for projected benefit values. An 8% contribution rate is considered better than average for a DC plan and yet a 1% multiplier is (or was) considered less than average for a DB plan. Therefore, DC plans in general are not as generous as DB plans.

The mid-range DC rate (5%) in Table 2 has a simulated median benefit of $681,501. This is 47.0% of the benefit that is produced by the mid-range DB median benefit ($1,448,882). Finally, over a long career, the mid-range DC rate (5%) in Table 3 has a simulated median benefit of $1,600,815. This is only 54.3% of the benefit that is produced by the mid-range DB median benefit ($2,950,163).

Table 2

Thirty five Years—Start Contributing Age 30—Retire Age 65

	Defined benefit			Defined contribution		
Contribution rate/Fixed benefit rate	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
8%/2%	$1,944,841	$1,931,843	$232,519	$1,341,659	$1,090,402	$948,552
5%/1.5%	$1,458,631	$1,448,882	$174,389	$838,537	$681,501	$592,845
2%/1%	$972,421	$965,921	$116,256	$333,563	$273,764	$231,596

Table 3

Forty Five Years—Start Contributing Age 20—Retire Age 65

	Defined benefit			Defined contribution		
Contribution rate/Fixed benefit rate	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
8%/2%	$3,976,011	$3,933,550	$545,029	$3,401,857	$2,561,304	$2,971,182
5%/1.5%	$2,982,008	$2,950,163	$408,772	$2,126,161	$1,600,815	$1,856,989
2%/1%	$1,988,005	$1,966,775	$272,514	$850,464	$640,326	$742,796

In addition, over a longer career (Table 2 and Table 3), the DC plan fares better and the 8% DC benefit get closer to being comparable to the 1.5% DB plan. The DB multiplier of 1.5%, considered an average DB multiplier, would require more than 8% contributions from a DC plan to provide the same retirement income.

Simulation 2—Comparison of Defined Benefit and Defined Contribution Lump Sum Amounts

This simulation varies the interest rates used to convert the defined benefit annual life annuity to a lump sum amount. The interest rates are sampled by discrete random selection of Moody Aaa corporate bond annual rates from 1976-2010. No changes have been made to the defined contribution simulations. Defined benefit simulations will be compared with the defined contribution results above.

As in Simulation 1, consider an employee aged 40, retiring at age 65. The first set of results simulates the defined benefit lump sum values assuming a 1.5% multiplier (1.5% times (years of service) times (final five average annual salaries) times (lump sum conversion factors)). One thousand simulation results are displayed in Figure 3.

Based on the results displayed in Figure 3, the mean value of the lump sum simulations is $499,973 (standard deviation = $93,897). This is significantly lower than the mean value of $655,238 (standard deviation = $65,078) computed in simulation 1. The reason for this difference is that interest rates are currently very low relative to the 35 years that are used for the simulation. Therefore most of the simulations use a higher interest rate and that results in lower lump sum factors.

Table 4, Table 5, and Table 6 summarize the simulations for employees' entering their retirement plan at ages 40, 30, and 20 respectively. All values assume retirement at age 65. Noting that there is no change to the defined contribution values.

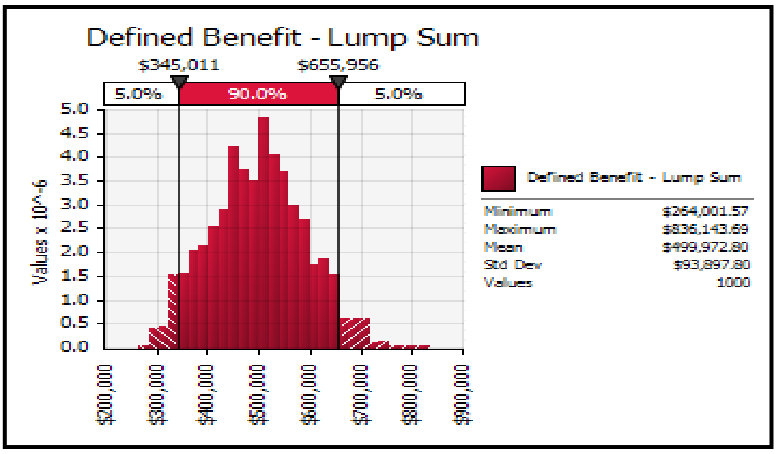

Figure 3. Defined benefit lump sum.

Table 4

Lump Sum—25 Years—Start Contributing Age 40—Retire Age 65

	Defined benefit			Defined contribution		
Contribution rate/Fixed benefit rate	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
8%/2%	$666,630	$669,292	$125,197	$494,007	$429,638	$274,575
5%/1.5%	$499,973	$501,969	$93,898	$380,754	$268,524	$171,609
2%/1%	$333,315	$334,646	$62,599	$123,502	$107,409	$68,644

Table 5

Lump Sum—35 Years—Start Contributing Age 30—Retire Age 65

	Defined benefit			Defined contribution		
Contribution rate/Fixed benefit rate	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
8%/2%	$1,484,418	$1,474,813	$297,951	$1,341,659	$1,090,402	$948,552
5%/1.5%	$1,113,314	$1,106,110	$223,463	$838,537	$681,501	$592,845
2%/1%	$742,209	$737,407	$148,976	$333,563	$273,764	$231,596

Table 6

Lump Sum—45 Years—Start Contributing Age 20—Retire Age 65

	Defined benefit			Defined contribution		
Contribution rate/Fixed benefit rate	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
8%/2%	$3,034,007	$2,989,222	$638,744	$3,401,857	$2,561,304	$2,971,182
5%/1.5%	$2,275,505	$2,241,916	$479,058	$2,126,161	$1,600,815	$1,856,989
2%/1%	$1,517,004	$1,494,611	$319,372	$850,464	$640,326	$742,796

Table 4 allows a comparison of lump sum benefit projections for a shorter career. The mid-range DC rate (5%) has a simulated median benefit of $268,524 (standard deviation = $171,609). This is only 53.5% of the benefit that is produced by the mid-range DB median benefit ($501,969, standard deviation = $93,898).

The mid-range DC rate (5%) in Table 5 has a simulated median benefit of $681,501. This is 61.6% of the benefit that is produced by the mid-range DB median benefit ($1,106,110). Finally, over a long career, the mid-range DC rate (5%) in Table 6 has a simulated median benefit of $1,600,815. This is only 71.4% of the benefit that is produced by the mid-range DB median benefit ($2,241,916).

It is worthy to note that for a long career (45 years) at the high DC plan rate (8%) and high DB plan rate (2%), the mean of the DC plan lump sum benefits ($3,401,857) is actually higher than the mean for the DB lump sum benefits ($3,034,007).

Conclusion and Discussion

The simulation of projected benefits clarifies the relationship between DC and DB plan retirement values. DB plans generally have a more stable life annuity benefit and are typically more generous than their DC plan counterparts. The DC plan benefits are much more volatile due to unpredictable stock market yield on the plan contributions. However, when DB plans offer lump sum benefits, the interest rate variability creates wide fluctuations in lump sum values from year to year. Simulation of interest rates used to convert the DB annual annuity to a lump sum benefit demonstrates this variability.

The more recent existence of hybrid plans is another interesting topic for discussion. These are DB plans, but also have features of a DC plan. Hybrid plans have benefits defined as account balances just as DC plans, and are offered as life annuities as well. The hybrid benefit balances are usually not dependent on the stock market but also have a much lower average return rate on contributions. The overall lump sum values of a hybrid plan is generally comparable or less than that of a DC plan. Simulation for a hybrid plan would likely show a more stable lump sum values than either the traditional DB or DC plan lump sums.

References

Bishop, J., Schumacher, P., & Heeder, K. (2011). Comparison of retirement benefit plans in a changing economy. *China-USA Business Review, 10*(6), 469-474.

Coombes, A. (2009, October 6). *Steady savers gained over 5-year period*. Retrieved from http://www.marketwatch.com/story/401ks-took-big-but-not-devastating-hit-in-2008-2009-10-06

Green, L. (2003, October 29). *What is a pension equity plan?* Retrieved from http://www.bls.gov/opub/cwc/cm20031016ar01p1.htm

Hamilton, B., & Burns, B. (2001, December 31). *Reinventing retirement income in America.* Retrieved from http://www.ncpa.org/pub/st248?pg=5

IRS. (2009, September 5). *Choosing a retirement plan: Defined benefit plan*. Retrieved from http://www.irs.gov/retirement/article/0,,id=108950,00.html

Kamenir, J. (2009). How to make defined benefit pension plans attractive to 21st century employers. *Benefits Quarterly, 25*(2), 51-56.

Lowman, T. (2000, July 7). *Actuarial aspects of cash balance plans*. Retrieved from http://www.soa.org/files/pdf/actuarial_aspects.pdf

McGill, D., Brown, K., Haley, J., & Schieber, S. (2005). *Fundamentals of private pensions*. Oxford, N.Y.: Oxford University Press.