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A Monte Carlo study of the strategies for 401(k) plans: dollar-cost-averaging, value-averaging, and proportional rebalancing

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Abstract

This study conducts Monte Carlo simulations to compare the performances of three popular asset allocation strategies in the financial press, that is, dollar-cost-averaging, value averaging, and proportional rebalancing, in the 401(k) plan framework. Value-averaging generates a higher terminal value for a retirement portfolio than the other two strategies. Total risk of the portfolio is lower under value averaging than under dollar cost averaging. Value averaging provides the highest reward-to-risk ratio as well as the highest likelihood of meeting the investment goal. Based on the overall consideration of terminal value, total risk, modified Sharpe ratio, modified Sortino ratio, and dominance frequency, a targeted annual growth rate of between 9% and 11% for the equity account should be used as the target growth rate in conducting value averaging. © 2010 Academy of Financial Services. All rights reserved.

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1. Introduction

Three strategies are frequently discussed in the financial press for retirement investing. They are dollar-cost-averaging (DCA), value-averaging, and proportional rebalancing (PR).[1] Under dollar-cost-averaging, investors make the same contribution to their portfolios at the

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same time each period regardless of whether the market is up or down. Similarly, the approach of proportional rebalancing requires that investors periodically adjust the composition of securities to their target proportion, for example, 30% in bonds and 70% in equities, the optimal mix. Under value averaging, investors mechanically move funds into or out of the portfolio so that a dollar amount target is reached in each period. All three are mechanical trading strategies that help avoid emotional pitfalls in investing.

Addressing the fact that most participants in 401(k) plans do not have the large amount of liquid funds required to allow them to pursue value averaging in its pure form, Chen and Estes (2007) propose a feasible value averaging approach (hereafter feasible VA) within the 401(k) plan framework. In this approach, investors use the bond portfolio as a capital reserve and the equity portfolio as the driver for the growth of the retirement account. For each investment period, surplus funds are moved out the equity account into the bond account if the growth target in the equity account is met, or additional funds from the bond account are moved into the equity account if the growth target is not met. Chen and Estes conducted back-testing with historical data and Monte Carlo simulations to show that feasible VA outperforms DCA in achieving a higher terminal value (TV) at retirement. However, they did not compare the performance of feasible VA approach against that of the proportional rebalancing strategy.

This study conducts simulations to compare the merits of all three strategies within the framework of a 401(k) plan. The rest of the paper is organized as follows. Section 2 provides a comparison of the three strategies. Section 3 discusses data and methodology. Section 4 reports simulation results. Section 5 summarizes and concludes.

2. Examples of the three strategies: a comparison

Table 1 presents a comparison of the three strategies. The DCA approach stipulates that an investor periodically makes the same contribution for example, $1,000/month with 30% in bonds and 70% in stocks, regardless of whether markets are up or down. As shown in Panel A of Table 1, at the beginning of Month 2, the new monthly contribution of $1,000 is divided based on the 30–70 ratio and invest into the bond account and the equity account automatically. Similarly, under the PR strategy, the sum of ending balance of Month 1 and the new monthly contribution are reallocated according to the predetermined optimal proportion, that is, 30% in bonds and 70% in stocks, at the beginning of Month 2.

In contrast, under feasible VA, the stock account is used as the driver and the bond account as a natural capital reserve. Because the predetermined growth rate for the stock account is met in Month 1, money is moved out of the stock account into the bond account to build up capital reserve. Therefore, the new contribution to the stock account at the beginning of Month 2 is only $686 under feasible VA, less than the amount of $700 under DCA or $694.75 under PA.

Panel B of Table 1 presents the adjustments in the case of a equity return below the monthly growth target. Because the equity return in a month is −10%, well below the 1% monthly growth target under the feasible VA, more funds are moved into the equity account from the bond account to make up the shortfall, provided that the amount of addition to the

Table 1 Comparison of DCA, feasible VA, and PR

Panel A. Positive equity return—Previous month's bond return of 0.5% and equity return of 3%		DCA		Feasible VA		PR	
Month		Bonds	Stocks	Bonds	Stocks	Bonds	Stocks
0	Ending balance	$300	$700	$300	$700	$300	$700
1	Ending balance	$301.5	$721	$301.5	$721	$301.5	$721
2	Adjustment	+$300	+$700	+$314	+$686	+$305.25	+$694.75
2	Beginning balance	$601.5	$1,421	$615.5	$1,407	$606.75	$1,415.75
Panel B: Negative equity return—Previous month's bond return of 0.5% and equity return of −10%							
0	Ending balance	$300	$700	$300	$700	$300	$700
1	Ending balance	$301.5	$630	$301.5	$630	$301.5	$630
2	Adjustment	+$300	+$700	+$223	+$777	+$277.95	+$722.05
2	Beginning balance	$601.5	$1,330	$524.5	$1,407	$579.45	$1,352.05

A monthly contribution of $1,000 and a target allocation is 30% for bonds and 70% for equities for all three strategies. In addition, a monthly growth target of 1% is assumed for the strategy of feasible VA. Given hypothetical returns for bonds and equities, adjustments are made under each strategy. Under DCA, an investor divides the monthly contribution and adds the portion to the previous balance of the bond account and the stock account, respectively. Under PR, an investor adds the monthly contribution to the combined balances of the bond and the stock accounts and divides the amount according to the target proportion. Under feasible VA, an investor adjusts the balance of the bond account and that of the stock account according to whether or not the monthly growth target for the stock account is met. Under feasible VA, the losses in the stock account is made up by moving funds in the bond account into the stock account to meet the growth target, limited by the balance of the bond account, as is the case in Panel B.

stock account does not exceed the balance of the bond account. For example, as shown in Panel b, there will be an infusion of $777 into the equity account under feasible VA, larger than either $700 under DCA or $722.05 under PR.

Results in Table 1 illustrate two important insights. First, all three strategies are mechanical, which helps individual investors to avoid the classic emotional rollercoaster ride in investing.[2] However, different from DCA, both the feasible VA strategy and the proportional rebalancing strategy are more active, which may afford investors a better opportunity to "buy low and sell high."

Of course, the results in Table 1 are hypothetical. Even though all three strategies start with the same amount in the first month, it is not possible to infer from the example in Table 1 how these three strategies will fare in terms of the TVs because of the fluctuations in the monthly returns for bonds and stocks in subsequent months. To shed light on the performance of the three strategies, we conduct Monte Carlo simulations.

3. Data, assumptions, and methodology

3.1. Data and assumptions

Chen and Estes (2007) based their return assumptions on historical data. For example, using monthly T-bill returns from 1934 to 2003 as provided by the Federal Reserve, they adopt a normality assumption for the return process with a mean return of 0.32% and standard deviation of 0.267% for the bond portfolio. Based on the monthly return of the Standard & Poor's 500 index from 1926 to 2003 as provided by the Center for Research in Security Prices (CRSP), they assume a mean return of 0.639% and standard deviation of 5.627%.

As in Chen and Estes (2007), we adopt a normality assumption for the return process for both bonds and stocks. However, we extend the T-bill returns data from 2003 to 2009. Based on the extended T-bill rate data, we assume that the average monthly rate of return is 0.32% and the standard deviation is 0.26% for the bond portfolio. On the other hand, we also extend the S&P 500 index returns to the period of 1900–2009 as provided by Global Financial Data. Based on the extended historical data, we assume a mean stock return of 0.61% and standard deviation of 0.461%.

Notice that all returns are nominal returns. Finally, using the data from 1934 to 2009, we calculate the correlation coefficient between T-bill returns and stock returns. The correlation coefficient is −0.02.

3.2. Methodology: simulation design

As in Chen and Estes (2007), we use an investment horizon of 360 months, that is, 30 years. A horizon of 30 years is typically used in simulations, see for example, Cooley, Hubbard, and Walz (2003), Stout and Mitchell (2006), and Ervin, Faulk, and Smolira (2009).[3] We use a monthly 401(k) contribution of $1,000 and an allocation ratio of 30–70 for bonds and stocks in DCA and PR.[4] The 30–70 ratio represents a moderately more aggressive balanced portfolio strategy than the typical allocation of the traditional 40% bonds, 50% stocks and 10% short term funds. For the growth rate under feasible VA, we choose several rates between 0.5% and 1.1%. We conduct 10,000 simulations for each monthly growth target.

Different from Chen and Estes (2007), we address the issue of what to do with the money when the retirement investing goal has been met midstream over the 360 periods. Chen and Estes (2007) assume that investors continue the strategy all the way to the end of the 30 years even if their investment goal has been met already. In practice, it is much more prudent to "take the money off the table" when the investment goal has been reached. As a result, we design the simulation to allow investors to put all the funds into the bond account as soon as their investment goal is reached at the end of any month. We select $1 million as the investment goal to symbolize the notion of retiring as a millionaire. In addition, it is close to the future value of investing $1,000 per month earning an average monthly return of 0.5%, which is about the weighted average of a bond return of 0.32% and an equity return of 0.61%.

3.3. Evaluation criteria

As discussed in Chen and Estes (2007), the focus is on the terminal values of the retirement account under the three strategies. Therefore, we first compare the performance based on the ending balance of the retirement account and their standard deviation. In addition, we adopt the following three evaluation criteria to compare the performances from the three strategies.

3.3.1. Modified Sharpe ratio

As in Eq. (1), Modified Sharpe ratio is the ratio of the mean TV in excess of a minimum acceptable level over the standard deviation. Notice that the reward-to-risk ratio is modified from the original definition of Sharpe ratio because of the use of a dollar return instead of a rate of return as the numerator. We select \$675,000 as the minimum acceptable TV, which is the future value of an annuity with monthly payment amount of \$1,000 earning a return equal to the T-bill rate over 360 periods.

$$\text{Modified Sharpe Ratio} = \frac{(Mean\ TV - Minimum\ Acceptable\ TV)}{\sigma(TV_t)} \quad (1)$$

where $T\bar{V}$ is the mean terminal value and *Minimum Acceptable TV* is the minimum acceptable terminal value. A higher ratio indicates a better reward-to-risk trade-off.

3.3.2. Modified Sortino ratio

Different from modified Sharpe ratio, modified Sortino ratio replaces the standard deviation of TVs with the downside risk measurement as shown in Eq. (2). It is also a return-to-risk trade-off measurement.

$$\text{Modified Sortino Ratio} = \frac{T\bar{V} - Minimum\ Acceptable\ TV}{Downsiderisk} \quad (2)$$

where $T\bar{V}$ is the mean TV. Again, we use \$675,000 as the minimum acceptable TV. Downside Risk as measured by the squared root of semivariance as in Eq. (3). The semivariance measures the average deviation of TV below the target level.

$$\text{Downside Risk} = \sqrt{\frac{1}{m}\sum_{1}^{m}(Minimum\ Acceptable\ TV - TV_t)^2} \quad (3)$$

Notice that only terminal values from m cases with below-the-target TV are included in the calculation in Eq. (3). The higher the modified Sortino ratio, the better is the reward-to-risk trade-off.

3.3.3. Dominance frequency

Dominance frequency measures the frequency that the TV from one strategy is higher than that from another strategy out of the n simulations. It is an indicator of relative performance by a strategy.

$$\text{Dominance Frequency} = \sum_{1}^{j} f(\Delta TV) \quad (4)$$

Table 2 Monte Carlo simulation results: terminal values

Panel A: Terminal values

Growth rate	Dollar-cost-averaging	Feasible VA	Proportional rebalancing
0.5%	$1,083,080	$1,050,012	$1,063,849
0.6%	$1,076,993	$1,069,313	$ 1059,557
0.7%	$1,075,230	$1,086,908	$1,058,450
0.8%	$1,072,778	$1,102,645	$1,057,429
0.9%	$1,074,821	$1,114,760	$1,058,527
1%	$1,074,893	$1,125,013	$1,058,649
1.1%	$1,072,413	$1,133,642	$1,055,927

Panel B: Difference in terminal values

Growth rate	Feasible VA-DCA	Feasible VA-PR	PR-DCA
0.5%	−$33,069 (−20.99**)	−$13,837 (−12.79**)	−$19,231 (−23.45**)
0.6%	−$7,680 (−5.39**)	$9,757 (9.74**)	−$17,436 (−21.95**)
0.7%	$11,678 (8.54**)	$28,458 (8.54**)	−$16,780 (−21.20**)
0.8%	$29,867 (23.62**)	$45,217 (23.62**)	−$15,350 (−20.59**)
0.9%	$39,939 (33.24**)	$56,236 (33.24**)	−$16,295 (−21.57**)
1%	$50,121 (41.19**)	$66,365 (41.19**)	−$16,244 (−21.32**)
1.1%	$61,229 (46.63**)	$77,715 (48.63**)	−$16,486 (−20.92**)

For each strategy, an investment horizon of 360 months is used and monthly contribution is $1,000. For all three strategies, the allocation ratio between bonds and stocks is 30% and 70%. For feasible VA, different growth rates are used. In parentheses are the *t*-statistics testing the null hypothesis that there is no difference in the mean TV from each of the three strategies. **Indicates statistical significance at the 0.01 level.

where ΔTV is the differences in terminal values and $f(\Delta TV)$ takes a value of one if it is positive and zero otherwise. Differences in TVs are calculated for three pairs, that is, (1) between feasible VA strategy and DCA strategy, (2) between feasible VA and PR, and (3) PR and DCA.

3.3.4. Shortfall frequency

Shortfall frequency measures how many times the TV is less than the target TV out of the n simulations for each strategy. As discussed in the previous section, we choose the target to be one million dollars to correspond to the notion of retiring with one million bucks.

$$\text{Shortfall Frequency} = \sum_{1}^{k} f(\Delta TV) \tag{5}$$

where $f(\Delta TV)$ takes a value of one if it is positive and zero otherwise.

4. Empirical results

4.1. Mean terminal values

Panel A of Table 2 presents the mean terminal values from the three strategies. Because feasible VA depends on the monthly growth target, simulations are conducted at each of the

7 monthly growth targets. The mean TV is more than $1 million for all three strategies. DCA always outperforms the proportional rebalancing strategy in generating a higher TV for the retirement account. However, the degree of outperformance by feasible VA over either DCA or PR depends on the monthly growth target.

We conduct a formal paired *t* test on the differences of terminal values in Panel B of Table 2. The out-performance by DCA over PR is statistically significant as indicated by the *t*-statistic. DCA also outperforms feasible VA when a monthly growth target rate below 0.7% is used in executing value averaging. However, when a monthly growth rate of 0.7% or higher is chosen, value averaging produces a higher TV than DCA. For example, at a monthly growth target of 1%, VA produces $50,121 more than DCA, which is both economically and statistically significant.

At a monthly growth rate no lower than 0.5%, value averaging also outperforms PR in generating a higher TV of the retirement account. Thus, results in Table 2 show that the approach of proportional rebalancing is a lesser attractive option. The results also confirm that value averaging does outperform both DCA and PR in generating a higher TV for the retirement account at a monthly growth target rate of no lower than 0.6% for the equity account, which is reasonable by historical standard.

4.2. Total risk profile

Fig. 1 shows the total risk as measured by the standard deviation of the terminal values for three strategies. Comparing against DCA, feasible VA has a lower total risk at any monthly growth target that is below 1%. Comparing against PR, feasible VA also has a lower total risk so long the month growth rate is below 0.8%. Notice that PR always has a lower total risk than DCA.

Because both feasible VA and PR permit more of "buy low and sell high" than DCA, results in Fig. 1 indicate a positive smoothing effect in reducing volatility under value averaging and proportional rebalancing. Nevertheless, for value averaging, the smoothing effect depends on the monthly growth rate selected.

When comparing feasible VA against DCA, a combining of the results in Table 2 and Fig. 1 indicates that a monthly growth rate should not be higher than 1% to capture the higher TV and lower total risk. On the other hand, comparing feasible VA against PR, a monthly growth rate below 0.8% should be used to allow a higher TV and a lower total risk.

4.3. Modified Sharpe ratio

Fig. 2 exhibits the modified Sharpe ratio, which compares the trade-off between reward and risk. Fig. 2 shows that feasible VA always has a better reward-to-risk trade-off than DCA and PR. At a monthly growth rate higher than 1%, the total risk is higher under VA than under DCA, which is shown in Fig. 1. However, such an increase in total risk is more than offset by the increase in TV. As a result, VA still has a higher reward-to-risk ratio than DCA.

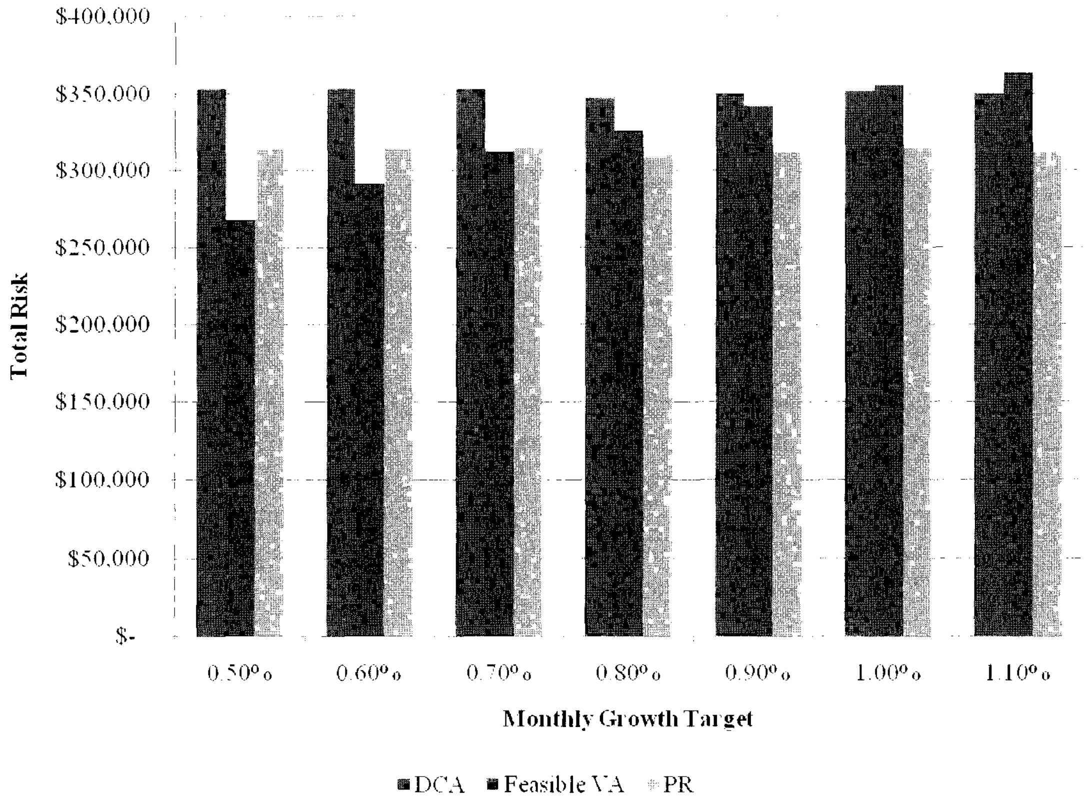

Fig. 1. Comparison based on total risk.

4.4. *Modified Sortino ratio*

Fig. 3 presents a comparison based on both downside risk and the modified Sortino ratio. Downside risk is measured by the semivariance of the shortfalls below the minimum TV of $675,000. Regardless of level of the monthly growth targets, VA has a higher downside risk than the other two strategies. Under feasible VA, downside risk also increases as the monthly growth rate increases. Such a result is caused by the nature of downside risk as a measurement of the severity of bad outcomes only. That is, only those occurrences with a TV less than the acceptable level of $675,000 contribute to the severity of bad outcomes, whereas those good occurrences are excluded. Clearly, the strategy of "buying low" would result in even greater losses if one market low is followed by more lows. On the other hand, a very low monthly growth rate such as 0.5% can results in too little exposure to equity, which can lead to lower ending balance of the retirement account. As a result, one needs to weigh the higher downside risk against other factors.

Similarly, feasible VA has a low modified Sortino ratio, which uses downside risk as the denominator to measure reward-to-risk trade-off. While more stable for both DCA and PR, the modified Sotino ratio fluctuates as the monthly growth target rates change under feasible VA. The modified Sortino ratio peaks at a monthly growth target of 0.9%.

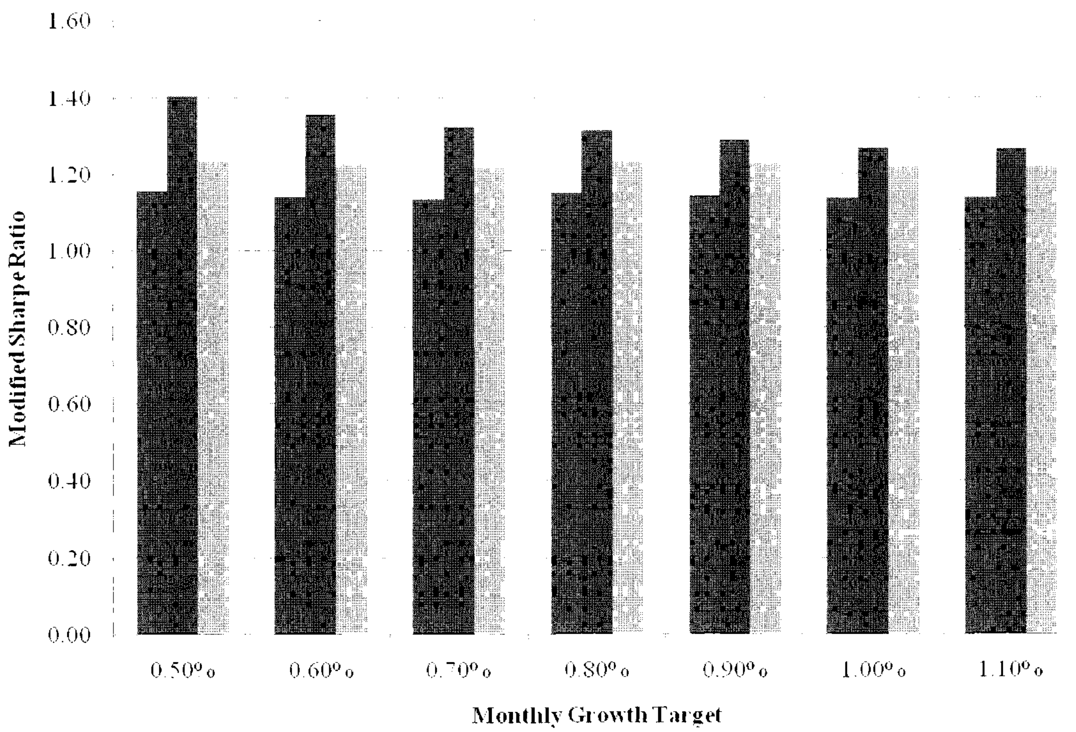

Fig. 2. A comparison based on modified Sharpe ratio.

4.5. Dominance frequency

Fig. 4 shows the frequency that a strategy generates a higher TV for the retirement account than the other strategy. Out of 10,000 simulated 30-year periods, there is a 53% chance that proportional rebalancing produces a higher TV than dollar-cost-averaging. On the other hand, depending on the monthly growth target selected, feasible VA dominates DCA and PR from 49% to 75%. For example, at a monthly growth target of 0.5%, feasible VA has a 49% chance and a 50% chance of generating a higher TV than DCA and PR, respectively. At a monthly growth target of 1.1%, feasible VA has a 74% chance and a 75% of generating a higher TV than DCA and PR, respectively.

A higher growth target rate would result in even more investment in stocks under feasible VA than under either DCA or PR. Therefore, the dominance by feasible VA over DCA and PR increase as growth target rate goes up. Such dominance by both feasible VA and PR over DCA may come from the fact these two strategies more likely result in steady investment in stocks during bear markets, which can pay off handy during future bullish periods.

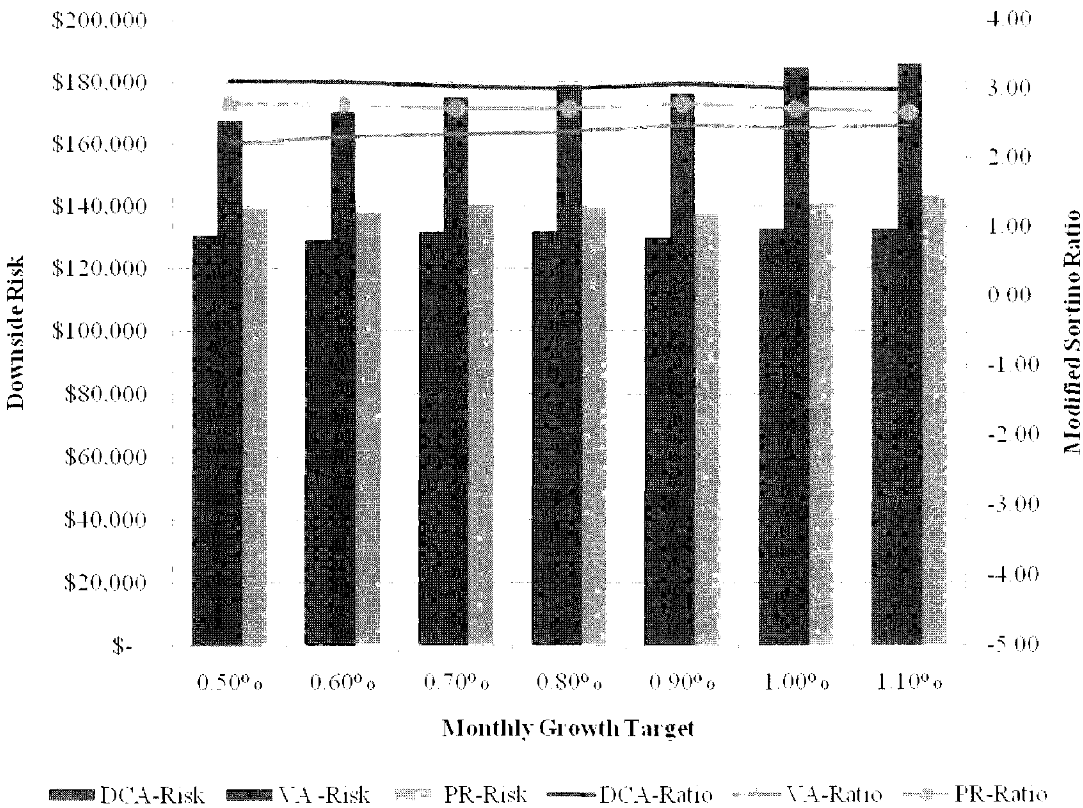

Fig. 3. A comparison based on modified Sortino ratio.

4.6. Shortfall frequency

Fig. 5 depicts the shortfall frequency of the three strategies. It shows how often the three strategies produce a TV below the $1 million target. As can be seen from Fig. 5, DCA has the highest average shortfall frequency at 40%. PR has an average shortfall rate of 39%. In contrast, feasible VA has the lowest shortfall frequency. In addition, shortfall frequency under feasible VA decreases as the monthly growth target rate increases. For example, the shortfall rate is about 33% with a monthly growth target rate of 0.5%, whereas it decreases to 31% with a monthly growth target rate of 1.1%.

The results in Fig. 5 are consistent with the dominance frequency in Fig. 4. The better performance of feasible VA is because of the fact that there is more "buy low and sell high" under feasible VA than under the other two strategies. In summary, investors are more likely to hit the goal of retiring with a million dollars under feasible VA than under the other two strategies.

4.7. Exposure to equity: a discussion

As shown in Fig. 3, VA has a higher downside risk than the other two strategies. Because the equity fund is used as the main driving force for achieving the retirement goal, a higher

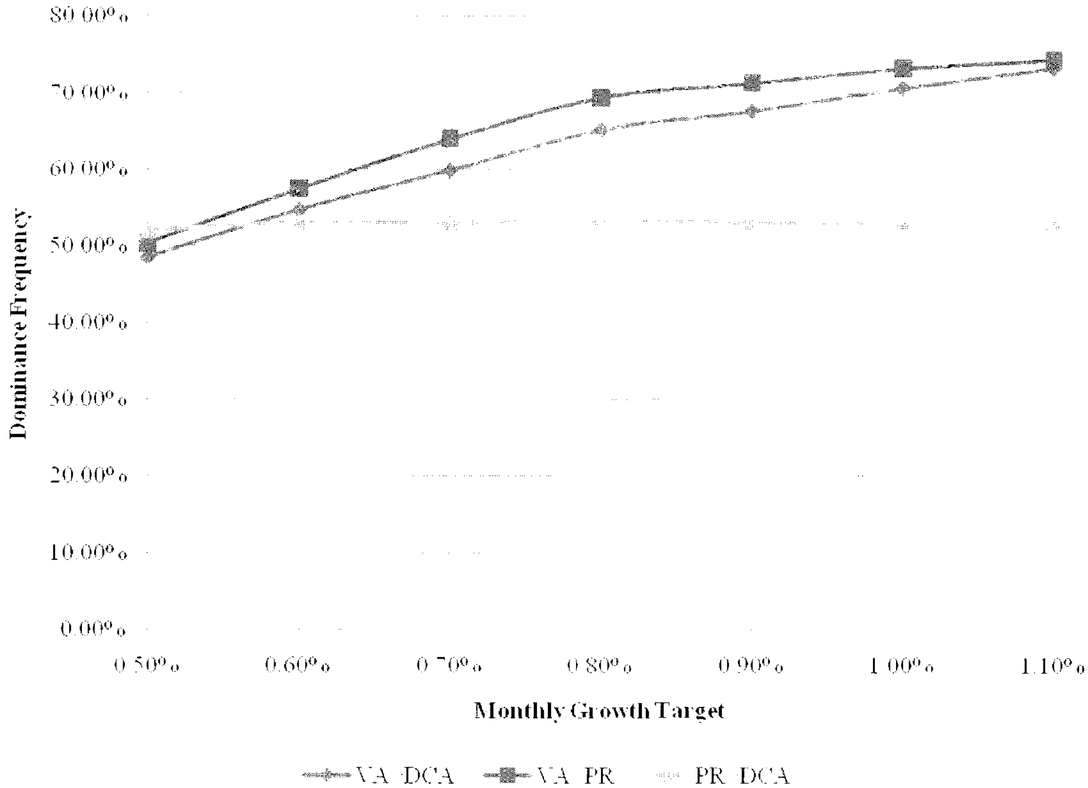

Fig. 4. Comparison based on dominance frequency.

monthly growth rate would result in more a tilting of contributions toward equity. How much of TV is made of equity, that is, exposure to equity, under each of the three strategies? For example, the optimal ratio between bonds is assumed to be 30% of the account balance under PR and the allocation of bonds of new contribution is also assumed to be 30% under DCA. Then, how often is the balance of the equity account hit 70% of the terminal values? To answer this question, we calculate the frequency that ending equity account balance is at least 70% of the terminal value.

Fig. 6 exhibits the results. Not surprisingly, the exposure to equity is fixed around 21% for PR because the allocation is always maintained at 30% for bonds and 70% for equity at the beginning of each period. For feasible VA, the equity exposure increases from 28% at a monthly growth rate of 0.5% to 31% at a monthly growth rate of 1.1%. However, DCA has the lowest equity exposure at an average rate of 23%.

The results in Fig. 6 are not only consistent with but also caused by those in Fig. 3. Recall the design of the simulation allows a transfer of equity balance into bond account when the retirement goal is reached. As a result, the equity exposure would not be reflected in Fig. 6 for DCA and feasible VA for those occurrences in which the retirement goal is reached before the end of the simulation. Consequently, the results in Fig. 6 are reflecting those cases in which the equity account fails to drive the retirement balance to top the goal. Intuitively,

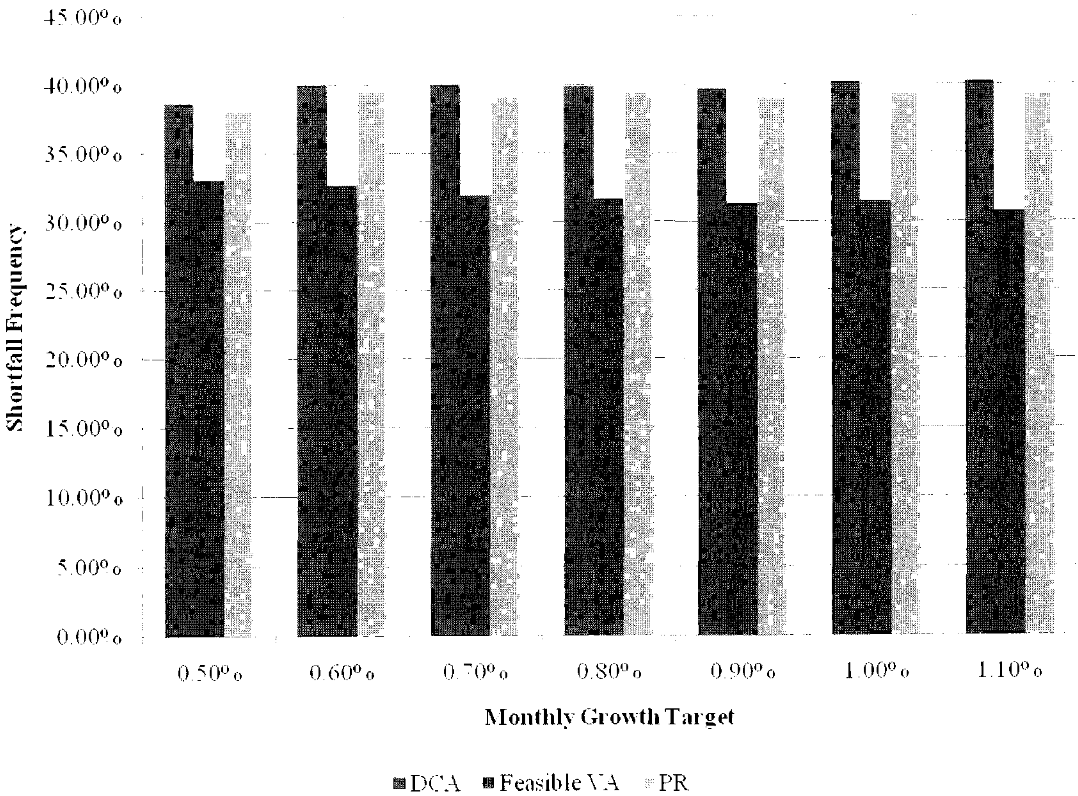

Fig. 5. Comparison based on shortfall frequency.

equity portion would decrease relative to bond in these "down" situations under DCA. In contrast, the equity portion would not decrease as much as would be the case under feasible VA because of moving more funds from bond account into equity account to make up the shortfall in equity. Therefore, a higher downside risk as in Fig. 3 would drive up the equity exposure under value averaging more than under dollar-cost-averaging. In return, a higher equity exposure at any period could also increase downside risk if a market low is followed by another market downturn.

It is comforting to notice that there is only a moderate increase in the average frequency of TV being composed of at least 70% of equity, for example, from 23% under DCA to 30% under feasible VA, as shown in Fig. 6. Overexposure to equity would result in a higher total risk for the retirement account's TV. Because Fig. 1 shows that the standard deviation of TV is lower under feasible VA than under DCA at a low monthly growth target, results in Fig. 6 further indicate the positive smoothing effect from value averaging. Of course, the PR approach also offers such a smoothing benefit and actually has the lowest TVs exposure to equity. Following the average investors reaction to the market downturn in 2008, the value of this smoothing effect needs to be appreciated because investors inevitably get it wrong and miss a high proportion of the upturn if they simply pull out of the market and wait for better times.

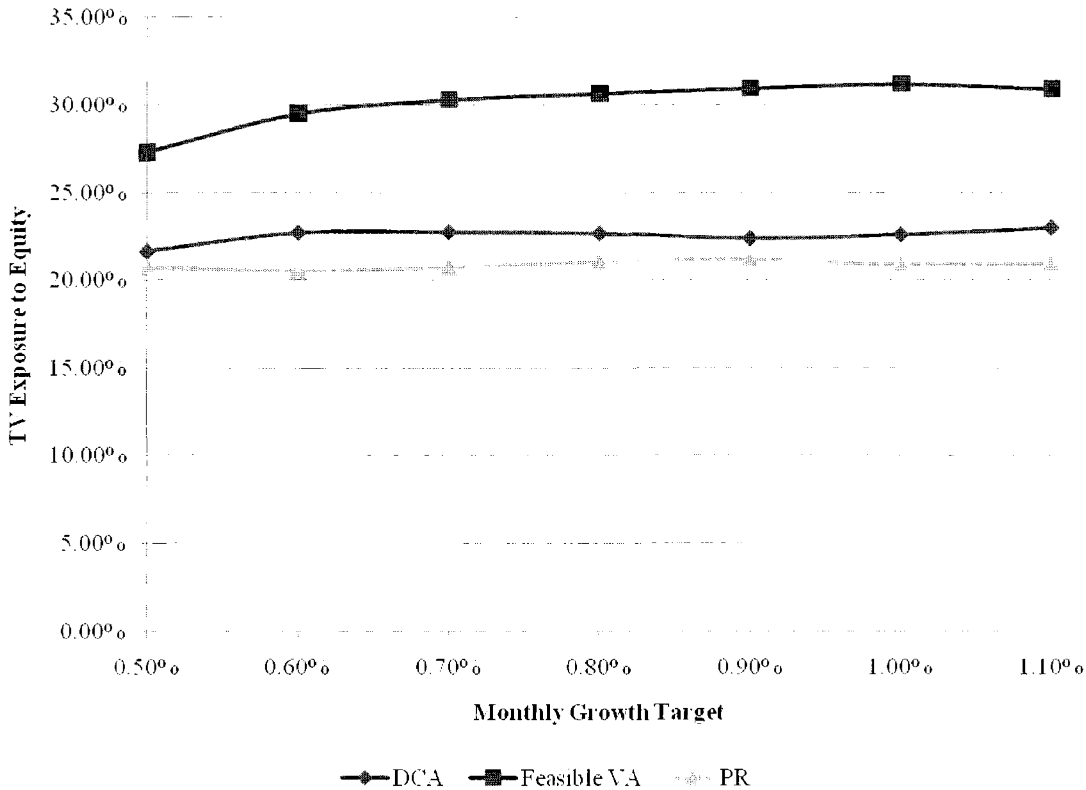

Fig. 6. Degree of terminal value's exposure to equity.

Given all the factors, how should we judge the merits of value averaging? As in any investing, reward comes with risk. Fig. 3 shows that feasible VA has a higher downward risk than DCA and PR. However, value averaging not only increases TV as shown in Table 2 but also has a lower total risk as shown in Fig. 1. Results of total risk in Fig. 1 and those of the reward-to-risk ratio in Fig. 2 clearly favor feasible VA over the other two strategies. We conclude that investor should use a monthly growth rate that is higher than 0.7% but lower than 1% to allow value averaging to capture the benefits of (1) higher TV, (2) a lower total risk, (3) a better reward-to-risk ratio, and (4) a 65% dominance frequency over the other two strategies.

5. Summary and conclusion

This study examines the performances of the three most popular asset management strategies in financial planning literature and press, that is, dollar-cost-averaging, a feasible value-averaging, and proportional rebalancing. Monte Carlo simulations show that value averaging at a monthly growth rate higher than 0.7% generates a higher TV for the retirement account than dollar-cost-averaging or proportional rebalancing. Further, TV has a lower standard deviation under value averaging than under dollar-cost-averaging when a monthly growth rate lower than 1% is used in conducting value averaging.

On the other hand, value averaging does have a higher downside risk than the other two strategies. However, the equity exposure under value averaging is not as high as feared. The modified Shape ratio clearly favors value averaging in terms of a higher compensation of reward for bearing the risk. In addition, at a monthly growth target of at 0.7%, value averaging has at least 60% chance of generating a higher TV over dollar-cost-averaging and a 65% chance over proportional rebalancing. Based on these empirical results, we conclude:

1. Both value averaging and proportional rebalancing have a higher positive smoothing effect in reducing total risk than dollar-cost-averaging.
2. Value averaging is the most preferred strategy over dollar-cost-averaging and proportional rebalancing in the framework of investing for retirement via 401(k) plans.
3. A monthly growth rate higher than 0.7% but lower than 1% for the stock account is optimal in conducting value averaging.

Notes

1. See for example, Knight and Mandell (1993), Marshall (2000), and Leggio and Lien (2003).
2. Instead of a calendar-based mechanical system, all three strategies can also be event-triggered.
3. Thirty-year horizon also allows for simplicity without touching on the issue of funds withdraw from the retirement account, see for example, Spitzer (2008) for a discussion on the optimal withdraw strategy.
4. We also (1) increase the standard deviation to 0.629% for stock returns, (2) use two monthly contribution levels at $500 and $1,500, and (3) use a ratio of 40–60 for bonds and stocks. Because the main conclusions remain qualitative the same, we only report the results from the setting of an allocation ratio of 30–70 with a monthly contribution of $1,000. The other results are available upon request.

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