Economic Horizons, September - December 2014, Volume 16, Number 3, 207 - 217
UDC: 33 eISSN 2217-9232

Original scientific paper
UDC: 005.311.12:519.865; 336.76
doi: 10.5937/ekonhor1403211D

MARKOWITZ PORTFOLIO REBALANCING WITH TURNOVER MONITORING

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Active portfolio management implies periodic rebalancing, i.e. a change in the structure of the existing portfolio. Rebalancing is aimed at improving the performance of the managed portfolio by adjusting it with respect to the given objective. The main objective of this research is to test two portfolio rebalancing strategies, one based on market risk and another on optimal risk-return tradeoff. We use optimal volatility or Sharpe of portfolio as a criterion for the initial portfolio allocation and rebalancing over the observed period. In order to obtain solutions that can be applied in practice, we impose rebalance triggers designed to control the portfolio turnover and corresponding transaction costs. the results suggest that the minimum volatility strategy can be accepted as an eligible investment alternative for risk adverse investors since it provides superior risk performance compared to the reference S&P 100 index and 1/n portfolio, with a relatively low level of turnover and a low rebalance frequency.

Keywords: portfolio management, volatility, Sharpe ratio, portfolio rebalancing, turnover

JEL Classification: C44, C61, G11

INTRODUCTION

Portfolio management starts with asset allocation. There is a consensus that asset allocation plays an important role in determining portfolio performance (Arshanapalli, Coggin & Nelson, 2001). Active portfolio management implies the rebalancing of the existing portfolio by buying and selling assets. The aim of rebalancing is to improve the performance of the managed portfolio by adjusting it to the current market conditions. However, portfolio rebalancing induces transaction costs which impact the overall portfolio return. Therefore, transaction costs must be considered when the aim is to develop dynamic portfolio models that perform satisfactorily under the real market conditions (Choi, Jang & Koo, 2007; Kozhan & Schmid, 2009).

For decades, market risk has typically been defined as a variance of portfolio returns. Traditionally, portfolio allocation is based upon H. M. Markowitz's mean-variance setup (Markowitz, 1952; Fabozzi, Focardi & Jonas, 2007). In this paper, we follow Markowitz's setup in choosing portfolio rebalancing strategies.

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Two different strategies are analyzed: 1) the periodic minimization of portfolio risk measured by volatility and 2) the periodic maximization of the portfolio W. F. Sharpe ratio (1966). The aim of the research is to test two rebalancing alternatives: the first one being based on market risk and the other one on the optimal risk-return tradeoff.

Portfolio allocation is always about a tradeoff between two opposing objectives - risk minimization and return maximization. Market risk (Alexander, 2008) is a risk resulting from adverse movements in the prices of liquid financial instruments. As long as regulators are concerned about the risk profiles of the portfolios under their consideration (Jaksic, 2012), investors seek return and only consider risk in relation to return (either realized or expected). As a rule, portfolio managers report on portfolio performance in terms of realized return per unit of risk taken in the observed period. The Sharpe ratio is the standard in reporting portfolio performance, such ratio being defined as return per unit of the standard deviation (Bacon, 2008).

Whether the periodic optimization of portfolio volatility (or, alternatively, the optimization of the Sharpe ratio) based on the past performance of constituent assets can result in a better-performing portfolio relative to chosen benchmarks is examined. Hence, two hypotheses are tested:

H1: The minimum volatility strategy results in a portfolio with better risk performances compared to chosen benchmarks.

H2: The maximum Sharpe strategy results in a portfolio with a higher Sharpe ratio compared to chosen benchmarks.

In order to control the turnover of the managed portfolios, different rebalancing triggers are introduced. For the purpose of this research, the opportunity set of securities composed of 40 constituents of the U. S. market index S&P 100 during the rebalancing period of two years are exploited. The risk-return and turnover performance of the managed portfolios to the performance of the S&P 100 index, adopted as the market benchmark[1], and the 1/n portfolio, adopted as a naïve portfolio strategy benchmark are compared.

Different investment objectives determine the rebalancing strategies to be applied (Hsu, 2012). B. Arshanapalli *et al*. (2001) examine the impact of asset allocation on the performance of the fixed-weight and different dynamic portfolios with and without a transaction costs assumption. C. Donohue and K. Yip (2003) examine the implied portfolio performance, the result of common heuristic rebalancing strategies, in terms of risk, return, the Sharpe ratio, turnover and transaction costs. The results intuitively suggest that there is a tradeoff between the optimal rebalancing and transaction costs[2]. K. Sippel (2013) analyzes the impact of the portfolio turnover on the performance of the specific strategy indices designed to target the required level of portfolio risk. The author introduces transaction buffers with the aim to decrease turnover and improve the cost-adjusted performance of the managed portfolio. V. DeMiguel, G. Lorenzo and U. Raman (2009) evaluate the out-of-sample performance of the portfolios with the optimal asset allocation, using Markowitz's model and its extensions (14 different models in total). The authors demonstrate that the naïve 1/n optimization rule generates a good proxy of the optimal portfolio that can be confronted with more complex portfolio designs. A. A. Gaivoronsky, S. Krylov and N. Van der Wijst (2005) analyze the portfolio selection approach when portfolio performance is defined relatively to the given benchmark (the benchmark tracking approach). The authors have developed several portfolio selection algorithms based on different risk measures, and they have tested them through a number of numerical experiments. The results show that their approach, based on benchmark tracking, can be an attractive investment strategy. In their study, J. R. Yu and W. Y. Lee (2011) analyze five different portfolio rebalancing models based on the combination of different rebalancing criteria, including risk, return, the short selling constraint and the skewness and kurtosis of return distribution, taking the transaction cost into consideration.

Upon the outbreak of the subprime crisis, investors and regulators became increasingly concerned about the risk of extreme quantiles. The risk of extreme quantiles is defined with the aim to estimate the impact of unfavorable and highly improbable events. Despite its unfavorable mathematical properties (Artzner, Delbaen, Eber & Heath, 1999; Szego, 2002), VaR is the predominantly used risk measure of extreme quantiles, in particular upon the introduction of the new banking regulations in 1996 (Basel Committee on Banking Supervision, 1996[3]). By t regulation, a bank's internal VaR estimates are incorporated into a capital charge which aims to provide a sufficient buffer for cumulative losses arising from adverse market conditions. For this reason, the VaR values of the examined portfolios will be calculated and presented here.

The remainder of this paper is organized as follows: in Section 2, the concepts of portfolio return and turnover are introduced. The risk and risk-adjusted measures that we base our rebalancing upon are introduced in Section 3. The optimization model is introduced in Section 4. In Section 5, the proposed rebalancing strategies are presented. Section 6 provides the empirical results. Our conclusions and suggestions for future research are given in Section 7.

THE MATHEMATICS OF PORTFOLIO RETURN AND TURNOVER

In this section, the basic relationships of the portfolio theory exploited in this research are introduced.

Percentage one-period return of the portfolio at time t is defined as:

$$r_{p,t} = \sum_{i=1}^{N} w_{i,t-1} r_{i,t} \quad , \tag{1}$$

where $r_{i,t}$ denotes the percentage one-period return of asset i at time t, and $w_{i,t}$ denotes the proportion of the capital invested in asset i at time t.

Expression (1) is the fundamental relationship in portfolio mathematics (Alexander, 2008).

Weighting factor $w_{i,t}$ is defined as:

$$w_{i,t} = \frac{n_i p_{i,t}}{\sum_{i=1}^{N} n_i p_{i,t}}, \quad i = 1,\ldots,N \ , \tag{2}$$

where n_i is the number of the shares of asset i and $p_{i,t}$ is the price per share of asset i at time t.

The number of shares n_i remains the same for each asset i for the period between the two rebalances (i.e. the portfolio remains static). On the other hand, the proportion of the capital invested in each asset $w_{i,t}$ changes over time, whenever the price of any asset in such portfolio changes.

Transaction (trading) costs, as a consequence of rebalancing, may have a great impact on the overall portfolio return. In practice, a portfolio manager must control the level of transaction costs in order not to ruin the overall portfolio performance. As a result, transaction costs are always considered as an important constraint in portfolio management. Transaction costs depend on multiple factors and follow different patterns; however, as a rule, they are directly affected by portfolio turnover (a trading volume). In this research, we restrain ourselves from going deeper into those different patterns. Due to simplicity, portfolio turnover as a proxy for transaction costs is used. Portfolio turnover at time t, expressed as the percentage of the portfolio value, is calculated using the following formula (DeMiguel *et al*, 2009):

$$Turnover(t) = \sum_{i=1}^{N} \left| w_{i,t} - w_{i,t-1} \right| \tag{3}$$

RISK AND RISK-ADJUSTED MEASURES USED AS THE OPTIMIZATION CRITERION

Volatility

Portfolio variability is commonly calculated as the variance of portfolio returns:

$\sigma_p^2 = \dfrac{1}{T} \sum_{t=1}^{T} (r_t - \overline{r}_p)^2$, where r_i is portfolio return at time t, $\overline{r}_p$ is the average portfolio return. Often, investors use the standard deviation σ_p, i.e. the squared root of the variance, as the measure of portfolio variability, given that the standard deviation is of the same order as the average return. The benchmark measure of portfolio variability is volatility, calculated as the annualized standard deviation of portfolio returns[4]:

$$volatility = \sigma_p \sqrt{252} \tag{4}$$

Sharpe ratio

The Sharpe ratio[5] measures portfolio return as per the unit of risk. It is one of the most frequently used measures of the risk-adjusted portfolio performance and quantifies the risk-return tradeoff. The return is commonly calculated relative to the given risk-free rate, while risk is measured using the standard deviation of portfolio returns. Of the two portfolios with the same return, a higher Sharpe ratio will favor the portfolio with less variability in returns, measured by the standard deviation. The Sharpe ratio is suitable for evaluating portfolios with different returns and different levels of risk for the same period. Formally, it is defined as:

$$Sharpe = \frac{\bar{r}_p - r_f}{\sigma_p}, \tag{5}$$

where $\bar{r}_p$ is the average portfolio return, r_f is the risk-free rate and σ_p is the standard deviation of portfolio returns.

OPTIMIZATION MODEL

This research analyzes two different portfolio rebalancing strategies based on: a) the minimization of portfolio volatility and b) the maximization of the portfolio Sharpe ratio. The general form of the optimization model is defined as follows:

$$\begin{aligned} &\text{a) } min\ \ volatility\ (r_p(\boldsymbol{w})) \\ &\text{b) } max\ \ Sharpe\ (r_p(\boldsymbol{w})) \end{aligned} \tag{6}$$

$$\sum_{i=1}^{N} w_i = 1 \tag{7}$$

$$0 \leqslant w_i \leqslant 1,\ i = 1, \ldots, N, \tag{8}$$

where w denotes the vector of weighting factors w_i, *volatility(rp(w))* denotes the volatility of a portfolio, *Sharpe(rp(w))* denotes the Sharpe ratio and N is the total number of assets.

Equation (6) defines the optimization models; Equation (7) describes the standard budget constraint requiring that weighting factors must sum up to 1; Equation. (8) describes the constraint that no short sales are allowed, implying that none of the weighting factors can be negative.

We emphasize that the optimization criterion (volatility or the Sharpe ratio estimate) of the portfolio is calculated using the time series of the realized portfolio returns (we fix portfolio holdings). To calculate the time series of the realized returns of the candidate portfolio, the daily recalculations of its weighting factors $w_{i,t}$ are needed.

REBALANCING STRATEGIES

The proposed rebalancing strategies are based on the daily portfolio optimization with respect to the chosen criterion (Equation (6)).

On the first day of the sample period, as the initial portfolio, we chose the optimized portfolio (in terms of: (a) minimal volatility, b) the maximal Sharpe ratio). The initial portfolio is defined by the set of weighting factors w_i. These weighting factors are transformed into portfolio holdings, assuming that the initial portfolio value is equal to $1 million.

For each next day within the observed rebalancing period, the portfolio optimization procedure is applied. If the stated minimal improvement of the optimization criterion is achieved and if the rebalancing condition (the trigger) is satisfied, the rebalance is performed so that the optimized portfolio becomes the actual portfolio to be managed in the future. Otherwise, the existing portfolio remains unchanged. Here, we set the minimal improvement condition to be 1%.

DATA AND RESEARCH RESULTS

In this section, the computational results obtained by applying the proposed strategies to the historical data set are displayed. For the purpose of this research, the 40 constituents of the S&P 100 index (based on: the historical prices of the S&P 100 index and its constituents) with the highest market capitalization as of September 6th, 2013 are exploited[6].

Rebalancing was performed within the period of two years (504 trading days), starting on January 2nd, 2009 and ending on December 31st, 2010. For volatility and the Sharpe estimation, 500 daily return observations were used.

In order to evaluate the performance of the proposed portfolio strategies, the performance of the managed portfolios are compared to the performance of the 1/n portfolio and the reference S&P 100 index.

Figure 1 shows the market value of the portfolios managed by applying minimal volatility (Min Volatility), the maximal Sharpe ratio (Max Sharpe) and the 1/n portfolio strategy together with the normalized level of the S&P100 index.

Pursuant to the Basel regulations framework, the 1-day ahead of 1% VaR estimate will be reflected in the level of the capital requirements for financial institutions. Figure 2 shows the evolution of the historical 1% VaR estimates over the rebalancing period for Min Volatility, Max Sharpe and the 1/n portfolios and the S&P100 index.

Table 1 accounts for the performance statistics for the managed portfolios.

As expected, the Min Volatility strategy provides the lowest volatility, and in addition, the lowest 1% VaR estimates over the rebalancing period. The Max Sharpe strategy results in the highest estimated Sharpe ratio accompanied by the highest volatility over the observed period. The high volatility of the Max Sharpe portfolio is the result of the extreme changes in the portfolio structure (see Table 1 for the total turnover statistics). The time series of the VaR estimates reveal the significant changes in the VaR level for the Max Sharpe portfolio as the result of the radical changes of the portfolio structure.

The results accounted for in Table 1 show that the Max Sharpe strategy provides a maximum return (the total and average daily return) and the maximum Sharpe

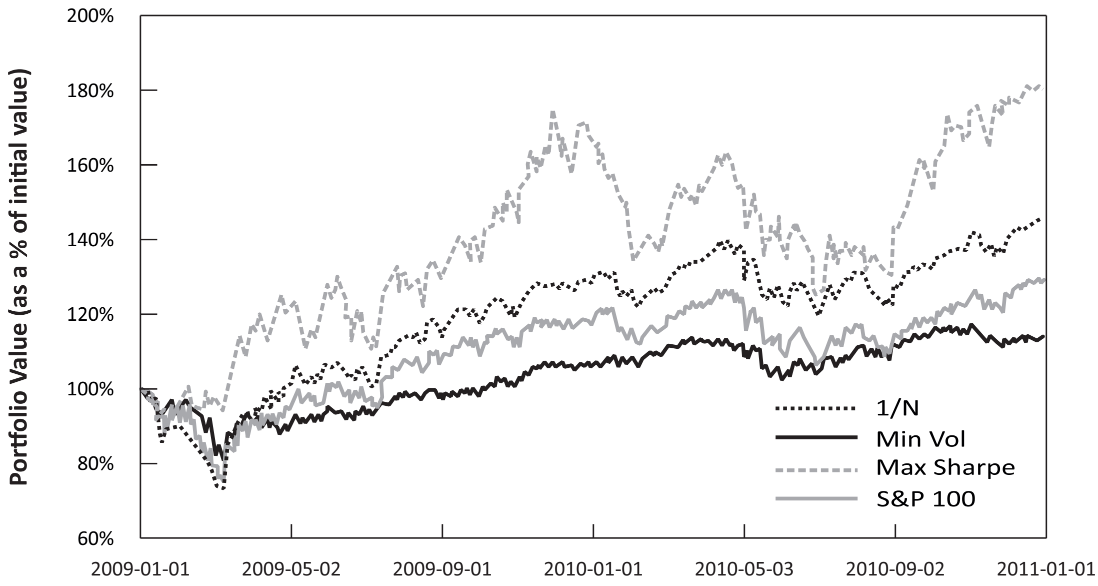

Figure 1 The market value of the managed portfolios obtained by using the Min Volatility and Max Sharpe rebalancing strategies, the 1/n portfolio strategy and of the benchmark S&P 100 index for the period from January 2nd, 2009 to December 31st, 2010

Source: Authors

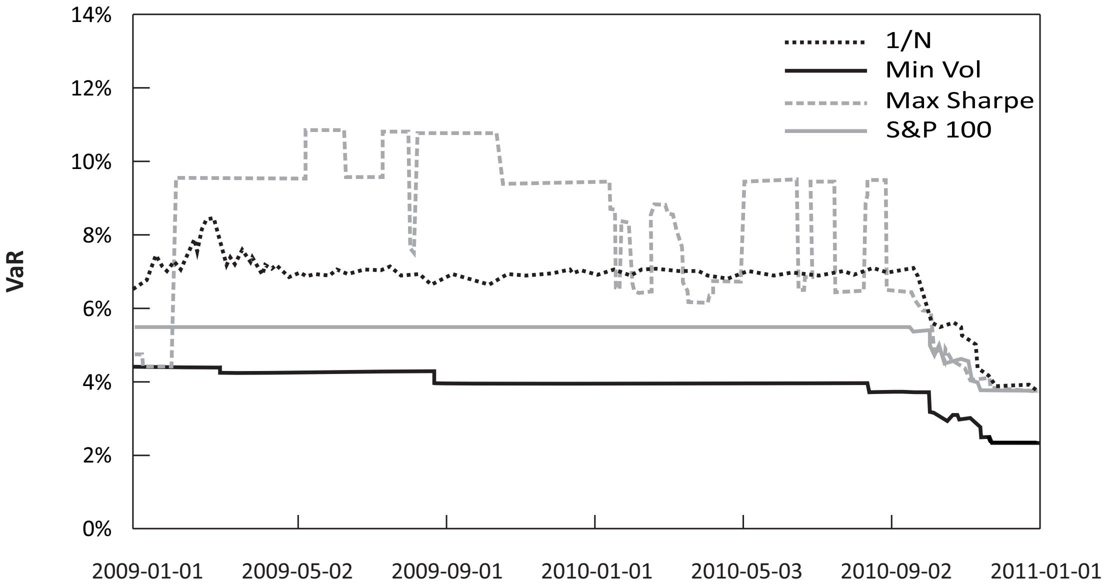

Figure 2 The time series of the 1%VaR estimates of the managed portfolios obtained by using the Min Volatility and Max Sharpe rebalancing strategies, the 1/n portfolio strategy, and of the benchmark S&P 100 index for the period from January 2nd, 2009 to December 31st, 2010

Source: Authors

Table 1 The performance statistics of the managed portfolios obtained by applying the Min Volatility and Max Sharpe rebalancing strategies, the 1/n portfolio strategy, and of the benchmark S&P 100 index for the period from January 2nd, 2009 to December 31st, 2010

	Min Volatility	Max Sharpe	1/N	S&P 100
Total return	11.18%	79.12%	43.68%	27.31%
Total turnover	204.06%	3658.67%	569.25%	-
No. of rebalances	7	46	504	-
Avg. return (ann.*)	6.31%	34.48%	21.11%	14.45%
Volatility	14.18%	32.56%	24.35%	21.70%
1%VaR	2.77%	4.65%	4.62%	4.05%
Max drawdown**	-8.03%	-8.97%	-8.56%	-7.84%
Sharpe***	0.42	1.05	0.86	0.65
Avg. no. of assets	7.2	1.6	40	100

*annualized

** The max drawdown is calculated as a maximum 3-day loss with the assumption that a 3-day horizon is the period long enough for closing the position in liquid markets.

*** The Sharpe ratio is calculated by applying the 1-year U.S. Treasury rate of 0.29% as of December 31st, 2010 as the risk-free rate. (The U.S. Department of Treasury)

Source: Authors

ratio at the expense of a very high turnover (over 36 average portfolio values). On the other hand, the Min Volatility strategy provides the lowest volatility and the 1%VaR at the expense of the lowest return. If compared to the performance of the benchmark S&P 100 index, the Min Volatility strategy provides a lower return as well as a significantly lower volatility and the 1%VaR (the same applies if compared to the 1/n strategy). Additionally, the VaR estimates over the observed period are the lowest for the Min Volatility portfolio and the highest for the Max Sharpe portfolio which implies a more (less) efficient use of regulatory capital. The naïve 1/n strategy delivers performance in between the Min Volatility and the Max Sharpe strategies, which is expected for the fixed-weighting-factor portfolio strategy (Arshanapalli *et al*, 2001).

It is emphasized that, as long as the rebalance frequency of the Max Sharpe strategy is acceptable in practical terms, the turnover values of individual rebalances are high in most occurrences. On the other hand, the 1/n strategy implies daily rebalancing. Consequently, each of these three strategies results in a very high total turnover, which implies transaction costs impossible to sustain under real market conditions.

In order to decrease the total turnover, the following turnover constraints are imposed:

For the Min Volatility and the Max Sharpe strategy, rebalancing is only performed if turnover is less than 50% of the total portfolio value (the sum of the total selling and the total buying), whereas in the case of the 1/n strategy, rebalance is only realized if turnover is greater than 5% of the portfolio value. Otherwise, the existing portfolio remains.

Figure 3 shows the market value of the portfolios managed by applying the Min Volatility, Max Sharpe and 1/n portfolio strategies with turnover constraints imposed, while Figure 4 shows the evolution of the VaR estimates over the rebalancing period for the same portfolios.

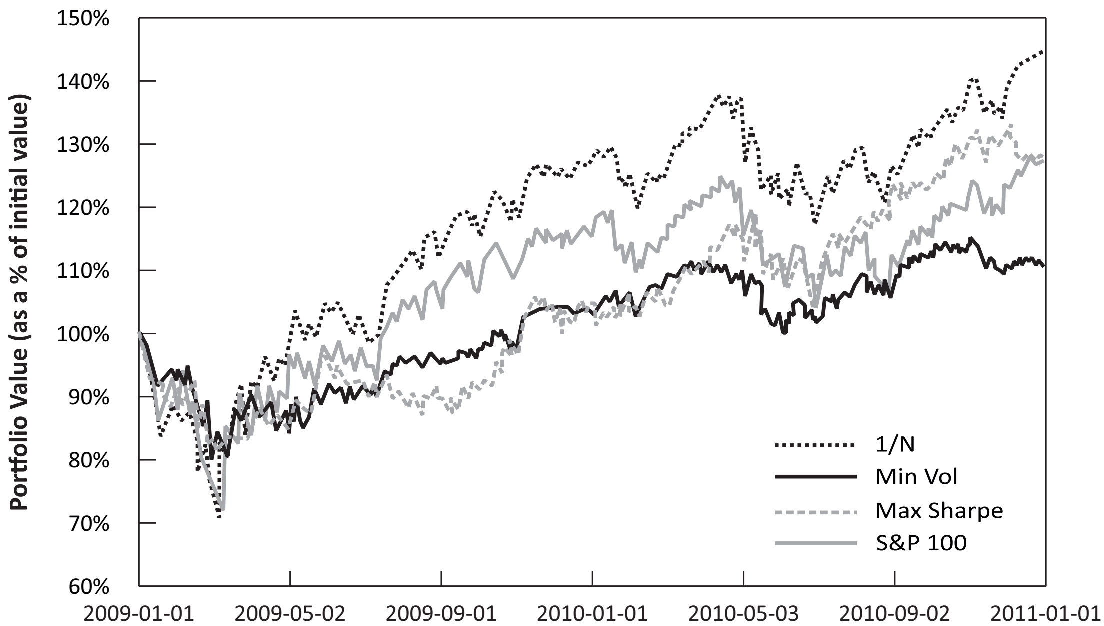

Figure 3 The market value of the managed portfolios obtained by using the Min Volatility and the Max Sharpe rebalancing strategies, with the maximum turnover constraint, the 1/n portfolio strategy with the minimum turnover constraint and of the benchmark S&P 100 index for the period from January 2nd, 2009 to December 31st, 2010

Source: Authors

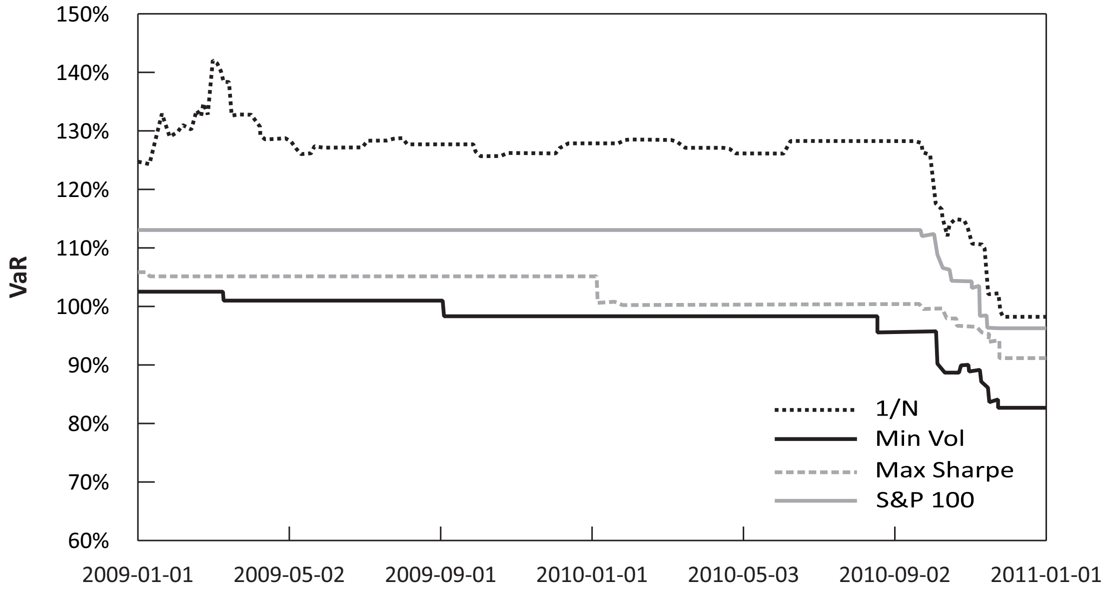

Figure 4 The 1%VaR estimates of the managed portfolios obtained by applying the Min Volatility and the Max Sharpe rebalancing strategies with the maximum turnover constraint, the 1/n portfolio strategy with the minimum turnover constraint and of the benchmark S&P 100 index for the period from January 2nd, 2009 to December 31st, 2010

Source: Authors

In Table 2, we present the performance statistics for the managed portfolios with the turnover constraints imposed.

After imposing the turnover constraints, the Min Volatility portfolio remains the same. On the other hand, the total turnover of the Max Sharpe strategy decreases to 13.73%, with only three realized rebalances with a decrease of more than 50% in the total return compared to the unconstrained version of the strategy. Furthermore, the Sharpe ratio is no longer the highest in the sample (but the VaR estimates are significantly lower).

Then again, the Min Volatility strategy delivers the lowest standard deviation and the 1%VaR.

Imposing the turnover constraint to the 1/n strategy results in the significantly lower total turnover (158.48% vs. 569.25%) within 29 instead of 504 rebalances, while the balanced overall performance still remains.

The aim of portfolio allocation is to induce diversification effects, i.e. to exclude the idiosyncratic risk of individual assets and deliver more balanced risk/return characteristics. Portfolio theory suggests that the more assets included the greater is the diversification effect (Markowitz, 1952). In practice, investors try to achieve maximum diversification effects with the minimum portfolio cardinality, thus avoiding high management costs. The presented strategies are applied to the opportunity set of 40 assets[7]. Including no more than two assets on average, the Max Sharpe strategy provides poor diversification effects, regardless of whether the turnover constraint is imposed or not. Simultaneously, the Min Volatility strategy delivers superior effects on risk values (volatility and VaR) relative to the 1/n strategy and the benchmark S&P 100 index, including only 7 assets on average, but at the expense of a modest return.In order to check the robustness of our results with respect to the observed period, the same tests for the new period of two years (504 trading days), starting on September 1st, 2011 and ending on September 4th, 2013 have been performed (S&P 100 index, https://finance.yahoo.

Table 2 The performance statistics of the managed portfolios obtained by applying the Min Volatility and the Max Sharpe rebalancing strategies with the maximum turnover constraint, the 1/n portfolio strategy with the minimum turnover constraint and of the benchmark S&P 100 index for the period from January 2nd, 2009 to December 31st, 2010

	Min Volatility turnover <50%	Max Sharpe turnover <50%	1/N turnover>5%	S&P 100
Total return	11.18%	27.72%	43.76%	27.31%
Total turnover	204.06%	13.73%	158.48%	-
No. of rebalances	7	3	29	-
Avg. return (ann.)	6.31%	14.08%	21.14%	14.45%
StdDev (ann.)	14.18%	19.09%	24.36%	21.70%
VaR1%	2.77%	3.05%	4.45%	4.05%
Max drawdown	-8.03%	-4.89%	-8.23%	-7.84%
Sharpe	0.42	0.72	0.86	0.65
Avg. no. of assets	7.2	2.0	40	100

Source: Authors

com). For the purpose of brevity, we only present the performance statistics of the portfolios obtained by applying the Min Volatility and the Max Sharpe rebalancing strategies with the maximum turnover constraint in Table 3. The results are consistent with those obtained for the 2009-2010 period (except for the fact that, this time, the Max Sharpe strategy has resulted in a higher number of rebalances and a higher turnover). For the reasons of comparability, the same Treasury rate of 0.29% as in the previous tests is used.

Table 3 The performance statistics of the managed portfolios obtained by applying the Min Volatility and the Max Sharpe rebalancing strategies with the maximum turnover constraint, the 1/n portfolio strategy with the minimum turnover constraint and of the benchmark S&P 100 index for the period from September 1st, 2011 to September 4th, 2013

	Min Volatility turnover <50%	Max Sharpe turnover <50%	1/N turnover>5%	S&P 100
Total return	23.54%	35.05%	43.92%	36.33%
Total turnover	82.15%	273.03%	67.19%	
No. of rebalances	5	9	14	
Avg. return (ann.)	11.14%	16.15%	19.39%	16.69%
StdDev (ann.)	10.45%	14.82%	15.15%	15.24%
1%VaR1	1.87%	2.37%	2.60%	2.59%
Max drawdown	-3.70%	-4.89%	-8.23%	-5.89%
Sharpe	1.04	1.07	1.26	1.07
Avg. no. of assets	5.4	3.4	40	100

Source: Authors

CONCLUSION

This paper presents two alternative portfolio management strategies: the first one is based on the minimization of volatility and the other one is based on the maximization of the Sharpe ratio. The resulting performance is compared to the benchmark, the 1/n portfolio strategy and the reference S&P 100 index.

Consistent to Hypothesis H1, the Min Volatility strategy delivers a portfolio with the minimum risk (in terms of volatility and 1%VaR). The Max Sharpe strategy delivers a portfolio with the maximum return (on an absolute and risk-adjusted basis, expressed by the Sharpe ratio) consistent to Hypothesis H2. Although theoretically appealing, the Max Sharpe solution portfolio is not feasible under real market conditions due to a very high total turnover[8]. In order to control the portfolio turnover, turnover constraints have been introduced.

It has turned out that imposing a turnover constraint on the Sharpe strategy in a way it is proposed here is not eligible since it induces a portfolio solution with very poor performances. However, the Min Volatility strategy still provides a superior risk performance in comparison with the reference S&P 100 index and the 1/n portfolio with a relatively low level of turnover and a low rebalance frequency. Therefore, this is an acceptable investment alternative to market capitalization and the equal-weighting-factor-based approach for risk adverse investors.

There is an empty room for future research into the impact of different transaction cost patterns on chosen rebalancing criteria. How a different length of historical data impacts the final solution should also be explored. There are two extreme rebalancing scenarios that have been applied in this paper: the one with no turnover constraint and the other with constraints imposed in a way that any turnover exceedance prevents the execution of a rebalance. It would be worthwhile to expand research into the rebalancing solutions that conform to the predefined daily level of turnover.

ACKNOWLEDGEMENTS

The research presented in this paper was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, No. OH 179005 and No. III 44010.

ENDNOTES

1 Nowadays, market indexes are easily investable through exposure to exchange-traded funds. See, for example, the factsheet for the iShares S&P 100 ETF (Ticker: OEF).

2 The optimal rebalancing strategy is the one minimizing the expected future transaction costs and the tracking error, defined to be a distance from the current asset ratios to the target ratios.

3 The 1988 Basel Capital Accord created the first risk-based capital adequacy requirement for banks, while the 1996 amendment to the Capital Accord brought some improvements of the original accord regarding market risk.

4 The number 252 stands for the number of trading days per year, while 250 is often alternatively used

5 The Sharpe ratio is initially introduced as a reward to the variability ratio (Sharpe, 1966; Bacon, 2008).

6 The first 40 S&P 100 constituents with the data available as at Dec. 3rd, 2007 are included in the sample.

7 These 40 assets (out of the 100 index constituents) comprise more than 70% of the market capitalization of the underlying S&P 100 index portfolio.

8 In addition, the unreported results show that the Max Sharpe strategy induces occasional, very large changes in the portfolio composition.

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Received on 9th July 2014,
after revision,
accepted for publication on 15th December 2014.

Published online on 22nd December 2014

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