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WHAT IS THE COST OF MAXIMIZING ESG PERFORMANCE IN THE PORTFOLIO SELECTION STRATEGY? THE CASE OF THE DOW JONES INDEX AVERAGE STOCKS

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Abstract. Portfolio selection is one of the main financial topics. The original portfolio selection problem dealt with the trade-off between return and risk, measured as the mean returns and the variance, respectively. For investors more variables other than return and risk are considered to select the stocks to be included in the portfolio. Nowadays, many investors include corporate social responsibility as one eligibility criterion. Additionally, other return and risk measures are being employed. All of this, together with further constraints such as portfolio cardinality, which mirror real-world demands by investors, have made the multicriteria portfolio selection problem to be NP-hard. To solve this problem, heuristics such as the non-dominated sorting genetic algorithm II have been developed. The aim of this paper is to analyse the trade-off between return, risk and corporate social responsibility. To this end, we construct pareto efficient portfolios using a fuzzy multicriteria portfolio selection model with real-world constraints. The model is applied on a set of 28 stocks which are constituents of the Dow Jones Industrial Average stock index. The analysis shows that portfolios scoring higher in corporate social responsibility obtain lower returns. As of the risk, the riskier portfolios are those with extreme (high or low) corporate social responsibility scores. Finally, applying the proposed portfolio selection methodology, it is possible to build investment portfolios that dominate the benchmark. That is, socially responsible portfolios, measured by ESG scores, must not necessarily be penalized in terms of return or risk.

Keywords: sustainable investment; corporate social responsibility; multi-objective portfolio optimization; LR power fuzzy numbers; NSGA-II

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JEL Classifications: G11

1. Introduction

Investors can implement different strategies to invest their capital in the equity markets. On the one hand, if their investment horizon is intraday or short-term, they will choose among different trading strategies (Oliver-Muncharaz & García, 2020; Oliver-Muncharaz, 2020; Ogiugo et al., 2020; Rutkauskas et al., 2021).

On the other hand, for medium and long-term investments, portfolio management strategies are the most common. In this area, investors will opt for passive management if they consider that it is not possible to beat the market and will limit themselves to replicating a benchmark stock market index (García, Guijarro, & Moya, 2013). Conversely, they will engage in active management if they think they can outperform the benchmark.

Today's active portfolio management strategies are based on the seminal work by Markowitz (1952). The objective of the methodology is to obtain investment portfolios that simultaneously maximize return and minimize risk. The original methodology has been improved over the years and, among other modifications, additional criteria have been included to be considered in the selection of the stocks that make up the portfolio and that are important for investors, such as liquidity (García, González-Bueno, Guijarro, Oliver, & Tamošiūnienė, 2020). Another important criterion is the socially responsible behaviour of the companies selected in the investment portfolio (Cesarone, Martino, & Carleo, 2022).

Socially responsible investment (SRI), also called sustainable, responsible, green or ethical investment, is defined as a decision-making process that integrates in the investment strategy environmental, social and governance (ESG) criteria together with financial criteria (Miralles-Quirós & Miralles-Quirós, 2017; Silvestre, Antunes, & Filho, 2018). That means, socially responsible investors consider companies' ESG performance in addition to the conventional variables that measure financial performance, such as return and risk.

Over the last decades, SRI has experienced remarkable growth (Oliver-Muncharaz & García, 2020). At present there is no doubt that sustainable investment is a major force shaping global capital markets. According to the Global Sustainable Investment Review, sustainable investment in major capital markets has reached 35.3 trillion in assets under management, having experienced a 15% growth in two years (GSIA Global Sustainable Investment Alliance, 2020).

The motivation for investing in socially responsible companies is twofold. First, the desire of investors to promote a more ethical and sustainable corporate culture that respects human rights and avoids climate change, among other things (Arribas, Espinós-Vañó, García, & Oliver, 2019). Second, it is assumed that socially responsible companies, at least in the medium and long term, will have a higher financial performance than conventional companies (García, González-Bueno, Guijarro, & Oliver, 2020b).

As for the performance of socially responsible companies, it has not been empirically demonstrated that it is superior to the performance of conventional companies. In the scientific literature, studies can be found that conclude that the financial performance of socially responsible investment funds and stock market indexes is superior to that of their conventional peers (Gómez-Bezares, Przychodzen, & Przychodzen, 2016; Wu, Lodorfos, Dean, & Gioulmpaxiotis, 2017). At the same time, however, other studies identify exactly the opposite (Lesser, Röble, & Walkshäusl, 2016; Revelli & Viviani, 2015; Trinks & Scholtens, 2017). Finally, numerous studies have found no significant differences between the financial performance of the two groups of companies (Espinós-Vañó, García, & Oliver, 2018; Revelli & Viviani, 2015).

One of the reasons for this disparity in results is how socially responsible behaviour is defined (Espinós Vañó & García, 2018). It has been shown that committing socially irresponsible actions does not prevent companies from

being included in socially responsible stock market indexes (Arribas, Espinós-Vañó, García, & Morales-bañuelos, 2019; Arribas, Espinós-Vañó, García, & Riley, 2021). In fact, the variable that most influences eligibility for the main sustainable stock market indexes is the size of the companies (Drempetic, Klein, & Zwergel, 2019).

The aim of this research is to determine whether it is possible to create investment portfolios that simultaneously maximize profitability and socially responsible behaviour while minimizing risk. For this purpose, the multicriteria decision making methodology will be used, which allows to reach compromise solutions between different conflicting objectives. This methodology has been widely applied in the field of financial investments (Masood, Tvaronavičienė, & Javaria, 2019) and the creation of investment portfolios (Basilio, de Freitas, Kämpffe, & Bordeaux Rego, 2018; García, González-Bueno, Guijarro, & Oliver, 2020a; Martinkutė-Kaulienė, Skobaitė, Stasytė, & Maknickienė, 2021; Pahade & Jha, 2021). Generally, investment funds and socially responsible stock market indexes use positive or negative screening to select the companies in their portfolios. As mentioned above, this approach is subjective and not without criticism. Evaluation of the degree of corporate social performance is one of the most discussed questions among academic researchers and practitioners (Lamata, Liern, & Pérez-Gladish, 2018). In contrast to this option, the multi-criteria methodology applied in this paper does not require a prior selection of eligible companies, but rather selects those companies that maximize the ESG score of the portfolio, while maximizing the expected return and minimizing the risk. It is an objective and transparent methodology that allows socially responsible investors to simultaneously incorporate three fundamental criteria in their investment strategy.

The proposed methodology was applied to companies included in one of the most important stock market indexes, the Dow Jones Index Average (DJIA). The results obtained are in line with previous studies. On the one hand, there is a trade-off between profitability and risk: portfolios with higher profitability must assume a higher level of risk, and vice versa. On the other hand, the relationship of these variables with the ESG score of the portfolio is not linear. Investment portfolios with a high ESG-score are dominated in terms of return and risk by portfolios with a lower ESG-score. But portfolios with lower ESG-scores do not dominate other portfolios with relatively high ESG-scores. When comparing the performance of the portfolios obtained with that of the index to which they belong (DJIA), it is found that they all beat the DJIA in terms of return. Furthermore, by applying the proposed methodology it is possible to beat the DJIA in the three criteria used: sustainability, profitability and risk. Therefore, we can conclude that the proposed methodology allows investors to build investment portfolios that maximize socially responsible behaviour without having to sacrifice other fundamental objectives, such as maximizing profitability and minimizing risk.

The rest of the paper is structured as follows. Section 2 introduces the theoretical background. This is followed by a description of the multi-criteria methodology that will be used to create the investment portfolios. Section 4 shows and comments on the results obtained. Finally, the main conclusions are presented.

2. Theoretical background

The problem posed by financial investment decisions consists of determining in which assets to invest and in what proportion, so as to maximize the profitability and minimize the risk of the investment. This is called the portfolio selection problem and was first proposed by Markowitz (1952). In the original model, the mean return and the variance were used to quantify the expected return and risk of the assets, respectively. Since then, numerous academics have proposed changes to adapt various aspects of the original model to the reality of financial markets. The new proposals have modified the way in which risk and return are quantified and have introduced new realistic criteria and restrictions.

In terms of risk quantification, the mean-variance model assumes that the return on financial assets follows a normal distribution, when in fact it is not (Narayan & Ahmed, 2014). To measure the risk of financial assets,

alternative measures have been used, such as, for example, semivariance (Markowitz, 1959), semi-absolute deviation (Speranza, 1993) or the CVar (Rockafellar & Uryasev, 2002), which are downside risk measures.

The Markowitz model assumes that the return of the financial assets is a random variable, so that their future performance can be reasonably well estimated from past data. However, financial markets are subject to different forms of uncertainty beyond randomness. To address this problem, fuzzy set theory can be applied (Zadeh, 1978). When analysing fuzzy phenomena, the shape of the membership function that best represents its historical evolution must be selected. In the case of the profitability of listed companies, triangular, trapezoidal and L-R power fuzzy numbers have been mainly used. The fuzzy theory has been welcomed by many authors, who use possibility measures to select the companies to be included in their investment portfolios (Liu & Zhang, 2018; Mansour, Cherif, & Abdelfattah, 2019; Pahade & Jha, 2022). But possibility measures lack the self-dual property, so they provide little information to investors and may confuse them. This problem was solved by Liu and Liu (2002), who proposed a self-dual credibility measure to study fuzzy phenomena. Since then, the credibility framework has been applied by many researchers to deal with the portfolio selection problem (Chen, Liu, & Wu, 2012; Jalota, Thakur, & Mittal, 2017a; Mohebbi & Najafi, 2018; Pahade & Jha, 2021; Vercher & Bermúdez, 2015).

Another improvement to the original mean-variance model has been the inclusion of additional criteria, such as liquidity (Gupta, Inuiguchi, Mehlawat, & Mittal, 2013; Yue & Wang, 2017; Yue, Wang, & Dai, 2015), skewness (Bhattacharyya, Kar, & Majumder, 2011) or kurtosis (Ma, Chen, Sun, & Zhu, 2021). An additional criterion used in some recent studies is the socially responsible behaviour of companies (Bilbao-Terol, Arenas-Parra, Cañal-Fernández, & Obam-Eyang, 2018; Fernando García, González-Bueno, Oliver, & Riley, 2019; Gasser, Rammerstorfer, & Weinmayer, 2017; Oliver, 2021). The use of criteria in addition to return and risk reflects investors' demand to satisfy other needs. Indeed, investors may be willing to sacrifice part of their expected return on their investment or increase their risk exposure if this negative situation is offset by improvements in other criteria, such as greater portfolio sustainability. In today's world, return and risk are not the only variables that guide the decision-making process of investors.

Along with the introduction of additional criteria, the original Markowitz mean-variance model has become more complex by introducing realistic constraints, such as cardinality, bound and budget constraints. As a consequence of the increased complexity of the model, the portfolio optimization model turns into a constrained NP-hard multi-objective problem. In this case, traditional optimization methods cannot be employed. Heuristic methods as multi-objective evolutionary algorithms must be used to solve the portfolio selection problem. One of the most widely used in the financial field is the Non-dominated Sorting Genetic Algorithm II (NSGA-II).

In this research paper, investment portfolios are created considering three criteria: profitability, risk and ESG-score, which is used as a measure of the ESG-engagement of the companies. Return and ESG-scores are assumed to be L-R power fuzzy variables in a credibility framework. The risk measure is the variance. Two constraints are included in the portfolio selection model: upper bound and cardinality. To solve the model, the NSGA-II is employed.

3. Methodology

The methodology used in the process of creating socially responsible investment portfolios is described below. First, it is explained how the L-R fuzzy numbers are calculated in the credibilistic framework to quantify return and ESG behaviour. Second, the multi-objective portfolio selection model and the use of the NSGAI algorithm to solve the model are presented.

3.1. Calculation of L-R fuzzy numbers and credibility values

The functions $L, R: [0,1] \rightarrow [0,1]$ are reference functions of a fuzzy number they satisfy the following conditions $A = (x, \mu_A(x))$, they satisfy the following conditions (Dubois & Prade, 1980):

- i) $L(1) = R(1) = 0, L(0) = R(0) = 1;$
- ii) $L(x)$ and $R(x)$ are strictly decreasing and upper semicontinuous functions.

A fuzzy number $M = (a, b, c, d)_{L\pi R\rho}$ is said to be an LR-type fuzzy number if its membership function has the following form (Dubois & Prade, 1980):

$$\mu_M(x) = \begin{cases} L_\pi\left(\frac{b-x}{b-a}\right), & \text{if } a \leq x < b \\ 1, & \text{if } b \leq x \leq c \\ R_\rho\left(\frac{x-c}{d-c}\right), & \text{if } c < x \leq d \\ 0, & \text{Otherwise} \end{cases} \tag{1}$$

where $(b - a)$ and $(d - c)$ show the left and right spreads of M , respectively. L_π and R_ρ are the reference functions that define the left and right shapes of M , respectively. Throughout this research, the left and right shapes of L-R fuzzy numbers are defined by $L_\pi(k) = 1 - x^\pi$, and $L_\rho(k) = 1 - x^\rho$, respectively. L-R power fuzzy numbers will be referred as $M = (a, b, c, d)_{\pi\rho}$ and the LR-fuzzy numbers used have the same reference functions L and R .

The crisp equivalent expression for the credibilistic expected value of a L-R power fuzzy variable $\xi = (a, b, c, d)_{\pi\rho}$, is obtained by deriving the expected value of a fuzzy variable (Jalota, Thakur, & Mittal, 2017b):

$$E(\xi) = \frac{1}{2} \left[b+c + \frac{(d-c)\rho}{\rho+1} - \frac{(b-a)\pi}{\pi+1} \right] \tag{2}$$

Therefore, the maximization of the expected return of the portfolio is expressed as:

$$\text{Max } F_1(\omega_i) = \sum_{i=1}^n \left[\frac{1}{2} \left[b_{r_i} + c_{r_i} + \frac{(d_{r_i} - c_{r_i})\rho_{r_i}}{\rho_{r_i} + 1} - \frac{(b_{r_i} - a_{r_i})\pi_{r_i}}{\pi_{r_i} + 1} \right] \omega_i \right] \tag{3}$$

The expression for the maximization of the expected ESG performance of the portfolio is following crisp objective:

$$\text{Max } F_2(\omega_i) = \sum_{i=1}^n \left[\frac{1}{2} \left[b_{\text{ESG}_i} + c_{\text{ESG}_i} + \frac{(d_{\text{ESG}_i} - c_{\text{ESG}_i})\rho_{\text{ESG}_i}}{\rho_{\text{ESG}_i} + 1} - \frac{(b_{\text{ESG}_i} - a_{\text{ESG}_i})\pi_{\text{ESG}_i}}{\pi_{\text{ESG}_i} + 1} \right] \omega_i \right] \tag{4}$$

The multiobjective credibilistic mean-semivariance-PER portfolio selection model seeks the maximization of portfolio's return ($\text{Max } F_1(\omega_i)$), the maximization of portfolio's ESG score ($\text{Max } F_2(\omega_i)$), being this score a proxy for companies' socially responsible behaviour, and the minimization of risk ($\text{Max } F_3(\omega_i)$), being the risk

calculated as portfolio's return variance. As mentioned above, both return and ESG score are L-R power fuzzy numbers. Moreover, the model includes some real-world constraints such as allocation of all the budget, upper bound, number of assets to be included in the portfolio and no short selling:

a) Capital budget constraint on the assets is denoted by

$$\sum_{i=1}^n \omega_i = 1 \quad (5)$$

b) Upper bound

$$\omega_i \leq u_i y_i, \quad i=1,2,\dots,n \quad (6)$$

c) Cardinality constraint

$$\sum_{i=1}^n y_i = k, \quad y_i \in \{0,1\}, \quad i=1,2,\dots,n \quad (7)$$

d) No short selling of assets

$$\omega_i \geq 0, \quad i=1,2,\dots,n \quad (8)$$

For this study, a feasible portfolio P is efficient if there does not exist another feasible portfolio P' such that, $P_{F1(\omega_i)} \geq P'_{F1(\omega_i)}$ and $P_{F2(\omega_i)} \leq P'_{F2(\omega_i)}$ and $P_{F3(\omega_i)} \leq P'_{F3(\omega_i)}$ with strict inequality for at least one of them. The set of efficient solutions is the so-called Pareto optimal set in the decision space and constitute the Pareto optimal frontier. Portfolios on this frontier are said to be non-dominated. There is no portfolio that simultaneously beats any portfolio on the frontier regarding the three criteria employed (return, risk and ESG-score).

The multi-objective portfolio selection model is not a classical quadratic optimization problem, but a quadratic mixed-integer problem that is NP-hard. To deal with this problem, a multiobjective evolutionary algorithms (MOEAs) is applied. Concretely, we use the Non-dominated Sorting Genetic Algorithm II (NSGA-II) (Liagkouras & Metaxiotis, 2015), which was introduced by Deb *et al.*, (2002). The structure of this algorithm is detailed in Palanikumar *et al.* (2009) and Deb *et al.* (2002). The experimental parameter configuration employed in this research is the following: Population size (400), distribution index for crossover (10), probability of crossover (0.9), distribution index for mutation (50); probability of mutation (0.01) and maximum number of generations 2000.

4. Results and discussion

The aim of this research is to analyse the trade-off between return, risk and corporate social responsibility in investment portfolios. The question is, whether investing in socially responsible companies is penalized in terms of return and risk or if it pays to be a socially responsible investor.

In order to carry out the study, the methodology described in the previous section was applied to a database covering 28 of the 30 stocks that make up the prestigious DJIA stock index in January 2022. The tickers of the companies included in our study are: MMM, AXP, AAPL, T, BA, CAT, CVX, CSCO, KO, XOM, GS, HD, IBM, INTC, JNJ, JPM, MCD, MRK, MSFT, NKE, PFE, PG, UNH, VZ, V, WBA, WMT, DIS. For each of these companies, daily information is available on the share price (P_i) for the period from 2nd January 2008 to 31st December 2019. From this information, the daily profitability has been calculated as $r_{it} = \ln(P_{it+1}/P_{it})$. Information on the corporate social responsibility performance of the 28 companies for this period is also available. These data have been obtained from the Bloomberg ESG disclosure Score. The ESG scoring quantifies the performance in the fields of environmental, social and governance activities using a scale from 0 to 100, being 100 the best possible score. The data relating to profitability and ESG performance have been treated as described in section 3. The variance has been obtained directly from the daily returns.

Table 1 shows, for each year from 2008 to 2019, how the companies in the sample have performed in terms of ESG, profitability and risk. For profitability and risk, the average values are shown, while for ESG performance, the information is broken down by quantiles.

Table 1. Descriptive analysis of the sample

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
ESG Min.	20,2	17,1	29,2	25,3	23,5	21,0	50,8	50,9	55,4	61,7	63,4	54,5
ESG 1st Qu.	56,3	64,4	61,7	64,0	63,1	62,4	63,1	66,6	67,1	68,1	68,0	70,2
ESG Median	69,6	71,4	68,8	71,6	72,5	69,8	68,8	73,3	74,1	71,8	72,9	74,4
ESG Mean	65,6	69,1	69,4	69,9	69,1	69,1	70,9	72,7	74,2	74,7	74,9	75,7
ESG 3rd Qu.	78,2	78,6	81,2	78,3	76,9	78,4	78,3	79,1	81,4	82,2	80,2	81,2
ESG Max.	91,6	95,1	94,8	92,8	91,2	92,3	92,5	93,1	91,2	90,3	93,2	93,2
Return	-0,0013	0,0010	0,0004	0,0002	0,0005	0,0010	0,0004	0,0000	0,0004	0,0007	-0,0001	0,0007
Risk	0,0011	0,0010	0,0006	0,0008	0,0005	0,0006	0,0005	0,0006	0,0005	0,0008	0,0007	0,0007

Source: The authors

As for the ESG score, the wide range between the highest and lowest scores is striking. This implies that the ESG performance of the companies in the sample is very uneven. It is not possible to obtain investment portfolios with ESG values well above 90. Nor is it to be expected that the portfolios with the worst ESG performance do not reach 40 points. The average for the period analysed is between 65 and 75 points. Another fact worth noting is that the minimum ESG values show an upward trend, which may be indicative of increased awareness of the companies in the sample of the importance of socially responsible behaviour. Return rates fluctuate between a minimum of -0.0013 in 2008 (the year of the financial crisis) and the maximum in 2009 and 2010 (0.0010). In terms of risk, the mean variance fluctuates between 0.0011 (year 2008) y 0.0005 (years 2012, 2014 and 2016).

Figure 1 shows the distribution of 400 pareto-efficient portfolios in the return, risk and ESG-score space. These portfolios have been chosen applying the methodology described in section 3. In this case, no cardinality or upper bound restrictions have been imposed. There is no portfolio that simultaneously achieves higher returns, lower risk and higher ESG-score. Portfolios that are not on the Pareto efficient frontier are beaten by those that are on the frontier in all these criteria. That is, they have lower returns, higher risk and lower ESG-score.

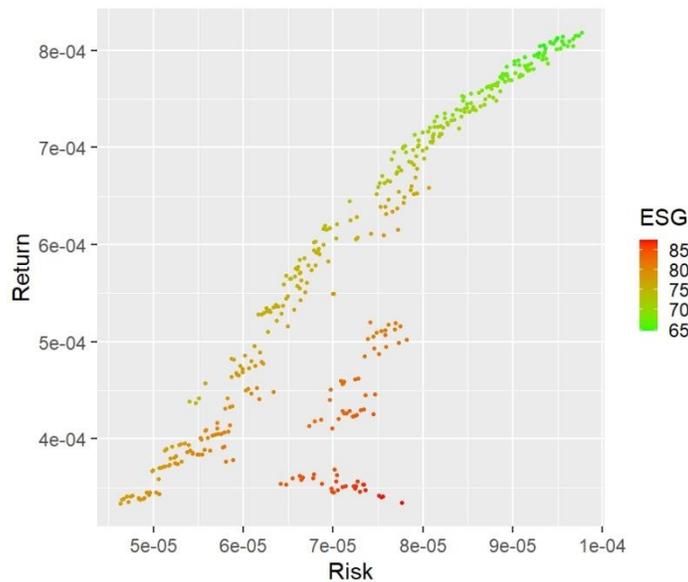


Figure 1. Pareto optimal frontier of the credibilistic multiobjective mean-variance-ESG portfolio model

Source: The authors

The multi-criteria methodology used yields non-dominated portfolios with very high ESG values. In these cases, investments are made in the companies with the highest ESG-score. These portfolios are dominated by many others in terms of profitability and risk. In other words, concentrating investments in the most socially responsible companies has negative consequences on the profitability of the portfolio and the risk borne. This is a curious fact, since in theory the higher the return, the higher the risk and vice versa.

It is also observed that portfolios can be created with relatively low ESG values by investing in companies with lower ESG-score. By sacrificing ESG performance, we obtain portfolios with high returns and high risk. These portfolios are dominated by many other portfolios in terms of risk and ESG-score.

In short, figure 1 shows the trade-off between the different criteria. It is interesting to note how, in the sample and period analysed, higher ESG implies lower profitability, contrary to what other papers in the literature suggest. The most profitable companies are the relatively less socially responsible ones. And for these companies, as economic theory suggests, higher profitability is associated with higher risk.

Following these results, we proceeded to create 400 more realistic investment portfolios by introducing all the restrictions according to the specifications in section 3. The number of companies in the portfolio was set at $k=10$ and the upper bound at 30%. From the totality of portfolios obtained, Figure 2 shows a selection. The portfolios have been selected by their quantile in relation to their ESG-score.

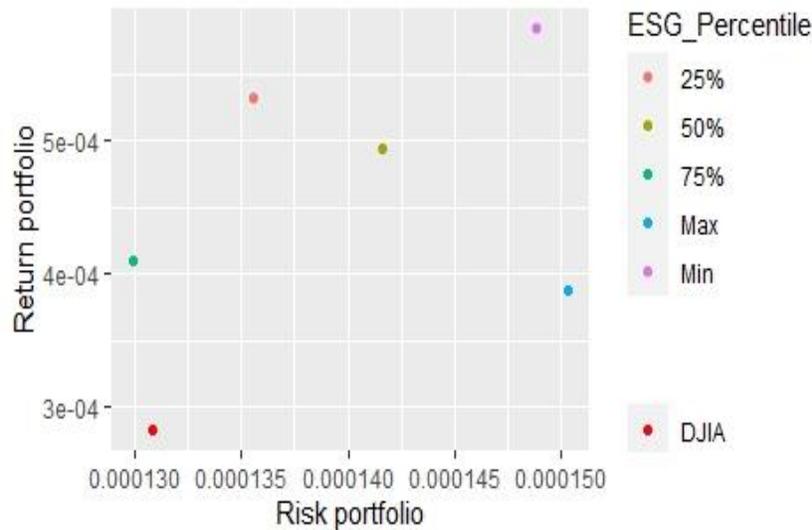


Figure 2. Pareto optimal selected portfolios of the credibilistic multiobjective mean-variance-ESG portfolio model

Source: The authors

The ESG-score of the portfolios shown in Figure 2 is as follows. The portfolio with the lowest ESG-score, the one corresponding to the minimum ESG performance, has an ESG-score of 66.32. The portfolio located in the percentile 25 has an ESG-score of 68.55. The one located in the median has an ESG-score of 70.82. The one located in the percentile 75 reaches 73.26 ESG-scores. Finally, the portfolio with the highest ESG-score has 76.25 points. On figure 2 is also drawn the portfolio that corresponds to the DJIA (red color), which has the one with the lowest return. Its ESG-score is 70.97.

The ESG-score range of the created investment portfolios is between 66.32 and 76.25. Considering the information in Table 1, it can be stated that they have a medium-high ESG level. The return (between 0.00035 and 0.006) is also relatively high, given the sample of companies available. It is striking how low the level of risk assumed by the selected portfolios is (0.00013 to 0.00015). The investment portfolio corresponding to the DJIA has a slightly higher ESG-Score than the sample average, and a relatively low level of return and risk.

As occurs when the model has no cardinality or upper bound restrictions, the profitability of the portfolios gradually decreases as the ESG-score increases. It can be concluded that the higher the ESG-score, the lower the portfolio return. The same is not true for risk. The riskiest portfolios are those with extreme ESG-score values (low or high). Therefore, the relationship between risk and socially responsible corporate behaviour is neither positive nor linear.

An important result is that, with the applied methodology, it is possible to beat the DJIA in terms of return, risk and ESG-score. As can be observed in Figure 2, the portfolio in percentile 75 dominates the portfolio representing the DJIA. Therefore, an investor seeking to maximize the ESG level of her portfolio needs not be penalized in terms of return or risk. In other words, with the proposed methodology, it is possible to construct socially responsible investment portfolios in terms of ESG without giving up returns or assuming more risk than the benchmark stock index. This is at least the case with the DJSI companies in the period analysed.

Finally, since many investors are particularly concerned about the performance of their portfolios, figure 3 shows the performance of the portfolios obtained and the DJSI from the beginning of 2008 to the end of 2019. As figure

3 shows, all the portfolios created with the multi-criteria model beat the DJIA index in terms of performance over the entire period.

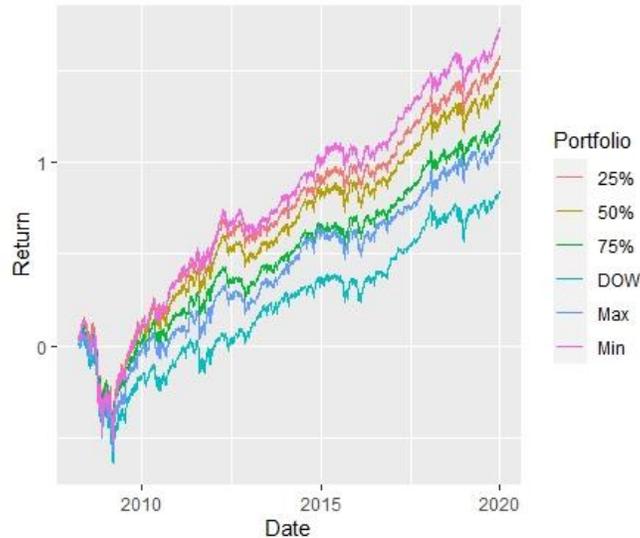


Figure 3. Evolution of the return of selected portfolios and DJIA

Source: The authors

It is clear that the most profitable portfolios are those with lower ESG scores. As for the time evolution, it is similar in all cases. Profitability fell sharply in 2008 and early 2009. From then on, it followed a strong upward trend.

Conclusions

In recent decades, investors' concern for the socially responsible behaviour of companies has increased considerably. This evolution is probably due to the increase in society's awareness of problems such as pollution and climate change, respect for human rights or labour conflicts. In response to this demand from investors, companies have emerged that specialize in quantifying the socially responsible behaviour of companies in terms of the environment, society and corporate governance (ESG). As a result, investors can include ESG performance of companies as a criterion for inclusion in their investment portfolios.

One of the questions that has attracted the attention of researchers in recent years is whether it is worth investing in socially responsible companies. On the one hand, it is assumed that sustainable companies will perform better in the medium and long term, which, in turn, will positively affect their stock price. But on the other hand, they face higher costs in the short term. Another fundamental question is how ESG performance is defined and measured.

In this paper we have applied a fuzzy multi-criteria portfolio selection model that includes in the decision process not only the usual criteria of profitability and risk, but also the ESG behaviour of the companies. In addition, real-world constraints such as cardinality or upper bound are included. To solve the model, which is NP-hard, the NSGA-II heuristic has been used. The model was applied to create investment portfolios with 28 companies included in the DJIA index over the period 2008-2019.

The results obtained show that higher ESG engagement of portfolio companies implies lower investment returns. This result is contrary to that of some previous studies. However, this is a very controversial issue, on which there is no unanimity among researchers. As for the relationship between ESG-score and risk, portfolios with extreme ESG-score values (i.e. both portfolios with higher ESG-score and portfolios with lower ESG-score) bear the greatest risk. There is therefore no simple relationship between ESG performance and risk. Finally, the application of the proposed multi-criteria portfolio selection methodology makes it possible to build portfolios that dominate the benchmark (DJIA) in all three criteria: performance, risk and ESG-score. Therefore, investors who wish to invest in socially responsible companies do not necessarily have to assume greater risk or renounce to the profitability levels achieved by the benchmark.

Obviously, the results obtained are largely due to the sample of companies selected and the period analysed. To make the results more robust, it is necessary to apply the methodology to other markets and to a larger number of companies. In addition, it would be interesting to use other measures to quantify the socially responsible behaviour of companies. It is also advisable to use other stock market indexes as benchmarks. Finally, changes can also be made to the methodology, such as using other measures to measure risk, such as CVar, and incorporating other real-world constraints, such as transaction costs.

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