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ASSESSMENT OF EFFICIENCY OF INVESTMENT IN COMPANIES BELONGING TO THE RARE EARTH METALS SECTOR[1]

Summary

Purpose – This paper aimed at assessing the efficiency of investment in companies belonging to the rare earth elements sector and examining the stability of the results.

Research method – The following performance measures were used in the study: modified Sharpe and Omega, Sortino, Calmar, Sterling and Burke ratios. The investigation is based on daily quotations of selected companies whose business activities were related to extraction, processing and recycling of rare earth metals in the period: from July 2018 to June 2023 and MVIS® Global Rare Earth/Strategic Metals Index representing the global market.

Results – The analysis for the entire period revealed a worse performance of investments in rare earth stocks than investment in risk-free assets. Only AREC outperformed other securities offering the best results for 3 of 6 ratios. To examine the stability of the results, the total investigation period was divided into 5 subperiods and all performance ratios were determined for each of them. A strong variation of results did not allow to recognise stable patterns. When the results for the entire investigation period were used as a benchmark, only MVREMX offered stable and attractive results of modified Sharpe ratio outperforming the five-year value in 4 out of 5 subperiods.

Originality/value/implications/recommendations – This study provides a new insight into the rare earths sector regarding its growing international importance and the efficiency of investments into listed rare earth firms. The examination uses two-dimensional

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measures offering the advantage of simultaneously combining return and risk into a single performance number. The findings imply the necessity of improving the stock price performance to attract investors' interest.

Keywords: rare earth metals, indirect commodity investments, risk-adjusted performance measures

JEL classification: G11, C10

1. Introduction

Since the time of the financial crisis of 2008, a bigger interest in investments on commodity market can be observed. Investors have different forms of investment at their disposal, both – direct and indirect ones. One of them is buying shares of the companies connected with commodity sector, for example entities dealing with extraction and/or processing of raw materials, like crude oil or gold. However, in recent years the importance of rare earth metals (REM) has been growing significantly as they are essential for a wide range of industrial and consumer product applications, such as wind energy turbines, photovoltaic cells or electric vehicles [Reboredo, Ugolini, 2020].

Over the last two decades the rare earth metals have become a separate strategic commodity class. They have also gained a lot of attention through news media and the Internet due to their unique properties and contributions to modern technologies [Assaf et al., 2023]. Additionally, the investors' enthusiasm toward rare earth metals' stocks has been increasing due to portfolio diversification opportunities. This sector draws also the attention of scientists who attempt to determine the link of different factors with the stock price performance of REM firms. According to Song et al. [2021], rare earth as a critical element and its historical evolution was first analysed in detail by Fernandez [2017] who used pairwise correlations and concluded that REM indices moved more closely with industrial metals and the general commodity index than with precious metals. However, the most recent literature mainly focuses on examining interdependencies between the rare earth market and other financial markets and on the volatility transmission [Reboredo, Ugolini, 2020; Özdurak, Ulusoy, 2020; Bouri et al., 2021; Song et al., 2021; Ul-Haq et al., 2022]. There are also some studies that investigate the existence of the long memory in Rare Earth Market Index [Assaf et al., 2023] or factors influencing the efficiency of clean energy firms and their stock price performance [Lee et al., 2022].

The purpose of this paper is to assess efficiency of investment in companies belonging to the rare earth elements sector. Rare earths production, mining and recycling are progressively attracting more attention, mainly due to their importance for clean energy-related technologies. This may bring the prosperity to the industries closely related to these activities. That is why one may formulate the hypothesis that the purchase of stocks of companies belonging to the rare earth materials sector might be an attractive form of investment available for individual investors. Thus this empirical research uses daily quotations of selected companies dealing with extraction, processing and recycling of rare earth elements and of MVIS® Global Rare Earth/Strategic Metals Index (MVREMX) in the period from 1 July 2018 to 30 June 2023. Along with the Sharpe approach, the study employs alternative risk adjusted performance measures, such as the modified Sharpe ratio, Omega ratio, Sortino ratio, Calmar ratio, Sterling ratio, and Burke ratio.

The rest of the paper is organised as follows. Section 2 provides a brief description of rare earth metals. Section 3 introduces methodology. Section 4 presents empirical data and results. The last section offers concluding remarks.

2. Rare earth metals – a brief description

The rare earth metals are cerium (Ce), dysprosium (Dy), erbium (Er), europium (Eu), gadolinium (Gd), holmium (Ho), lanthanum (La), lutetium (Lu), neodymium (Nd), praseodymium (Pr), promethium (Pm), samarium (Sm), scandium (Sc), terbium (Tb), thulium (Tm), ytterbium (Yb), and yttrium (Y). They are often found in minerals with thorium (Th) and (less commonly) uranium (U) [Özdurak, Ulusoy, 2020]. Since the beginning of the 21st century, prices of most of them have been higher than the price of gold. One of the reasons for that is steadily increasing demand for rare earth materials due to a wide range of their use, starting from military technology, through energy technology, electronics, motorisation, luminescence, optics, finishing with medicine, and many others. For example, without neodymium, which has strong magnetic properties, it is impossible to manufacture turbines for wind power stations. Dysprosium is also required in high-strength wind turbines. Nuclear electric power technology relies on thorium. Lanthanum is necessary for production of small but effective engines for electric cars, etc. With no doubt, rare earth elements are needed by atomic power stations, as well as household appliances or smartphones. Because of their distinctive petrochemical, magnetic and conductive properties they have

become an integral part of modern manufacturing, construction and new energy industries. Table 1 shows the usage of specific rare earths in various sectors and industries.

TABLE 1

Rare earth elements and their applications

Sector/Industry	Usage of rare earths
Clean Energy	Dysprosium, Neodymium, Terbium, Praseodymium, Yttrium
Electronic & Telecommunication	Dysprosium, Lanthanum, Cerium, Europium, Praseodymium, Neodymium, Gadolinium, Terbium, Yttrium, Scandium, Thulium
Defence & Aerospace	Erbium, Neodymium, Praseodymium, Dysprosium, Yttrium, Terbium, Cerium, Promethium, Scandium
Health care	Gadolinium, Europium, Lanthanum, Yttrium, Samarium, Teebium, Neodymium, Erbium, Thulium, Holmium

Source: Bouri et al., 2021, p. 5711.

At the beginning, rare earth elements were provided to the world market by the Republic of South Africa and India. In the 60s of the 20th century, the US, having the most technologically advanced industry, has become their biggest producer. However, in the 80s, China has taken over leadership. At present, China has cornered the global market of these materials. This country has the highest reserves of rare earth minerals at 44 million MT [Özdurak, Ulusoy, 2020] and dominates world production of them, accounting for more than 90 percent of world supply and production [Assaf et al., 2023]. Table 2 presents world reserves of rare earth materials (the numbers refer to 2020). The existing supply of rare earths is concentrated in just a few countries.

The global focus towards clean energy transition will increase the rare earth metals demand due to their indispensable role in new energy industries from solar photovoltaic cells and wind turbines to electric vehicles and battery storage [Sun, 2022]. Global Market Insights Inc.'s 2020 research predicts that the annual growth rate of rare earth elements would be increased by 10.8 percent from 2022 to 2026 [Ul Haq et al., 2022]. According to Nassar et al. [2016], the demand for rare earth metals is expected to increase by around 34 percent by 2040 for cleaner energy production alone, whereas the European Union estimates that by 2050 its demand for rare earth elements will increase ten times [Kublik, 2021]. In the

next decade, Australia and North America intend to increase the supply of rare earths in order to satisfy future demand.

TABLE 2

World reserves of rare earths by principal countries

Country	Reserves in tonnes	% share
Australia	3,400,000	2.81
Brazil	22,000,000	18.17
Canada	830,000	0.69
China	44,000,000	36.35
Greenland	1,500,000	1.24
India	6,900,000	5.70
Malaysia	30,000	0.02
Malawi	140,000	0.12
Russia	18,000,000	14.87
South Africa	860,000	0.71
Vietnam	22,000,000	18.17
USA	1,400,000	1.16

Source: Ul-Haq et al., 2022, p. 4.

3. Methodology

The methodology covers the range of two-dimensional (risk-adjusted) measures. They offer the advantage of simultaneously combining return and risk into a single performance number. The most widely known performance measure is the Sharpe ratio:

$$SR_i = \frac{r_i^d - r_f}{\sigma_i}. \tag{1}$$

This ratio considers the relationship between the excess return or risk premium, which is the excess of the obtained return (r_i^d) over the risk-free interest rate

(r_f), and the standard deviation (σ_i). The excess return can be negative or positive. According to Israelsen [2005], the reliability of the Sharpe ratio decreases when the excess return is negative. Thus, he suggests to modify the standard Sharpe ratio by adding an exponent to the denominator. The exponent is: excess return divided by the absolute value of excess return (see also [Magiera, 2010]).

Replacing standard deviation in the Sharpe ratio with the downside deviation measure – the lower partial moment of order 2 $(LPM_{2i})^2$ provides the Sortino ratio:

$$SOR_i = \frac{r_i^d - \tau}{\sqrt{LPM_{2i}(\tau)}} \tag{2}$$

This downside risk measure allows to modify the risk concept so that only negative shifts of the return from a predetermined minimum return or target return (τ) are perceived as risk. The τ is the minimum rate of return acceptable to the investor and can be taken as an average rate of return, a value of zero or a risk-free rate of return.

Other risk-adjusted popular measures are [Eling, 2008]:

- the Omega measure (O_i) that considers the excess of the asset return over a minimal acceptable return τ in relation to the lower partial moment of order 1 (LPM_{1i}) and
- the Calmar ratio (CR_i), which is the excess of the security return over r_f divided by the maximum drawdown (MD_i).

They are given by the following formulas:

$$O_i = \frac{r_i^d - \tau}{LPM_{1i}(\tau)} + 1 \tag{3}$$

and

$$CR_i = \frac{r_i^d - r_f}{|MD_i|}. \tag{4}$$

Maximum drawdown (MD_i) is:

$$MD_i = \frac{\text{Trough Value} - \text{Peak Value}}{\text{Peak Value}}, \tag{5}$$

[2] Lower partial moment of order n is: $LPM_{ni}(\tau) = \frac{1}{T}\sum_{t=1}^{T} max\left[\tau - r_{it}, 0\right]^n$.

where Trough Value is the lowest value ("Bottom") and Peak Value is the highest value ("Top"). From the investor's point of view, the biggest loss is buying assets at the highest price in a given period and selling them at the lowest price. The MD_i determined in this way always takes a negative value.

In addition to these measures, two other ratios are also often considered: Sterling (ST_i) and Burke (BU_i) ratios. They are calculated as:

$$ST_i = \frac{r_i^d - r_f}{\frac{1}{n}\sum_{j=1}^{n}\left|MD_{i,j}\right|} \tag{6}$$

and

$$BU_i = \frac{r_i^d - r_f}{\sqrt{\sum_{j=1}^{n}\left(MD_{i,j}\right)^2}}. \tag{7}$$

The Calmar, Sterling and Burke ratios constitute a specific subgroup of indicators. They are based on the analysis of the average return on security i (r_i^d) and on the analysis of the i-th security risk measured by the maximum decrease in the rate of return (MD_i). Sterling ratio compares the average rate of return obtained on the i-th stock over risk-free assets to the average level of risk expressed as the average value of the n largest drawdowns. Burke ratio, on the other hand, measures the ratio of the excess of the average rate on equities and risk-free assets to the square root of the sum of squares of n maximum drawdowns recorded in the analysed period. It is postulated to assume $n = 5$ maximum decreases in the rate of return [Mikulec, 2011].

4. Empirical results

4.1 Analysis from July 2018 to June 2023

The empirical data used for the analysis was sourced from Bloomberg [www 2], NASDAQ [www 9] and Yahoo Finance [www 4] and covers daily quotations of selected rare earth companies from 1 July 2018 to 30 June 2023 with the starting date determined by data availability. Shares of the following established and high-performing companies with a track record of profits over several years were taken for the analysis: Rare Element Resources from the USA, Lynas Rare Earths

Limited and Northern Minerals Limited from Australia, Canada Rare Earth Corp., Ucore Rare Metals Inc., from Canada and also, companies that recycle rare earth elements: American Resources Corp., Matrix Service Company from the USA and Geomega from Canada. Investing in such companies can provide exposure to the rare earth market while also offering a hedge against any future supply disruptions. Moreover, one of them – Lynas Rare Earths – is among the ten top components of MVREMX index.

The Rare Element Resources Ltd. is a publicly traded, strategic materials company focused on delivering rare earth products for technology, energy and defence applications by advancing the Bear Lodge Critical Rare Earth Project in North East Wyoming [www 11]. Its common shares are traded on the NASDAQ under the symbol "REEMF".

Ucore Rare Metals Inc. is a well-funded development-phase mining company focused on establishing rare metal resources with near term production potential. It carries out many projects across North America located at Bokan Mountain on Prince of Wales Island, Alaska [www 12]. Its shares are also traded on the NASDAQ under the symbol "UURAF".

Lynas Rare Earths Ltd. is a public company registered in Western Australia and an integrated source of rare earths from mine to customer. Lynas has a portfolio of aligned assets to explore, develop, mine and process rare earth minerals. The Lynas Mt Weld mine in Western Australia is acknowledged as one of the world's premier rare earths deposits. Lynas also operates the world's largest single rare earths processing plant in Malaysia where it produces high-quality separated rare earth materials for export to manufacturing markets in Asia, Europe and the United States [www 6]. It is listed on the Australian Securities Exchange (ASX) under symbol "LYC".

Northern Minerals Limited from Australia aspires to be a principal supplier of ethically produced Rare Earth Metals and separated products from the world's largest Heavy Rare Earth Element inventory, specifically dysprosium, lutetium and terbium. The Company has a large landholding in Western Australia and the Northern Territory that is highly prospective for this element [www 10]. It is listed on the Australian Securities Exchange (ASX) under symbol "NTU".

Canada Rare Earth Corporation is a mineral exploration company that explores for rare earth element deposits throughout North America. The Company has operations in Ontario and Eastern Canada, where it explores for metals that include scandium, yttrium, and lanthanides. The Company provides a variety of rare earth products. Its products include high-purity simple oxides, nano and large particle rare earth products and custom products. The Company is involved

with projects in North America, South America and Southeast Asia [www 3]. It is listed on the Toronto Stock Exchange (TSX) under symbol "LL.V", and its shares are also traded on the over-the-counter (OTC) markets under the symbol "RAREF".

American Resources Corporation is a company that recycles rare earth elements and is a leading provider of high performance refining capacity of rare earth and battery elements [www 1]. Its shares are listed on the Nasdaq Capital Market ("NASDAQ-CM") under the symbol "AREC".

Geomega Resources Inc. offers a clean, innovative solution to rare earth extraction and separation without any organic solvents. Their activities are based on recycling and gradually increasing to reach mining capacity while generating cash flows [www 5]. It is listed on the TSX Venture Exchange under the symbol GMA and also on the other OTC under the symbol "GOMRF".

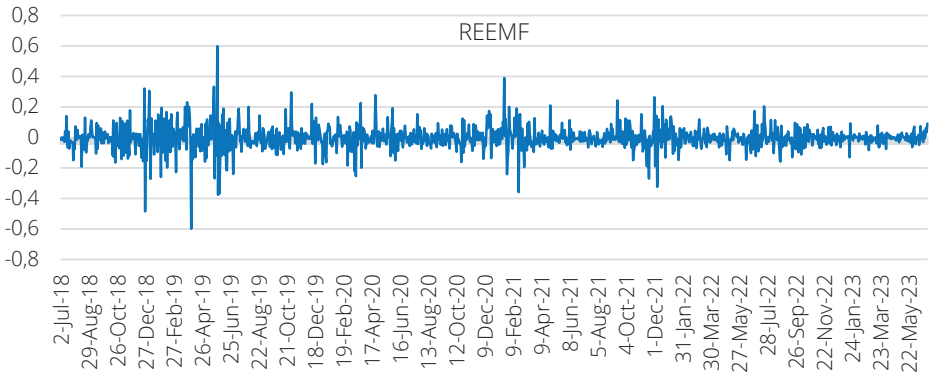
Matrix Service Company, through its subsidiaries, is a leading North American industrial engineering, construction, and maintenance contractor headquartered in Tulsa, Oklahoma with offices located throughout the United States and Canada, as well as Sydney, Australia and Seoul, South Korea [www 8]. Its shares are listed on the Nasdaq under the symbol "MTRX".

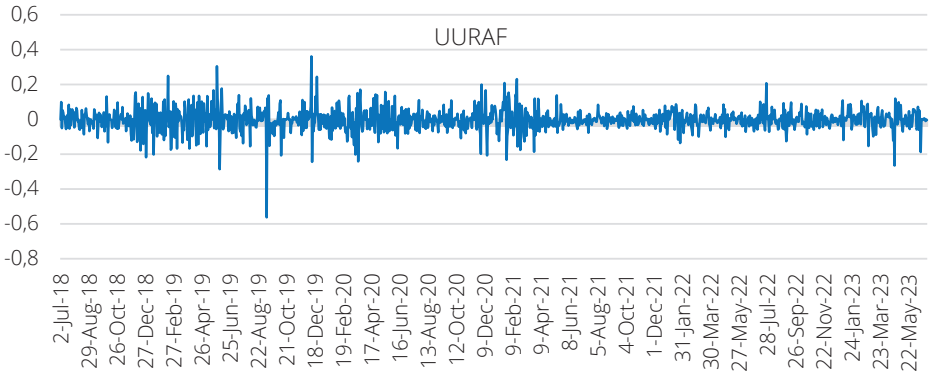
Additionally, to track changes in the performance of rare earth companies globally, the MVIS® Global Rare Earth/Strategic Metals Index (MVREMX) is used. It includes refiners, recyclers, and producers of rare earth and strategic metals and minerals. MVREMX covers at least 90% of the investable universe [www 7].

For the purpose of the preliminary statistical analysis, basic characteristics of daily returns are considered. Chart 1 displays the returns.

CHART 1

Stocks and MVREMX index returns in the period from 1 July 2018 to 30 June 2023

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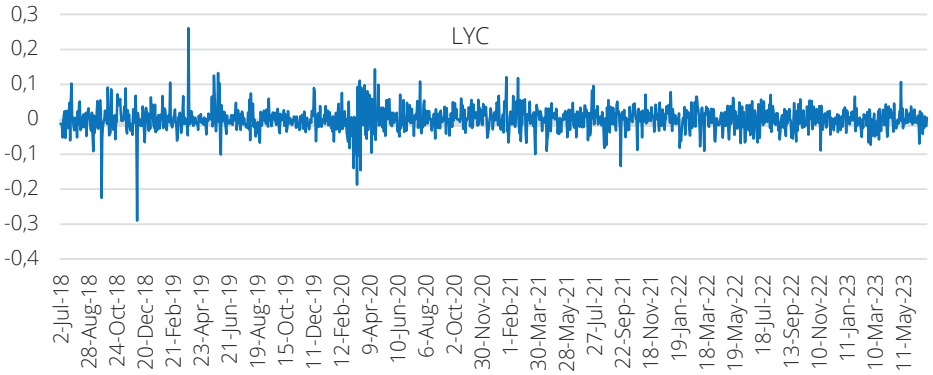
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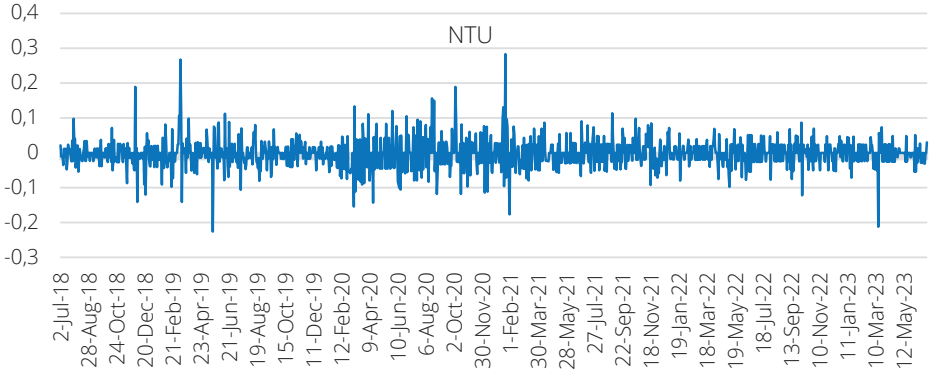
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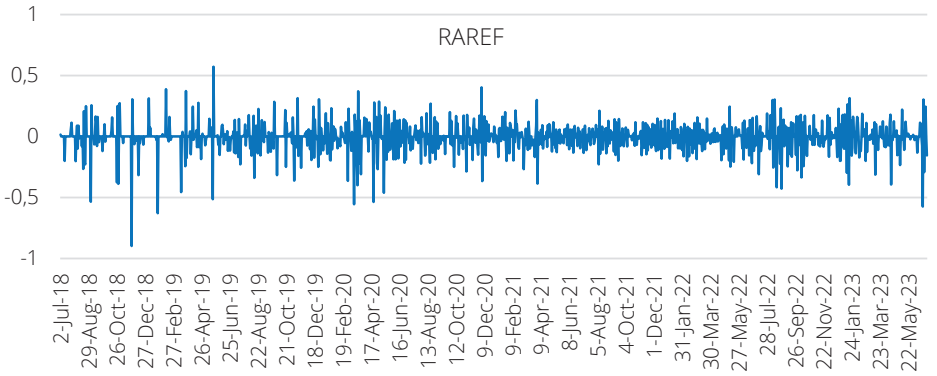
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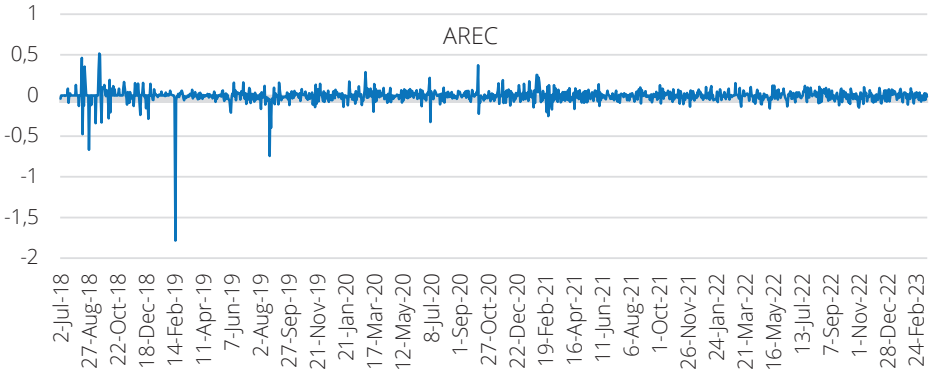
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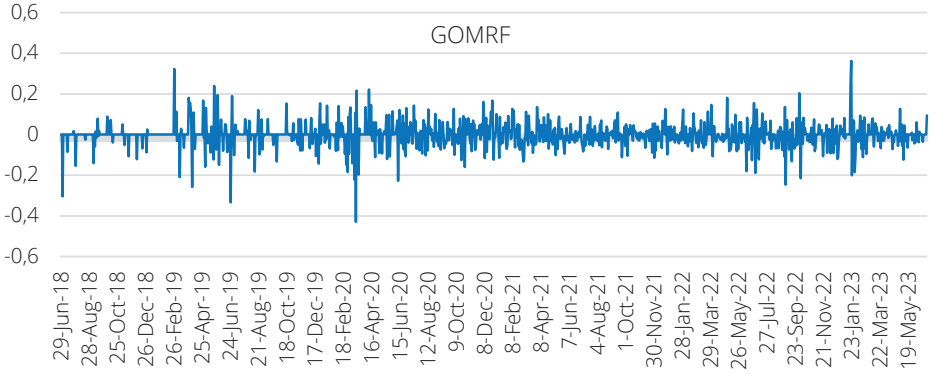
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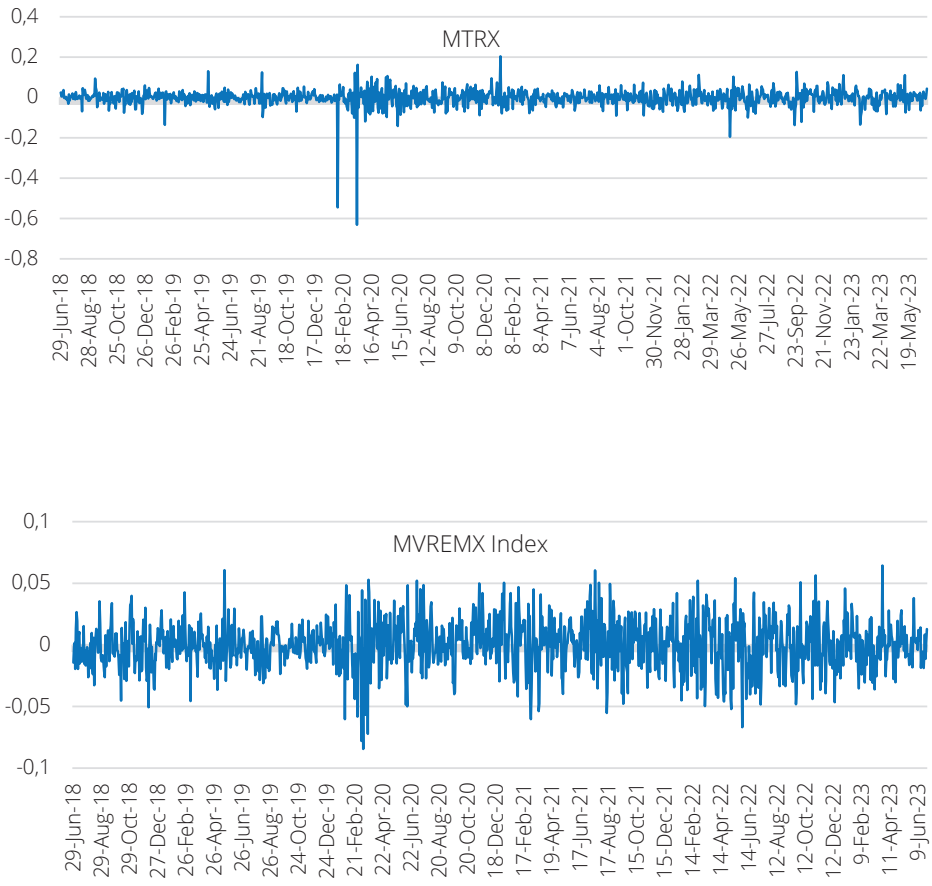

Source: authors' own elaboration.

Table 3 presents statistical properties of daily returns shown in Chart 1. Although average daily returns are negative for all stocks (except LYC), the global index generated positive average. The highest standard deviation is for RAREF, whereas the lowest standard deviation is for the index, which is also the asset with the smallest size of the range. The largest range was obtained for AREC. All distributions are negatively skewed and leptokurtic. Unfortunately, negative skewness and positive excess kurtosis are distributions properties, which investors do not appreciate, because they imply more overall large returns (positive and negative) compared to the normal distribution. What is more, the larger negative returns are generally not compensated for by larger positive returns [see Füss et al., 2008].

TABLE 3

Statistical properties of daily returns

Asset	Mean	Standard deviation	Kurtosis	Skewness	Range
REEMF	-0.00274	0.07885	12.03345	-0.10150	1.19933
UURAF	-0.00247	0.06360	10.46727	-0.44285	0.92343
LYC	0.00024	0.03528	11.56454	-0.30660	0.55099
NTU	-0.00164	0.04141	8.57197	0.38432	0.50913
RAREF	-0.00707	0.11626	9.62994	-0.97957	1.46798
AREC	-0.00304	0.09041	130.41710	-6.55683	2.29969
GOMRF	-0.00157	0.05874	10.47333	-0.24832	0.79125
MTRX	-0.00171	0.04204	65.07295	-4.37194	0.83514
MVREMX	0.00005	0.01970	3.81890	-0.18934	0.14882

Source: authors' own calculations.

In the next step, the analysis focuses on financial ratios, described in Section 3, for the entire investigation period. The minimal acceptable return τ is set to 0 and the mean return of U.S. 3 Month Treasury Bill is used as the risk-free interest rate. Table 4 shows the obtained results.

TABLE 4

Analysis of total investigation period

Asset	Modified Sharpe	Omega	Sortino	Calmar	Sterling	Burke
REEMF	-0.0015	0.8982	-0.0482	-0.0201	-0.0270	-0.0120
UURAF	-0.0012	0.8924	-0.0525	-0.0232	-0.0324	-0.0143
LYC	-0.0006	1.0196	0.0094	-0.0246	-0.0421	-0.0176
NTU	-0.0008	0.8889	-0.0560	-0.0216	-0.0328	-0.0141
RAREF	-0.0008	2.0000	-0.0361	-0.0266	-0.0306	-0.0135
AREC	-0.0018	0.8778	-0.0404	-0.0198	-0.0266	-0.0117
GOMRF	-0.0011	0.9107	-0.0367	-0.0218	-0.0331	-0.0148
MTRX	-0.0008	0.8769	-0.0494	-0.0206	-0.0316	-0.0139
MVREMX	-0.0004	1.0060	0.0032	-0.0267	-0.0474	-0.0207

Source: authors' own calculations.

The results for the entire period, presented in Table 4, reveal that all securities performed worse than the risk-free investment. Their performances vary widely across the six measures. Based on Calmar, Sterling and Burke ratios, AREC outperformed other assets. Although UURAF performance is the worst, all securities show poor risk and return characteristics which implies they produced rates of return lower than the risk-free rate or did not achieve the minimum acceptable return (except for LYC).

4.2 Analysis of different time periods

To analyse the stability of the results, the total investigation period of 5 years is divided into five subperiods of equal length. Subsequently, all financial ratios are determined for each subperiod. Table 5 shows the results.

TABLE 5

Analysis of results stability

Measure	Period	Asset								
		REEMF	UURAF	LYC	NTU	RAREF	AREC	GOMRF	MTRX	MVREMX
Mean	07.2018–06.2019	-0.0052	-0.0020	-0.0006	-0.0016	-0.0090	-0.0052	-0.0014	0.0000	-0.0014
	07.2019–06.2020	0.0012	-0.0052	-0.0019	-0.0065	-0.0085	-0.0064	-0.0022	-0.0047	-0.0013
	07.2020–06.2021	0.0004	-0.0027	0.0038	0.0010	-0.0036	0.0000	0.0020	-0.0003	0.0033
	07.2021–06.2022	-0.0067	-0.0030	0.0012	0.0001	-0.0076	-0.0035	-0.0029	-0.0035	-0.0001
	07.2022–06.2023	-0.0035	0.0006	-0.0013	-0.0011	-0.0068	-0.0001	-0.0034	-0.0001	-0.0003
Standard deviation	07.2018–06.2019	0.1191	0.0769	0.0441	0.0447	0.1322	0.1545	0.0619	0.0267	0.0158
	07.2019–06.2020	0.0748	0.0814	0.0391	0.0419	0.1324	0.0799	0.0671	0.0657	0.0198
	07.2020–06.2021	0.0709	0.0634	0.0303	0.0515	0.0969	0.0762	0.0552	0.0342	0.0198
	07.2021–06.2022	0.0659	0.0353	0.0325	0.0346	0.0861	0.0498	0.0468	0.0357	0.0234
	07.2022–06.2023	0.0451	0.0497	0.0277	0.0309	0.1264	0.0504	0.0610	0.0367	0.0188

Measure	Period	Asset								
		REEMF	UURAF	LYC	NTU	RAREF	AREC	GOMRF	MTRX	MVREMX
Modified Sharpe	07.2018–06.2019	-0.0034	-0.0019	-0.0010	-0.0011	-0.0042	-0.0044	-0.0015	-0.0006	-0.0004
	07.2019–06.2020	-0.0008	-0.0014	-0.0006	-0.0008	-0.0027	-0.0015	-0.0010	-0.0011	-0.0003
	07.2020–06.2021	0.0000	-0.0002	0.1040	0.0061	-0.0004	0.0000	0.0237	0.0000	0.1338
	07.2021–06.2022	-0.0007	-0.0002	-0.0001	-0.0001	-0.0010	-0.0004	-0.0003	-0.0003	-0.0001
	07.2022–06.2023	-0.0021	-0.0021	-0.0013	-0.0014	-0.0061	-0.0022	-0.0028	-0.0016	-0.0009
Omega	07.2018–06.2019	0.8746	0.9318	0.9556	0.8889	0.7203	0.8267	0.8919	1.0044	0.7878
	07.2019–06.2020	1.0489	0.8252	0.8717	0.6445	0.8163	0.7624	0.8828	0.7452	0.8313
	07.2020–06.2021	1.0165	0.8864	1.4178	1.0574	0.8958	1.0016	1.1021	0.9778	1.5432
	07.2021–06.2022	0.7423	0.7968	1.0984	1.0048	0.7903	0.8312	0.8379	0.7661	0.9873
	07.2022–06.2023	0.7999	1.0340	0.8808	0.8914	0.8414	0.9970	0.8243	0.9953	0.9649
Sortino	07.2018–06.2019	-0.0592	-0.0354	-0.0195	-0.0535	-0.0831	-0.0387	-0.0298	0.0021	-0.1226
	07.2019–06.2020	0.0245	-0.0836	-0.0653	-0.1931	-0.0803	-0.0953	-0.0419	-0.0790	-0.0826
	07.2020–06.2021	0.0085	-0.0603	0.2023	0.0306	-0.0497	0.0008	0.0542	-0.0123	0.2485
	07.2021–06.2022	-0.1354	-0.1113	0.0483	0.0026	-0.1125	-0.0937	-0.0882	-0.1250	-0.0071
	07.2022–06.2023	-0.1037	0.0163	-0.0655	-0.0469	-0.0684	-0.0016	-0.0767	-0.0024	-0.0194
Calmar	07.2018–06.2019	-0.0381	-0.0393	-0.0636	-0.0413	-0.0532	-0.0332	-0.0442	-0.0585	-0.0641
	07.2019–06.2020	-0.0175	-0.0287	-0.0223	-0.0241	-0.0330	-0.0214	-0.0248	-0.0248	-0.0310
	07.2020–06.2021	-0.0005	-0.0055	0.0146	0.0006	-0.0069	-0.0010	0.0029	-0.0027	0.0108

Measure	Period	Asset								
		REEMF	UURAF	LYC	NTU	RAREF	AREC	GOMRF	MTRX	MVREMX
Calmar [cont.]	07.2021–06.2022	-0.0128	-0.0132	-0.0096	-0.0076	-0.0172	-0.0135	-0.0129	-0.0128	-0.0106
	07.2022–06.2023	-0.0636	-0.0947	-0.1067	-0.1399	-0.0794	-0.0618	-0.0793	-0.0850	-0.1539
Sterling	07.2018–06.2019	-0.0579	-0.0781	-0.1045	-0.1034	-0.0718	-0.0590	-0.0850	-0.1293	-0.1477
	07.2019–06.2020	-0.0278	-0.0405	-0.0572	-0.0575	-0.0535	-0.0496	-0.0528	-0.0547	-0.0685
	07.2020–06.2021	-0.0008	-0.0096	0.0264	0.0012	-0.0123	-0.0017	0.0045	-0.0040	0.0206
	07.2021–06.2022	-0.0242	-0.0328	-0.0131	-0.0140	-0.0366	-0.0239	-0.0245	-0.0321	-0.0230
	07.2022–06.2023	-0.1700	-0.1724	-0.2205	-0.2487	-0.1267	-0.1496	-0.1733	-0.1740	-0.2690
Burke	07.2018–06.2019	-0.0257	-0.0341	-0.0445	-0.0435	-0.0315	-0.0251	-0.0349	-0.0541	-0.0625
	07.2019–06.2020	-0.0119	-0.0177	-0.0222	-0.0242	-0.0234	-0.0189	-0.0205	-0.0221	-0.0273
	07.2020–06.2021	-0.0003	-0.0042	0.0114	0.0005	-0.0052	-0.0007	0.0019	-0.0018	0.0083
	07.2021–06.2022	-0.0102	-0.0139	-0.0058	-0.0056	-0.0155	-0.0102	-0.0104	-0.0133	-0.0097
	07.2022–06.2023	-0.0725	-0.0740	-0.0918	-0.1023	-0.0559	-0.0593	-0.0758	-0.0653	-0.1151

Source: authors' own calculations.

Table 5 shows that for all financial ratios there is a strong variation of results for different time periods. First of all, individual ratios favour or penalise different securities in the same periods. However, in the first period (July 2018 – June 2019), all risk-adjusted measures (except the modified Sharpe) indicated the MVREMX index as the least attractive investment. On the contrary, AREC outperformed other assets offering the best values of Calmar and Burke ratios. Moreover, MTRX was recognised by Omega and Sortino ratios as the best investment. In the second period, from July 2019 to June 2020, all ratios (except the modified Sharpe) fa-

voured REEMF and almost all of them penalised MVREMX. The results obtained for the next period (July 2020 – June 2021) are the most consistent across the ratios. Then, LYC stocks or MVREMX index turned out to be the best investments. On the contrary, UURAF and RAREF performed the worst offering the worst values of modified Sharpe, Omega and Sortino ratios (UURAF) and of Calmar, Sterling, Burke ratios (RAREF). In the subperiod from July 2021 to June 2022 LYC outperformed other assets with the best values of modified Sharpe, Omega, Sortino and Sterling ratios. Other ratios placed these stocks in the second place. LYC and NTU shares were alternately ranked first or second in terms of investment attractiveness, whereas four out of five indicators ranked MVREMX third. In the last period, from July 2022 to June 2023, RAREF outperformed other assets offering the best values of Sterling and Burke ratios. Also UURAF was recognised by Omega and Sortino ratios as the best investment.

Moreover, each of the ratios favours and penalises different securities in subsequent periods as their values vary widely over time. Based on Sterling ratio, REEMF and LYC outperformed other securities in two subsequent periods (REEMF in the first two subperiods, LYC in the third and the fourth of the subperiods). Moreover, based on Sterling and Burke ratios, MVREMX performed the worst in three subsequent periods (the first, the second and the last of the subperiods).

When the results for the entire investigation period were used as a benchmark for the analysis of different subperiods, it appeared that only few stable patterns could be recognised. First, MVREMX offered stable results of modified Sharpe ratio exceeding the five-year value in each of the subperiods (except for the last one). Next, from July 2020 to June 2021 all assets offered modified Sharpe, Calmar, Sterling and Burke ratios that outperformed their values for the entire period.

5. Conclusions

According to Ul Haq et al. [2022], increasing magnet use, rising global economic growth and technological advancement are key drivers boosting demand for rare earth metals. Actually, the economic importance of rare earth materials has thrived in the last decade since they have been identified as crucial elements in various environmentally sustainable technologies. Not surprisingly investments in rare earths sector have recently been attracting investors' attention and their interest in purchasing rare earth stocks [Reboredo, Ugolini, 2020].

This paper aimed at assessing the efficiency of investment in companies belonging to rare earth elements sector through the application of several risk-ad-

justed performance measures, such as the modified Sharpe ratio, Omega ratio, Sortino ratio, Calmar ratio, Sterling ratio, Burke ratio. The data covered daily quotations of selected companies whose business activities were related to extraction, processing and recycling rare earth metals in the period from 1 July 2018 to 30 June 2023 and MVIS® Global Rare Earth/Strategic Metals Index representing the global market.

The preliminary statistical analysis revealed negative average daily returns for all stocks (except LYC). The positive average MVREMX return was combined with the lowest standard deviation. All distributions were negatively skewed and leptokurtic. The analysis of risk-adjusted measures revealed that investments in rare earth stocks exhibited a much worse efficiency than investments in risk-free assets. However, AREC outperformed other stocks and index offering the best results for 3 out of 6 ratios (Calmar, Sterling and Burke ratios).

In order to examine the stability of the results, the total investigation period was divided into five subperiods and all performance ratios were determined for each of them. A strong variation of results did not allow to recognise any stable patterns. Nevertheless, results obtained for the period July 2020 – June 2021 were the most consistent across the ratios recognising LYC stocks and MVREMX index as the best investments. When the results for the entire investigation period were used as a benchmark for the analysis of different subperiods, it appeared that only MVREMX index offered stable results of the modified Sharpe ratio exceeding the five-year value in each of the subperiods (except for the last one).

Based on the findings for the period under consideration, we have to reject the hypothesis that the purchase of stocks of companies belonging to the rare earth materials sector might have been an attractive form of investment available for individual investors. In our opinion, investments into listed rare earth firms can be increased along with the improvement of their efficiency and stock price performance. However, investors are not only interested in the risk-return profiles, but also in portfolio diversification opportunities. Thus, it is reasonable to monitor the market as well as to extend future research through considering portfolio implications.

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