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COMMODITIES AND PORTFOLIO DIVERSIFICATION: EMPIRICAL EVIDENCE FROM CRISIS DURESS

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ABSTRACT

Even though portfolio diversification has been extensively studied, it remains a dynamic field necessitating ongoing research. The challenge of diversifying investment portfolios with commodities is resurfacing, given the increasing complexity of optimizing portfolios due to the integration of financial markets, among others, caused by occurrence of systemic crises. We focus our attention on the impact of Covid-19 crisis on the diversification benefits of commodities. Several types of commodity investment were studied as to provide insight into which type of commodity investment show better diversification performance under crisis duress. The performances of four portfolios diversified with alternative commodity investments were analysed and compared to performance of traditional portfolio comprised of stocks and bonds, both in pre-pandemic and pandemic period. We employed correlation analysis, mean-variance method and Sharpe ratio for this purpose. Our findings show that adding commodities to traditional portfolio results with diversification benefits in the form of higher realised excess return for each unit of risk and those benefits to be the highest for commodity futures. However, those benefits are slightly lower in times of crisis when considering all but the portfolio diversified with commodity indices.

Key words: *portfolio diversification, commodity indices, commodity futures, crisis effect, Covid-19.*

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1. INTRODUCTION

Investors base their investment choices by considering the anticipated returns they might yield. This process entails examining the past performance of individual assets and portfolios of assets. Portfolio diversification has been a subject of interest for both investors and academics for quite some time, with commodity futures being hailed as effective diversification tools for investment portfolios. However, their potential tends to fluctuate during times of crisis, as was evident during the 2008 financial crisis and became even more pronounced amid the Covid-19 pandemic and Russia-Ukraine war. The main aim of this paper was to investigate the role of commodities as diversifiers of traditional portfolios in periods of economic shocks and crisis. The studied crisis period was characterized by two massive shocks that are Covid-19 pandemic and the Russian invasion of Ukraine. Due to the fact we have clear dates for the beginning and the end of the first crisis while the second one is still ongoing, more focus was devoted to the pandemic affect.

Theoretical understanding suggests that there should be a minimal correlation in returns between commodities and stocks. This is due to the distinct fundamental drivers influencing commodity prices, such as global demand, productivity growth rate, weather conditions, geopolitics, and supply constraints, differing from those impacting stock values.[1] Moreover, commodities, unlike conventional assets like stocks and bonds, can act as a hedge against inflation or safe havens. Because of these reasons, investors are interested in integrating commodity futures into their investment portfolios to enrich diversification and reduce potential losses. Numerous research studies demonstrate a low correlation in returns between the commodity market and the stock market. However, recent research indicates an increasing correlation between these two markets, as they are both influenced by shared factors and because commodities are now heavily financialized.[2]

The role of commodities in diversification of a portfolio of traditional asset classes like stocks and bonds has been debated for a long time. Some of the research says that commodities are too broad as an asset class of its own and need to be divided into subcategories to get a better answer.[3] These authors found that the diversification gains of commodities hold both for physical commodi-

[1] Daskalaki, C, Skiadopoulos, G.: Should investors include commodities in their portfolios after all? New evidence, *Journal of Banking & Finance*, 35(10) 2011, pp. 2606-2626.

[2] Hammoudeh, S. et al.: Dependence of stock and commodity futures markets in China: Implications for portfolio investment, *Emerging Markets Review*, (21) 2014, pp. 183-200.

[3] Belousova, J., Dorfleitner, G.: On the diversification benefits of commodities from the perspective of euro investors, *Journal of Banking and Finance*, (36) 2012, pp. 2455-2472.

ties and commodity futures. Yan and Garcia found that including commodities in a portfolio did little to improve portfolio Sharpe ratio. The only exception to this is a third-generation commodity index based on momentum strategy that can sustainably enhance portfolio performance.[4] There are many other authors who undermine the role of commodities as a diversifier[5] as well as those who found a positive impact of commodities either on returns or risk of a portfolio[6]. Jawadi et al. found that diversification properties of commodities work only in short time frames while in the long run such effects diminish.[7] The fact that commodities transform from physical to financial asset further complicates and diminishes their role as diversifiers.[8]

Migliavacca et al. conducted an extensive meta-literature review encompassing 242 articles published between 1974 and 2022.[9] Their analysis unveiled the most impactful facets of the literature and highlighted over 60 lingering research questions. This highlights that while portfolio diversification has been the subject of extensive study, it remains a dynamic field necessitating ongoing investigation. The challenge of diversifying investment portfolios with commodities is resurfacing, given the increasing complexity of optimizing portfolios due to the integration of financial markets. Factors such as globalization, the surge in international trade, and the occurrence of systemic crises have heightened the correlation among financial markets, potentially inhibiting portfolio diversification. The emergence of novel asset classes like cryptocurrencies prompts fresh research endeavours to comprehend their correlation with traditional investment categories. Additionally, diversifying investment portfolios could potentially be achieved through geographical diversification, considering that developing markets exhibit distinct economic cycles when compared to developed nations.

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4 Yan, L., Garcia, P.: Portfolio investment: Are commodities useful?, *Journal of Commodity Markets*, (8) 2017, pp. 43-55.

5 Daskalaki, C, Skiadopoulos, G.: Should investors include commodities in their portfolios after all? New evidence, *Journal of Banking & Finance*, 35(10) 2011, pp. 2606-2626.

6 Bansal, Y., Kumar, S., Verma, P.: Commodity Futures in Portfolio Diversification: Impact on Investor's Utility, *Global Business and Management Research: An International Journal*, 6(2) 2014, pp. 112-121.

7 Jawadi, F., Ftiti, Z., Hdia, M.: Assessing efficiency and investment opportunities in commodities: A time series and portfolio simulations approach, *Economic Modelling*, (64) 2017, pp. 567-588.

8 Adams, Z., Kartsakli, M: Have Commodities Become a Financial Asset? Evidence from Ten Years of Financialization, University of St. Gallen, School of Finance, *Research Paper*, (10) 2017.

9 Migliavacca, M., Goodell, J. W., Paltrinieri, A.: A bibliometric review of portfolio diversification literature, *International Review of Financial Analysis*, 90 (102836) 2023.

Research indicates that commodity futures can provide advantages in terms of diversification. However, this diversification is typically observed within particular commodity groups even when these commodities are integrated into conventional stock and bond portfolios. Conversely, commodity futures might demonstrate limited effectiveness during periods of financial instability. With the pandemic now officially declared over, it becomes possible to examine and assess whether the Covid-19 pandemic had any impact on the diversification potential of commodity futures, and if it did, to what extent.

The aim of the paper is to give theoretical foundation for further studies on diversification potential of commodity futures and to conduct empirical analysis on the matter. Following research questions are defined:

RQ1. How did economic shocks affect the diversification potential of commodities?

RQ2. Which types of commodity investments show better diversification performances under the crisis duress?

In order to provide answer to these questions, an empirical analysis was performed. Time span of seven and half years was observed, from January 2015 to June 2023, as to include both the Covid-19 crisis period and years that preceded it. Correlation analysis was conducted in order to detect any changes in market dynamics. Next, five different investment portfolios were designed and mean-variance method was used in assessment of obtained diversification benefits.

The paper is structured as follows. After the introduction to research topic, a literature review is presented. Literature review gives an overview of studies on diversification potential of commodity futures with special emphasis being put on portfolio investment during economic shocks and systemic crisis. Next, performed analysis is explained, including data and methods used. Obtained results are presented in fourth and discussed in fifth section of the paper. The sixth and final section summarizes the theoretical knowledge and obtained empirical insights.

2. LITERATURE REVIEW

2.1. DIVERSIFICATION POTENTIAL OF COMMODITY FUTURES

Historically, commodity futures returns have been largely uncorrelated with one another. It is why a diversified portfolio of commodity futures seems to be an excellent diversifier of a traditional stock and bond portfolio.[10] Numerous

[10] Erb, C., Harvey, C.: The Strategic and Tactical Value of Commodity Futures, *Financial Analysts Journal*, (62) 2006, pp. 69-97.

studies offer empirical evidence that commodity futures act as effective diversifiers of investment portfolios. Diversification aims to mitigate the impact of unpredictable and unsystematic risk events within a portfolio by ensuring that the gains from certain investments offset the losses from others. The advantages of diversification are realized when the assets in the portfolio are not highly correlated, meaning they react differently to market forces, frequently in opposing directions. Investors design their investment portfolios in a way that reflects their risk tolerance and financial goals.

Early literature found clear advantages of adding commodities to stock and bond portfolios. From 1950 to 1976, the average return on the benchmark commodity futures portfolio was about the same as the average return on common stocks. On the other hand, commodity futures tended to rise in years when stock prices fell, and vice versa. Bodie and Rosansky contemplated that with a portfolio consisting of investments in stocks and commodity futures, in a way that 60% was invested in stocks and 40% in commodity futures, an investor could reduce the variability of returns by one third without sacrificing any return.[11] Furthermore, their data analysis showed that commodity futures had proven to be a very good hedge against inflation since four of their best years coincided with four out of seven years of accelerating inflation. Conover et al. found that investors can reduce risk without sacrificing return by switching from a stock portfolio to a portfolio with stocks and commodities over the periods 1950–1976, 1976–1985, and 1970-2007.[12]

Demiralay et al. constructed six hypothetical investment portfolios and results show that the portfolio consisting of the commodity futures and the emerging stock markets have the lowest correlation level.[13] Findings reveal that the inclusion of commodity futures into the emerging and developed market portfolios increases the diversification benefits. However, as authors point out, these benefits deteriorate negligibly in the episodes of financial turmoil. Broken down by commodity categories, cross-sectional differences in the bivariate correlations show that the energy and metal futures have the highest level of correlation with the equities. On the other hand, the futures that offer the highest diversification benefits are lean hogs, feeder cattle, natural gas, orange juice, and gold.

[11] Bodie, Z., Rosansky, V. I.: Risk and return in commodity futures, *Financial Analysts Journal*, 36(3) 1980, pp. 27–39.

[12] Conover, C. M. et al.: Is Now the Time to Add Commodities to Your Portfolio? *The Journal of Investing*, 19(3) 2010, pp. 10-19.

[13] Demiralay, S., Bayraci, S., Gencer, H.: Time-varying diversification benefits of commodity futures, *Empirical Economics*, (56) 2019, pp. 1823-1853.

Belousova and Dorfleitner studied the diversification effect of various commodities in the context of a euro-based investor.[14] The findings demonstrate significant variations in the diversification benefits of different commodities. Specifically, industrial metals, agricultural products, and livestock contribute to risk reduction, whereas energy and precious metals not only reduce risk but also enhance returns. It is evident that adjusting exposure to individual commodities can enhance portfolio performance.

The study of Cheung and Miu provides evidence of low and positive correlations between equity and commodity markets, suggesting that commodity futures are a desirable asset class for portfolio diversification.[15] Nonetheless, the authors suggest that the diversification advantages of commodity futures may not be a universally applicable phenomenon, unlike what has been extensively demonstrated for U.S. investors. Similarly, the authors emphasize that commodity futures represent an asset class better suited for conservative investors who exhibit a relatively high degree of risk aversion.

The price dynamics of commodity futures have noticeably changed over the last decade, due to the rising demand from developing economies, frequent changes in the supply and demand conditions and growing financialization of commodity markets.[16] Financialization refers to the growing involvement of financial investors in commodity markets, a trend that has been hastened by the accessibility and affordability offered by financial innovations.[17] As a result, commodity markets have become more volatile. Moreover, a study by Daskalaki and Skiadopoulos has shown that diversification benefits of commodity futures change in time and tend to decrease because of their growing correlation with other assets.[18] Tang and Xiong attribute the growing dependence on other markets to the commodity markets financialization, more specifically, boom of commodity index investments, as it has increasingly exposed commodity prices to market-wide shocks.[19]

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[14] Belousova, J., Dorfleitner, G.: On the diversification benefits of commodities from the perspective of euro investors, *Journal of Banking and Finance*, (36) 2012, pp. 2455-2472.

[15] Cheung, C. S., Miu, P.: Diversification benefits of commodity futures, *Journal of International Financial Markets, Institutions and Money*, 20(5) 2010, pp. 451-474.

[16] Sensoy, A., Hacihasanoglu, E.; Nguyen, D.: Dynamic convergence of commodity futures: Not all types of commodities are alike, *Resources Policy,* (44) 2015, pp. 150-160.

[17] Fattouh, B., Kilian L., Mahadeva, L.: The Role of Speculation in Oil Markets: What Have We Learned So Far? *The Energy Journal,* 34(3) 2013, pp. 7-33.

[18] Daskalaki, C, Skiadopoulos, G.: Should investors include commodities in their portfolios after all? New evidence, *Journal of Banking & Finance*, 35(10) 2011, pp. 2606-2626.

[19] Tang, K., Xiong, W.: Index investment and the financialization of commodities, *Financial Analysts Journal,* 68(6) 2012, pp. 54-74.

Long-term investors and hedge funds use commodities as a means of hedging within their investment portfolios or as a potential source of additional returns. Moreover, private investors have increasingly participated in commodity markets through passive investment instruments. Over the past few years, a growing body of research has explored the effects of financialization on various aspects of commodity markets. Typically, financialization is alleged to have an impact on commodity prices, the volatility of returns, and the correlation between different commodity prices and stock prices.[20] Sensoy et al. analysed the dynamic comovement of commodity futures returns across various categories such as energy, precious metals, industrial metals, and agriculture during the period spanning from 1997 to 2013.[21] They examined how these dynamics were influenced by the financialization of commodity markets. The findings of their research indicated the possibility of diversification advantages within specific commodity categories. However, the study also emphasized that the primary driver behind commodity futures price dynamics was the balance between physical supply and demand, rather than global financial factors.

2.2. THE EFFECT OF CRISIS ON DIVERSIFICATION POTENTIAL OF COMMODITIES

The correlation pattern among various assets plays a pivotal role in asset allocation and portfolio management. According to modern portfolio theory, investors can significantly enhance returns of their portfolios by investing in assets with less than perfect correlations, such as those with negative or low correlations, as these assets do not move closely in tandem. Conversely, a portfolio consisting of highly correlated assets may experience substantial losses during times of uncertainty and bearish market conditions. Past research has indicated that not only do asset correlations evolve over time, but they also tend to escalate notably during turbulent market conditions due to the spill over of shocks and contagious effects.[22]

When examining the recent years, it becomes evident that there is a growing connection between commodity and equity prices. They seem to react more to news related to the global macroeconomic situation rather than idiosyncratic market shocks. The findings indicate that these correlations, which remained

[20] Ludwig, M.: Speculation and its impact on liquidity in commodity markets, *Resources Policy,* (61) 2019, pp. 532-547.

[21] Sensoy, A., Hacihasanoglu, E., Nguyen, D.: Dynamic convergence of commodity futures: Not all types of commodities are alike, *Resources Policy,* (44) 2015, pp. 150-160.

[22] Markwat, T. D., Kole, E., van Dijk, D.: Contagion as a domino effect in global stock markets, *Journal of Banking and Finance*, 33(11) 2009, pp. 1996-2012.

close to zero for over a decade, have significantly risen since around mid-2008 and the beginning of the global financial crisis. Oil prices prove to be a driving force in the process.[23]

The study of Charlot et al. confirmed the detrimental effect of 2008 financial crisis on diversification potential of commodity futures, but authors point out that the nature of the financial crisis effect is temporary.[24] Authors performed a vast analysis that included daily data for the four major commodity indices and 32 individual commodity futures returns, along with stock and bond returns, spanning a period from 2000 to 2014. The extensive time frame under examination enabled the analysis to encompass periods before and after financialization, as well as during the financial crisis and its ensuing alterations. This comprehensive approach aimed to distinctly differentiate between the impacts stemming from financialization and those linked to the crisis on the shifting correlation trends. The return to pre-crisis levels of correlations, both among various commodities and between commodities and traditional assets, by April 2013, serves as confirmation that financial factors significantly influence the movements in commodity prices.

Second shock to financial markets occurred in 2019. What started as a sanitary crisis, progressed to worldwide economic and financial turmoil. The worldwide stock markets experienced a financial contagion during the Covid-19 pandemic, which had its origins in China. Specifically, the implementation of restrictions in China, as well as in other nations, led to a decrease in manufacturing activities and exports from China. This had a detrimental effect on other countries that have strong economic ties with China, especially those reliant on oil exports. The reduced demand for crude oil from China had a direct impact on the global energy market, causing a significant decrease in crude oil prices. Furthermore, the conflict between key players in the oil market, including Russia and Saudi Arabia, as a result of the declining demand for crude oil, led to the most significant oil price crash in decades. A handful of studies investigated the problem of portfolio diversification potential of commodity futures during the Covid-19 crisis, and since the studies were conducted in the early months of pandemic and not many made comparison to the pre-pandemic time, the results and any new insights should be taken with caution.

Tarchella and Dhaoui conducted the analysis of Chinese stock market, since China is considered the origin of pandemic, and found that commodities

[23] Lombardi, M. J., Ravazzolo, F.: On the correlation between commodity and equity returns: Implications for portfolio allocation, *Journal of Commodity Markets*, 2(1) 2016, pp. 45-57.

[24] Charlot, P., Darné, O., Moussa, Z.: Commodity returns co-movements: Fundamentals or "style" effect? *Journal of International Money and Finance*, (68) 2016, pp. 130-160.

offer diversification benefits in the long-term, with WTI crude oil showing slightly better diversification performance than gold.[25] The findings indicate that the correlation between the Chinese stock market and commodities is weaker compared to its correlation with financial variables. The author included only year 2019 as the pre-pandemic period and first five months of 2020 as the pandemic period. Comparing the correlation of returns between pre-pandemic and pandemic period, results show that both crude oil and gold show higher correlation with equity index and bonds. Moreover, whereas gold remains to keep positive correlation with equities and negative correlation with bonds through the pre-pandemic and pandemic period, oil shows positive correlation with bonds in the pandemic as opposed to negative correlation in the pre-pandemic period. The pandemic evidently changed market dynamics. Dynamics were not changed only between markets but within commodity market as well, across different commodity categories. Wang et al. studied how the Covid-19 pandemic affected the interrelationships between crude oil and agricultural futures markets.[26] The findings from their study revealed that the influence of Covid-19 resulted in increased persistence, with the cross-correlations exhibiting the highest multifractality between the crude oil and sugar futures markets. Furthermore, all agricultural futures demonstrated heightened cross-correlations following the emergence of Covid-19, except for the orange juice futures market.

Vuković et al. focused their analysis on the first wave of pandemic and the response of cryptocurrency market, but argue that gold and oil, as typical global commodities, could serve as portfolio diversifiers.[27] Umar et al. examined the impact of Covid-19 pandemic on commodity price volatility, encompassing different commodity categories such as energy, agriculture and livestock, precious metals and non-precious metals.[28] Their analysis covered the first half of 2020. Authors recorded periods of low, moderate, and high coherence between the coronavirus panic index and fluctuations in commodity prices. The volatility in energy prices exhibits a strong correlation with the panic caused by Covid-19, reducing thus the potential for diversification when investing

[25] Tarchella, S., Dhaoui, A.: Chinese jigsaw: Solving the equity market response to the COVID-19 crisis: Do alternative asset provide effective hedging performance? *Research in International Business and Finance*, (58) 2021, pp. 101499.

[26] Wang, J., Shao, W., Kim, J.: Analysis of the impact of COVID-19 on the correlations between crude oil and agricultural futures, *Chaos, Solitons & Fractals*, (136) 2020, pp. 109896

[27] Vuković, D. et al.: COVID-19 Pandemic: Is the Crypto Market a Safe Haven? The Impact of the First Wave. *Sustainability*, 13(15) 2021, pp. 8578.

[28] Umar, Z., Gubareva, M., Teplova, T.: The impact of Covid-19 on commodity markets volatility: Analyzing time-frequency relations between commodity prices and coronavirus panic levels, *Resources Policy*, (73) 2021, pp. 102164.

in energy commodities. On the other hand, other commodity groups showed lower coherence and these intervals with low coherence highlight the opportunity for diversification in commodity investments during a systemic crisis like Covid-19 pandemic. Further on, authors conclude that precious metals can act as a viable safe haven asset even amidst a global crisis like Covid-19, whereas non-precious metals demonstrate a greater potential for diversification during the recovery from economic downturns and worldwide crises.

3. DATA AND METHODS

The study analyses the returns of commodities compared to returns of traditional asset classes in order to investigate whether the inclusion of commodity futures offer portfolio diversification benefits. Analysed data encompass average monthly returns of relevant assets from January 2015 to June 2023. The observed time period is divided into two sub-periods: (1) pre-pandemic ranging from January 2015 to December 2019 and (2) pandemic ranging from January 2020 to June 2023. Data used in the analysis are retrieved from investment and news platform Investing.com.

As a first step, Pearson's correlation coefficients were calculated for each pair of analysed assets, both for the pre-pandemic and the pandemic period. Coefficients were assessed within and across asset categories, and compared between the pre-pandemic and pandemic periods.

Next, portfolio diversification benefits were computed by asset category and compared between the pre-pandemic and pandemic periods. Portfolio diversification benefits are measured by mean-variance approach established by Harry Markowitz in the early 1952.[29] Markowitz's ground-breaking work on portfolio investing earned him a Nobel Prize and was published in the book "Portfolio Selection: Efficient Diversification of Investments," which is now widely recognized as the foundation of modern portfolio theory. This theory provides a practical framework for selecting investments with the goal of maximizing their overall returns while maintaining an acceptable level of risk. In the context of modern portfolio theory, investors aim to choose a portfolio that offers the highest return for a given level of risk. Conversely, when considering a specific level of return, investors seek a portfolio with the lowest possible risk. The mean-variance theory accomplishes this by comparing the expected (mean) return of a portfolio to its standard deviation, which quantifies the volatility of returns and serves as a measure of risk. A number of stu-

[29] Markowitz, H.: Portfolio Selection, *The Journal of Finance*, 7(1) 1952, pp. 77-91.

dies investigate the role of commodities under the Markowitz mean–variance asset allocation setting (see e.g. Pouliasis and Papapostolou[30]; Hoang et al[31]).

Under the mean-variance theory, the expected portfolio return is a weighted combination of returns of each individual asset in the portfolio. Expected portfolio return was calculated according to the following formula:

$$E(R_p) = \sum_i w_i \, E(R_i), \qquad \sum_i w_i = 1 \tag{1}$$

where R_p is a portfolio return, R_i is return of each individual asset i, and w_i is weight of asset i. Asset weights were calculated as the portion of value of each individual asset in total value of the portfolio. Determining portfolio variance is not as straightforward as merely taking the weighted average of the variances of the individual investments and it takes into consideration the relations between variances of individual assets within the portfolio, allowing thus for diversification effect. Portfolio variance was calculated according to following formula:

$$\sigma_p^2 = \sum_i \sum_j w_i w_j cov_{ij}, \qquad cov_{ij} = \sigma_i \sigma_j \rho_{ij} \tag{2}$$

where cov_{ij} is the covariance of the returns on the two assets i and j, σ_i and σ_j are standard deviations of returns of assets i and j, and ϱ_{ij} is the correlation coefficient between the returns on assets i and j. The risk of portfolio is measured as volatility of returns, expressed as standard deviation:

$$\sigma_p = \sqrt{\sigma_p^2} \tag{3}$$

Five portfolios were designed: A, B, C, C1 and C2 (Table 1). Portfolios were designed to cover developed financial markets with assets being traded at American futures exchanges. Portfolio A represented traditional investment portfolio consisting of stocks (GOOGL, GM, KO, KOS, VRTX, BRKb), bonds (US10YR) and equity indices (Nasdaq100, SP500). Portfolio B consisted of portfolio A diversified with stocks of companies engaged in commodity mining, manufacturing and producing (HMY, RIO, CVX, BG). Portfolio B is at the cross-border between traditional and alternative investment portfolio as it is still composed of stock and bonds, even though some stocks are indirectly connected to commodity prices. Portfolio C consisted of portfolios A and B diversified with both commodity indices (DJCI, GSG) and commodity futu-

[30] Pouliasis, P., Papapostolou, N.: Volatility and correlation timing: The role of commodities, *Journal of Futures Markets,* 38(11) 2018, pp. 1407-1439.

[31] Hoang, T., Lean, H., Wong, W.: Is Gold Good for Portfolio Diversification? A Stochastic Dominance Analysis of the Paris Stock Exchange, *International Review of Financial Analysis*, (42) 2015, pp. 98-108.

res (USWheat, Copper, Gold, WTI). Two more variations of portfolio C were designed in order to explore which form of commodity investment offer the highest diversification benefits: C1 and C2. Portfolio variation C1 included portfolios A, B and commodity indices only. Portfolio variation C2 included portfolios A, B and commodity futures only.

Table 1. Portfolios design

Portfolio			**Variable code**	**Asset**
Portfolio C	Portfolio B	Portfolio A	Nasdaq100	Nasdaq 100
			SP500	Standard & Poor's 500
			GOOGL	Alphabet Inc. Class A
			GM	General Motors Company
			KO	Coca-Cola Co.
			KOS	Kosmos Energy
			VRTX	Vertex Pharmaceuticals Inc.
			BRKb	Berkshire Hathaway B
			US10YR	United States 10-Year bond yield
			HMY	Harmony Gold Mining Company Limited
			RIO	Rio Tinto ADR (activity: mineral mining)
			CVX	Chevron Corp (activity: energy)
			BG	Bunge Limited (activity: agriculture)
	C1 subgroup GSG		DJCI	Dow Jones Commodity Index
			iShares S&P GSCI Commodity-Indexed Trust	
	C2 subgroup Copper Gold WTI		USWheat	US Wheat Futures (ZW)
			Copper Futures (HG)	
			Gold Futures (GC)	
			Crude Oil WTI Futures (CL)	

4. RESULTS

4.1. RESULTS OF CORRELATION ANALYSIS

Table 2 gives an overview of mean prices and accompanying standard deviations of analysed assets. By comparing the descriptive statistics between the pre-pandemic and the pandemic period, the following can be deducted. All

assets show increase in standard deviation between the two periods. However, the increase in risk was not justified unequivocally by the increase in mean prices. The greatest percentage increase in mean price was demonstrated by GOOGL, combined with massive increase in standard deviation as well. Equity indices performed reasonably well, with steeper increase in prices than in accompanying standard deviations. Nasdaq100 showed much better resilience that SP500 which can be attributed to Nasdaq's heavy focus on top-performing industries such as technology, consumer services and healthcare. Bonds, here represented by US10YR, showed poor performance in the pandemic period resulting in negative average return and steep risk increase. Likewise, stocks of commodity companies do not show consistent performance. Commodity indices and commodity futures manifest poor resilience to Covid-19 shock with gold futures again acting as an exception from the commodity class.

Table 2. Summary statistics of prices

Variable	Pre-pandemic		Pandemic		Mean price change %	Std. Dev. change %
	Mean price	Std. Dev.	Mean price	Std. Dev.		
Nasdaq100	5904.79	1348.47	12637.36	2115.798	114.02	56.90
SP500	2459.863	365.5193	3900.857	529.1903	58.58	44.78
GOOGL	46.54983	11.35632	104.4231	24.99818	124.33	120.13
GM	35.69817	3.571975	40.88619	11.27663	14.53	215.70
KO	45.17517	4.023202	56.02643	6.170369	24.02	53.37
KOS	6.644667	1.222608	4.197286	2.243715	-36.83	83.52
VRTX	138.9202	39.10105	255.8371	45.52209	84.16	16.42
BRKb	174.6372	30.52731	269.2064	48.76268	54.15	59.73
US10YR	2.244633	.440695	2.026429	1.169819	-9.72	165.45
HMY	2.203133	.8683195	3.971667	.9143835	80.27	5.30
RIO	41.39717	9.558538	65.65476	11.28796	58.60	18.09
CVX	109.3527	12.19209	123.1233	35.88081	12.59	194.30
BG	67.70133	10.71905	79.48905	22.9716	17.41	114.31
DJCI	571.637	54.06531	873.4736	208.9475	52.80	286.47
GSG	16.10833	1.9629	16.79119	4.647862	4.24	136.79
USWheat	477.0032	46.10171	712.9114	148.5314	49.46	222.18
Copper	2.644617	.3238372	3.712779	.6954334	40.39	114.75
Gold	1273.098	105.8754	1820.998	112.565	43.04	6.32
WTI	53.45683	9.185374	67.96786	23.17322	27.15	152.28

Tables 3 to 8 show pairwise correlations between analysed assets measured by Pearson's coefficients. Table 3 to 5 pertain to the pre-pandemic period and Tables 6 to 8 to the pandemic period.

Pre-pandemic patterns are as following. Within traditional portfolio A, all assets exhibit high positive correlation with each other, exception being KOS stock with low positive and negative correlation patterns. US10YR displays low to medium correlation with other traditional assets (Tables 3 and 4). Stocks of commodity companies exhibit negative and low positive correlation with each other due to the diverse nature of their activities, exception being CVX and RIO since both are in the business of extracting raw materials. Commodity indices show low positive correlation (Table 4). Commodity futures show low positive correlation within category with the exception of high correlation between Copper and WTI crude oil (Table 5), both often referred to as the mirrors of the economic activity. Looking at the price comovements across different asset classes, the following is inspected. Within commodity company stocks, again no consistency is observed, since the extant of price comovements is based on the company activity itself. RIO and HMY show high positive correlation with equity indices and stocks, and medium correlation with bonds, whereas HMY and BG offer greater diversification potential due to their low positive and negative correlation with traditional investment classes. It can be argued that in time of no crisis, companies engaged in gold mining and agriculture offer higher diversification potential as opposed to companies engaged in mining and drilling of raw materials such as oil. Comparing comovements of commodity indices to traditional assets, GSG reveals higher diversification benefits that DJCI (Tables 3 and 4). Commodity futures exhibit medium to high positive correlation with traditional assets with the exception of USWheat which displays low correlation coefficients. Beside wheat, diversification benefits in the pre-pandemic could have been achieved by adding Gold to a bonds portfolio since it shows negative correlation.

Table 3. Pearson's correlation coefficients, pre-pandemic 1/3

	Nas-daq100	SP500	GOOGL	GM	KO	KOS	VRTX
Nasdaq100	1.0000						
SP500	0.9947*	1.0000					
GOOGL	0.9650*	0.9559*	1.0000				
GM	0.6182*	0.6522*	0.5759*	1.0000			
KO	0.8058*	0.8031*	0.7858*	0.3545*	1.0000		
KOS	-0.0193	0.0122	-0.1591	0.3037*	-0.2643*	1.0000	
VRTX	0.8910*	0.8761*	0.8100*	0.5796*	0.6915*	0.1240	1.0000
BRKb	0.9624*	0.9714*	0.9319*	0.6677*	0.7496*	-0.0192	0.8539*
US10YR	0.3750*	0.3693*	0.3947*	0.4957*	-0.1040	0.2117	0.4091*
HMY	0.0398	0.0658	0.0629	-0.2390	0.3354*	-0.2724*	-0.1969
RIO	0.8666*	0.8765*	0.7525*	0.7264*	0.5996*	0.2188	0.8477*
CVX	0.7902*	0.8288*	0.7474*	0.7512*	0.5331*	0.2348	0.6138*
BG	-0.4858*	-0.4477*	-0.5597*	0.0061	-0.6541*	0.5660*	-0.3218*
DJCI	0.8221*	0.8505*	0.7417*	0.7315*	0.4805*	0.2717*	0.7248*
GSG	-0.1270	-0.1109	-0.3224*	0.1371	-0.3414*	0.7821*	0.1080
USWheat	0.2791*	0.2499	0.1539	0.0565	0.2128	0.2307	0.4926*
Copper	0.5827*	0.6196*	0.5161*	0.8150*	0.2052	0.3760*	0.5931*
Gold	0.6901*	0.7089*	0.6497*	0.3432*	0.7920*	-0.1949	0.5153*
WTI	0.6625*	0.6795*	0.5685*	0.5939*	0.2284	0.5153*	0.6145*

Note: * significant at 0.05 level

Table 4. Pearson's correlation coefficients, pre-pandemic 2/3

	BRKb	US10YR	HMY	RIO	CVX	BG	DJCI
BRKb	1.0000						
US10YR	0.4731*	1.0000					
HMY	0.0311	-0.6019*	1.0000				
RIO	0.8723*	0.4190*	-0.1039	1.0000			
CVX	0.8393*	0.4416*	0.1219	0.8173*	1.0000		
BG	-0.4263*	0.1313	-0.3460*	-0.2115	-0.2118	1.0000	
DJCI	0.8731*	0.5432*	-0.0160	0.8973*	0.9154*	-0.1032	1.0000
GSG	-0.1159	0.2022	-0.3502*	0.2108	0.0550	0.6018*	0.2149
USWheat	0.2139	0.2211	-0.2999*	0.3365*	0.0485	0.0366	0.2157
Copper	0.6846*	0.6142*	-0.2637*	0.7791*	0.7478*	0.1755	0.8451*
Gold	0.6596*	-0.2547*	0.6283*	0.5985*	0.5876*	-0.4590*	0.5792*
WTI	0.6732*	0.6299*	-0.1847	0.7465*	0.7721*	0.0796	0.8757*

Note: * significant at 0.05 level

Table 5. Pearson's correlation coefficients, pre-pandemic 3/3

	GSG	USWheat	Copper	Gold	WTI
GSG	1.0000				
USWheat	0.4529*	1.0000			
Copper	0.2798*	0.1069	1.0000		
Gold	-0.2634*	0.0250	0.3160*	1.0000	
WTI	0.4807*	0.3017*	0.7184*	0.2881*	1.0000

Note: * significant at 0.05 level

The outbreak of the pandemic brought several changes to the market with a potential for disruption of established knowledge and practices. The comovements of prices within traditional asset portfolio remained rather the same as in the pre-pandemic period, rather strong and positive. However, compared to the pre-pandemic values, a lower correlation is inspected, with some pairwise correlations turning from high positive to negative (Table 6). Correlations within stocks of commodity companies again cannot be unequivocally interpreted as they are liable to company activities. Commodity indices significantly strengthened their correlation and alternated from low positive correlation in the pre-pandemic period to nearly perfect correlation in the pandemic (Table 7). Commodity futures strengthened their correlation within asset category as well, with wheat taking the lead (Table 8).

The pandemic brought changes to market movements across asset categories as well. Stocks of commodity companies displayed contrasting results, regarding of their business activity. HMY sustained its negative and low positive correlation to traditional assets, with no consistent change in correlation. RIO and CVX predominantly weakened their correlation to traditional assets, which still reaches to strong coefficients. BG endured the biggest shift by strengthening its correlation to stocks and bonds and in several instances changed its correlation from negative to positive, hampering thus its diversification benefits (Tables 6 and 7). Regarding commodity indices, GSG underwent comparable change. The biggest changes occurred within commodity futures category. Wheat strengthened its correlation to traditional assets, altering from low correlation in the pre-pandemic to medium and high correlation in the pandemic period. Copper and WTI sustained their high correlation to stocks and bonds, confirming themselves again as an economical generator, with the difference that copper grew the correlation even stronger whereas comovements of WTI are rather inconsistent. On the other hand, gold generally manifested lower correlations than in the pre-pandemic period (Figure 1), with coefficients in low to medium range (Table 6), thus asserting itself as a potential portfolio diversifier. The negative pre-pandemic relationship to bonds transformed into low positive in the pandemic, putting thus additional burden to its diversification potential (Figure 2, Table 7).

Table 6. Pearson's correlation coefficients, pandemic 1/3

	Nas-daq100	SP500	GOOGL	GM	KO	KOS	VRTX
Nasdaq100	1.0000						
SP500	0.9435*	1.0000					
GOOGL	0.9321*	0.9490*	1.0000				
GM	0.7917*	0.7572*	0.7509*	1.0000			
KO	0.3803*	0.6367*	0.5173*	0.1793	1.0000		
KOS	0.1741	0.4506*	0.3052*	-0.0089	0.8814*	1.0000	
VRTX	-0.2606	-0.1139	-0.2824	-0.6031*	0.3943*	0.5726*	1.0000
BRKb	0.6579*	0.8451*	0.7357*	0.4159*	0.8880*	0.7999*	0.2929
US10YR	0.1434	0.3959*	0.2363	-0.0521	0.7962*	0.9090*	0.6655*
HMY	0.2400	0.0631	0.0100	0.0649	-0.2398	-0.3553*	-0.0464
RIO	0.6549*	0.6862*	0.5935*	0.7381*	0.3448*	0.2210	-0.2327
CVX	0.1974	0.4744*	0.3298*	-0.0196	0.8799*	0.9587*	0.6304*
BG	0.5930*	0.7998*	0.7019*	0.4387*	0.8740*	0.8248*	0.2231
DJCI	0.5710*	0.7768*	0.6919*	0.3806*	0.8817*	0.8225*	0.2484
GSG	0.3806*	0.6346*	0.5460*	0.1887	0.9299*	0.9182*	0.3853*
USWheat	0.3857*	0.5739*	0.5643*	0.2813	0.7068*	0.6646*	0.0795
Copper	0.8555*	0.9232*	0.8686*	0.7927*	0.5740*	0.4213*	-0.2049
Gold	0.4184*	0.3746*	0.2516	-0.0031	0.2680	0.2172	0.3784*
WTI	0.5181*	0.7299*	0.6781*	0.3564*	0.8762*	0.7998*	0.1876

Note: * significant at 0.05 level

Table 7. Pearson's correlation coefficients, pandemic 2/3

	BRKb	US10YR	HMY	RIO	CVX	BG	DJCI
BRKb	1.0000						
US10YR	0.7604*	1.0000					
HMY	0.1106	-0.3814*	1.0000				
RIO	0.5513*	0.1390	0.2343	1.0000			
CVX	0.8261*	0.9305*	-0.3480*	0.2062	1.0000		
BG	0.9487*	0.7643*	-0.2269	0.5519*	0.8420*	1.0000	
DJCI	0.9227*	0.7578*	-0.2299	0.5368*	0.8384*	0.9737*	1.0000
GSG	0.8837*	0.8475*	-0.3535*	0.3505*	0.9203*	0.9300*	0.9609*
USWheat	0.7106*	0.5591*	-0.3052*	0.3952*	0.6779*	0.8373*	0.8802*
Copper	0.7943*	0.3445*	0.0903	0.8576*	0.4183*	0.7998*	0.7796*
Gold	0.3974*	0.1891	0.6758*	0.4021*	0.2267	0.2906	0.3133*
WTI	0.8599*	0.6868*	-0.2688	0.4784*	0.7969*	0.9247*	0.9716*

Note: * significant at 0.05 level

Table 8. Pearson's correlation coefficients, pandemic 3/3

	GSG	USWheat	Copper	Gold	WTI
GSG	1.0000				
USWheat	0.8481*	1.0000			
Copper	0.6069*	0.6312*	1.0000		
Gold	0.2026	0.1049	0.3942*	1.0000	
WTI	0.9585*	0.8884*	0.7245*	0.2175	1.000

Note: * significant at 0.05 level

Figure 1. Correlation of gold futures to equity indices, by period

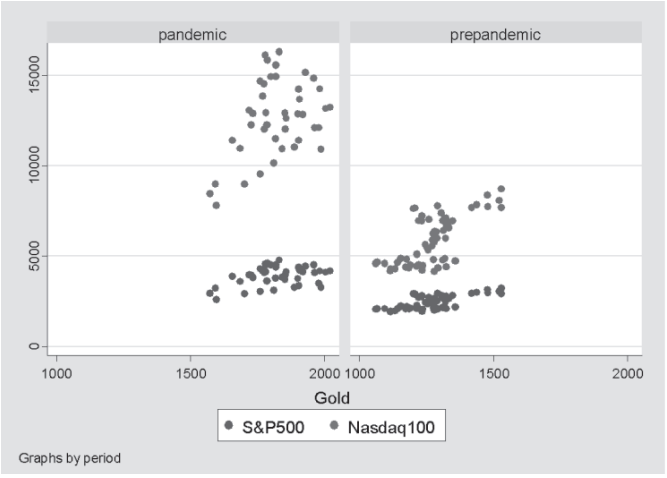
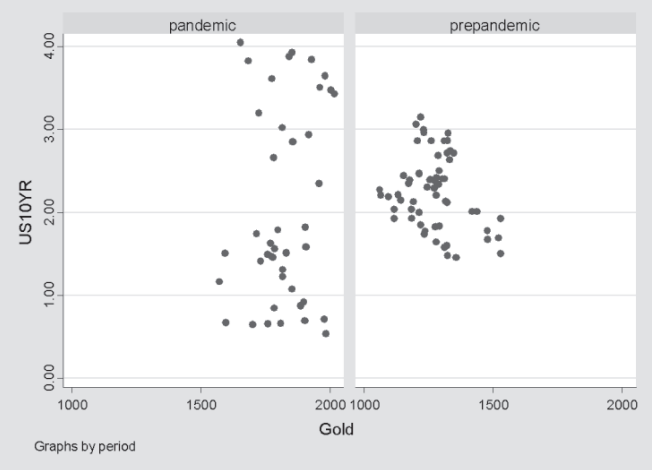


Figure 2. Correlation of gold futures to bonds, by period



4.2. RESULTS OF MEAN-VARIANCE ANALYSIS

Two main components of mean-variance analysis are expected returns and accompanying standard deviations of portfolios. Table 9 gives an overview of mean returns and standard deviations in the pre-pandemic and pandemic periods for each asset in the portfolio, by asset category. An overall assessment of traditional asset performance reveals that the pandemic resulted in increase in both risk and return. GM, KOS and US10YR displayed massive increase in average return accompanied by lesser relative increase in standard deviation, positioning themselves thus as good individual investments. Solely VRTX exhibited decrease in return and standard deviation. The performance of stocks of commodity companies again showed inconsistent results, with RIO displaying the poorest results with lower return and higher risk as a result of the pandemic. On the other hand, BG positioned itself as a good individual investment since its return shifted from negative to positive accompanied by slight increase in standard deviation. Both commodity indices showed increase in average return and accompanying risk, while BSG managed to achieve positive return in the pandemic compared to negative one in the pre-pandemic period. Among commodity futures, Copper and WTI showed the highest increase in return, while accompanied by lesser relative increase in risk. Looking at the risk-return ratio, USWheat positioned itself as a safe investment with increase in average return and decrease in standard deviation. Gold endured small increase in both risk and return. Within the category, WTI seems most suitable for investors with high risk tolerance whereas those with high risk aversion would seem to prefer Gold. It is a pattern than existed in the pre-pandemic period and it became even more accentuated during the pandemic.

Table 9. Returns and standard deviations, by asset category and period

ASSET CATEGORY	PREPANDEMIC		PANDEMIC	
	Return	Std. Dev.	Return	Std. Dev.
EQUITY INDICES				
Nasdaq100	1.31%	0.04324	1.56%	0.06865
SP500	0.81%	0.03426	0.93%	0.05743
STOCKS				
GOOGL	1.72%	0.05855	1.76%	0.08513
GM	0.34%	0.07258	0.92%	0.12561
KO	0.51%	0.03442	0.38%	0.05945
KOS	0.24%	0.13193	4.10%	0.27488
VRTX	1.48%	0.09474	1.43%	0.07586
BRKb	0.76%	0.03943	1.18%	0.06420
BONDS				
US10YR	0.26%	0.09499	2.98%	0.15937
STOCKS OF COMMODITY COMPANIES				
HMY	3.65%	0.24815	2.16%	0.19973
RIO	0.85%	0.08180	0.71%	0.09524
CVX	0.27%	0.05561	1.21%	0.10846
BG	-0.50%	0.07291	1.59%	0.08942
COMMODITY INDICES				
DJCI	0.29%	0.03500	1.12%	0.05772
GSG	-0.34%	0.05190	0.79%	0.08070
COMMODITY FUTURES				
USWheat	0.23%	0.08063	0.66%	0.07719
Copper	0.14%	0.05587	0.93%	0.06694
Gold	0.50%	0.03775	0.64%	0.04223
WTI	0.65%	0.09140	2.00%	0.18718

Table 10 presents comparable results of alterative portfolios between the pre-pandemic and the pandemic period. Expected returns were calculated according to formula 1 and standard deviations according to formulas 2 and 3. First, portfolio performances were analysed within the periods, and then compared. In the pre-pandemic period, portfolio A exhibited both the highest return and the highest risk, denoting thus traditional assets as an overall risky investment category. Each following addition of a form of commodity investing added to lower risk but lower return as well. The investors need to make

trade-off between risk and return and design their portfolio according to their risk tolerance. Risk tolerant investors are going to put higher emphasize on return, whereas risk aversive investors are going to put higher emphasize on risk. Within diversified portfolio alternatives B, C1, C2 and C, investors with high risk tolerance would prefer stocks of commodity companies and commodity indices as portfolio diversifiers, whereas investors with risk aversion would choose commodity futures. The lowest levels of risk are achieved through diversification with all analysed form of commodity investing. In the pandemic period, portfolio A composed of traditional assets remains most desirable to investors with high risk tolerance due to its high risk and high return, whereas fully diversified portfolio C remains preferable to risk aversive investors. Looking at the pandemic effect (change column, Table 10), it can be observed that increase in expected returns was accompanied by multiple increase in standard deviations of analysed portfolios. Portfolios A and B exhibit somewhat similar effect that is milder compared to the effect of portfolios C1, C2 and C. Such results can be attributed to indirect relationship between stocks of commodity companies and commodity prices.

Table 10. Expected returns and standard deviations of alternative portfolios, by period

PORTFOLIO	PREPANDEMIC		PANDEMIC		CHANGE (%)	
	Expected return	Std. Dev.	Expected return	Std. Dev.	Expected return	Std. Dev.
PORTFOLIO A	1.15%	3.9863%	1.41%	6.4013%	22.61	60.58
PORTFOLIO B	1.13%	3.9562%	1.40%	6.3671%	23.89	60.94
PORTFOLIO C1	1.08%	3.7853%	1.39%	6.1765%	28.70	63.17
PORTFOLIO C2	1.01%	3.2702%	1.31%	5.6628%	29.70	73.16
PORTFOLIO C	0.98%	3.1729%	1.30%	5.5310%	32.65	74.32

Diversification benefit of adding certain form of commodity investment to traditional asset portfolio was measured and compared by diversification benefit indices of alternative portfolios (Table 11). Diversification benefit occurs if adding a certain asset improves Sharpe ratio. The Sharpe ratio indicates how well a portfolio has performed relative to the risk taken, measuring realised excess return of a portfolio per unit of portfolio risk. As a benchmark for a risk free asset a 3-month U.S. treasury bill was used. Base value of diversification benefit index was set to the value of Sharpe ratio of portfolio A. The higher the Sharpe ratio, the higher the diversification benefit, not taking into account risk preferences of investors. An index value above 100 means that adding

assets to traditional portfolio results in diversification benefits, whereas index value below 100 means that adding assets to traditional portfolio detriments diversification benefits.

Table 11. Diversification benefits of alternative portfolios, by period

PORTFOLIO	PREPANDEMIC		PANDEMIC	
	Sharpe ratio	Diversification benefit index	Sharpe ratio	Diversification benefit index
PORTFOLIO A	0.288739	100.000000	0.218668	100.000000
PORTFOLIO B	0.285880	99.009991	0.218272	99.818892
PORTFOLIO C1	0.285578	98.905409	0.223389	102.158784
PORTFOLIO C2	0.309155	107.070911	0.229526	104.965503
PORTFOLIO C	0.309181	107.079733	0.233188	106.639941

Firstly, it can be observed that the pandemic crisis resulted in drop of a Sharpe ratio of more than 20% for all analysed portfolios. The drop can be attributed to large increase in volatility (as showed in Table 10) confirming thus investing to be riskier in times of crisis. Comparing the diversification benefit index within the periods, it can be concluded that adding commodities to traditional asset portfolio offers diversification benefits both in the pre-pandemic and pandemic periods but they differ between forms of commodity investment. Adding stocks of commodity companies (portfolio B) proved to detriment diversification benefits both in the pre-pandemic and the pandemic period. Portfolio C1 showed a positive effect of Covid-19 crisis on diversification benefit exhibiting a shift from index below 100 to one above 100. Commodity indices, while not offering diversification benefits in the pre-pandemic period, manifested as beneficial in times of crisis. Including commodity futures in a portfolio instead of commodity indices (portfolio C2) shows much higher diversification benefits, somewhat higher in the pre-pandemic than the pandemic period. And last, adding all analysed forms of commodity investments to traditional portfolio (portfolio C) manifests the highest diversification benefits, both in the pre-pandemic period and during the pandemic, with slight decrease in times of crisis.

5. DISCUSSION

When interpreting presented results several remarks need to be made. The pandemic resulted in many unprecedented economic activities the aim of which was to restore human safety and functioning of key institutions of our so-

ciety. Some of these measures, like stimulus packages, resulted in large increase of money supply. According to IMF estimates, solely in 2020, an amount of 9 trillion dollars was deployed as direct spending or loans, equities and guarantees.[32] Although our research analyses two distinct periods we need to stress the importance of these measures for the prices of all asset classes. It can be seen in other research (e.g. Zhang et al.) that measures like a zero-percent interest rate and unlimited quantitative easing (QE) had huge impact on financial markets but the first reaction was typically a substantial increase in risk related to pandemic responses.[33] It is why when discussing our results one needs to take into account that the big difference between the two analysed periods is in implemented monetary policy and level of risk associated with financial markets. Each alternative portfolio is measured by expected return and risk and results show that the pandemic resulted with higher returns but accompanying risk as well.

Regarding the diversification potential of commodities in crisis, obtained results demonstrate that adding certain types of commodities to traditional portfolio results with diversification benefits. However, those benefits are slightly lower in times of crisis when considering all but the portfolio C1 diversified with commodity indices. Portfolio C diversified with commodity indices and commodity futures and portfolio C2 diversified with commodity futures show highest diversification benefits both in the pre-pandemic and pandemic times.

As Anson noted, commodity indices are designed to be long-term only investments, therefore in shorter time frames futures are a better option of investing in commodities.[34] According to Chong and Miffre, the correlations between the S&P 500 Index and several commodities also fell in periods of above-average volatility in equity markets.[35] Therefore, it can be argued that commodity futures are a better tool for strategic asset allocation in times of crisis.

Next, a role of commodities in the economic cycle needs to be emphasized. Commodities tend to do exceptionally well compared to stocks and bonds in the period of economic overheat. In this case, such overheat was created by stimulus packages mainly in financial markets and much less in real economy.

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[33] Zhang, D., Hu, M., Ji, Q.: Financial markets under the global pandemic of COVID-19, *Finance research letters*, (36) 2020, pp. 101528

[34] Anson, M. J.: Spot Returns, Roll Yield, and Diversification with Commodity Futures, *The Journal of Alternative Investments*, (1) 1998, pp. 16–32.

[35] Chong, J., Miffre, J.: Conditional Correlation and Volatility in Commodity Futures and Traditional Asset Markets, *The Journal of Alternative Investments*, 12(3) 2009, pp. 061 - 075.

One of the surprising consequences of the pandemic period was a big decoupling between real and financial sector.[36] As evidenced by Davidovic, the pandemic induced risk exposure (expected shortfall) increasing volatility and stronger cross-market integration across stock, commodity and cryptocurrency markets.[37] In the pandemic period all asset classes performed well according to realised returns, but when taking into account accepted risks, it can be noted that the results are weaker than in the pre-pandemic period. Likewise, the data on risk/return show that the differences between portfolios diminished due to stronger integration.

6. CONCLUSION

The role of commodities in portfolio diversification has been debated for a long time. On one hand, many studies have empirically confirmed diversification benefits of adding commodities to traditional asset portfolio. On the other hand, there are studies that show that including commodities does rather little to improve portfolio Sharpe ratio and argue that commodities are too diverse as an asset class to be studied as a single category.

With our study we aim to build on theoretical foundation regarding diversification benefits of commodities and to provide empirical evidence regarding the impact of crisis on portfolio diversification and portfolio performance. The study analyses the returns of commodities compared to returns of traditional asset classes in order to investigate whether the inclusion of commodities offers portfolio diversification benefits. An empirical analysis encompassed time frame from January 2015 to June 2023, as to include both the Covid-19 crisis period and the years that preceded it. First, correlation analysis was conducted in order to detect any changes in market dynamics. Next, five different investment portfolios were designed and mean-variance method and Sharpe ratio were used in assessment of obtained diversification benefits, both in the pre-pandemic and pandemic periods.

Summarized, in the pre-pandemic period the following alternative assets offered the highest diversification potential due to their low positive and negative correlation with traditional assets: stocks of companies not operating in mining (excluding gold mining) and oil drilling, GSG commodity index and wheat futures. Gold futures could have been used for diversification purposes

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[37] Davidovic, M.: From pandemic to financial contagion: High-frequency risk metrics and Bayesian volatility analysis, *Finance Research Letters*, (42) 2021, pp. 101913.

only to offset downturns of bonds performances. Examining the correlations within asset categories, the pandemic disrupted the market movements in a way that traditional assets weakened their correlations whereas commodity indices and commodity futures strengthened their correlations. Inspecting the correlations across different asset categories, it can be noticed that BG strengthened it correlation to traditional assets leaving thus diversification possibility solely to HMY, among analysed stocks. GSG commodity index evolved in a similar manner. Among commodity futures, Covid-19 induced market shock, deteriorated diversification benefits of wheat but enhanced those of gold. Strengthening of correlations within asset category provides opportunities for shocks spill-over whereas strengthening of correlations across different asset categories detriments diversification benefits. Adjusting exposure to individual commodities can enhance portfolio performance.

An overall assessment of asset performance reveals that the pandemic resulted in increase in both risk and return. When comparing changes between the periods in portfolio diversification (Tables 10 and 11) to changes between the periods in correlation (Tables 5 to 8) it can be concluded that the pandemic brought changes to the market that are evident in the form of market dynamics and are more pronounced when considering individual assets. The pandemic substantially enhanced diversification benefits of commodity indices due to the strengthening of correlation within asset category. Portfolio consisting of traditional assets show performance that would seem appealing to investors with high risk tolerance. On the other hand, portfolio consisting of traditional assets diversified with stocks of commodity companies, commodity indices and commodity futures shows performance that would seem appealing to risk aversive investors.

It can be concluded that adding commodities to investment portfolio results in diversification benefits that are manifested in higher realised excess return for each unit of risk. Diversification benefits differ between forms of commodity investment and are highest for commodity futures in the pre-pandemic and the pandemic period. Crisis diminished Sharpe ratio of all alternative portfolios due to the massive increase of individual asset return variability. Such development of events had heterogeneous effect on diversification benefits of alternative portfolios. Whereas including commodity indices shifted to beneficial, inclusion of stocks of commodity companies maintain to underperform compared to traditional portfolio. On the other hand, the crisis exhibited most detrimental effect on commodity futures that still remain most beneficial diversification asset especially when combined with other forms of commodity investment.

The contribution of our study is that it adds to a handful of studies that investigated diversification benefits of commodities in the times of crisis. Furthermore, since we included the entire pandemic period and not only early months,

the full impact of crisis was analysed and elaborated. As a recommendation for future studies, it would be valuable to study the effect of crisis within an econometric model with money supply as a control variable. A clear limitation of our study is that we were unable to isolate the effect of Covid-10 crisis because of the simultaneous Russian invasion of the Ukraine.

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