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Do investors care about carbon risk? The impact of the Paris agreement on the inflation hedging performance of commodities

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Abstract

It is growingly recognized that a transition to sustainable finance is of utmost importance to scale up the low-carbon investments required to reach the global climate goals. However, financial capital is still widely allocated into economic activities whose profits rely significantly on fossil fuels' extraction, combustion and use, and that do not align to the Paris agreement (PA) targets. This study tests whether the PA has redefined the role of commodities in the portfolio allocation of asset managers, and has unleashed the potential to use this class of assets as an inflation hedge. It assesses whether financial markets are pricing the PA by decreasing the portfolio weights of carbon-intensive commodities afterwards. A dynamic portfolio analysis has been conducted to assess the impact of the PA on the inflation hedging abilities of energy commodities, industrial metals and precious metals. We find evidence that the weight of the copper- one metal that is expected to be a cornerstone of a low-carbon future- within an optimal portfolio tends to increase after the PA. With focus on efforts to achieve a low carbon economy continuing to grow, investors started to consider copper and other industrial metals including cobalt, nickel and aluminum as appealing investment opportunities, but they remain cautious on divesting from the carbon-intensive assets. Overall, our findings suggest that investors are responding to opportunities but less to risks in a low carbon pathway.

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1. Introduction

The inflation hedging properties of several asset classes (for instance, treasury inflation-protected securities, commodities, and real estate) has received significant attention, as unexpected inflation can have a pronounced effect on the market and investors' portfolios. Historically, commodity prices were significantly associated with inflation changes and sometimes business cycles (Bernanke, 2009). Commodities and the consumer price index tend to have a positive linkage, making them a natural candidate as an inflation hedge (Liu et al., 2023). In addition, commodity prices are largely perceived to be able to incorporate new information more speedily than consumer prices (see Mahdavi and Zhou, 1997). Moreover, commodities tend to behave dissimilarly than traditional asset classes, particularly when commodity price shocks are determined by unusual changes in supply. One can cite the impact of wheat and oil disruption after the Russia-Ukraine crisis, or the extended shutdown of Chinese factories amid a long-standing national zero-COVID policy. Over the last three decades, commodities have had a statistically significant and largely consistent positive inflation beta, or predicted reaction to a unit of inflation. A recent research by Vanguard reveals that over the last decade, commodities' inflation beta has fluctuated significantly between 7 and 9. This implies that a 1% rise in unexpected inflation (i.e., the difference between projected and realized inflation) would produce a 7% to 9% rise in commodities (see Figure A1 in Appendix).

To date however, the effectiveness of commodities to act as an inflation hedge remains in debate. The existing literature has devoted a particular attention to the assessment of the inflation-hedging abilities of either an aggregate commodity index (for instance, Erb and Harvey, 2006, Gorton et al., 2013, Hoevenaars et al., 2008) or precious metals (see inter alia, Apergis et al., 2019, Bampinas and Panagiotidis, 2015). Even though various prior studies claim that commodities, especially precious metals, are effective hedges against rising inflation risks (Bampinas and Panagiotidis, 2015, Beckmann and Czudaj 2012; Levin and Wright, 2006; Worthington and Pahlavani, 2007; McCown and Zimmerman, 2010; Wang et al. 2011; Rubbaniy et al., 2012), others deduce that commodities lack the capacity to serve as hedges against inflation risks in long-term horizons (Beckmann and Czudaj, 2012, Van Hoang et al., 2016). These contradictory findings call for a thorough investigation of the inflation hedging abilities of different commodities.

Nowadays, investors are starting to recognize that climate change, and the policy reactions to it, could pose a huge risk to their investments. Indeed, the climate-related risks, whether physical or related to a transition to a lower carbon economy, are changing the risk-return profile of companies, prompting new and rising risks in investors' portfolios. It is, therefore, expected that investment strategies screening companies based on some environmental criteria have increased significantly over the past years. Accordingly, the practice of investing in companies that focus on fulfilling financial returns, while accounting for positive environmental impact, is gaining more popularity among investors (Ochoa et al., 2022; Selmi et al., 2021). This trend reflects a shift in preferences toward investment opportunities that would help contain the climate crisis and a concern about the policy responses to accelerate the transition to a low carbon economy. Investors are under pressure to align their strategies with a maximum global temperature increase of 1.5°C as targeted by the Paris Agreement, raising questions about how to do so while respecting other investment constraints. One may do so by overweighting companies on a credible decarbonization path or those offering green solutions, underweighting ones poorly positioned for a low-carbon-economy transition and limiting exposure to physical risks (Doole et al., 2020).

Recently, an increasing number of recent works suggest that, in the face of accelerating climate change, investors are making capital allocations in an attempt to decarbonize portfolios by limiting the carbon emissions of their holdings (see inter alia, Atta-Darkua, 2020; Cheema-Fox et al., 2019, Monasterolo and de Angelis, 2020; Smith, 2022). Accordingly, Monasterolo and de Angelis (2020) find that after the Paris agreement (PA), the correlation among low-carbon and carbon-intensive indices decreases. The systematic risk for the low-carbon indices decreases consistently, whereas the stock markets' responses is relatively moderate for most carbon-intensive indices. They add that the weight of the low-carbon indices within an optimal portfolio is likely to increase after the PA. In the same context, Smith (2022) claim that the climate transition mainly focuses on the contribution financial markets must play towards achieving a transition to low-carbon economies. For investment management, net zero portfolios are one of the newest front-line tools. Such moves may redefine the role of different assets such as commodity indexes in the portfolio allocation of asset managers (Cheema-Fox et al., 2021). Nevertheless, how to hedge inflation amid decarbonization from a financial decision-making perspective remains largely understudied.

The present research seeks to explore the performance of portfolio decarbonization strategies and investor behavior towards decarbonization in periods of soaring inflation. We assess whether the transition to a carbon-neutral world will redefine the role of different commodities in the portfolio allocation, and unleash the potential to use this class of assets as an inflation hedge. Kim (2022) argue that industrial metals such as copper have done well in inflationary environments, dominantly due to the metal's strong correlation with inflation, the role it plays in the traditional economy, and the one it is set to play with the shift to carbon neutrality. This study adds that the balance between green and non-green demand for copper and other base metals (such as, lithium, cobalt, aluminum, and graphite) is expected to switch speedily, where green demand is anticipated go from 5% in 2020 to 16% at the end of 2030. The present research complements these works by documenting the impacts of policies that lead the economy to a low carbon transition through the lenses of different assets. It provides a novel perspective to this emerging literature by assessing the impact of decarbonization policies on the inflation hedging potential of energy commodities and industrial metals, in addition to popular precious metals (in particular, gold). Even if it seems difficult to get accurate answers of whether investors and/or asset managers are actively decarbonizing their portfolios, this paper sidesteps these limitations by assessing the inflation hedging performances of energy commodities (oil), industrial metals (copper, nickel, cobalt and aluminum) and precious metals (gold)[1] before and after the Paris Agreement. In fact, the PA has marked a milestone as it is the first international agreement to state explicitly the role of finance. Since the announcement of the PA, the number of international financial initiatives for disclosing and evaluating climate risks in investors' portfolios has risen significantly (Monasterolo and de Angelis, 2020). The PA was followed by an unparalleled consensus among policy makers and financial institutions on the fact that climate change mitigation cannot be achieved without the engagement of the financial sector. (Alessi et al., 2021). This would undoubtedly necessitate the scaling up of investments in low-carbon activities, and the divestment from carbon-intensive activities (Kruse et al. 2020).

Even though the PA, the research outcomes on climate-related financial risks, and the responses of central banks and financial regulators, represent powerful market signals, no conclusive evidence has been offered on how investors have started to respond to the PA. In this paper, we contribute to fill this gap by developing a comprehensive empirical analysis of the inflation hedging performances of different commodities (i.e., energy commodities, industrial commodities and precious metals), before and after the PA. We, first, use a dynamic downside risk analysis to explore the inflation hedging effectiveness of these commodities for various scenarios (i.e., different market conditions and target rates). Second, we test if the Paris aligned stocks- a new index composed of U.S. large and mid-capitalization stocks that is designed to be compatible with the objectives of the Paris Agreement[2]- value the energy transition minerals and penalize carbon-intensive assets.

After the Paris agreement, it is found that the decarbonization has led to an increase in downside risk to energy commodities and industrial metals. But oil, gold and copper remain the best assets for optimal hedging portfolios. Moreover, we show a pronounced (modest) correlation between Paris aligned stock returns and copper (oil) returns. This highlights that investors started to value copper as an investment opportunity, but they are still cautious on divesting from the carbon-intensive assets. In other words, the financial capital is still allocated into carbon-intensive assets, and that do not align to the PA targets. Our findings can contribute to inform the portfolios' risk management strategies of investors in the transition to sustainable finance.

The remainder of the article is organized as follows: Section 2 discusses the data and provides a detailed account of the methodology. Section 3 reports and discusses the empirical findings. Section 4 concludes and provides some investment implications and directions of future research.

[1] For several years, energy, industrial metals and precious metals (in particular, gold) outperformed traditional asset classes during periods of high inflation (see Figure A3).

[2] This index includes U.S. large and mid-capitalization stocks following a decarbonization trajectory, reducing exposure to climate-related transition and physical risks and increasing exposure to companies favorably positioned for the transition to a low-carbon economy. For more details about this index, please refer to this link: https://www.ishares.com/us/products/325725/ishares-paris-aligned-climate-msci-usa-etf/

2. Methodology and data

2.1.Methodology

Despite the fact that the PA policy announcement, the outcomes on the materiality of climate-related financial risks, and the response from central banks and financial regulators, represent all strong market signals, investors' responses to such signals are still ambiguous and unclear. In this study, we fill this gap by exploring the impact of the Paris agreement on the inflation hedging performances of different commodities. We consider a dynamic portfolio invested in oil, coal, copper, nickel, cobalt, aluminum and gold before and after the Paris agreement.

Under the risk allocation approach, the investor has a desired asset allocation and does not plan to move away from it. Nevertheless, it is documented in the existing literature that the risk and the dependence between assets vary conditional on diverse scenarios. Hoevenaars et al. (2008) and Amenc et al. (2009) are the first to assess optimal portfolios regarding inflation hedging. This research extends the models with different assets and examines optimal portfolios for investors exposed to inflation risk. Accordingly, Brière and Signori (2012) argue that inflation hedge portfolios can be significantly affected by various market conditions. Instead to prior research, these authors do not carry out the conventional mean-variance framework to extract an optimal allocation of several assets. They optimize the portfolios by focusing on shortfall probabilities, while overlooking the expected shortfall. They consider that since the portfolio's excess returns above target may be volatile but remain lower than investor's purposes, the investor may face a high risk. In such circumstances, the notion of safety-first -introduced by Roy (1952) seems more appropriate. Roy (1952) claims that investors think in terms of a minimum acceptable outcome, which he dubbed the "disaster level". The safety-first strategy is to select the investment with the smallest probability of falling below that disaster level. Nevertheless, a less risk-averse investor may be willing to attain a higher return, but with a more pronounced probability of going below the threshold.

The novelty of our paper lies in extending Brière and Signori (2012)'s study by assessing the shortfall with an inflation target, in addition to the shortfall probability. A large strand of the empirical literature has used the semi-variance approach in a portfolio context. However, none has examined the roles of oil, industrial metals and precious metals in an inflation-protecting asset allocation framework.

Besides the correlation conditional on inflation regimes and market states, we attempt to explore the optimal portfolio choice for the investor seeking to attain a fixed target for real returns on his investment horizon, with a shortfall probability constraint. The concept of Lower Partial Moments (LPM), initiated by Fishburn (1977), is appropriate for measuring portfolio risks in this respect since it helps to depict the downside risks of the return distribution. In general, the LPM is denoted as.

$$LPM_n(\iota) = \int_{-\infty}^{\iota} (\iota - r_i)^n f(r_i) dr_i \qquad (1)$$

where ι is the target rate, r_i is the return of asset i, and $f(r_i)$ is the density function of the i_{th} asset return. The n order of *LPM* can be described as a risk aversion parameter. Higher values of n imply greater deviations of returns below the target rate and a higher inflation risk.

In this study, we focus on three *LPM* classes, the shortfall probability (n=0), the expected shortfall (n=1), and the semivariance (n=2). For a portfolio, we attempt to detect the downside covariances among the various asset returns under consideration. Accurately, the semi-covariances are identified based on the co-Lower Partial Moments (*CLPM*).

$$CLPM_{ij}(\iota) = E\left[\max(0,(\iota - r_{it})).\max(0,(\iota - r_{jt}))\right] = \frac{1}{T}\sum_{t=1}^{T}\left[\max(0,(\iota - r_{it})).\max(0,(\iota - r_{jt}))\right] \qquad (2)$$

When considering the six assets under study, we obtain the semi-covariance matrix. According to Estrada (2008), we minimize the downside risk measure by performing a minimum semivariance portfolio choice written as follows:

$$\min_{\omega} LPM_{2,p} = \sum_{i=1}^{6} \omega_i CLPM_i(\iota)$$

subject to

$$\sum_{i=1}^{6} \omega_i = 1; \omega_i \geq 0, i = 1,...,6 \qquad (3)$$

where the vector $\omega = (\omega_1, \omega_2, \omega_3, \omega_4, \omega_5, \omega_6)$ corresponds to the weights of the six assets to be assessed in our minimum downside risk portfolio.

The optimal portfolio at time t results from employing the information in Eq (3) from a conditional quantile estimation of a GARCH model.[3] During the times of turmoil, the loss distribution of an asset return tends to shift upward, leading to wider expected losses above over the normal situations. The conventional downside risk measures may be insufficient to effectively hedge against inflation pressures. We, therefore, focus in this paper on inflation protection under diverse market regimes (i.e., bear, normal, bull market conditions). Such an investigation aims at: (a) determining the minimum semivariance portfolios with the target rate equal to 0 by reducing the risk of negative real return; (b) considering a more ambitious investor by focusing on portfolios with a higher target rate of 1%; and (c) obtaining distributional information such as conditional quantiles that plays a pivotal role in the risk measurement of the portfolios.

2.2.Data and descriptive statistics

We use monthly data on West Texas Intermediate (WTI) crude oil, copper, nickel, cobalt, aluminum and gold prices, and consumer price index (CPI) of the U.S. economy spanning from January 2010 to January 2023, with the start and end dates being purely driven by data availability on all the seven variables under consideration. The data on copper, nickel, cobalt, aluminum and gold are expressed in U.S. dollar per ounce, and are obtained from www.kitco.com. WTI crude oil prices are extracted from the Federal Reserve Bank of St. Louis (https://fred.stlouisfed.org/series/DCOILWTICO). The CPI is obtained from the Federal Reserve Bank of St. Louis (https://fred.stlouisfed.org/tags/series?t=inflation%3Bmonthly). Since the expected inflation rate is not directly observable, multiple econometric tools have been employed to estimate the expected inflation. The most frequently used technique to compute the expected inflation is the univariate time series Box-Jenkins/ARIMA estimates derived from risk-free rate proxied by the 1-month Treasury bill (Fama and Schwert, 1977). All series are transformed into their natural logarithmic form.

Table 1 provides the descriptive statistics of the return series for periods prior to and post-the Paris agreement (Panel A from January 2010 to October 2016 and Panel B from November 2016[4] to January 2023, respectively). Before the PA (Panel A), the average monthly returns are positive for all the return series (except, oil) over the sample period. Gold exhibits the highest average return followed by copper and aluminum. The WTI crude oil is the highest volatile market followed by the nickel and the aluminum, while the lowest volatility is for the gold market which is known for its hedge and safe haven roles in distressing times. The skewness coefficients are negative and the kurtosis coefficients are above three for all return series, indicating that the probability distributions of the return series under study are skewed and leptokurtic, thereby rejecting normality which is also confirmed by the Jarque-Bera statistics. After the PA (Panel B), oil becomes more volatile. The volatility of industrial metals and gold increase modestly. The returns are still non-normal, justifying the conduct of asset allocation strategy under various scenarios based on extreme value distributions.

Table 1. *Descriptive statistics of return series*

	WTI	*Copper*	*Nickel*	*Cobalt*	*Aluminum*	*Gold*	*US Inflation*
Panel A. Prior to the Paris agreement: From January 2010 to October 2016							
Mean	-0.0456	0.1780	0.0498	0.1165	0.1537	0.1845	0.0148
Median	-0.0381	0.3235	0.3012	0.3457	0.3669	0.2476	0.0159
Std. Dev.	4.1562	1.5267	4.0839	2.2456	3.1452	1.2783	2.6223
Skewness	-0.3827	-0.2508	-0.3475	-0.5715	-1.2891	-0.1036	-0.1950
Kurtosis	5.7238	4.6565	4.8730	5.3730	10.124	4.3057	4.6266
Jarque-Bera	130.91*	107.97*	143.86*	250.06*	123.38*	100.15*	165.72*

[3]According to Xiao and Koenker (2009), we perform a two-step approach of the quantile regression estimation for the GARCH time series. The first step consists of carrying out a quantile autoregression approximation for the GARCH model by combining the information over several quantile levels. The second step aims at applying the GARCH model to the first stage minimum distance estimation of the scale process of the time series.

[4]For the period post the Paris agreement, we consider the period when the agreement entered into force on 4 November 2016.

Panel B. Post- the Paris agreement: From November 2016 to January 2023							
Mean	-0.0821	0.2436	0.0876	0.0883	0.2019	0.2456	0.0345
Median	-0.0653	0.3587	0.4131	0.4053	0.4693	0.3756	0.0303
Std. Dev.	7.0341	1.7957	4.2192	2.4011	3.1789	1.3456	2.6892
Skewness	-0.9865	-0.5560	-0.6124	-0.4982	-0.6792	-0.1567	-0.3567
Kurtosis	5.1267	4.8138	4.0975	4.2673	5.0623	3.9876	5.1042
Jarque-Bera	138.94*	136.79*	141.80*	153.84*	112.49*	100.95*	124.56*

Notes: Std. Dev. symbolizes the Standard Deviation; the asterisk * denotes the significance at 1% level.

3. Main findings

This study seeks to: (1) determine the optimal asset allocation that will preserve the investor's capital from inflation with an acceptable probability of shortfall, and (2) answer whether the PA announcement affects the optimal portfolio composition. We consider cases of an investor simply wanting to hedge inflation, having a target real return of 0%, and another investor having a more ambitious target real return of 1%.

Table 2 reports the minimum semivariance portfolios for investors exposed to inflation risks for periods prior and post-the Paris agreement conditional on different regimes and various target rates. For the two periods under study, we perform three *LPM* classes, the shortfall probability (n=0; LMP_0), the expected shortfall (n=1; LPM_1), and the semivariance (n=2; LPM_2). We then explore the optimal portfolios for investors with a real return target of 0%, and for more ambitious investors with positive real return of 1%.

Prior to the Paris agreement (Panel A), the minimum semivariance portfolio is dominantly invested in gold, oil and copper under different market circumstances, and less importantly in nickel, cobalt and aluminum under the bear and normal market conditions (θ=0.1, 0.2, 0.3, 0.4, 0.5). The probability of collapsing of returns below the inflation rate appears strong, with values ranging from 32% to 69% over the bearish states (for θ=0.4 and θ=0.1, respectively, see Table 2(a)). These portfolios have expected shortfalls and semivariances greater than 1%. However, if we focus on the bullish states (θ=0.6, 0.7, 0.8, 0.9), we see that the portfolio weights of oil, gold and copper do not change substantially. However, the weights associated with nickel, cobalt and aluminum seem more pronounced when considering their normal and bull market conditions. These are industrial metals which are sensitive to the business cycle.

After the Paris agreement (Panel B), the results reveal that the PA announcement has created downside risk to energy commodities and industrial metals. But oil, gold and copper (in this order) are still the best assets for optimal hedging portfolios. Despite the high weight of energy within commodity indices, we obtain diversification benefits from allocating several commodities. While oil, gold and copper play the greatest roles (strong weights) under various scenarios, the proportion assigned to aluminum in the optimal portfolios appears also important when the market is bullish. The allocations to nickel and cobalt are, however, small compared with aluminum.

Assuming thereafter more ambitious investors, we investigate the optimal semivariance portfolios with a positive real return target. For the two considered periods, it is shown that when raising the target real return to 1%, we note that shortfall probabilities (LPM_0) increase sharply (more down risk) whatever the market conditions (bear, normal or bull) are. That is, it increases the risk that a portfolio return will fall short of the level of return considered acceptable by an investor. The other downside risk measures, the expected shortfall (LPM_1) and the semivariance (LPM_2) also rise with higher target returns. We show that investors who want an additional premium reduce their allocations to oil and invest more in gold and copper. Such accurate findings provide useful information to market participants and investors to help ensure better asset allocation in inflationary environments.

Table 2. *Minimum semivariance portfolios prior to and post-the Paris agreement*

Market states	θ=0.1	θ=0.2	θ=0.3	θ=0.4	θ=0.5	θ=0.6	θ=0.7	θ=0.8	θ=0.9
Panel A. Prior to the Paris agreement: From January 2010 to October 2016									
(a) Target: Real return 0%									
WTI	0.17	0.21	0.18	0.19	0.24	0.29	0.27	0.29	0.29
Copper	0.20	0.22	0.18	0.16	0.23	0.22	0.24	0.23	0.22
Nickel	0.03	0.04	0.04	0.06	0.07	0.07	0.09	0.08	0.04
Cobalt	0.04	0.05	0.03	0.04	0.04	0.04	0.08	0.07	0.06
Aluminum	0.05	0.06	0.07	0.06	0.11	0.20	0.13	0.16	0.13
Gold	0.30	0.27	0.26	0.24	0.31	0.42	0.40	0.41	0.42
LPM_0	69.08%	48.91%	52.14%	32.49%	6.32%	9.46%	11.08%	9.71%	14.52%
LPM_1	1.75%	2.34%	1.18%	2.07%	0.87%	1.13%	0.98%	1.62%	1.44%
LPM_2	1.03%	1.69%	1.59%	1.15%	0.04%	0.65%	0.42%	1.01%	0.96%
(b) Target: Real return 1%									
WTI	0.16	0.18	0.16	0.19	0.19	0.18	0.18	0.21	0.22
Copper	0.24	0.26	0.28	0.27	0.30	0.32	0.33	0.31	0.33
Nickel	0.07	0.05	0.06	0.06	0.08	0.11	0.08	0.09	0.07
Cobalt	0.08	0.06	0.06	0.05	0.06	0.12	0.11	0.09	0.09
Aluminum	0.11	0.10	0.09	0.11	0.10	0.14	0.12	0.13	0.10
Gold	0.23	0.25	0.25	0.25	0.27	0.24	0.28	0.27	0.26
LPM_0	73.10%	59.51%	42.89%	34.58%	27.14%	19.56%	16.04%	10.04%	11.38%
LPM_1	7.19%	9.02%	4.61%	3.16%	2.87%	3.17%	1.56%	1.11%	2.26%
LPM_2	4.23%	5.11%	3.24%	2.27%	1.54%	2.18%	0.42%	0.19%	1.15%
Panel B. Post- the Paris agreement: From November 2016 to January 2023									
(a) Target: Real return 0%									
WTI	0.16	0.15	0.15	0.16	0.18	0.18	0.17	0.16	0.18
Copper	0.21	0.20	0.19	0.21	0.22	0.22	0.21	0.20	0.23
Nickel	0.05	0.06	0.05	0.04	0.06	0.04	0.05	0.06	0.07
Cobalt	0.02	0.06	0.05	0.07	0.05	0.06	0.06	0.07	0.08
Aluminum	0.11	0.11	0.12	0.12	0.11	0.11	0.12	0.12	0.12
Gold	0.18	0.19	0.21	0.18	0.20	0.22	0.22	0.22	0.21
LPM_0	62.75%	58.72%	49.85%	51.23%	41.58%	23.72%	20.56%	18.76%	12.34%
LPM_1	3.09%	3.10%	2.16%	1.98%	1.46%	1.82%	1.62%	2.34%	2.62%
LPM_2	2.12%	2.34%	1.54%	1.23%	1.42%	1.29%	1.45%	0.87%	0.93%
(b) Target: Real return 1%									
WTI	0.13	0.15	0.17	0.15	0.14	0.15	0.18	0.17	0.16
Copper	0.23	0.23	0.25	0.22	0.22	0.19	0.24	0.25	0.24
Nickel	0.09	0.07	0.04	0.05	0.06	0.05	0.08	0.07	0.09
Cobalt	0.11	0.05	0.03	0.03	0.07	0.10	0.12	0.10	0.11
Aluminum	0.10	0.11	0.05	0.11	0.11	0.11	0.13	0.11	0.12
Gold	0.21	0.20	0.22	0.16	0.19	0.21	0.22	0.23	0.22
LPM_0	68.92%	57.84%	56.73%	46.52%	30.09%	25.72%	17.84%	14.56%	10.89%
LPM_1	2.43%	2.14%	2.76%	2.41%	2.78%	3.09%	2.26%	2.38%	2.12%
LPM_2	2.06%	1.97%	2.23%	2.08%	2.24%	2.41%	2.09%	2.24%	1.14%

To ascertain the robustness of our results, we test whether the MSCI world Paris aligned stocks- a new index composed of U.S. large and mid-capitalization stocks that is designed to be compatible with the objectives of the Paris Agreement- value the energy transition minerals and penalize carbon-intensive assets. More specifically, we assess the correlation between MSCI Paris aligned stocks and each of copper and oil, in comparison with the MSCI world stocks[5]. If these stock markets do not value energy transition minerals (including copper) and penalize carbon-intensive assets, then we would expect the effect of Paris agreement is not statistically different from zero or relatively moderate. We can note from Figure A4 (in Appendix) that there no large difference between the dependence between oil and each of the MSCI World stock returns and the MSCI Paris aligned returns. However, a sharp difference is shown for copper. We observe that the link

[5] For some details about the performances of the MSCI World Climate Paris Aligned Index versus the MSCI World Index, please refer to Figure A3 in Appendix.

between copper returns and the Paris aligned stock returns is more pronounced. This suggests that investors started to consider copper as appealing investment opportunity, but they remain cautious on divesting from the carbon-intensive assets (in particular, oil).

4. Conclusions and some investment implications

How financial investors may react to policy announcements related to sustainability and climate change mitigation in particular, is a major question with relevant implications for sustainable finance and financial stability. Because the challenge of decarbonization is so broad and spans several departments and initiatives, a portfolio-based approach is the way to best reach emissions reduction objectives. But a main barrier to portfolios' decarbonization is the lack of conclusive evidence on whether low-carbon investments add value to a portfolio, and on whether markets react to climate announcements. To fill this gap, this study uses a downside risk analysis to test if financial markets are pricing the Paris Agreement (PA) by decreasing the portfolio weights carbon-intensive commodities afterwards.

The conducted analysis reveals that after the Paris agreement, the dependence between inflation and different commodities (i.e., energy, industrial metals and precious metals) continue to hold. However, oil, gold and copper are still the best assets for optimal hedging portfolios amid decarbonization. Investors who want an additional premium lessen their allocations to oil and invest more in gold and copper. Oil has historically moved with inflation due to its significant weight in the inflation basket since it is utilized in all parts of the economy. The gold mining companies are increasingly aware of many climate hazards and have taken action to reduce their vulnerabilities. Copper has done well in persistently inflationary environments because of this metal's strong correlation with inflation, and the substantial role played in the transition towards green economy. Every major sector of the global economy uses copper, from new home construction and factories to the automobile industry and power generation, amongst many others. The upstream nature of copper makes it easy for producers to pass rising prices through the supply chain to end consumers. As a result, copper prices tend to rise before general consumer prices rise. When investors contemplate metals in the renewable energy transition, then nickel, cobalt, aluminum, and other rare earth metals may first come to mind. Nevertheless, copper is perceived as one of the core material building blocks for the renewable power grid because it has the highest conductivity of all non-precious metals. This makes copper an ideal metal in the industrial electrical wiring used for electric vehicles and infrastructure projects as it can carry more electrical current than other industrial metals.

By looking at the dependence between Paris aligned stocks and each of copper and oil, we find evidence that even investors seeking to implement net-zero strategies in their portfolios and aligned with the objectives of the Paris Agreement are still cautious on divesting from the carbon-intensive assets. These results are consistent with Kruse et al. (2020) and Monasterolo and de Angelis (2020), underscoring that investors are responding to opportunities but less to risks in a low carbon economy. These findings have some relevant policy implications. First, our findings can contribute to inform the portfolios' risk management strategies of investors in the transition to sustainable finance. Indeed, taking a portfolio-based view of emissions reduction during times of high inflation expectations can help market participants prioritize their decarbonization investments and develop a strategic roadmap for attaining the set targets. By analyzing the impact of decarbonization efforts on the hedging capabilities of different commodities under various scenarios, investors and risk managers will have a better understanding of their options to decarbonize, the access to comparative data, and more information to make more appropriate decisions. This can enhance the chances of success to maximize emission reductions over time. Having a comprehensive portfolio strategy is critical to successful decarbonization. An effective strategy ultimately will allow to successfully achieve the highest overall emissions reduced with low risk and low or recoverable costs in periods of high inflationary pressures. Second, elucidating the understanding on how investors respond to climate policy announcements can inform policy makers in the design of appropriate low-carbon transition policies. Third, the successful redirection of global financial flows towards climate action needs a clear signal from the global community of policy makers.

This study only explores the inflation hedging roles of oil, copper, nickel, cobalt, aluminum and gold, but can be extended in future research to other largely used assets such as stocks, bonds and real estate, without ignoring other alternative assets including environmentally oriented or green stocks and infrastructure which have recently received a close attention from investors (i.e., pursuing EGS investing). Interestingly, decarbonization may intensify inflation pressures. Demand for renewables is high and trending higher, which would spur prices higher as the supply struggles to meet demand. In this framework, the materials employed to accelerate the transition towards renewables, such as copper, cobalt, nickel and aluminum, follow the supply-demand principles, i.e., higher demand than supply would push costs higher. Such an inflation potential owing to the additional costs of the development of decarbonization strategies in businesses is underestimated and has not yet been taken into consideration by the markets. This question is beyond the scope of this paper. An interesting development of this work would be to take these different elements into account.

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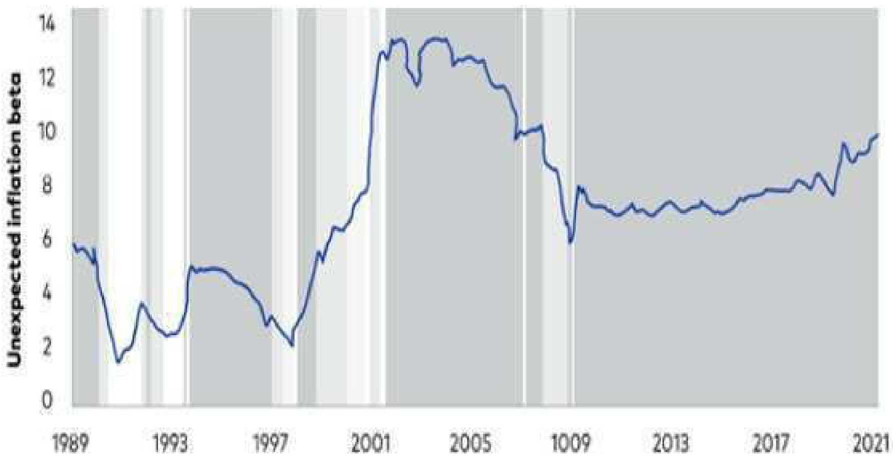
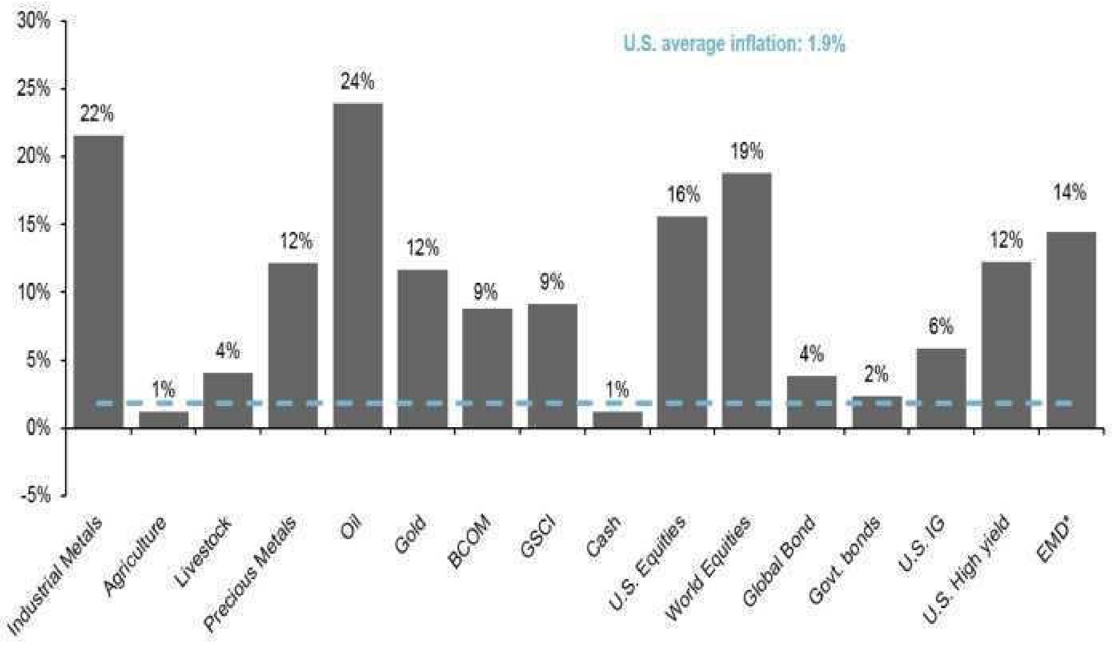
Appendix

Figure A1. *The evolution of the commodities' inflation-hedging power*



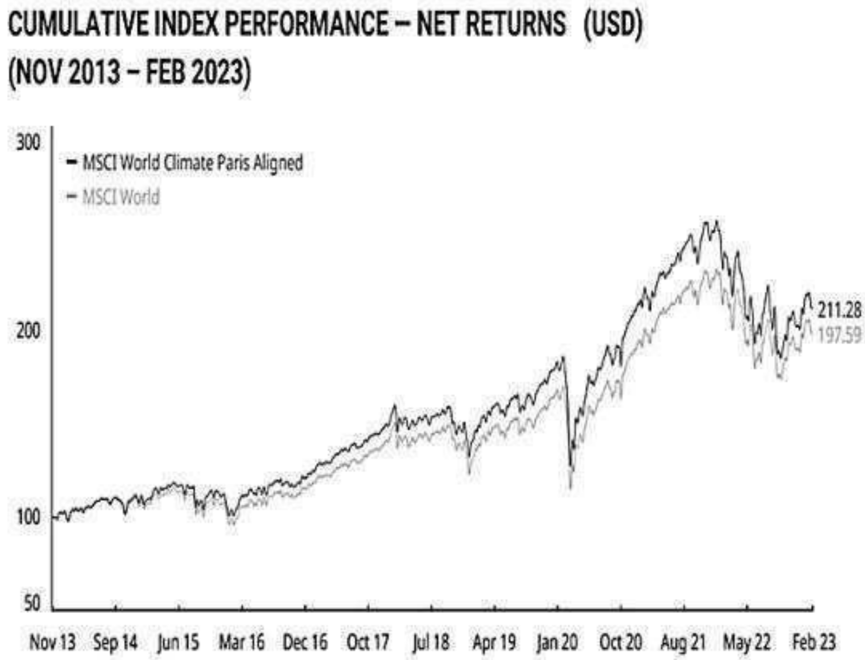
Notes: The blue line corresponds to the rolling 10-year beta to unexpected inflation of the Bloomberg Commodity Index. The chart's shading denotes the significance of the inflation beta, with darker shades corresponding to pronounced significance. Inflation beta significance is a statistical measure determined by both the magnitude and volatility of the beta. Inflation beta with wider significance has a stronger potential effect as a hedging mechanism; Sources: Vanguard calculations, using data from Bloomberg and the University of Michigan Surveys of Consumers through March 31, 2021.

Figure A2. *The most-to-least performing assets during periods of rising U.S. inflation*



Source: Bloomberg, J.P. Morgan Asset Management.

__Figure A3.__ The MSCI World Climate Paris Aligned Index versus the MSCI World Index: The cumulative index performance

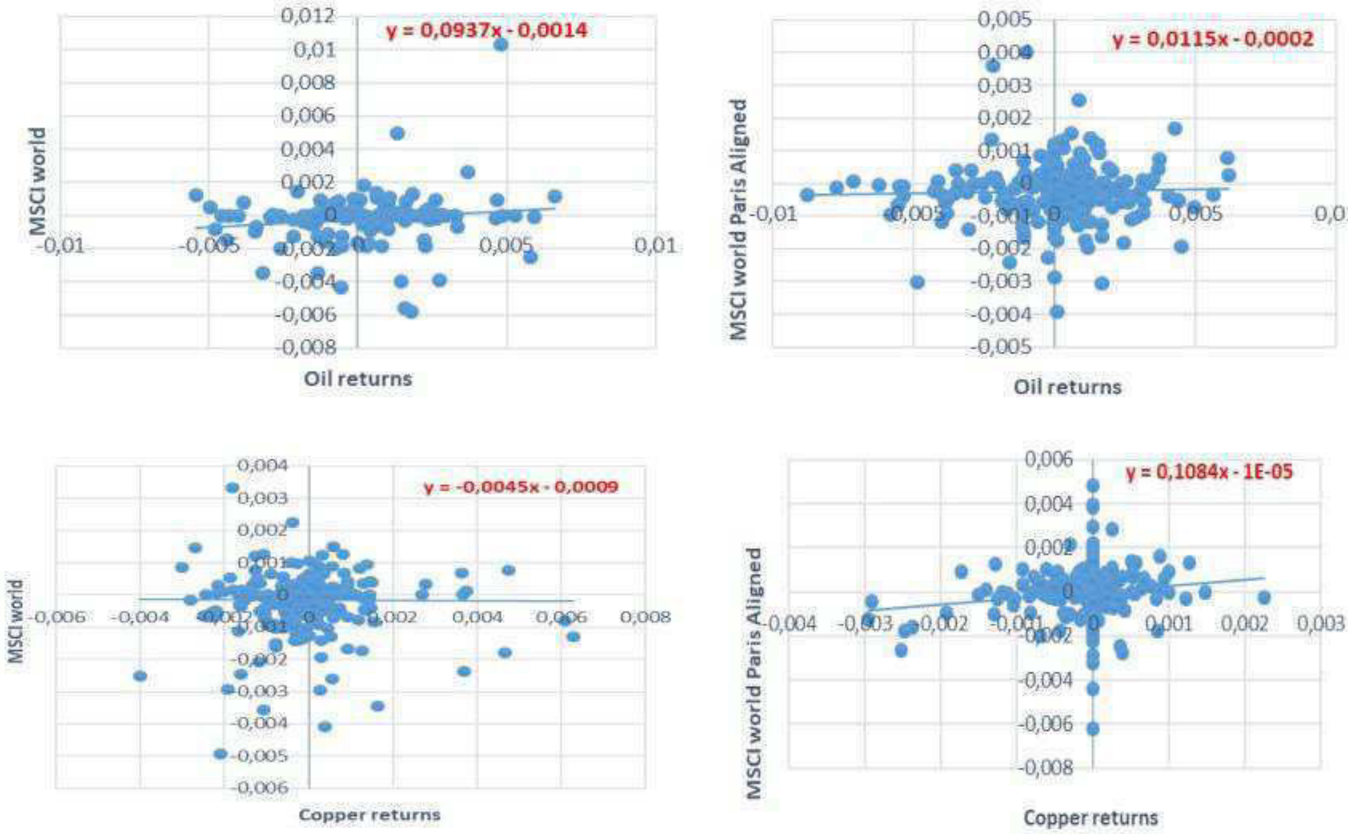


ANNUAL PERFORMANCE (%)

Year	MSCI World Climate Paris Aligned	MSCI World
2022	-21.57	-18.14
2021	21.86	21.82
2020	18.18	15.90
2019	29.37	27.67
2018	-7.50	-8.71
2017	23.78	22.40
2016	8.14	7.51
2015	1.47	-0.87
2014	6.94	4.94

Source: MSCI; https://www.msci.com/our-solutions/esg-investing/esg-indexes/climate-paris-aligned-indexes

__Figure A4.__ Dependence between Paris aligned stock returns, energy transition minerals (copper) and carbon-intensive assets (oil)



Source: Author’s calculations.