Diamonds and Precious Metals for Reduction of Portfolio Tail Risk

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Abstract

We study the performance of diamonds compared to gold and other precious metals in mitigating the tail risk of a diversified equity market portfolio over the period June 2007 to October 2018. Our results display a diversification benefit of some diamond indices, which also improve the portfolio reward-to-risk ratio. To corroborate this evidence, we study the dependence structure and tail dependence of diamonds and a broad equity market portfolio and compare it to the dependence obtained with gold and other precious metals. Results from fitting a bivariate copula show that the average left tail dependence reaches its minimum when diamonds are used. We also show that using shares of diamond-mining companies does not provide the same benefits.

JEL Classification: G10; G11.

Keywords: Diamonds; Precious metals; Diversification; Copula functions; Tail dependence.

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1. Introduction

The 2008 financial crisis and the recent episodes of high volatility in the stock market worldwide have encouraged many investors to look at alternative assets able to act as a store of value. Gold used to be a key instrument to this regard, exhibiting countercyclical returns during downturn market periods, and therefore acting as a "safe haven" to investors (e.g., Baur and Lucey, 2010; Baur and McDermott, 2010); the recent period has shown that this role has been declining. The usefulness of other precious metals (namely, silver, platinum, palladium, and rhodium) to protect an investor's portfolio has also been investigated in the literature. Investing in diamonds has recently attracted the attention of the general public, maybe because of the increased maturity of the diamond industry. According to a recent report (Bain, 2017), the global supply of rough diamonds is expected to decline by 1 to 2 percent a year until 2030. The uncertainty around these figures is very low, as the production is rather predictable. Even in the best-case scenario, the production of rough diamonds is expected to remain stable, following the depletion of existing mines. Instead, the annual demand is expected to grow from 2 to 4 percent, mainly driven by the US, China and India. This trend, along with greater transparency, price discovery and market liquidity, have brought the attention toward diamond investing. According to a survey by Barclays, one third of precious jewelry holders own diamonds for security reasons, as diamonds are perceived as a "solid and tangible" investment which should preserve its value over time (Barclays, 2012).

In contrast to gold, silver, and other precious metals which can easily be traded with small transaction costs, either directly or through liquid exchange-traded funds, getting exposure to diamonds is more complex. Moreover, the limited types and trading volumes of Futures contracts—only offered by the Indian Commodity Exchange (ICEX) for now—and hence of a visible reference index make the diamond market opaque. An alternative is to get indirect exposure to diamonds by owning a portfolio of publicly-traded diamond companies, as the industry is very concentrated and the largest

five companies combine more than 70 percent of the global diamond production.[1] A number of ETFs related to the diamond industry also exist. The market of direct diamond investing is also developing. For investment purposes, apart from purchasing a retail stone, it is now possible to get access to standardized exchange-traded investment grade diamond baskets or single stones through the Diamond Bullion Exchange in Singapore (SDiX), launched in 2015 (Nannicini and Tan, 2015). The ICEX recently launched systematic investment plans (SIPs), which allow small investors to acquire diamonds by paying monthly installments (for instance, a monthly installment of 900 Indian rupees, equivalent to around $14, would lead a retail investor to physically acquire a 0.3 carat diamond after 30 months). ICEX also started on August 28, 2017 to trade the world's first diamond futures contract. On November 3, 2017, at the expiry of such contract, 26.27 carats were delivered, representing 0.53 percent of the total traded quantity since the launch of the contract, meaning that most of the trading activity was not targeting physical delivery.

There exists a large academic literature documenting the diversification potential of gold and its role as a hedge against financial assets' volatility (Hillier, Draper, and Faff, 2006; Baur and Lucey, 2010; Baur and McDermott, 2010; Reboredo, 2013; Bredin, Conlon and Potì, 2015; Baur and McDermott, 2016; Iqbal, 2017). Precious metals (such as silver, platinum, palladium, and rhodium) have also been thoroughly investigated (Hillier, Draper, and Faff, 2006; McCown and Zimmerman, 2006; Conover, Jensen, Johnson, and Mercer, 2009; Belousova and Dorfleitner, 2012; Bredin, Conlon and Potì, 2017; Lucey and Li, 2015; Reboredo and Uddin, 2016; Li and Lucey, 2017). The usefulness of adding precious metals to portfolios is generally confirmed. O'Connor, Lucey, Batten, and Baur (2015) and Vigne, Lucey, O'Connor, and Yarovaya (2017) provide an excellent review of the academic literature on the financial economics of gold and precious metals, respectively, including their benefits for portfolio diversification. On the contrary, the literature on diamond investing is sparse and concentrated in the very last years. Renneboog and Spaenjers (2012) study the performance of diamonds and other gems using auction transaction prices for high-

[1] Production and exploration diamond companies include few major global players, i.e. Alrosa, the world's leader with market share close to 30 percent, De Beers which follows with a market share of 20 percent, Rio Tinto (13 percent), Dominion Diamond Corporation and Petra Diamonds (3 percent), with a market share of 6 and 3 percent, respectively (Bain, 2017).

quality stones over the period 1990-2010. Their results show that diamonds outperformed stocks during the period of analysis. Auer and Schuhmacher (2013) use diamond price indices issued by PolishedPrices, an independent diamond market data provider, and investigate the role of diamonds as a diversifier of a world portfolio in the time period 2002-2012. Their results show that an investment in diamonds outperforms a well-diversified stock index especially (and unsurprisingly) during bearish market periods. They also note that the 1.0-carat diamond index contributes most to the portfolio performance. Auer's (2014) paper adds to Auer and Schuhmacher's (2013) study in that it compares diamonds' performance to that of gold and silver, and also investigates the hedging properties of diamonds against market volatility. Again, the 1.0-carat diamond index significantly increases the investment performance. Low, Yao, and Faff (2016) also use PolishedPrices data for the period 2003-2013 and compare the performance of diamonds to that of precious metals. They find a general confirmation of a low or negative correlation with globally diversified equity portfolios and precious metals. However, when comparing diamonds to precious metals in terms of hedging qualities, they find that precious metals show superior performance, and in general investing in physical diamonds rather than diamond indices is beneficial. A recent paper by D'Ecclesia and Jotanovic (2018) studies the investment benefits of diamonds using proprietary quality-based diamond indices. Diamonds act as a hedge in most of the countries they analyze. Also, Jotanovic and D'Ecclesia (2019) suggest that investing in stocks of diamond-producing companies is not an alternative to investing in diamond as a commodity, since the correlation between diamond prices and stocks of diamond producers is weak.

This paper follows the lines of Auer and Schuhmacher (2013), Auer (2014), and Low, Yao, and Faff (2016), and studies the performance of diamond investing employing PolishedPrices data to proxy the different characteristics of diamonds (color and clarity) and their size. However, the emphasis is on portfolio selection, as measured by the reward-to-risk characteristics of diamonds when combined to a globally diversified market portfolio. While the previous literature is mainly focused on disentangling the role of diamonds as hedges and follow the conditional regression approach of Baur and Lucey (2010), we also consider the performance of a portfolio which combines diamonds (and other precious metals, for comparison) to an already

diversified equity market portfolio. We measure portfolio risk both through a symmetric measure, such as volatility, and by means of tail risk measures (i.e., value-at-risk and expected shortfall), as it has been mentioned that diamonds perform particularly well during distressed market periods. Our results show that the defensive properties of diamonds are in general superior to those of gold and precious metals, as some indices improve the reward-to-risk ratio of a well-diversified equity market portfolio. This improvement is not reached by diversifying through gold investing, and also other precious metals deliver more limited benefits. Motivated by this evidence, we further investigate the defensive properties of diamonds during extreme market conditions, by fitting a bivariate cumulative distribution function for diamonds and a well-diversified global equity portfolio and focusing on the left tail of such a joint probability distribution. Copulas are a flexible statistical tool to this purpose, as they allow studying the whole dependence structure of the considered asset classes and also focusing on their tail dependence. Left tail dependence is an important attribute in portfolio diversification, as the lower its value, the less likely large and negative returns of one asset to be paired with large negative returns of the other. Our results show that the average left tail dependence reaches its minimum when diamonds, rather than gold or other precious metals, are employed.

The remainder of the paper is organized as follows. The next section describes our dataset and displays the descriptive statistics. Section 3 presents the empirical setting and studies the performance of diamond investing when combined to a globally diversified equity portfolio, with a focus on tail risk measures and tail dependence. Finally, section 4 concludes.

2. Data and descriptive statistics

2.1 Data

We collect daily prices on ten diamond indices, five listed diamond-producing companies, five precious metals, and five global and regional stock market indices, to proxy a well-diversified equity market portfolio. For the latter, we choose total return MSCI indices, as they are widely tracked benchmarks, and tradeable through liquid ETFs. Specifically, we choose the MSCI World index as a wide global equity

benchmark for developed countries, the MSCI Emerging Markets index covering the most important rapidly-growing economies, and the MSCI Europe, MSCI EAFE, and MSCI Pacific to represent regional portfolios, focused on developed European, non-US and Canada, and Asia-Pacific countries, respectively. For precious metals, besides gold and silver, we choose three platinum-group metals (i.e., platinum, palladium, and rhodium), for which a demand for investment purposes (much lower than that for gold and silver) exists.[2] PolishedPrices diamond indices data are employed to proxy diamond investing, as previous studies on diamonds did. PolishedPrices is an independent diamond data provider which publishes on a daily basis several indices based on the quality of diamonds (color and clarity) and size, using wholesale transaction-based diamond prices. The prices are submitted by various wholesalers in different diamond trading centers by 8 am London's time each morning. For this study, we use nine indices classified by type (fine, commercial, and mixed) and weight (0.3, 0.5, and 1.0 carat), along with an overall index. Fine indices include diamonds of best quality, whose color is classified as I or above (i.e., from "near colorless" to "absolutely colorless"), and whose clarity is from VS2 to IF (i.e., from "very slightly included" to "internally flawless"). Commercial indices comprise diamonds of lower quality relative to fine indices, characterized by a color of K or J (i.e., "noticeable color" to "near colorless") and clarity of SI3 or better (i.e., from "slightly included" to "internally flawless"), or a color of I or better and a clarity between SI3 to SI1 ("slightly included"). Mixed indices include the remaining diamonds, classified as up to M ("noticeable color") for color, and up to I3 ("included") for clarity. Finally, the overall diamond index can be viewed as a comprehensive (and more diversified) diamond portfolio which invests into diamonds of various quality and size.[3] We also analyze stock prices of the five largest publicly-traded diamond-producing companies, i.e., Alrosa, Anglo American, Rio Tinto, Dominion Diamond, and Petra Diamonds.[4] Investing in such stocks (both individually, and in an equally-weighted portfolio) should proxy indirect diamond exposure. To compare the performance of such investments

[2] Gold prices are derived from the London Bullion Market (LBMA), silver prices come from Handy & Harman, London Metal Exchange prices are used for platinum and palladium, while rhodium prices are derived from Johnson Matthey.

[3] PolishedPrices website (https://www.polishedprices.com/go/methodology#Submitters) reports further information on how the diamond indices are calculated.

[4] Anglo American took control of De Beers in 2011, raising its stake in the equity of the diamond producer to 85% from 40% as before.

with diamonds and precious metals we use total return time series, as we assume that dividends are reinvested in the matching dividend-paying stocks. All price data was gathered from Thomson Reuters Datastream for a period of about 11 years, from the 1st of June 2007 to the end of October 2018. Datastream provides diamond indices since the year 2002, but up to June 2007 prices are reported generally with a weekly frequency and a number of gaps. Therefore, we limit our analysis to the abovementioned period, for which all daily series in our sample can be contrasted.[5] All time series are expressed in USD.[6]

2.2 Descriptive statistics

Table 1 summarizes our data and shows the main descriptive statistics of our sample.

Please insert Table 1 here

Over the decade, all diamond indices exhibit a very close to zero average daily return, with the exception of the 0.3-carat mixed index, whose return is positive and comparable to that of MSCI indices (other than the MSCI World index), or silver. Stocks of diamond-producing companies have a more heterogeneous performance, with a large positive daily return observed for Alrosa and Rio Tinto, a large negative daily return for Dominion Diamond and Petra Diamonds, and a return near zero for Anglo American.[7] Their equally-weighted mix exhibits a positive daily return not different from regional MSCI indices. In terms of volatility, the daily standard deviation of diamond indices ranges from a minimum of 1.20 percent (for the overall index) to a maximum of 3.97 percent (for the 1.0-carat fine diamond index) over the considered

[5] One exception is rhodium, as prices only up to the end of January 2015 are available. Hence, for rhodium we limit our analysis to a shorter time period. Also, Alrosa carried out an IPO on October 28, 2013 at the Moscow Stock Exchange, while Dominion Diamond was acquired by Washington Companies and delisted from the Toronto Stock Exchange and the NYSE on November 2, 2017. Therefore, for such stocks a shorter time period is analysed.

[6] For diamond producing companies, we convert their total return prices in USD at the prevailing daily exchange rates (USD/RUB for Alrosa, USD/GBP for Anglo American, Rio Tinto and Petra Diamonds, and USD/CAD for Dominion Diamond).

[7] Since Alrosa went public in the last quarter of 2013, its performance reflects the positive drift of the global equity market and does not include its collapse in 2008.

period. A lower volatility of the overall index is not surprising, as it represents a more diversified basket. The volatility also increases when moving from mixed to fine diamond indices, as the larger the size and the quality of the gems, the more reactive they are to supply and demand imbalances and market price swings. The volatility of diamond-producing companies is also sizeable, ranging from 2.43 percent for Alrosa to 3.31 percent for Petra Diamonds. Again, an equity portfolio including all five diamond producers is less risky, with a daily standard deviation of about 2 percent. In general, diamonds are more volatile than precious metals, but when considering the overall index its volatility is very similar to that of gold (about 1.2 percent).

Table 1 also shows the maximum and the minimum daily return, along with the extreme percentiles on both tails of the distribution and a measure of skewness (i.e., the standardized third moment of daily return distribution). In general, the diamond asset class (either physical diamond indices or shares of diamond-producing companies) confirms itself as being riskier than precious metals, while MSCI indices are the least risky investments. However, two observations are in order. First, not only are the negative extreme quantiles larger for diamonds than the ones of the other assets, but also are the positive ones, meaning that the "risk" of diamond investing is symmetric. Also, comparing the difference between the 99th and the (absolute value of) the 1st percentile to the same difference for the other assets, it is apparent that extreme positive returns are generally larger in size for diamonds (but not for Anglo American, Rio Tinto and Dominion Diamond, when looking at shares of diamond companies), the opposite being true for all other assets. This is important evidence and corresponds to the positive skewness of diamond returns, as confirmed by the last column of table 1, and also documented by Auer and Schuhmacher (2013), and Low, Yao, and Faff (2016). Second, among the different diamond indices, the 0.3-carat mixed index exhibits the lowest minimum (in absolute value) and the third-to-lowest 1st and 5th percentiles, and these figures are comparable to those of precious metals. Also, the (absolute value of the) 1st and 5th percentiles of the overall diamond index are lower than the corresponding figures of gold.

Besides the descriptive statistics, also relevant to our analysis is the inspection of the joint dynamics of the considered asset classes. Figure 1 depicts the nine diamond individual indices (excluding the overall index) and contrasts them to the MSCI World

market portfolio; Figure 2 compares the dynamics of the overall diamond index to that of the five precious metals, and Figure 3 shows the pattern of stock prices of listed diamond-producing companies.

Please insert Figure 1 here

Please insert Figure 2 here

Please insert Figure 3 here

From a visual inspection of Figure 1, the dynamics of the nine diamond indices look rather correlated, and large price swings are observed. However, the volatility of the diamond indices is markedly different, with unsurprisingly lower volatility for the mixed indices. Also, the dependence between diamonds and a well-diversified equity portfolio, as represented by the MSCI World index, appears as weak. During the market collapse of 2008 and early 2009, the performance of diamonds was generally steadier, yet negative. Afterwards, the diamond market recovered quicker than the equity market with a peak in July 2011. Since then, diamonds seem to have moved in the opposite direction of the world market index. Interestingly, the dependence between the two asset classes appears to gradually become more negative in the period of analysis. Figure 2 shows the dynamics of the overall diamond index and precious metals relative to the MSCI World index. A diversified diamond portfolio is less volatile than precious metals (its volatility is comparable to that of gold), and its correlation to precious metals appears low. This evidence might support the conjecture that diamonds offer diversification benefits not achieved by other precious metals. Figure 3 compares the performance of the five diamond-producing companies (total return, in USD) to that of the MSCI World index. We have already observed that the volatility is quite heterogeneous, and Petra Diamonds is more volatile than the other stocks. In terms of their performance, the dynamics of the stock prices look much more correlated to the global equity market portfolio than diamond indices are. This is not surprising, as stock

returns are partly driven by systematic risk factors affecting the global equity market. Regarding the five companies, the different price patterns are explained by the differences in their business model (for instance Rio Tinto operates in mining activities across many metals), and idiosyncratic factors (such as the different geographic locations of diamond mines).

3. Portfolio analysis

In this section, we study the diversification benefits of diamonds and precious metals by analyzing the performance and risk of a well-diversified equity portfolio which marginally or markedly invests in either diamond indices, diamond-producing companies, or precious metals. We use one of the MSCI indices presented in the previous section as the reference portfolio and compute the average return and risk of mixed portfolios over a one-year (250 trading days) rolling window. For risk measures, we use the daily standard deviation, as well as the value-at-risk (VaR) and expected shortfall (ES), both at the 99 and 95 percent confidence levels. We also compute reward-to-risk ratios, namely the ratio between the average return and one of the chosen risk measures. The larger this ratio the better, and a negative ratio reflects the negative average return of the asset within a given window. Figure 4 depicts our empirical strategy. Overall, we obtain 2,729 one-year trading windows from the 1st of June 2007 to the 31st of October 2018.

Please insert Figure 4 here

3.1 Portfolio performance

Panel A of Table 2 reports the average return, volatility, VaR, and ES (at 99 and 95 percent confidence levels) over the 2,729 windows. Other than MSCI indices, a portfolio fully invested in diamonds, diamond-producing companies, and precious metals is added for comparison. Panel B of the same table computes reward-to-risk ratios.

Please insert Table 2 here

The results of panel A are comparable to the basic descriptive statistics of the overall sample. Panel B shows that diamond investing *per se* is inefficient, as reward-to-risk ratios are consistently negative across all diamond indices (with the exception of the 0.3-carat commercial and mixed indices, for which return-to-risk ratios are mostly positive but small). Investing in stocks of diamond producers yields a mixed evidence, as for some of them (i.e., Alrosa and Rio Tinto) the reward-to-risk is significantly positive (but as already pointed out, Alrosa went public in October 2013, way after the financial crisis), whilst for others (i.e., Anglo American, Dominion Diamond and Petra Diamonds) it is either negative or positive but close to zero. An equally-weighted portfolio of diamond-producing companies offers a positive reward-to-risk ratio not too distant from that of gold. Among industrial precious metals, two of them—platinum and rhodium—show negative reward-to-risk ratios (in particular, rhodium collapsed in the second half of 2008, from a record-high of about $10,000 per Troy ounce in July 2018 to $1,000 at the end of November 2008). A well-diversified equity portfolio is instead a rather efficient investment choice, as regardless of the geographic area we consider (including the MSCI World index), all reward-to-risk ratios are positive.

We now proceed to replicate the same investment strategy as before, mixing one of the MSCI indices at a time with a marginal investment in either diamonds, shares of diamond-producing companies, or precious metals. We choose a 10 percent weight for the investment in diamonds and precious metals. Later in the paper, we repeat the same experiment with a 30 percent weight, so to encompass the case of a more marked investment in such assets.

Please insert Table 3 here

Panel A of Table 3 reports the average return, volatility, VaR, and ES (at 99 percent confidence level) over the 2,729 periods of a portfolio investing in MSCI indices, but marginally also in either diamonds, diamond stocks, or precious metals.

Panel B of the same table presents the average reward-to-risk ratios which are computed accordingly. The figures reported in Table 3 are comparable to those shown in the previous table, and contrasting the corresponding reward-to-risk ratios should shed light on the efficiency of diamond and precious metal investing rather than an entire equity portfolio. For example, from Table 2 (panel B) we note that the average reward-to-risk ratio of a portfolio which is fully invested in the MSCI World index is 1.96, when a 99 percent VaR is considered as the risk measure. The corresponding figure lowers to 1.76 when we marginally add the 0.3-carat fine diamond index to such a portfolio (from Table 3, panel B). Continuing to compare reward-to-risk ratios of Table 3 to the corresponding figures in Table 2, we draw some conclusions on the benefits of adding diamonds and precious metals to a well-diversified equity portfolio. For clarity, panel B of Table 3 reports reward-to-risk ratios in bold when they are larger than those of the corresponding MSCI index alone.

Our first comment is that mixed diamond indices perform better than commercial and fine indices, regardless of the gem size (i.e., 0.3, 0.5, and 1.0 carat). Reward-to-risk ratios of a portfolio that marginally adds one of the three mixed diamond indices to the MSCI World index are consistently larger than those of the MSCI World portfolio alone. This property holds for both tail risk measures as well as for volatility, with the only exception of the 0.5-carat mixed index (the reward-to-risk ratio is 4.43 versus 4.79 for the MSCI World index alone). Since panel A of Table 2 shows that the return over the considered time period is larger for the MSCI World index portfolio than that of any diamond index, the improvement of reward-to-risk ratios comes from a significant (and more than proportional) reduction of the portfolio (tail) risk. When considering stocks of diamond producers, only Alrosa significantly enhances the reward-to-risk ratios. An equally-weighted portfolio of diamond-producing companies brings some reward-to-risk improvements, even if these are small. Among the considered precious metals, only palladium increases the MSCI World index reward-to-risk, but the increment is modest. Interestingly, gold and silver do not seem to improve portfolio reward-to-risk. Rhodium is the worst performer, as a consequence of its large and negative return over the decade. Overall, the lesson we draw at this point is that some diamond indices seem to outperform precious metals in the role of diversifiers of a global equity portfolio. A portfolio of stocks of diamond-

mining companies mostly outperforms precious metals, and it is comparable to gold, but does not have a clear effect on improving the reward-to-risk of the equity portfolio.

When proceeding to investigate the reward-to-risk ratio of alternative portfolios composed of one of the regional stock indices and either diamonds or precious metals, the previous conclusions are further confirmed. Diamonds appear to significantly enhance reward-to-risk ratios of MSCI Emerging Markets and MSCI Pacific indices, irrespective of size and quality. An equally-weighted portfolio of diamond equities is also beneficial in increasing the reward-to-risk ratio. When looking at MSCI Europe and MSCI EAFE indices, the results are more similar to those described for the MSCI World index. In general, when comparing diamonds to precious metals, the better performance of the former is also confirmed for regional equity indices.

Please insert Table 4 here

Table 4 repeats the previous exercise, but now the portfolio more markedly invests in diamonds, diamond equities, and precious metals (with a 30 percent weight). The general conclusion drawn from inspecting Table 4 is that the performance of such portfolios is worse than that of the corresponding MSCI index, with two notable exceptions. For diamonds, the 0.3-carat mixed diamond index and the Alrosa stock improve the reward-to-risk ratios of almost all MSCI indices. The second exception is palladium, which enhances the performance of MSCI portfolios except for the MSCI World and EAFE indices, but the increment is more modest. In a nutshell, the insight from jointly inspecting Tables 3 and 4 is that investing in diamonds is generally beneficial to the performance of a well-diversified equity portfolio, and this conclusion holds especially for smaller size and lower quality gems. A portfolio of shares of diamond producers is less effective for this purpose. Also, diamonds appear to embed an incremental diversification power relative to gold and precious metals in general.

In particular, on this matter we carry out a further investigation.[8] In the same spirit of Table 3, we compose a portfolio which invests in each of the MSCI indices (80 percent weight) and a combination of gold and diamonds (10 percent weight each). In other words, we study how diamond investing affects the performance of a portfolio that contains gold and equities. These results (unreported in the paper) show that such a portfolio is generally dominated by a combination of equity and diamonds, i.e. the portfolio as in Table 3, thus corroborating the better incremental diversification power of diamonds relative to gold.

Finally, since some individuals and institutions might be interested in investment horizons that go beyond one year, we repeat the analyses of this section using a broader time window (3 years instead of 1 year). When we compare the new reward-to-risk ratios (unreported) to those of Table 3, we note that our conclusions are not appreciably altered.

The next subsection focusses on the diversification properties of diamonds and precious metals during extreme events in the equity markets, i.e., conditional on an outcome taking place in the left tail of the distribution of a MSCI index.

3.2 Downside risk analysis

3.2.1 Reduction of downside risk

We investigate in this section the role of diamonds, stocks of diamond producers, and precious metals during extreme and negative market conditions. We replicate our previous exercise, but now study the reward-to-risk ratio of our previously composed portfolios conditional on an extremely negative outcome occurring in the main equity market index. We define such outcomes relative to the 99- and 95-percent VaR, when looking at the previous 250 trading days. We compute the return of a portfolio which marginally invests in either diamonds or precious metals, average these returns and compare this number with the average return of the equity portfolio. In other words, we compare the expected shortfall of the equity index to the portfolio expected shortfall conditional on the index return being lower than a given percentile. Table 5 shows the results of our exercise and reports the percentage change of the expected

[8] We thank an anonymous referee for suggesting this additional análisis as well as the one we carry out in the next paragraph.

shortfall of a MSCI index mixed with diamonds, diamond stocks, or precious metals. The two panels of Table 5 are drawn for a confidence level of 99 and 95 percent, respectively, when considering the left tail of the MSCI index.

Please insert Table 5 here

From inspecting Table 5, we note that the positive figures are obtained for rhodium, consistently with the evidence earlier reported. The other assets (except for Anglo American, Rio Tinto and Dominion Diamonds) attenuate the expected shortfall of the considered equity portfolio, but in different ways. For example, gold reduces that of the MSCI World index by approximately 10 percentage points over the whole time period, and this is the best result among old precious metals. The performance of diamond indices and equities is mixed. In general, the defensive property of the overall diamond index is not dissimilar to that of gold, performing slightly less well for the MSCI World index (9.0 percent expected shortfall reduction versus 9.7 reduction for gold, at the 99 percent confidence level), but markedly larger for the MSCI Europe, EAFE and Pacific indices. When considering the different diamond indices, the 0.3 and 0.5-carat mixed indices show the best performance across all MSCI indices, with a downside risk reduction obtained through the 0.3 and 0.5-carat mixed diamond larger than that of gold. For example, the 0.5-carat mixed diamond index reduces the expected shortfall of the MSCI World index by almost 17 percent, compared to less than 10 percent for gold. When going to regional equity indices, the results are even more significant, and almost all diamond indices outperform gold in reducing the expected shortfall of the considered equity portfolio. Among the stocks of diamond-producing companies, Petra Diamonds is the most effective in reducing the downside risk of a well-diversified equity portfolio.

Table 6 repeats the exercise, but using a portfolio more markedly invested in diamonds, stocks of diamond-producing companies and precious metals.

Please insert Table 6 here

The downside risk of a well-diversified equity portfolio is greater, but the comparison between diamonds and precious metals offers qualitatively unchanged insights.

3.2.2 Copula estimation and results

To shed light on tail dependence, we now estimate the joint cumulative distribution function of pairs of assets comprising one of the MSCI indices and either diamonds, stocks of diamond producers, and precious metals. The empirical methodology we employ to fit such a distribution is estimating a bivariate copula function. Cherubini, Luciano and Vecchiato (2004) and Cherubini, Gobbi, Mulinacci, and Romagnoli (2012), present a wide range of applications of copulas in finance. Among the many existing copulas, we choose the Archimedean family, mainly represented by three explicit copula functions, i.e., Clayton, Gumbel, and Frank copulas. Archimedean copulas are very popular as they allow obtaining a variety of dependence structures in a simple way: the dependence structure is represented by a single univariate function (the generator) and is uniquely defined through one parameter linked to a correlation measure (such as Kendall's tau coefficient).[9] To estimate the copula dependence parameters from our data we follow the algorithm of Frees and Valdez (1998).

Table 7 shows the average linear correlation coefficient and Kendall's tau of each pair of investment assets and provides an investor with the average dependence between the considered MSCI index and either diamonds or precious metals for the investment portfolio during the period.

Please insert Table 7 here

[9] More formally, given a decreasing and convex function $\theta : (0, 1] \rightarrow [0, +\infty)$, such that $\theta(1) = 0$, the function $C(u, v) = \theta^{-1}(\theta(u) + \theta(v))$, $\forall u, v \in (0, 1]$, is a bivariate Archimedean copula with generator θ. Different choices of θ define different families of Archimedean copulas.

On average, over the 2,729 windows, the dependence of diamond indices with MSCI indices is close to zero, and in some cases consistently negative (e.g., for the 0.3-carat fine and the 0.3 and 1.0-carat mixed indices). Gold exhibits the lowest dependence with equity indices across all precious metals, but still positive regardless of the MSCI index we consider. Stocks of diamond producers show a positive and sizeable dependence with MSCI indices, confirming the graphical evidence of Figure 3. Only Petra Diamonds is comparable to precious metals in this regard.

Tail dependence, i.e., the likelihood that two paired returns are in the lower or upper tail of their joint cumulative distribution is examined in Table 8, which shows the results of fitting an Archimedean bivariate copula function to our data.

Please insert Table 8 here

In the Archimedean class, we fit Gumbel, Clayton, and Frank copulas. The Clayton copula is suitable in the case of strong left tail dependence, while the Gumbel copula accounts for right tail dependence. Frank copula is symmetric and appropriate for data that exhibit weak or no tail dependence. The inspection of mean square errors allows us to identify the optimal copula function that is reported in bold. The average copula parameter is also indicated. These results offer two main important insights.

First, looking at the copula fitted parameters, we note that their value is always smaller for diamond indices relative to precious metals. Since the copula parameters are functionally linked to Kendall's tau (as in Table 7), they offer the same information, i.e., an average lower dependence of diamonds across all time windows analyzed.

Second, and most importantly, the relationship between diamonds and the MSCI World index is best represented by the Frank copula (in 7 out of 10 indices, and the overall diamond index), whilst gold, among precious metals, leads to choose the Clayton copula. The financial implication of this evidence is that diamond indices offer superior defensive characteristics, because of a weak dependence with the world equity and on average no left tail dependence. Gold, instead, exhibits negative tail dependence,

as in 40 percent of the time its extreme losses occur at the same time as those of the MSCI World index.

Interestingly, silver and rhodium display right tail dependence when paired with the MSCI World index, but as our previous analysis has shown in Tables 3 and 4, there is little evidence of improving an investor's reward-to-risk ratio through these assets. Stocks of diamond-producing companies offer mixed insights. Again, Petra Diamonds has the lowest dependence parameter, but from Tables 3 and 4 we know that this does not correspond to a reward-to-risk improvement over a diversified equity portfolio. A portfolio which invests in all five stocks of diamond producers leads to choose the Frank copula in 52 percent of the time windows analyzed, sharing this defensive property with most diamond indices. When replacing the MSCI World index with a regional equity index these considerations are mostly unchanged.

Finally, in Table 9 we report the average and the highest tail dependence parameter (multiplied by 100) over the 2,729 1-year rolling windows. Given the properties discussed earlier, we extract right tail dependence from Gumbel copula and left tail dependence from Clayton copula for each of the 2,729 windows, depending on the best copula fitted within the considered time period. Therefore, we can interpret the left (right) tail dependence results of Table 9 as a signal of diamonds and precious metals delivering an extreme and negative (positive) performance conditional to an extreme and negative (positive) performance of the corresponding MSCI index. In particular, from inspecting left tail dependence, we note that this conditional probability is on average close to zero for diamond indices, about 6 percent for gold, and 20 to 30 percent for silver, platinum and palladium.

When turning to analyze the maximum left tail dependence over the considered 2,729 one-year periods, diamonds display lower figures than precious metals, and again in agreement with our previous conclusions. Stocks of diamond producers have instead much larger tail dependence (both left and right). Despite this, looking at the portfolio of diamond equities, in about one-half of the considered windows (52 percent, from Table 8) the best copula suggests no tail dependence, sharing this attribute with diamond indices. This pattern is qualitatively unchanged when we look at regional indices. Combining this final piece of evidence with that of previous tables, we

conclude that diamond indices, rather than a portfolio of diamond-producing companies, exhibit superior defensive properties relative to precious metals.

Finally, we wish to mention that fancy colored diamonds, a category of high-end diamonds, increased in value by 0.4 percent over the first three quarters of 2018, to be compared to a decline of 5.1 percent over the whole year 2018 for the S&P500, of 10 percent for the Stoxx Europe 600, of 2.2 percent for gold. The fancy colored diamond has steadily increased from a nominal of 100 in January 2005 to a level of 260 in October 2018, with a single move down during the second half of 2008 and a remarkably low volatility otherwise (Wall Street Journal, 31/12/2018). For now, the precise index data are private property of the Fancy Color Research Foundation; obviously, these data would become part of our analysis should they become publicly available.

4. Conclusion

The large episodes of high volatility experienced in the equity markets over the last few years have encouraged many investors to look at alternative assets able to act as a store of value. While the role of gold in protecting an investor's portfolio has been extensively studied, only a few papers have analyzed the defensive role of diamonds (in the form of diamond indices or shares of diamond-producing companies), despite the increased transparency of the diamond industry. We have analyzed in this paper the role of diamonds in mitigating the risk of a globally or regionally diversified equity portfolio and improving its reward-to-risk ratio. We have also compared their performance with that of gold and other precious metals, classically perceived as a safe and tangible investment preserving their value over time.

Our results are supportive of a superior diversification potential of diamonds when compared to gold and other precious metals. Measuring portfolio risk both through volatility and tail risk measures, we have found that some diamond indices significantly improve the reward-to-risk ratio of a well-diversified equity portfolio, a result not achieved by gold and other precious metals. To focus on tail risk properties, we fitted a bivariate copula for diamonds (as well as for gold and other precious metals)

and a diversified global or regional equity market portfolio. Our results show that the average left tail dependence reaches its minimum when diamonds, rather than gold or other precious metals, are paired with a diversified equity portfolio.

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