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Do Diamond Stocks Shine Brighter than Diamonds?

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Abstract: This paper addresses two practical investment questions: Is investing in the diamond equity market a more feasible and liquid alternative to investing in diamonds? Additionally, is diamond equity affected by polished diamond prices? We assemble an original database of diamond mining stock prices traded on main stock exchanges in order to assess their relationship with diamond prices. Our results show that the market of diamond-mining stocks does not represent a valid investment alternative to the diamond commodity. Diamond equity returns are not driven by diamond price dynamics but rather by local market stock indices.

Keywords: diamond stocks; diamond prices; investment asset; capital asset pricing model

JEL Classification: G10; G11; G15

1. Introduction

Diamonds are emerging as a new investment asset, providing great opportunities for trading, investing and diversification. Hedge funds and financial intermediaries have shown increased interest in the market and recent available data allow us to study its features and dynamics. However, the lack of a standardization system for the diamond commodity prevented the existence of an exchange regulated trading platform for diamonds, leaving diamond-mining companies' stocks as the unique officially tradable asset of the diamond industry. Over the last decade, diamond stocks have been considered as a promising financial asset for investors' portfolios according to finance professionals (Carlin 2017; McKeough 2015; Sizemore 2015; Cameron 2014), though, to our best knowledge, neither academic scholars nor industry professionals have tested this hypothesis.

A diamond-based financial index has not yet emerged as a tradable asset on official exchanges. Commercial experts have been planning to introduce diamond derivatives that could be used to hedge risk in the diamond market; nevertheless, no such product has been launched on official exchanges until the present moment.

In this paper we study the sensitiveness of diamond-mining companies' stocks to diamond prices in order to examine whether they could be a good alternative investment exposure to the diamond market, while still fulfilling the condition of market liquidity. In such a case, the behavior of diamond stock prices would be driven by the diamond market dynamics and would not be influenced by the idiosyncratic risks of the stock markets where they are traded. More precisely we try to give an answer to the following research questions: are diamond mining stocks a good substitute to investing in a diamond-based financial asset? Do they correctly represent the dynamics of the diamond market?

We use the entire set of international diamond stock prices firstly to analyze their statistical features and dynamics and then to test their dependence on diamond prices using the standard CAPM approach (Tufano 1998).

Our results find that diamond stocks should not be considered as a valid tradable substitute for a diamond-based investment tool.

2. Some Recent Research

Literature on the analysis of diamond markets' features and dynamics is quite scarce. Most research primarily tackles the diamond commodity market. Several scholars have studied the dynamics of diamond prices in the last decade (Low et al. 2016; Auer 2014; Auer and Schuhmacher 2013; Vaillant and Wolff 2013; Renneboog and Spaenjers 2012; Scott and Yelowitz 2010; Lu et al. 2010; Cardoso and Chambel 2005; Ariovich 1985), while others analyzed the structure of the diamond market (Spar 2006; Shevelyova 2006; Levenstein and Suslow 2006; Karo 1968).

Commercial reports examining the dynamics of diamond pricing and diamond financial benefits are more common but mostly represent discussions based on general knowledge of the diamond industry (Wieczner 2014; Chesters 2014; Treadgold 2013; Mcgee 2013; Zimnisky 2013; Golan 2012, 2013; Steinberg 2012; Gupta et al. 2010; Adler 2010; Rapaport 2009; Even-Zohar 2012; Turrell 1982; Kempton 1995).

Despite the fact that diamond stocks have attracted interest as financial assets in the commercial financial literature, research studies have remained limited. Bain and Company, Bain and Company and Antwerp World Diamond Center (2011, 2012, 2013, 2018) (AWDC) reports analyzed the overall structure of the mining market and presented the leading companies, without providing any financial analysis of the behavior of the relevant stocks.

Carlin (2017), Sizemore (2015) and Cameron (2014) described diamond stocks as a new investment asset class that could be very beneficial for the financial world. McKeough (2015) and O'Keefe and Bermel (2014) focused on Canadian diamond mining stocks, praising them as financial assets that will hold their value during market setbacks, thus acting as a safe haven. However, apart from O'Keefe and Bermel (2014), no quantitative analysis has been performed in order to test these claims for the overall diamond equity market and the claims are strictly based on the general opinion of the industry's experts.

To authors' best knowledge, no recent research examining the financial potential of diamond stocks and their sensitivity to the price of the diamond commodity has been performed yet. The reason for the absence of research in this scientific domain could be the industry's monopolistic past, as well as the general lack of data transparency.

3. The Market of Diamond Mining Stocks

Diamond mining companies are involved in two major activities of the diamond value chain: exploration and mining. In the exploration phase companies search for diamondiferous kimberlitic rocks, which could represent possible viable sources of diamonds. They do so by testing the ground for changes in the magnetic field. The mining process consists of diamond ore's extraction from kimberlitic pipes using different techniques, such as open-pit mining, underground mining, alluvial mining and marine mining, depending on the origin and location of kimberlites.

Upon mining, diamond ore goes through several stages of crushing and processing in order to extract rough diamonds from it. A very small amount of diamond ore consists of diamonds, as less than 1% of it represents the material with a concentration of diamonds.

The majority of the global diamond reserves[1] are concentrated in Russia, which represents the largest producer of rough diamonds by volume (Figure 1). Russia declared diamonds to be of strategic importance and all mining companies and their exploration processes are, at least partly, state-owned with free access to all country regions. The mining conditions are, however, extremely severe and a large portion of these diamond resources remains unexploited. Africa is the richest world region in

[1] Reserves are a part of resources whose extraction is economically justifiable, based on feasibility studies.

terms of estimated diamond resources that could be mined in the future. Nevertheless, their extraction depends on economically feasible processes. In Figure 1 we report annual rough diamond production by country in billions of U.S. dollars during 2013–2018.

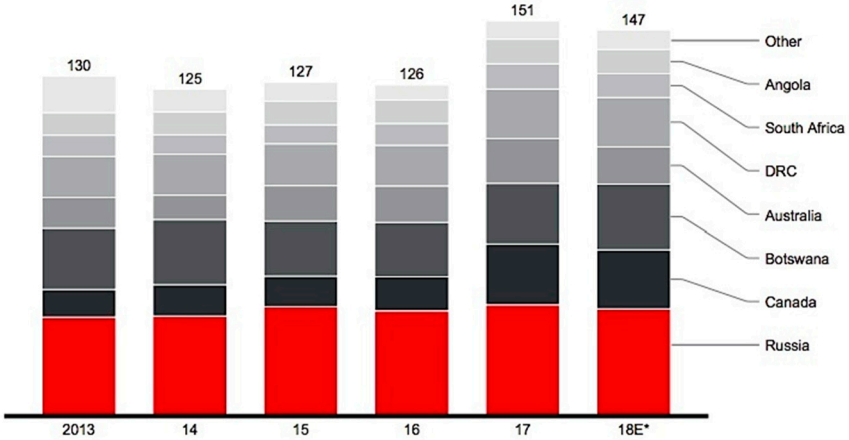

Figure 1. Annual rough diamond production by country in billions of U.S. dollars (2013–2018). Notes: The figure presents annual rough diamond production by country in billions of dollars. Only diamonds tracked by Kimberley Process are included. 2018 data is preliminary estimate. DRC is Democratic Republic of the Congo. *Source*: (Bain and Company and Antwerp World Diamond Center 2018).

Current diamond reserves are divided into projects and mines, owned by different diamond mining companies. The overall diamond mining sector represents the part of the diamond industry value chain that has been achieving the highest profit margins, as reported in Figure 2.

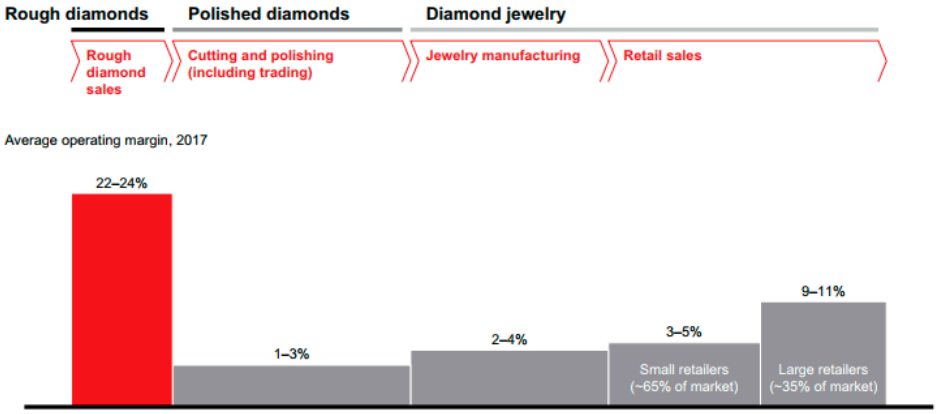

Figure 2. Profit margins of the diamond value chain in 2017. Notes: The figure presents profit margins of the mining value chain in 2017. The analysis of exploration and production is based on data for ALROSA, De Beers Group, Rio Tinto, Dominion Diamond Mines, Petra Diamonds. The analysis of large chains is based on data for Chow Sang Sang, Chow Tai Fook, Gitanjali Jewels, Lukfook, Signet Jewelers, Tiffany & Co., Titan Company. *Source*: (Bain and Company and Antwerp World Diamond Center 2018).

Despite the fact that many international and local companies are involved in the diamond exploration and mining industry, the market is driven by the top five industry players: Alrosa, De Beers, Rio Tinto, BHP Billiton and Dominion Diamond. These five companies accrued 78% of the industry's revenues in 2012 (Bain and Company and Antwerp World Diamond Center 2013). In 2013 BHP Billiton sold its diamond business to Dominion Diamonds, bringing the number of players to four.

Alrosa is the largest diamond volume producer, based on the number of diamond carats produced (Figure 3). De Beers, who had the monopoly of the industry until 2003, is now owned by Anglo

American and remains the largest rough diamond producer in value terms as shown in Figures 3 and 4. This advantage is not unattainable for others, as several competitors are approaching the levels of De Beers' diamond value sales. For instance, while De Beers in 2012 held 37% of the overall rough diamond value sales, while Alrosa's share of the market was 30%.

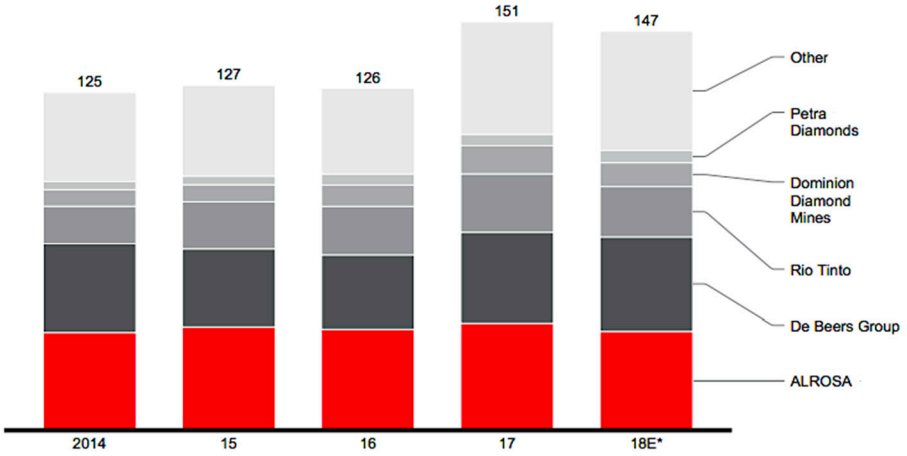

Figure 3. Major producers of rough diamonds in millions of carats (2014–2018). Notes: The figure presents major diamond mining companies and producers of rough diamonds in millions of carats in 2017. *Source*: (Bain and Company and Antwerp World Diamond Center 2018).

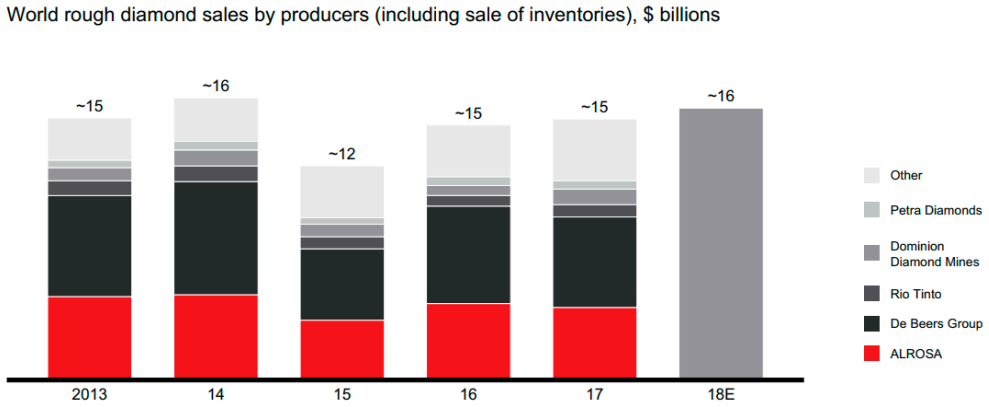

Figure 4. Sales of rough diamonds by producers in billions of dollars, including inventories (2013–2018). Notes: The figure presents major diamond mining companies and producers of rough diamonds in billions of dollars. Estimated realized price is based on an estimate of carats sold if data is published, if not, based on production data. ALROSA revenues represent diamond sales only. Dominion Diamond Mines 2017 results based on H1 2017 as the company was delisted and no longer publishes the data. Petra Diamonds data converted from year ending in June to year ending in December, based on company reports for full year and half year. Only diamonds tracked by Kimberley Process are included. Other is estimated assuming no price change for the players of this segment. E is an estimate. In order to estimate average price per carat sold, total value of diamonds sold is divided by total volume of diamonds sold. *Source*: (Bain and Company and Antwerp World Diamond Center 2018).

4. Methodology

The aim of this work is to investigate the relationship between diamond mining stocks and the price of the diamond commodity. For this purpose, we study statistical features and dynamics of stock prices in levels and log returns by firstly testing for stationarity using the ADF test. We then test the occurrence of structural breaks, using the Bai-Perron (Bai and Perron 1998) test. We further employ the ARCH LM test to examine the presence of heteroscedasticity in log returns. In the case of volatility clustering, we estimate the time-varying conditional variance for each return series by

choosing among ARCH, GARCH, TARCH or E-GARCH volatility models (Engle 1982; Nelson 1991). To study the relationship existing between diamond equity prices and diamond prices we use a time varying correlation approach using the DCC-GARCH model (Engle 2002), and the standard CAPM approach presented in Tufano (1998).

5. Data

The database used in this research, composed of price series of diamond mining stocks, has been collected by the authors following thorough background research and represents an original contribution of the paper. It includes daily prices of all companies (21) involved in the diamond-mining sector and traded on different exchanges. It is, to our best knowledge, the only database of diamond-mining companies' stock prices that are traded regularly.

The information on diamond prices are provided by the polished diamond price indices developed in D'Ecclesia and Jotanovic (2018), following a proprietary basket index methodology. In order to account for the different features of diamond prices due to differences in their quality, we use the Mid-range Diamond Index-MDI—corresponding to polished diamonds of mid quality, and the Higher-range Diamond Index-HDI—corresponding to polished diamonds of higher quality. The dynamics of the two indices are reported in Figure 5.

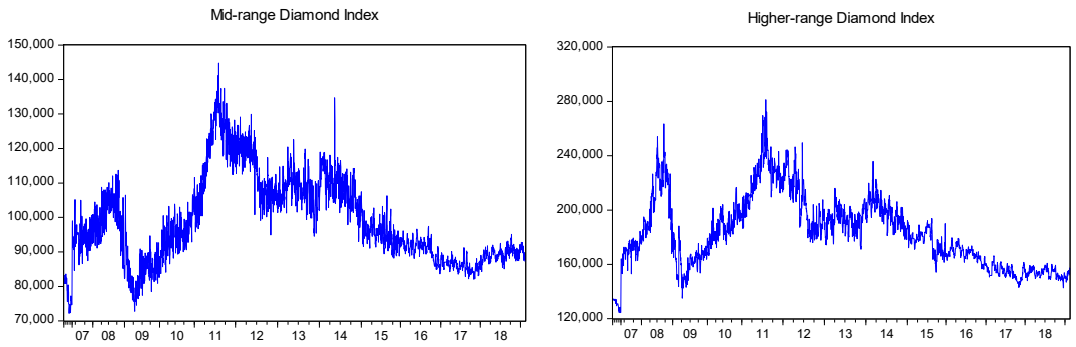

Figure 5. Mid-range and Higher-range diamond indices price dynamics. Notes: Price dynamics of diamond price indices: Mid-range Diamond Index (MDI) and Higher-range Diamond Index (HDI) in their original currencies (USD) for the period 4 June 2007–15 February 2019: *Source*: Polished Prices and D'Ecclesia and Jotanovic (2018).

The list of the stocks included in the database is reported in Table 1. Stock price data were obtained from Bloomberg and Yahoo Finance data platforms. The time interval of the data varies for each stock due to different Initial Public Offering (IPO) dates. All diamond stock prices are daily real traded closing prices from the date of the company's IPO until 15 February 2019.

The selected diamond stocks fulfill the following criteria:

1. All companies are involved in the process of diamond exploration and mining;
2. All companies are publicly traded on one or more Stock exchanges.

Some of the diamond mining companies are traded on several exchanges with one of the exchanges serving as the flagship market. In such a case we report only the flagship market of the equity.

The biggest player in the industry today, in terms of billions of carats produced, is Alrosa, listed on the Moscow Stock Exchange-MICEX, followed by Anglo American and Rio Tinto. Another important diamond producer, Dominion Diamond, was acquired in July 2017 by a privately held group of mining businesses, The Washington Companies, and since then has operated as a standalone, private company without being listed on any exchange.

In Table 1 we report all the mining companies traded on exchanges whose main business is related to diamond mining activity. The two exceptions are Anglo American and Rio Tinto that mine a wide range of other metals and minerals as well as diamonds. Nevertheless, these two companies represent

important diamond producers and an important part of their revenues is linked to diamond mining, as can be detected by looking at their balance sheets. Moreover, Anglo American owns 85% of De Beers, the previous industry's monopolist and the current leader in diamond production in value (Bain and Company and Antwerp World Diamond Center 2013).

Table 1. Diamond-mining stocks traded at different exchange markets.

No	Company	Ticker	Exchange	Currency	IPO (mm/dd/yy)	Av. Volume
1.	Alrosa *	ALRS.ME	MICEX	RUB	11/29/11	8,468,875
2.	Anglo American	AAAL.L	LSE	GBP	05/24/99	4,551,716
3.	Rio Tinto	RIO.L	LSE	GBP	01/07/88	4,149,613
4.	BlueRock Diamonds *	BRD.L	LSE	GBP	04/09/13	4,021,770
5.	Petra Diamonds *	PDL.L	LSE	GBP	04/01/00	1,963,700
6.	Botswana Diamonds *	BOD.L	LSE	GBP	02/02/11	826,091
7.	Lucara Diamond Corp. *	LUC.TO	TSX	CAD	08/14/07	408,936
8.	Stornoway Diamond Corp. *	SVY.TO	TSX	CAD	08/08/96	349,232
9.	Star Diamond Corp. *	DIAM.TO	TSX	CAD	02/10/87	202,216
10.	Newfield Resources Ltd. *	NWF.AX	ASX	AUD	01/05/11	173,439
11.	Mountain Province Diamonds *	MPVD.TO	TSX	CAD	01/05/96	158,342
12.	Firestone Diamonds *	FDI.L	LSE	GBP	08/14/98	109,490
13.	GEM Diamonds *	GEMD.L	LSE	GBP	02/14/07	84,299
14.	North Arrow Minerals Inc. *	NAR.V	TSXV	CAD	10/25/07	41,904
15.	Pangolin Diamonds Corp. *	PAN.V	TSXV	CAD	08/20/14	37,185
16.	Diamcor Mining *	DMI.V	TSXV	CAD	08/08/96	26,621
17.	Trans Hex Group Ltd. *	TSX.JO	JSE	ZAR	01/08/90	12,312
18.	Tsodilo Resources Ltd.	TSD.V	TSXV	CAD	10/25/07	11,440
19.	Diamond Fields Resources Inc.	DFIFF	TSXV	CAD	01/14/99	611
20.	Archon Minerals Ltd. *	ACS.V	TSXV	CAD	08/16/12	122
21.	Alrosa Nurba *	ALNU.ME	MICEX	RUB	08/12/11	60

Notes: The table presents, to our best knowledge, all diamond-mining companies traded on official stock Exchanges, sorted by the average daily volume during the last 3 months (25 November 2018–25 February 2019). * Companies that are only involved in diamond mining and explorations and no other base or precious metals. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

The companies listed in Table 1 differ substantially based on their dates of initial public offering (IPO) as well as their liquidity (average volume of transactions). In order to have a robust and reliable dataset for our analysis we selected the stocks that satisfy the following criteria:

1. Diamonds as the main activity: The company is involved exclusively in diamond mining activities;
2. Liquidity: The average traded volume of the equity is at least 100,000;
3. Time series length: The company has been listed on an Exchange since 6 April 2007.

In addition to the chosen companies that satisfy the above criteria we include in the research sample the biggest market players traded on official exchanges—Rio Tinto, Alrosa and Anglo American. These three companies do not satisfy the above criteria, as Rio Tinto and Anglo American remain involved in mining and exploration of other metals and minerals as well as diamonds, while Alrosa only became listed on the Moscow Stock Exchange in 2011. Nevertheless, we believe they can provide us with valuable information due to their high stakes in the industry.

Finally, the following 8 diamond stocks were selected for the analysis:

1. Alrosa (ALRS.ME)
2. Anglo American (AAAL.L)
3. Rio Tinto (RIO.L)

} Biggest players in the market

4. Petra Diamonds (PDL.L)
5. Stornoway Diamond Corp. (SVY.TO)
6. Star Diamond Corp. (DIAM.TO)
7. Mountain Province Diamonds (MPVD.TO)
8. Firestone Diamonds (FDI.L)

} Liquid stocks, with diamonds

The 8 selected stocks are traded on Moscow (MICEX), London (LSE) and Toronto Stock Exchanges (TSX). The common time span is 4 June 2007–15 February 2019, while their price dynamics are reported in Figure 6. All 8 companies exhibited a significant price decrease in their values at the time of the Global Financial Crisis of 2008, after which different dynamics for each stock can be observed. Alrosa, Anglo American and Rio Tinto all reported an increasing trend in the last three years while the other five showed a period of high instability (Mountain P. D. and Petra D.), reducing trend (Stornoway D. C.) or constant behavior (Firestone D. and Star D. C.). Firestone Diamonds and Star Diamond Corporation exhibited similar dynamics with no price recovery after the crisis. On the other hand, Mountain Province Diamonds and Petra Diamonds exhibited similar price increases on different occasions, such as during the recovery process in 2010 and then again in 2016.

We further provide additional financial information of the 8 selected companies, reported in Table 2.

Table 2. Financial information of the 8 studied diamond-mining stocks.

Company	Market Value (Millions in USD)	Market to Book Ratio Price/Book	Growth Rate of Sales (%)	Growth Rate of Assets (%)
Alrosa	10,686.00	2.70	8.80	−3.90
Anglo American	34,144.00	1.40	5.21	−4.30
Rio Tinto	97,896.00	2.18	1.20	−5.00
Petra Diamonds	211.00	0.40	25.50	−3.50
Stornoway D. C.	120.00	0.29	0.60	−4.20
Star D. C.	77.00	1.44	no revenues *	−0.03
Mountain P. D.	194.00	0.51	82.80	9.50
Firestone D.	17.00	0.20	1.24	−2.20

Notes: The table presents financial information of the selected 8 diamond-mining stocks. Market value is the market capitalization of a company (number of shares × their current price), expressed in millions of USD. Market to book ratio corresponds to the ratio between market capitalization and company's net asset value. Growth rates correspond to percentage changes between 2017 and 2018, expressed in %. * The company does not currently operate any producing properties and, as such, is dependent upon the issuance of new equity to finance its ongoing obligations. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

As reported in Table 2 we observe that Alrosa operates with the highest market to book ratio, implying that the investors are willing to pay a higher price than its actual net asset value. This could be explained by investors' expectations of future profitability of the company supported by its very high Return on Equity (ROE) of around 36%. Moreover, the management of Alrosa has been very successful in reducing the company's debt and retaining good profits at the same time.

Most of the companies involved solely in diamond mining, with the exception of Stornoway D. C., exhibit market to book ratios that are smaller than 1. This signifies that the investors are skeptical about their profitability and growth, valuing them lower than their net asset values.

Growth rates of sales differ noticeably across diamond mining companies in terms of their values but all result positive, in accordance with the expected increase in diamond sales in 2018 (Bain and Company and Antwerp World Diamond Center 2018). On the other hand, asset growth rate results were mostly negative across diamond–mining companies. The reason for this can be found in increased diamond mining, which reduces the value of diamond mines while no new mines are being acquired. Another possible reason for negative asset growth in balance sheets can be found in the reduction of diamond stock due to the increase in sales.

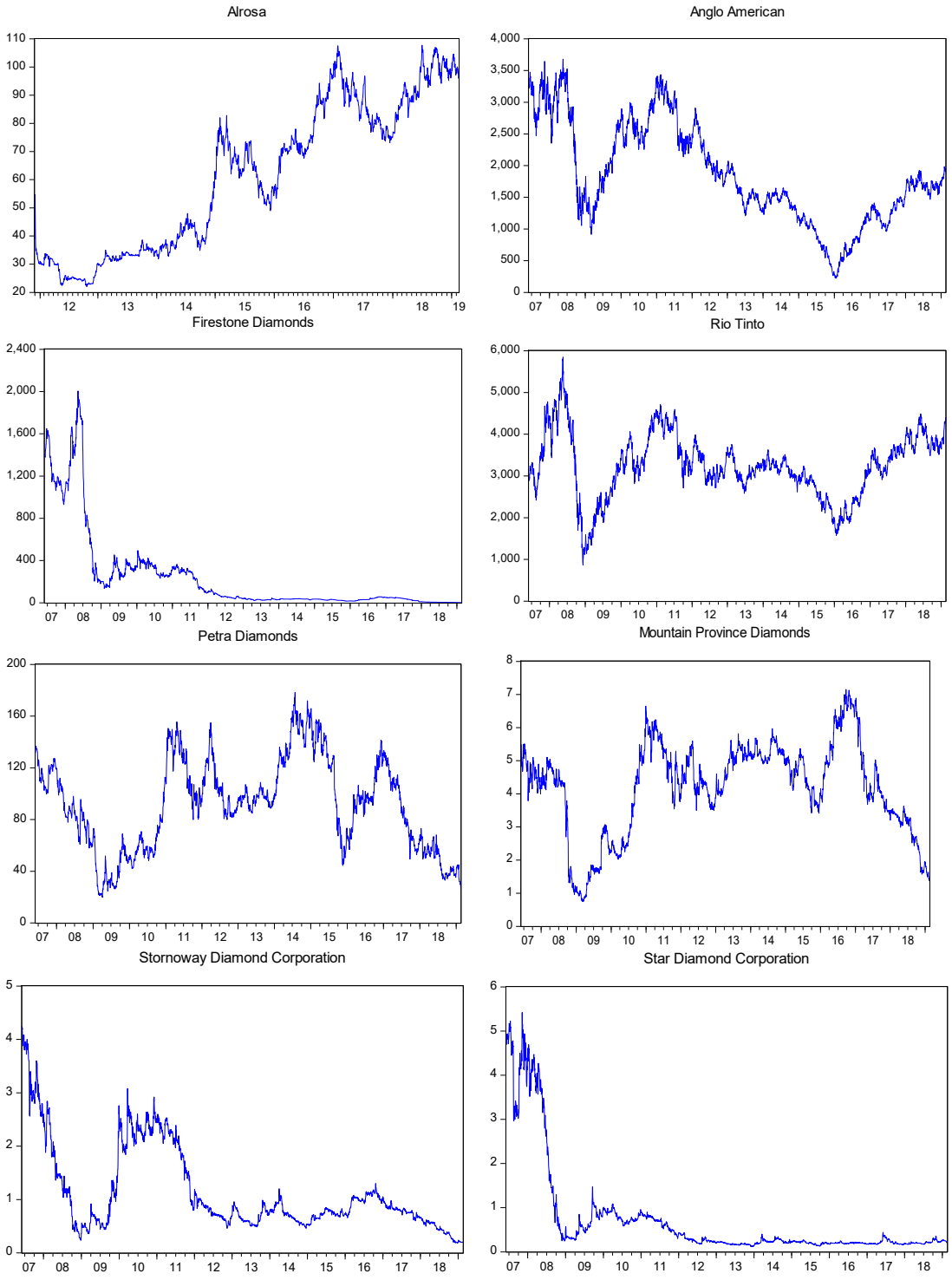

Figure 6. Price dynamics of diamond stocks. Notes: Price dynamics of 8 diamond stocks included in the analysis sub-sample in their original currencies for the period 4 June 2007–15 February 2019: Alrosa (RUB), Anglo American (GBP), Firestone Diamonds (GBP), Rio Tinto (GBP), Petra Diamonds (GBP), Mountain Province Diamonds (CAD), Stornoway Diamond Corporation (CAD) and Star Diamond Corporation (CAD). Alrosa is only listed in 2011. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

6. The Diamond Stock Market

Stock prices are quoted in local currency of the Stock exchange where they are traded. The goal of the paper is not to forecast their dynamics but only to identify whether the drivers of their volatility are governed by the risk factors originating from the global diamond market. We therefore analyze the log returns of each company and study their statistical features.

In Table 3 we firstly report the basic summary statistic for diamond mining stock prices and diamond indices in levels.

Table 3. Summary statistics for diamond stocks and diamond indices in levels (original currencies).

Company		Mean	Min	Max	Prc. 5%	Prc. 95%
Diamond Stock Prices						
Alrosa	Level	60.48	22.00	107.70	24.66	100.52
	Return	0.00	−0.21	0.34	−0.03	0.03
Anglo American	Level	1807.40	221.10	3680.00	643.09	3227.45
	Return	0.00	−0.24	0.21	−0.05	0.05
Rio Tinto	Level	3198.80	818.70	5847.20	1762.20	4419.01
	Return	0.00	−0.46	0.20	−0.04	0.04
Petra Diamonds	Level	91.68	11.53	178.32	31.77	150.69
	Return	0.00	−0.23	0.29	−0.05	0.05
Stornoway D. C	Level	1.13	0.18	4.32	0.39	2.68
	Return	0.00	−0.22	0.19	−0.05	0.05
Star D. C.	Level	0.67	0.12	5.42	0.17	3.90
	Return	0.00	−0.31	0.43	−0.06	0.06
Mountain P. D.	Level	4.19	0.68	7.15	1.35	6.25
	Return	0.00	−0.33	0.35	−0.04	0.05
Firestone D.	Level	226.03	2.63	2005.00	5.34	1175.00
	Return	0.00	−0.54	0.32	−0.06	0.05
Diamond Price Indices						
MDI	Level	98,910.00	72,206.00	14,4760.00	83,136.00	122,710.00
	Return	0.00	−0.17	0.22	−0.06	0.06
HDI	Level	18,3023.00	124,472.00	281,240.00	149,519.00	231,381.00
	Return	0.00	−0.15	0.19	−0.04	0.04

Notes: Summary statistics for 8 diamond stocks included in the analysis sub-sample in levels (in their original currencies for the period 4 June 2007–15 February 2019: Alrosa (RUB), Anglo American (GBP), Firestone Diamonds (GBP), Rio Tinto (GBP), Petra Diamonds (GBP), Mountain Province Diamonds (CAD), Stornoway Diamond Corporation (CAD) and Star Diamond Corporation (CAD)). Alrosa is only listed in 2011. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

In Table 4 we report the ADF test statistics for stock price series in levels. In line with the standard features of stock prices, all price series result integrated processes of order 1—$I(1)$, together with the two diamond indices. Following the assumption that stock prices follow a lognormal distribution, we further transform the prices into log-returns and perform the following research studies using this stationary transformation of price data[2].

Bai Perron structural break test results, reported in Table 5, indicate how price dynamics of the various stocks and the two indices are rather different. Several structural breaks occur for each time series in the observed decade but all in quite different dates. Structural breaks in diamond indices seem to be completely unrelated to structural breaks occurring for diamond stock prices. The only

[2] The stationarity of log returns has been tested and confirmed and the results can be obtained upon request.

exception may be represented by the structural break of the Mid-range Diamond Index occurring on 10 October 2016, which may have caused breaks in Anglo American and Rio Tinto stock price series that occurred in November and December 2016, respectively.

Table 4. ADF test statistics for diamond stocks and diamond indices in levels.

$\Delta P_t = \alpha + \beta P_{t-1} + \delta t + \sum_{i=1}^{p} \gamma_i \Delta P_{t-i} + \varepsilon_t$					$H_0: \beta = 0$		$H_A: \beta < 0$
P_t	α	t_α	β	$t_{\beta(ADF)}$	δ	t_δ	$I(d)$
Diamond Stock Prices							
Alrosa	0.09	1.14	0.00	−0.80	*** 0.01	3.51	$I(1)$
Anglo American	7.59	1.43	0.00	−2.00	0.00	−0.66	$I(1)$
Rio Tinto	16.98	2.37	−0.01	−2.69	0.00	0.23	$I(1)$
Petra Diamonds	0.25	1.53	0.00	−2.02	0.00	−0.22	$I(1)$
Stornoway D. C.	0.01	2.09	* −0.01	−3.15	0.00	−1.18	$I(1)$
Star D. C.	0.00	0.88	* 0.00	−3.27	0.00	−0.57	$I(1)$
Mountain P. D.	0.01	1.42	0.00	−1.73	0.00	−0.11	$I(1)$
Firestone D.	1.18	1.35	−0.01	−2.55	0.00	−1.19	$I(1)$
Diamond Price Indices							
Mid-range D. I.	1238.05	2.33	−0.01	−2.15	−0.11	−1.54	$I(1)$
Higher-range D. I.	*** 2903.46	3.40	−0/01	−3.19	−0.32	−2.58	$I(1)$

Notes: The table presents ADF test statistics of 8 studied diamond stocks in levels in their original currencies for the period 4 June 2007–15 February 2019. The estimated equation includes a constant and a linear trend. Mackinnon critical (asymptotic) values are used for the rejection of the null hypothesis. *** and * indicate 1% and 10% significance levels respectively. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

Table 5. Bai Perron test statistics for diamond stock price series and diamond indices.

Series	No.	F-Stat.	1st Break (mm/dd/yy)	2nd Break (mm/dd/yy)	3rd Break (mm/dd/yy)	4th Break (mm/dd/yy)	5th Break (mm/dd/yy)
Diamond stock prices							
Alrosa	4	36.54	09/18/2013	12/15/2014	01/19/2015	09/05/2016	-
Anglo American	4	92.56	11/13/2009	05/14/2012	12/11/2014	11/22/2016	-
Rio Tinto	4	35.52	08/03/2010	05/04/2012	06/15/2015	12/05/2016	-
Petra Diamonds	5	91.80	03/03/2009	12/02/2010	11/11/2013	08/14/2015	05/18/2017
Stornoway D. C.	4	31.56	12/21/2009	10/20/2011	08/17/2015	05/17/2017	-
Star D. C.	2	283.43	03/05/2009	11/17/2011	-	-	-
Mountain P. D.	3	24.65	09/02/2010	05/13/2013	04/27/2017	-	-
Firestone D.	4	134.49	03/03/2009	09/19/2011	06/26/2013	05/18/2017	-
Diamond price indices							
Mid-range D. I.	4	220.38	12/15/2010	08/13/2012	12/03/2014	10/12/2016	-
Higher-range D.I.	4	134.82	11/03/2010	07/09/2012	08/10/2015	05/30/2017	

Notes: The table presents Bai Perron test statistics for 8 diamond stocks (in their original currencies) and the two Diamond Indices for the period 4 June 2007–15 February 2019. The model tests the null hypothesis of L against $L+1$ sequentially determined structural breaks. The estimation was performed with 0.15 trimming and maximum breaks set to 5 at 5% significance level. The third column reports F statistics for the selected number of breaks, subject to critical values tabulated by Bai and Perron (2003). *Source*: Elaboration on Bloomberg and Yahoo Finance data.

We also tested the presence of structural breaks by using the improved model suggested by Lee and Strazicich (2003) that allows up to two structural breaks, and obtained similar results[3].

Stock returns and indices returns result heteroskedastic as shown by the ARCH LM test reported in Table 6. We use a GARCH approach to measure the volatility of each series. The estimated GARCH parameters for each stock and the two indices are reported in Table 7, while the single conditional variances are presented in Figure 7. We estimated the most appropriate GARCH model for each individual time series, choosing among ARCH, GARCH, TARCH and E-GARCH. We determined

[3] Results can be obtained upon request.

our choice for the most appropriate model for each series by contemplating the values of Akaike and Shwarz information criteria, after estimating all possible models on each series.

Table 6. ARCH LM test statistics for diamond stock prices and diamond indices.

$u_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \ldots + \alpha_p u_{p-1}^2$ H_0:$\alpha_0 = \alpha_1 = \ldots = \alpha_p = 0$ H_A:$\alpha_0 = \alpha_1 = \ldots = \alpha_p \neq 0$					
P_t	**F-Stat.**	**Prob. (F-Stat.)**	**Obs.*R^2**	**Prob. Chi-Square (m)**	**ARCH Effect**
Diamond Stock Prices					
Alrosa	*** 70.28	0.00	*** 67.56	0.00	YES
Anglo American	*** 112.74	0.00	*** 108.32	0.00	YES
Rio Tinto	*** 45.79	0.00	*** 45.06	0.00	YES
Petra Diamonds	*** 3.01	0.01	*** 17.93	0.01	YES
Stornoway D. C.	*** 72.24	0.00	*** 70.36	0.00	YES
Star D. C.	*** 130.26	0.00	*** 124.21	0.00	YES
Mountain P. D.	*** 87.80	0.00	*** 85.03	0.00	YES
Firestone D.	*** 31.67	0.00	*** 31.33	0.00	YES
Diamond Price Indices					
Mid-range D. I.	*** 74.37	0.00	*** 80.86	0.00	YES
Higher-range D. I.	*** 40.07	0/00	*** 39.28	0.00	YES

Notes: the table presents ARCH LM test statistics of 8 diamond stocks in their original currencies for the period 4 June 2007–15 February 2019. The null hypothesis of homoskedasticity is tested against the alternative of heteroskedasticity (ARCH effect). u_t denotes the residual series of the least squares regression on the dependent variable Y_t. Number of lags for the test was chosen based on the AIC. The test is the usual F statistic for the regression on the squared residuals. Obs. *R^2 denotes the LM test statistic for the null hypothesis. The statistic follows a χ^2 distribution with m degrees of freedom. *** indicates 1% significance level. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

Table 7. GARCH parameters for diamond stock prices.

P_t	**Model**	ω	α	β	γ
Diamond Stock Prices					
Alrosa	E-GARCH (1,1)	*** −1.29 (−11.26)	*** 0.31 (11.44)	*** 0.66 (66.43)	*** −0.06 (3.52)
Anglo American	E-GARCH (1,1)	*** −0.11 (−7.51)	*** 0.09 (9.05)	*** 0.90 (665.09)	*** −0.05 (−7.60)
Rio Tinto	E-GARCH (1,1)	*** −0.14 (−7.67)	*** 0.11 (10.13)	*** 0.86 (645.24)	*** −0.06 (−8.15)
Petra Diamonds	E-GARCH (1,1)	*** −0.17 (−7.89)	*** 0.12 (10.39)	*** 0.78 (406.73)	*** −0.03 (−4.76)
Stornoway D. C	TARCH (1,1)	*** 0.00 (9.85)	*** 0.34 (11.20)	*** 0.51 (14.69)	** 0.08 (0.01)
Star D. C.	TARCH (1,1)	*** 0.00 (7.24)	*** 0.09 (7.33)	*** 0.88 (175.66)	*** 0.05 (5.30)
Mountain P. D.	E-GARCH (1,1)	*** −0.18 (−12.35)	*** 0.14 (17.57)	*** 0.82 621.45	*** −0.04 (−9.23)
Firestone D.	TARCH (1,1)	*** 0.00 (17.87)	*** 0.01 (13.98)	*** 0.96 782.21	*** 0.03 14.99
Diamond Price Indices					
MDI	E-GARCH (1,1)	*** −0.09 (−6.31)	*** 0.12 (8.79)	*** 0.89 (724.59)	** −0.01 (−2.39)
HDI	TARCH (1,1)	*** 0.00 (3.68)	*** 0.01 (10.01)	*** 0.95 (258.45)	** 0.02 (2.44)

Notes: The table presents conditional variances and their parameters of 8 studied diamond stocks in their original currencies for the period 4 June 2007–15 February 2019 estimated by the GARCH family models. α denotes the symmetric ARCH term, β represents the GARCH term measuring the persistence of conditional volatility, while γ measures the leverage effect and asymmetric ARCH term. The leverage affect is confirmed if γ is positive and significant in the case of TARCH. The numbers reported in brackets are z-statistics. *** and ** indicate 1% and 5% significance levels, respectively. *Source*: Elaboration on Bloomberg data. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

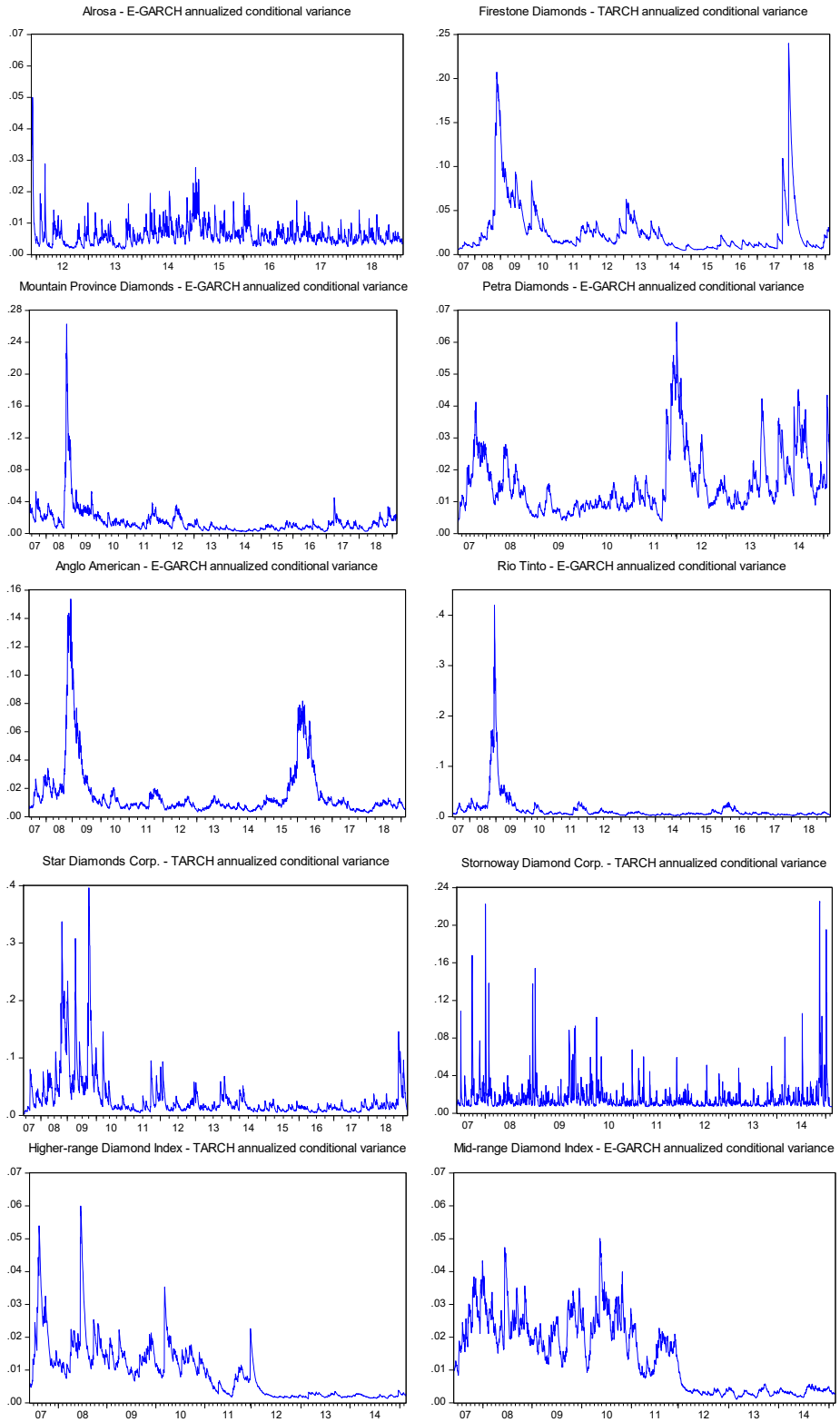

Figure 7. GARCH conditional variances of log returns of diamond stocks and indices. Notes: The figure presents estimated conditional variances (E-GARCH) of log returns of 8 studied diamond stocks (Alrosa, Firestone Diamonds, Mountain Province Diamonds, Petra Diamonds, Anglo American, Rio Tinto, Star Diamond Corporation, Stornoway Diamond Corporation) and 2 diamond indices (Higher-range DI and Mid-range DI) for the period 4 June 2007–15 February 2019. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

Conditional variances show quite different patterns for each stock. Rio Tinto, Mountain Province and Star D. C., after exhibiting an enormous increase in volatility during the GFC, show a pattern of average volatility. Alrosa, Petra D. and Anglo American show several periods in which volatility increases quite aggressively. For instance, the stock Petra D. shows a return to volatility in 2011 that was higher and more erratic than the one that occurred in 2008, and several volatility spikes during the period 2011–2018. Alrosa, on the other hand, shows a very noisy volatility pattern for that entire period.

Diamond Stocks vs. Diamond Prices

Diamond stocks and diamond indices do not show similar dynamics in levels; Moreover, their returns show structural breaks occurring at different dates, not providing evidence that a common driver may explain diamond stocks volatility. We further investigated the relationship between diamond stock returns and the two diamond indices by estimating the Dynamic Conditional Correlation-E-GARCH (1,1) over the studied period. The choice of the model was based on the Akaike information criterion. The DCC-E-GARCH approach allows measuring the short-run correlation existing between the various pairs of securities. A long run relationship may be measured using a cointegration approach.

In Table 8 we firstly report the cross-correlation matrix between the price returns of all studied diamond stocks and the two diamond price indices. We observed very low correlations between diamond stocks and diamonds, with correlation values close to zero. Moreover, the two diamond price indices exhibited a fairly low correlation (0.28), giving further evidence to their different dynamics, as reported in D'Ecclesia and Jotanovic (2018). While the simple correlations among the stock prices of diamond companies result low on average, the stock price returns of Anglo American and Rio Tinto, the two mining giants, were highly correlated (0.80), which could be explained by the common factors affecting the overall mining sector, as well as the fact that both stocks are traded on the London Stock exchange.

Table 8. Cross-correlation matrix among diamond-mining stocks and diamond price indices.

Cross-Correlation Matrix	Alrosa	Anglo A.	Rio Tinto	Petra D.	Stornoway D. C.	Star D. C.	Mountain P. D.	Firestone D.	Mid DI	Higher DI
Diamond Stock Prices										
Alrosa	1.00	0.11	0.15	0.08	0.02	−0.03	0.05	0.00	0.05	0.04
Anglo A.	0.11	1.00	0.80	0.25	0.08	0.01	0.08	0.02	−0.02	0.04
Rio Tinto	0.15	0.80	1.00	0.25	0.07	0.00	0.08	0.04	−0.01	0.06
Petra D.	0.08	0.25	0.25	1.00	0.04	−0.01	0.12	0.04	0.00	−0.04
Stornoway D. C.	0.02	0.08	0.07	0.04	1.00	0.01	0.04	0.00	−0.01	0.03
Star D. C.	−0.03	0.01	0.00	−0.01	0.01	1.00	0.03	0.01	0.00	0.04
Mountain P. D.	0.05	0.08	0.08	0.12	0.04	0.03	1.00	−0.01	0.04	0.06
Firestone D.	0.00	0.02	0.04	0.04	0.00	0.01	−0.01	1.00	0.01	0.02
Diamond Price Indices										
Mid-range DI	0.05	−0.01	−0.01	0.00	−0.01	0.00	−0.01	−0.01	1.00	0.28
Higher-range DI	0.04	−0.01	0.01	0.04	0.03	−0.02	0.02	0.00	0.28	1.00

Notes: The table presents cross-correlation matrix of log returns of 8 studied diamond stocks in their original currencies and diamond price indices for the period 4 June 2007–15 February 2019. The series have been individually matched to maintain the maximum number of observations for each pairwise correlation analysis. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

In Figure 8 we further report some of the time-varying DCC-E-GARCH correlations estimated between diamond stocks and the two diamond price indices[4]. The DCC correlation parameters corresponding to all performed estimations are reported in Table 9. The results show that the diamond stock returns are not related to diamond prices given that, on average, each stock shows an average zero correlation with both diamond indices. This might be explained by the fact that stock returns are

[4] The remaining correlation series have not been reported, as they do not differ significantly from those reported in Figure 8. All results are available upon request.

not driven by diamond prices but rather by other factors related to the book values of the companies. In addition, one possible explanation for the lack of correlation found between stock prices and diamond indices may be explained by the fact that polished diamonds are not a direct output of the mining companies. Rough diamonds pass through several value chains before they reach the polished diamond market and the prices for rough diamonds are only available with a monthly frequency. Hence, a different approach must be used to test any possible dependence.

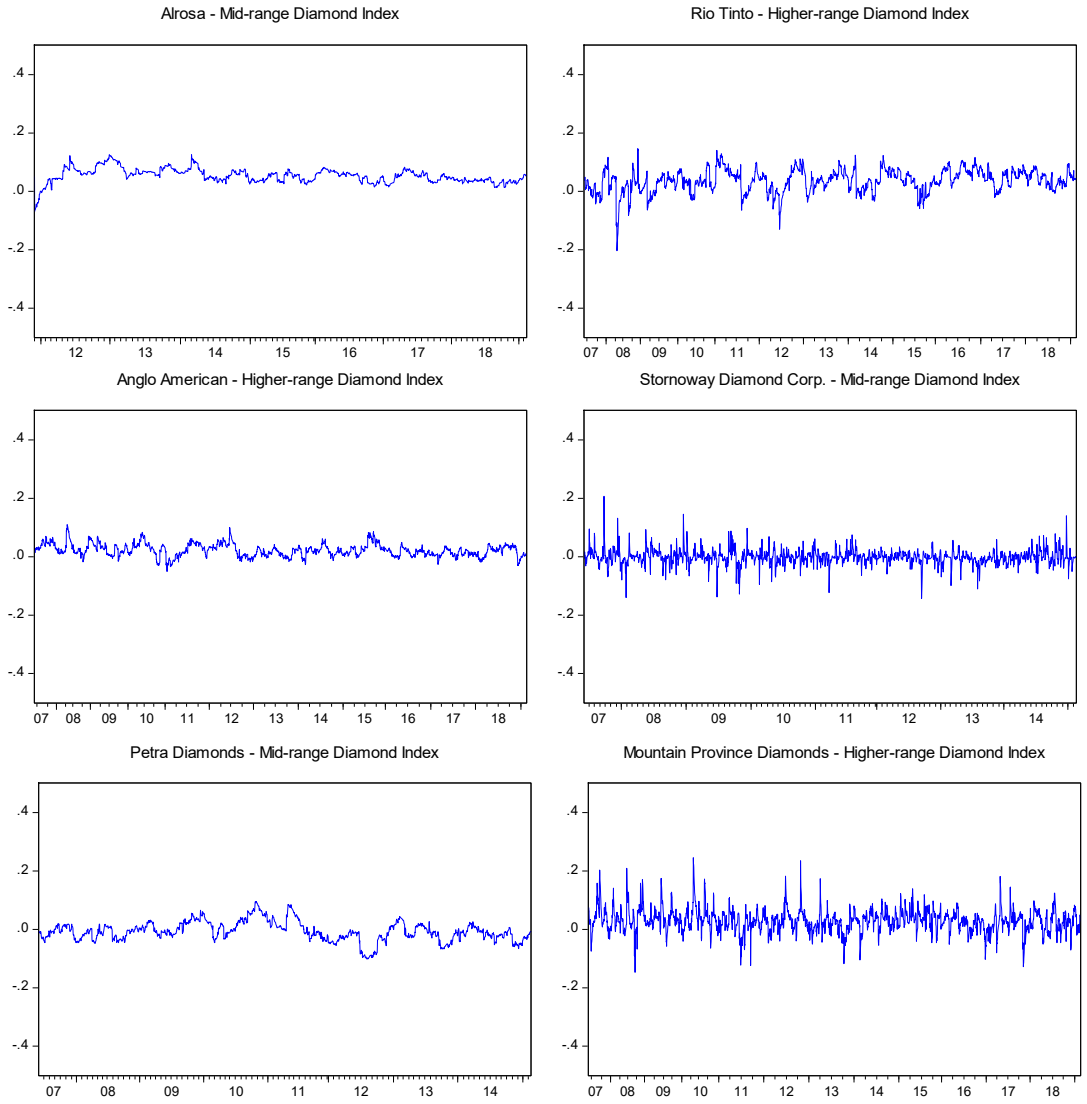

Figure 8. DCC-E-GARCH correlations among diamond stocks and diamond indices. Notes: The figure presents some of the estimated time-varying correlations (DCC-E-GARCHs) between log returns of studied diamond stocks and 2 diamond indices: (Alrosa - Mid-range DI, Rio Tinto - Higher-range DI, Anglo American – Higher-range DI, Stornoway Diamond Corporation – Mid-range DI, Petra Diamonds – Mid-range DI and Mountain Province Diamonds – Higher-range DI) for the period 4 June 2007–15 February 2019. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

Table 9. DCC parameters from the DCC-EGARCH correlation estimations.

Series	Mid-Range Diamond Index				Higher-Range Diamond Index			
	a	z-Stat	b	z-Stat.	a	z-Stat	b	z-Stat
Alrosa	*** 0.99	61.23	** 0.00	2.56	*** 0.78	45.79	*** 0.00	14.35
Anglo A.	*** 0.83	6.82	** 0.02	2.23	*** 0.95	18.48	0.01	0.97
Rio Tinto	*** 0.92	16.89	*** 0.02	10.81	*** 0.98	37.65	* 0.01	1.91
Petra D.	*** 0.98	26.64	0.01	0.75	0.71	0.59	0.52	0.60
Stornoway D. C.	0.64	1.32	* 0.02	1.93	* 0.79	2.19	0.02	0.89
Star D. C.	0.63	1.28	*** 0.02	3.10	0.69	1.37	0.02	1.14
Mountain P. D.	*** 0.76	2.59	0.01	0.95	*** 0.82	7.86	* 0.02	1.72
Firestone D.	0.80	0.38	*** 0.00	2.87	0.80	1.25	*** 0.00	17.94

Notes: The table reports DCC parameters from the DCC-EGARCH correlation estimations of 8 studied diamond stocks and 2 diamond indices for the period 4 June 2007–15 February 2019. ***, ** and * indicate 1%, 5% and 10% significance levels, respectively. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

We further test a possible relationship between the diamond stock prices and the diamond indices using the multifactor approach presented in Tufano (1998), where the author tests how firms engaged in gold mining can be affected by the price of gold. In this paper we analyze the risk exposure of the share returns of the eight firms engaged in diamond mining to changes in the price of diamonds (or their returns).

Managers and investors express share price exposure to the input prices in terms of elasticities; for each percentage change in the input prices they estimate that mining shares would change by 2 to 10 percent, due to financial and operating leverage. These predictions can be confirmed by estimating a multifactor market model, as in Jorion (1990). To estimate the exposure of diamond mining firms to diamond prices, we developed the following market model:

$$R_{s,it} = \alpha_{it} + \beta_1 R_{m,it} + \beta_2 R_{d,it} + \varepsilon_{it}$$

where

$R_{s,it}$—measures the daily return of stock i at time t;
$R_{m,it}$—measures the daily return of regional market stock index i at time t;
$R_{d,it}$—measures the daily return of diamond index i at time t;

For the regional market stock index, we chose the most important market index built in each exchange we analyzed. The coefficients β_1 and β_2 represent the sensitivity of stock i's return for a 1 percent return to holding diamonds, after controlling for movements in broad equity indices that affect the return on these stocks independent of diamond price movements.

In order to obtain unbiased beta estimates, we used the approaches suggested by Dimson (1979), as corrected by Fowler and Rorke (1983), and calculated five sets of diamond and market betas for each diamond mining firm over the entire sample period. These sets of betas differed by the method of adjustment. The adjustments used one lead and one lag term, as adding more than one lead or lag term does not significantly change the measured mean betas. The diamond mining stock returns exhibit the ARCH effect (Table 6) and, hence, we estimated two regressions for each stock using GARCH. The three different stock indices chosen for each of the exchanges we are studying are:

1. MICEX, Russian Stock Index;
2. The S&P/Toronto Stock Exchange 60;
3. FTSE 100 Index, corresponding to London Stock Exchange.

The estimated coefficients from the GARCH mean equations are reported in Table 10. It is interesting to notice that diamond stock returns results were only affected by their respective stock market indices. The Higher-range or the Mid-range diamond indices do not have any role in the

diamond stock returns. This provides further support to the previous result showing that shares of firms engaged in diamond mining cannot be used as an alternative to diamond investments and, therefore, cannot be used as a safe haven.

Table 10. GARCH regression coefficients from the mean equation.

Y_t	MDI ($R_{d,it}$)	Market Index ($R_{m,it}$)	HDI ($R_{d,it}$)	Market Index ($R_{m,it}$)
Alrosa	0.02 (0.22)	*** 0.65 (21.62)	0.00 (0.13)	*** 0.65 (21.75)
Anglo American	0.00 (0.26)	1.63 (64.28)	0.00 (−0.05)	1.63 (63.99)
Rio Tinto	−0.01 (−0.72)	*** 1.52 (66.78)	0.00 (−0.20)	*** 1.52 (67.00)
Petra Diamonds	0.02 (0.46)	*** 0.84 (14.23)	0.03 (1.19)	*** 0.84 (14.14)
Stornoway D. C	−0.02 (0.28)	*** 0.64 (11.88)	0.02 (0.38)	*** 0.63 (11.77)
Star D. C.	−0.01 (0.02)	*** 0.60 (9.36)	−0.06 (−2.34)	*** 0.59 (9.36)
Mountain P. D.	** 0.04 (2.23)	*** 0.71 (14.14)	* 0.07 (3.10)	*** 0.71 (14.07)
Firestone D.	0.01 (0.51)	*** 0.37 (8.32)	−0.01 (−0.33)	*** 0.37 (8.36)

Notes: The table reports estimated betas of diamond mining stocks for the period 4 June 2007–15 February 2019. ***, ** and * indicate 1%, 5% and 10% significance levels, respectively. *Source*: Elaboration on Bloomberg and Yahoo Finance data.

7. Concluding Remarks

Diamonds represent the last hidden commodity that was long neglected by the financial world, given the lack of its fungibility and price transparency. The recent financial crisis encouraged investors to look for alternative assets to protect their portfolios. This brought financial attention to diamonds, which were perceived as a possible new investment asset and eventually viewed as a hedge or a portfolio diversifier. Given that a tradeable diamond financial derivative is still not traded on a regulated exchange, in order to study the potential role of diamonds in the investment context we analyzed the shares of firms engaged in diamond mining. We verified whether they can be a potential liquid substitute to investing in diamonds. We collected a unique dataset of stock prices of all 21 diamond mining companies which are traded on official stock exchanges and studied their price dynamics and possible relationship with diamond prices. For this purpose, we used the Mid-range and Higher-range diamond basket indices built by D'Ecclesia and Jotanovic (2018) as a proxy for the diamond market prices. We then analyzed the relationship between diamond mining stock prices and diamond prices by examining their long-term conditional correlations. Moreover, we also estimated a multifactor market model to verify a possible influence of diamond prices on diamond stock returns. We found that stock returns are only exposed to stock market index returns.

The results show that diamond stocks are not affected by diamonds price dynamics and are not correlated with the diamond market indices.

This paper represents a first step in the scientific analysis of the diamond stock market and leaves plenty of scope for further research. We hope that the original database of diamond mining stocks presented in this article will encourage scholars and facilitate future research in the field.

Author Contributions: V.J. and R.L.D. conceived the presented idea and developed the methodology. V.J. collected the database, performed the computations using the Eviews software and prepared the original draft.

R.L.D. validated the results, reviewed the manuscript and supervised further improvements. V.J. produced the visualizations and further edited the paper.

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