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How stock market reacts to environmental disasters and judicial decisions: A case study of Mariana's dam collapse in Brazil☆

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ABSTRACT

This study examines the stock market reaction to one of the major environmental disasters of the world mining industry: the Mariana dam collapse in Brazil. Based on an event study, we evaluated the impact on the mining companies' abnormal returns surrounding the disaster and also investigated whether post-event judicial decisions affected the companies. Our results show a significant negative effect around the days of the event, reporting a 5 % drop in daily returns. Regarding the legal efforts, our findings suggest the coordination time and the benefits granted by authorities as being interpreted positively, reducing market's expectation of an agile or severe punishment following Mariana's dam disaster.

1. Introduction

One of the most relevant socio-environmental disasters in Brazilian history took place in the city of Mariana, Minas Gerais State. In the year of 2015, the Samarco's Fundão tailing dam - a joint venture owned by the blue bloods of the industry Vale and BHP Billiton – collapsed and nearly 45 million cubic meters of waste were launched directly into the environment. By the date, the rupture represented the largest mining disaster in the world in terms of volume regarding material that was released by the collapse (Losekann et al., 2019). In addition to the pollution of 668 kms of watercourses from the Doce River Basin to the Atlantic Ocean - main water supply for two Brazilian states, Minas Gerais and Espírito Santo - the event also resulted in the death of 19 people and the destruction of a subdistrict, which housed nearly 600 residents (IBAMA, 2018). Nonetheless, even with the level of global visibility and sensibility given to the disaster, the perception of mining companies' investors may not have been of absolute pessimism regarding the resilience of the companies and the output to be produced by Brazilian law enforcement in a post-event scenery.

Considering the scale of the event, in this study we measure the extent of market-imposed sanctions in environmental disasters in Brazil. We implemented a quantitative assessment of the Mariana dam failure impact on the abnormal returns of the mining companies involved in the event. Additionally, we provide the first study to estimate judicial decisions' impact on share values of the companies involved in the same disaster. For that purpose, our approach follows the developments of the Federal Prosecutor's Office legal proceedings. At each new announcement, we assessed whether the judicial decisions associated with the R$ 155 billion public civil action (approximately US$40 billion) generated a stock market's reaction.

Firstly, to assess investors' response of Samarco's parent companies (Vale and BHP Billiton) shortly after the occurrence of the disaster, we compared investors' behaviour of another set of companies similar to Samarco, however unrelated to the event. Our findings indicate that Samarco`s dam collapse in Mariana conveyed new information relevant to the financial market, which is manifested in statistically significant negative stock abnormal returns for firms that held Samarco`s operations. These results help us understand how the mining companies ultimately involved in the dam's collapse failed to anticipate the event. Only after the dam collapse information becomes publicly available, the event was incorporated into stock prices being traded – as can be noticed when we look at the drop in returns after November 5, 2015.

Secondly, we shed some light on the market's reaction to the Brazilian judicial system's performance in seeking to penalize the company directly involved in the event. Our results illustrate well how the same institutional response produces a distinct effect on the market over time. Initially, we observe a negative shock caused by the opening of the Public Civil Action, but next, we note the market losing sensitivity given

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the action's developments. It can be noted that much of the immediate price reactions in the 1st decision given by the authority were due to fear that a harsh and coordinated punishment from the Federal Prosecutor's Office (the highest public prosecutor body in the Brazilian judicial system) would take place against the companies. However, as the prosecution process proved to move slower than expected and the terms companies had to comply with mild, the following decisions given by the authority cease to have a negative effect on companies' returns.

This study is associated with two strands of the literature. Studies assessing the correlation between stock variation and the occurrence of environmental accidents (Cagle, 1996; Worthington and Valadkhani, 2004) reveal that an immediate negative fluctuation is found in portfolios affected by such events. These studies are based on the premise that in stock valuation models - which assumes rationality - the decrease in value should occur if expectations indicate a drop in the firm's future cash flow. Therefore, the perception of risk deepens in cases such as environmental disasters, since companies involved in those events must experience additional costs related to reparation, litigation and decommissioning in some of its plants. Araújo et al. (2017) also propose the assessment of Mariana's disaster and stock performance of the two firms involved - Vale and BHP Billiton. Adopting an event study methodology, the authors found a significant variation in the share prices of the companies. However, this effect was identified, first, in the Brazilian market and, later, in the Australian.

Our study, compared to Araújo et al. (2017), adopts a different strategy, as well as aims to answer additional questions concerning stock market reaction to the judicial system in the Mariana disaster. As in Guidolin and La Ferrara (2010), we associated an event study to the Fama-French three-factor model (1993), and a set of control companies also from the mining sector was considered as a comparison measure. This later exercise makes the causal relationship between share value losses in the face of exogenous shocks clearer. In addition, our study also shed light for the first time on the investors' response to legal developments in Mariana's event with a long-term analysis that assesses the impact of judicial announcements on share performance.

The other branch of literature aligned to our study refers to the impact of news associated with environmental disasters or unwanted environmental conduct of firms. Hamilton (1995) clarifies that the daily loss companies register after having their pollution levels publicly disclosed can be linked to the costs related to regulatory compliance in favour of reducing pollution levels, or costly future obligations due to pollution cases. The conclusions drawn by Carpentier and Suret (2015) indicate that the market anticipates a low capacity for punishing environmental events. The authors highlight that, without government action, companies face an even lower cost imposed by investors. Dohlman et al. (2015) also point out that regulatory events have a negative impact on stock prices, indicating a drop in profit expectation and market share of companies.

The remainder of the paper is organized as follows. In Section 2 we bring a literature review. The institutional framework is briefly described in Section 3. Our estimation strategy and database are presented in Section 4. Section 5 describes the results, and, finally, Section 5 concludes.

2. Literature review

The relationship between so-called unforeseen shocks and firm losses is a theme that finds varied approaches in economic literature. Barrot and Sauvagnat (2016) investigate the effect of disasters on production networks (suppliers and customers). Looking at the occurrence of natural disasters where firms are located, the authors find evidence of a temporary effect on sales (drop) after one of the firm's suppliers is hit by a natural disaster. Hill and Schneeweis (1983) identify a greater negative impact on the stock return of nuclear sector companies (compared to those of other sectors) after the nuclear accident on Three Mile Island in 1979. The study argues that investors, as agents endowed with rationality, will expect reduction in the cash flow of the nuclear firms due to the change in risk perception in cases such as environmental accidents. After these events, companies must experience additional costs such as those related to repairs, litigation and closure of activities in some of their plants.

Stock market reaction involving accidents or environmental disasters relies, predominantly, on the literature discussion of change in risk perception by the firm's stakeholders. Dessaint and Matray (2017), for example, study how company managers of firms located in areas near to hurricane events behave after an event. The authors demonstrate that, temporarily, the liquidity risk perception increases, causing precautionary measures to be taken. Froot (2001) and Ramírez and Altay (2011), also carry out analyses in which it becomes possible to conclude that natural disasters represent a relevant source of uncertainty in stock markets.

Assisted by the economic theory, it is expected that the behavior of agents - here, specifically, stock market investors - is driven by their ability to form expectations and react based on the available information (Keynes, 2013). Therefore, the news effect is an important analysis to be carried out when we look at major events. In the case of environmental disasters, it is expected to represent a strong influence on the decision-making process of investors. Hamilton (1995) investigates whether the release of news by the United States Environmental Protection Agency (EPA) related to the pollution levels practised by companies impacts on the share performance of these firms. The author concludes that on the date the information becomes public, an average daily loss of US $ 4.1 million in share value is recorded by the companies.

Capelle-Blancard and Laguna (2010), looking at a range of news sources, discover that, in cases of industrial accidents involving contamination and/or loss of life, stock losses for companies are higher, with an average additional of US $ 164 million / death and $ 1 billion in cases of chemical leaking. Carpentier and Suret (2015) find a market deterrent effect after mapping episodes in which firms have had involvement in environmental and non-environmental accidents with great prominence in the media in the last 50 years - printed on the cover of the newspaper The New York Times. The results indicate stock market having a weak capacity for punishment in cases of environmental accidents. The authors also point out that adjustments on the part of firms that aim to mitigate the chances of new accidents are only verified when the government takes action in the matter. Otherwise, the market presents an even less punitive conduct concerning companies involved in environmental accidents. Dohlman et al. (2015) demonstrate that regulatory events - usually installed by governments, to prohibit, postpone or limiting the introduction of their product in markets - had a negative impact on stock prices. In this case, it's noted a drop in the expectation of profits and market share of the companies involved.

The theory of market efficiency proposes that, as soon as information becomes public, it should spread fastly, being immediately incorporated into stock prices being traded. Therefore, news informed at $t + 1$ should affect the prices at $t + 1$, and this variation would be independent of any variations occurred in t (Malkiel, 2003). Pursuing this line of research and aiming to argue against the work that had been refuting the correlation between market volatility and new information (Roll, 1988; Berry and Howe, 1994; Tetlock, 2007), Boudoukh et al. (2013) carry out an extensive study on news identification. With the assistance of text analysis programs, the authors compare days without news, days with unidentified news and days with identified news on several dimensions. The conclusion drawn is that the volatility on no-news days and unidentified news days is identical. However, on identified news days, it is verified that stock price volatility is over double than on other days.

With a study that shares some similarities with ours, Araújo et al. (2017) analyze the behavior of the stock market after Mariana's disaster. Using an event study methodology, the authors investigate the variation in systematic risk and returns of the companies involved in the event. The study concludes identifying a negative reaction of the Brazilian and

Australian stock market in the period after the environmental accident. However, the oscillations observed did not arise immediately. It was also found that the negative impact on the stock market first affected the Brazilian and then the Australian market.

In our paper we seek to quantitatively evaluate whether stock losses are experienced by companies connected to the disaster unfolded in Mariana (MG). Simultaneously, we also aim to identify the effect of news concerning judicial decisions on the return of these firms. Predecessor works as Brito (2005), based on an event study methodology (Brown and Warner, 1985), found that the Brazilian stock market between the years 1997–2004 showed a significantly negative reaction to environmental disasters or accidents news[1] - for an analysis of up to 20 days. Similarly, Nogueira and Angotti (2011) implement an event study, identifying that the market reacts negatively when facing accidents that occurred in the oil sector. However, the authors point out that it is only after a few days that it becomes possible to verify this behavior.

3. A mining sector overview

The iron ore market is highly concentrated. The 10 largest producers are responsible for 62 % of the world volume produced. Only the three largest - Vale, BHP Billiton and Rio Tinto - hold 44 % of the world volume (UNCTAD, 2016). This scenario might find justification in the heavy initial investment involved in the iron ore extraction activity poses a substantial entry barrier to new companies into this sector (FERREXPO PLC, 2015).

In 2015, the Brazilian company Vale was the largest iron ore producer in the world, also leading the production of pellets (Rosas and Goés, 2015). In 2017, the company achieved a record in both iron ore production - 366.5 million tons - and pellets - 50.3 million tons. Founded in 1942 and headquartered in Brazil, Vale is a global company operating in 30 countries. Owning activities in the mining, logistics, energy and steel sectors, it distributes its worldwide operations in the form of its units and joint ventures.

Placed in third among the giants of the world mining sector, after the English Rio Tinto, is the Anglo Australian BHP Billiton. Founded in the year of 2001, after the merger between Australian Broken Hill Proprietary Company Limited and Anglo-Dutch Billiton. Operating in the Americas and Australia in the mineral and energy industry - the latter also participating in Europe and Africa -, in 2017 the mining company produced 231 million tons of iron ore (BHP, 2017). China is its largest consumer, being responsible, in 2017, for 49 % of the company's revenues, which were distributed among 61% iron ore, 22 % copper, 16 % coal and 1 % nickel (BHP, 2017).

Vale and BHP Billiton, in 1977, entered into a partnership by founding the privately held mining company SAMARCO MINERAÇÃO SA. After the environmental disaster unfolded in Mariana (MG) in November 2015, the joint venture operations were interrupted, ending, unexpectedly, this source of iron ore pellet supply in the global market. Therefore, both Samarco's parent companies became susceptible to an impact on their performance due to the event of Mariana. In addition to the activities' shutdown of one of its units, Vale and BHP Billiton have come to be subject to potential damages of a litigious nature. The companies became subject of multiple reparation processes from those affected by the disaster, as well as faced the possibility of condemnation for the Samarco dam failure (BHP, 2017).

The mining company directly involved in the event, Samarco Mineração S / A, located in the Quadrilátero ferrífero (MG) region - the richest geologically area of iron reserves in Brazil (DNPM, 2016) - integrates the prominent mining activity in Brazil. Headquartered in the city of Belo Horizonte (MG), the company owns mining and industry units throughout the states of Minas Gerais (Mariana and Ouro Preto municipalities) and Espírito Santo (Anchieta). Until 2014, it directly employed three thousand workers and indirectly 3.5 thousand (SAMARCO, 2014). In 2015, Samarco was the second among the world's largest producers of iron ore pellets (Rosas and Goés, 2015), having associated customers in 20 countries around the world (SAMARCO, 2015). Its pellet exports were mainly shipped to markets located in Africa, the Middle East, Asia, Europe and America, with China being the largest importer of Samarco's product - 16.5% of its total in 2014 (SAMARCO, 2014). In 2013, the volume of pellet production in the world was 492.45 million tons, with Samarco being responsible for nearly 21 million tons (Carvalho et al., 2014, *apud* CRU, 2013; SAMARCO, 2013).

The company had been robustly expanding its production levels in the last decade. From 2004–2014, its volume increased from 15.1 million tons of iron pellets to 25.075 million tons - an evolution of approximately 66% for the period (SAMARCO, 2005; SAMARCO, 2014). Even in the year of 2015, when affected in the fourth quarter by the failure of Fundão tailing dam, the mining company's annual production recorded 25.453 million tons - an increase of 1.5% over the previous year Samarco (2017).

4. Empirical strategy and data

4.1. Methodology

The event study method (Brown and Warner, 1980, 1985) is used in this work to measure the impact of events of great magnitude over a short period. In the case of assessing stock behavior, the method captures the effect on the average companies' abnormal returns around the date of the event (Duso et al. 2010; Elad and Bongbee, 2017). Therefore, the method reports the reaction triggered by the environmental disaster on the stock market. Another characteristic of the methodology is the high-frequency data to be evaluated. In the case of our study, daily observations cover several analysis windows. Therefore, for each event date we establish - the dam collapse and release of judicial decisions - the model is fit measuring variations in stock prices for the period.

Our aim is to estimate stocks' normal returns of the two parent companies: Vale and BHP Billiton. In order to do so, we align the event study approach to the Fama-French three-factor model (Fama and French, 1993). The model is widely adopted in finance, a landmark for stock portfolios valuation and extensively employed in the academy.

The equation to estimate the residuals of interest – called abnormal returns – is as follows:

$$Er_{i,t} = \alpha_i + \beta_i MRP_t + g_i SMB_t + z_i HML_t + \varepsilon_{i,t} \quad (1)$$

where $Er_{i,t}$ (expected return), is the daily return in log[2] stock (***t***) of company ***i***; *MRP* (market risk premium), the market premium factor calculated by subtracting the free-risk rate from the expected return; *SMB* (small minus big), captures size and *HML* (high minus low) book-to-market effects; and, ε, refers to an unexplained residual called the abnormal return.

From the estimation performed in (1), we rearrange the parameters $\widehat{\alpha}_i, \widehat{\beta}_i, \widehat{g}_i, \widehat{z}_i, \widehat{\varepsilon}_i$:

$$Ar_{i,t} = Er_{i,t} - (\widehat{\alpha}_i + \widehat{\beta}_i MRP_t + \widehat{g}_i SMB_t + \widehat{z}_i HML_t) \quad (2)$$

From the estimated residuals in (2) we generate the series of cumulative abnormal returns $\{CAR_t\}$ as $CAR_t = \sum_{j=t_0}^{t} e_j$ where $t_{0\ is}$ the first day of the event window.

CAR_t^T

[1] The sectors analyzed in our study covered companies that also included those of the miner sector.

[2] As discussed in Morettin (2017), log return can be obtained after the transformation $r_t = \log P_t / P_{(t-1)}$, in which the logarithm is in base e.

The abnormal returns estimated for the companies Vale and BHP Billiton in (2) are separately assessed based on the event study methodology. Therefore, distinct windows are tested in order to validate the effect of the Mariana dam failure on the stock return of the portfolio. For each event, we use different event windows (i.e. intervals around the event date over which markets are likely to have incorporated changing expectations) and estimation windows (i.e. pre-event days during which model (1) can be estimated).

A 3-year pre-event window (756 daily quotations), which captures the trends that the market presented prior to the event on 5 November 2015 (t = 0), is used as the estimation window for establishing 'normal' parameters for the study. As for the event window, it is estimated in two different type of windows: one symmetrically, around the event (−3; +3) and the other asymmetrically, after the event (0; +3). In this shorter evaluation window, we expected to attest with greater precision whether the mining companies experience atypical behavior on their normal return, as well as the magnitude of the shock on the expected stock variation.

Firstly, the full estimation window is calculated (September 21, 2012, to October 15, 2015, for Vale and September 12, 2012, until October 16, 2015, for BHP Billiton).[3] Secondly, the CAR of the symmetrical window (October 30 to November 10, 2015, for Vale and November 2 to November 10, 2015, for BHP) and for the asymmetric post-event window (November 5–10) 2015 for both companies).[4] The null hypothesis tests whether the abnormal return (CAR) is zero in correspondence to the event, against the alternative that it is different from zero. Therefore, the central hypothesis of our work is tested, which seeks to directly relate environmental disasters to stock losses.

In order to reinforce that the impact on the mining companies' abnormal returns can be explained by their indirect involvement with Samarco's dam failure, a set of mining companies (Atlas Iron, Mount Gibson Mining Iron, Rio Tinto, MMX Mineração e Metálicos, and Cleveland-Cliffs) is also tested. Based on this comparison exercise we aim to see whether, after the succession of an event as Mariana's, the effect over stocks is restricted only to the two parent companies, or if there is an overflow to other similar enterprises.

Additionally, Samarco participating in one of the biggest social and environmental disasters in Brazilian history initiated a series of legal proceedings brought by various authorities against the company - such as fines, administrative, civil and criminal lawsuits, reparation measures, indemnities, among others. However, Public Civil Action of R$ 155 billion (approximately US$40 billion) filed by the Federal Prosecutor's Office can be seen as the most prominent of the negotiations between the Brazilian authorities and the companies. In addition to being the most valuable lawsuit among all those that were filed after the disaster, it has lead the parties involved to enter into a final agreement regarding Mariana's disaster - the "Termo de Ajustamento de Conduta (TAC)".

Therefore, we also follow the strategy of assessing the market's reaction to the legal developments of the R$ 155 billion Public Civil Action - hereinafter referred to as "justice effect". Legal news of relevance to the investors of both companies and the stock market as a whole are collected. Each news release date will simulate a new event (t = 0), allowing, once again, the event study methodology, combined with the Fama-French three-factor model, to capture the behavior of the abnormal returns in response to the release of legal developments.

In our approach we track a total of 11 main developments decisions over time. Due to the high frequency of relevant events that reach the market, conducting a long-term analysis requires our assessment to become more objective. Considering that, to restrict the local effect of these decisions, a narrower (−1;+1)[5] window for the Public Civil Action (see Fig. 5) is adopted for the justice effect analysis.

It is noteworthy that, due to the fact that the investigated action extended for more than two years, facing successive delays, such slow-paced development may have corroborated so that the companies involved didn't experience significant losses. The disbelief in an effective punishment - or that this occurred forcefully - could then have led the stock market to present a negative reaction in an increasingly reduced form. The hypothesis of no reaction at all to new legal developments of the environmental disaster is also investigated.

4.2. Data

Financial data is taken from the São Paulo (BOVESPA) and New York (NYSE) stock exchanges. A panel analysis is conducted gathering daily stock quotations initiated in September 2012 until November 2015.[6] Market parameters are taken from Kenneth R. French repository and the Brazilian Center for Research in Financial Economics of the University of

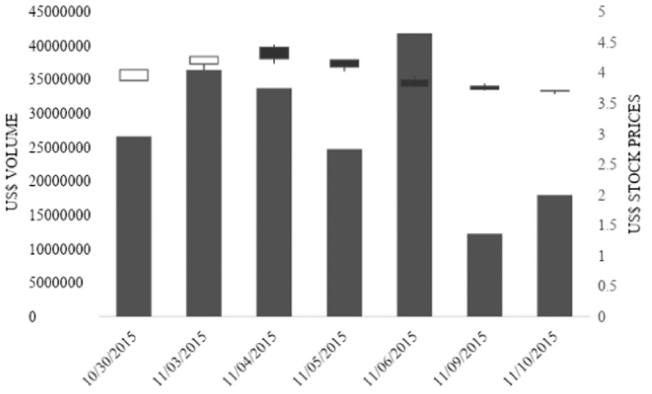


Fig. 1. Opening and closing stock values and traded volume – Vale. *Note:* The drop-down boxes indicate the opening and closing stock values - right column. In empty boxes, the closing price was higher than the opening price (the stock appreciated on the date), and in full boxes, the closing price was lower than the opening price (the share depreciated on the date). The vertical lines indicate the maximum-minimum range values reached on the date - right column. The vertical columns report traded volume – reference to the left column.

[3] We made the choice to dismiss 10 trading days that separate the control window from the event windows as a procedure to reinforce the behavior of the two periods to be isolated. Additionally, the disparity between the trading days of the Brazilian and North American stock exchanges makes the dates vary between companies; however, the estimation windows include the same number of trading days for the mining companies.

[4] We also test this larger symmetric window since we can only assume the shock to be almost exogenous, and not completely exogenous. Therefore, the hypothesis that, preliminarily, the near-certain occurrence of the dam collapse was known by some of the interested party is not ruled out. During the investigation of Brumadinho's dam collapse (MG), a later disaster that took place in January 2019 also involving Vale, documents indicate the company's management awareness of the imminent risk of a structural collapse since 2017. The investigations have also shown that two days before the dam collapses, e-mails reporting unusual behaviour of sensors responsible for monitoring the stability of the dam were exchanged between Vale's employees and employees of the company providing the structure's safety consultancy (G1 2019).

[5] Once again, the estimation window we adopt is the one preceding the event (756 quotation days), given that, after the dam collapse, a large volume of lawsuits against Samarco is filled. Therefore, by adopting an estimation window that does not precede the disaster may be leading to an evaluation that will be not capturing the parent's companies' "normal" performance, but one under the effect of several legal developments that occurred after the disaster.

[6] The daily data refer to the days on which stocks are traded, therefore, excluding weekends and holidays.

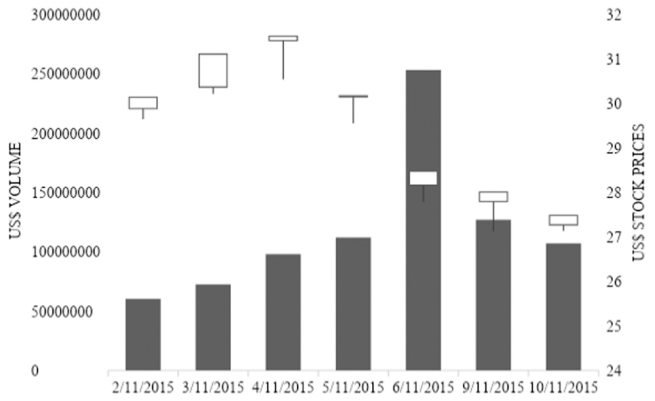


Fig. 2. Opening and closing stock values and traded volume – BHP BILLITON. *Note:* The drop-down boxes indicate the opening and closing stock values - right column. In empty boxes, the closing price was higher than the opening price (the stock appreciated on the date), and in full boxes, the closing price was lower than the opening price (the share depreciated on the date). The vertical lines indicate the maximum-minimum range values reached on the date - right column. The vertical columns report traded volume – reference to the left column.

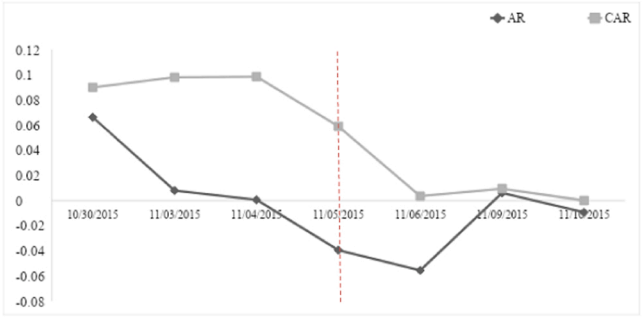


Fig. 3. Abnormal return (AR) & cumulative abnormal return (CAR) – Vale. *Note:* Fig. 3 plots Abnormal return (AR) and cumulative abnormal return (CAR) of mining companies Vale and BHP Billiton surrounding Mariana's dam collapse.

Fig. 4. Abnormal return (AR) & cumulative abnormal return (CAR) - BHP Billiton. *Note:* Fig. 4 plots Abnormal return (AR) and cumulative abnormal return (CAR) of mining companies Vale and BHP Billiton surrounding Mariana's dam collapse.

São Paulo (NEFIN).[7] Our strategy looks at the two Samarco's parent companies since the mining company does not have its capital listed on any stock market. Therefore, the effect of the disaster is measured through the Brazilian Vale and the Australian company BHP Billiton - which have a 50/50 co-ownership of the mining company directly involved in the event.

We adopted a set of control companies to measure the comparative effect of the dam disruption. Therefore, we select a group of mining companies and evaluate how they perform in the event windows being assessed. Selection criteria observed the following: i) open access financial data available covering the control and event-window (from September 12, 2012 until November 10, 2015); ii) traded in the New York Stock Exchange (NYSE) or the Brazilian Stock Market (BOVESPA); iii) being representative iron ore producers. The control group is therefore formed by the mining companies Atlas Iron, Mount Gibson Mining Iron, Rio Tinto, MMX Mineraç ão e Metálicos, and Cleveland-Cliffs. We stress the fact that alongside Vale and BHP Billiton, the mining companies Atlas Iron, Mount Gibson Mining Iron, Rio Tinto, and Cleveland-Cliffs were in the top 10 iron ore producers' list in 2015 (Mining, 2020).

In the Appendix section, we present additional data on the comparability of the companies used in our study. Appendixes A and B report daily returns from January 1, 2015, to November 10, 2015. Appendixes C and D display Pearson's correlation test for this same period in order to have a measure of the strength and direction of association that exists in the companies' returns. Appendixes E and F present selected financial indicators for the year 2014, which will assist in understanding the scale of these companies in the mining industry.

The reunion of judicial decisions also integrates our strategy. All the post-event data are taken from the Securities and Exchange Commission of Brazil (CVM) - the official source for the Brazilian stock market - and from the annual reports released by the companies Vale and BHP Billiton. This later source is responsible to inform relevant events for quarterly results. Additionally, the news is also verified in secondary sources, which include Brazilian and foreign communication vehicles - newspaper, websites - and also the official website of the prosecuting parts.[8]

5. Results

The following two graphs display some data on stock behaviour around the days of the event. Traded volume and opening and closing prices of the companies' stocks provided an initial indication of how the market receives the event. The figures signal the possible stress suffered. We noted that the mining company Vale showed continuous devaluations since November 4, 2015 - on the eve of the dam failure. In contrast, BHP Billiton registers devalued stocks only on the date of the event, November 5, 2015. However, it is the accentuation of stocks traded by both companies on the day following the event that shows us market particular behaviour in response to Mariana.

5.1. Dam's failure impact

Figs. 3 and 4 contain one of our main results. They show the evolution of the abnormal return (AR) and the cumulative abnormal return (CAR) of the mining companies Vale and BHP Billiton around the date of the event (vertical line). We observed a continuous declining CAR for the two companies. Driven by the negative variation of the AR after the disaster, on November 5 (date of the event), Vale showed a 4% variation in its abnormal returns, while BHP Billiton around 3%. However, it is on the day after the dam failure that both companies experience the greatest loss for the period. On November 6, we note a negative variation of 5.5% in their AR. In comparative terms, the variation that occurred on

[7] The data can be accessed at https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html and http://www.nefin.com.br/

[8] Federal Prosecutor's Office, Minas Gerais and Espírito Santo State Prosecutor's Offices, Court of Appeals of the State of Minas Gerais, Attorney's Office of the State of Espírito Santo, Brazilian Environmental Institute (IBAMA); as well as high-visibility Brazilian and international newspapers, such as: O Estado de São Paulo, Folha de São Paulo, Veja, Exame, G1 (Globo) and Reuters.

Date	*Information reported to the market*
May 4, 2016	Federal Prosecutor's Office files the Public Civil Action suing the companies Samarco, Vale and BHP Billiton, establishing a preliminary amount for repair, the amount of R$ 155 billion, and the prohibition on encumbering assets and distribution of companies' profits, as an additional guarantee for the reparation of damages.
January 19, 2017	Federal Prosecutor's Office signs the Preliminary Adjustment Term with the mining companies.
March 16, 2017	Partial homologation of the Preliminary Adjustment Term signed with the Federal Prosecutor's Office.
May 15, 2017	Justice extends the deadline for the presentation of a Final Reparation Agreement with the Federal Prosecutor's Office.
June 30, 2017	Justice extends the deadline for the presentation of a Final Reparation Agreement with the Federal Prosecutor's Office.
July 18, 2017	Vale informs on the suspension of the Public Civil Action filed by the Federal Prosecutor's Office.
October 31, 2017	Justice extends the deadline for the presentation of a Final Reparation Agreement with the Federal Prosecutor's Office.
November 20, 2017	Justice extends the deadline for the presentation of a Final Reparation Agreement with the Federal Prosecutor's Office.
April 20, 2018	Justice extends the deadline for the presentation of a Final Reparation Agreement with the Federal Prosecutor's Office.
June 25, 2018	Celebration of the Conduct Adjustment Term among Samarco, its shareholders and Brazilian authorities.

Fig. 5. Federal Prosecutor's Office Public civil action timeline. *Note:* Fig. 5 displays a chronological gathering of Federal Prosecutor's Office civil action's main developments throughout the prosecuting process against Samarco and its parenting companies – Vale and BHP.

November 6 would have represented a loss in market value for Vale and BHP Billiton in the order of US$ 2.255 billion and US$ 12.375 billion, respectively.[9]

The AR's evolution over the days indicates that the shock was gradually absorbed. However, it is worth noting that, during the first three days after the date of the event, the abnormal returns have consistently remained negative for the Australian company. As for the Brazilian company, Vale, the AR is positive, but it declines another time. Looking at the 1 trading day delay for the shock to reach its peak, followed by a deep adjustment with the smoothing of abnormal returns, we can identify a market with low efficiency to assimilate the new information – and also evidence of overreaction by this market.

Regarding the abnormal returns' behavior until the main event ($t = 0$), we observed a similar behavior between the two companies. Although BHP Billiton, in contrast with Vale, registering a good variation at $t = -2$, a priori, the mining companies shows us approximated CAR - as well as both report an extremely low AR on November 4, 2015.

Our event study methodology in the tradition of Fama et al. (1969) build on the view that capital markets will quickly incorporate the financial consequences of extreme events. As discussed in Worthington & Valadkhani, 2004, the first and most obvious is that stock owners, because of the future payments to be made in order to compensate for the damage caused by their company's operation, will incur large losses. Therefore, for the most part the expectation is that these losses should cause Vale and BHP Billiton`s stocks to decline at the time of the disaster.

In Table 1, we tested whether the effect displayed in the graphs are statistically significant (Figs. 3 and 4). Specifically, the table reports the results of the parametric and nonparametric tests of the null that the dispersion around the CAR average of the two mining companies is equal to zero against the alternative hypothesis that the dispersion around the CAR is different from zero. The top part of the table reports

Table 1
Assessing the impact of the dam failure.

Event window	VALE		BHP Billiton	
(−3, +3)	-0.146 ***	-3.222 ***	-0.082 ***	-2.774 ***
	(0.0027)	(0.0013)	(0.0189)	(0.0055)
(0,+3)	-0.179 ***	-2.896 ***	-0.113 ***	-2.625 ***
	(0.0053)	(0.0038)	(0.0147)	(0.0087)

Notes: This table reports mining companies' CAR within symmetrical and asymmetrical intervals surrounding Mariana's dam collapse. Individually, abnormal returns are estimated, through a Fama-French three-factor model, in the range of 756–10 trading days before the event date - estimation window - and in the range of 3 trading days prior to the event to 3 trading days after the event – event window. We chose to dismiss 10 trading days that separate the control window from the event windows as a procedure to reinforce the behavior of the two periods to be isolated. The columns display the statistics of the parametric (t-test) and nonparametric (rank-sum). The null hypothesis will test whether the abnormal return (CAR) is zero in correspondence to the event, against the alternative that it is different from zero. P-values (parametric test) and z-value (nonparametric test) in parentheses. *** $p < 0.01$.

[9] At the end of the last quarter of 2014, mining company Vale was valued at a market value of US $ 41.0 billion (Vale, 2015) and BHP Billiton at US $ 225 billion (Trading Economics, 2019).

the effect of the event in a longer and symmetric window (−3, + 3) and, at the bottom, the effect in a shorter asymmetric window (0, + 3). Constructing our test statistics using abnormal returns, we verified that the effect is statistically significant. The effect that is captured by both parametric and nonparametric[10] tests at 1 per cent level indicates Samarco's parent companies having their CAR negatively affected during the event window. And, as expected, the asymmetric window sustains a significant variation following the event.

A well-known control design in the event study literature consists of comparing the "target" companies to a set of control companies, and investigating whether the event under consideration has a significantly different impact on their abnormal returns. The main idea is to evaluate how these firms unrelated to the Mariana event perform in the dam collapse window- i.e. whether after the succession of an event as Mariana's the effect over stocks is restricted only to the two parent companies, or if there is an overflow to other similar enterprises.

The control group is formed by the mining companies Atlas Iron, Mount Gibson Mining Iron, Rio Tinto, MMX Mineraç ão e Metálicos, and Cleveland-Cliffs.

Table 2 reports the results of our control and comparative group, where no significant negative variation is observed within the event widows. The Brazilian market-traded MMX MineraãoMinerao e Metálicos presented a significant and positive variation in its returns, indicating that not surprisingly the Mariana dam collapse and the involvement of some of their competitors (Vale, BHP Billiton and Samarco) were a beneficial event for the company. From the remaining control companies, only Atlas displayed a level of positive effect for the non-parametric test in the (0;+3) window while the others did not present any significant variation. As expected although most of these companies do not benefit from the disaster involving the image of its competitors, we do not verify a negative CAR during the event, i.e. Rio Tinto, Atlas, Mount Gibson, and Cleveland-Cliffs were not affected by Mariana's event.

Our findings indicate that the Samarco`s dam collapse in Mariana conveyed new information relevant to the financial market, which is manifested in statistically significant negative stock abnormal returns for firms that held Samarco`s operations. These results help us understand how the mining companies ultimately involved in the dam's collapse failed to anticipate the event. Only after the dam collapse information becomes publicly available, the event was incorporated into stock prices being traded – as can be noticed when we look at the drop in returns after November 5, 2015. This finding also follows the market efficiency theory, which discusses that news being informed at t + 1 should affect the prices at t + 1, and this variation would be independent of any variations that occurred in t (Malkiel, 2003).

5.2. Do authorities' response lead to market punishment?

Fig. 5 displays the chronological listing and a brief description of all the main announcements regarding the Federal Prosecutor's Office Public Civil Action. The lawsuit is filed on May 4, 2016 - six months after the dam collapse - and ends on June 25, 2018. It's in this date that a final agreement between the parties is signed and the R$ 155 billion fine (approximately US$40 billion) is suspended. It is worth noting that, throughout the developments of the lawsuit, the Brazilian court granted a total of 5 deadline extensions for the presentation of the agreement terms by the companies. Therefore, the authority suspended the execution of the R$ 155 billion fine at each new extension.

Table 3 displays the "justice effect" measured by the R$ 155 billion lawsuit filed by the Federal Prosecutor's Office against Samarco. The effect is assessed in a symmetrical window (−1; +1) around the date of each new development previously listed (see Fig. 5). When we evaluate the abnormal stock returns reported in the face of these judicial decisions related to Mariana`s disaster, we find that most of the initial negative returns are no longer significant throughout the entirety of the prosecution process. From a total of 11 decisions, our test statistics show the initial and final announcements presenting a significant effect on the companies involved. In fact, the 1st decision (opening of the Public Civil Action), characterised by the prohibition of asset encumbrance and the distribution of profits of the three companies involved, Samarco, Vale and BHP Billiton, was a clear and strong indication of the Brazilian authority disposition to pursue a severe punishment for the case.

This decision shifted dramatically the market's perception concerning the burden that the mining companies would have to bear for Mariana's disaster. In March 2016, only two months before the release of the R$ 155 billion lawsuit, the companies had firmed an agreement with the Union and the states of Minas Gerais and Espírito Santo. In this agreement, a R$ 20 billion reparation fine was designated for the disaster. As a consequence, six months after the dam collapse, we observe a significant market negative reaction as a potential response to the Federal Prosecutor's Office announcement - substantiated by the parametric and non-parametric test.

In the following 10 decisions, of which 5 correspond solely to deadline extensions for presenting the terms for the final agreement, at least for the Brazilian company (Vale), the Federal Prosecutor's Office's lawsuit did not result in any loss for the company. It is even possible to note a positive CAR on the closing date of the Public Civil Action – but without statistical significance. Regarding BHP Billiton, our findings show that in the third and fourth decisions there is a significant variation. These variations, however, may be under effect of other relevant facts that occur around these dates. March 16 and May 15, 2017, correspond to a strike period in one of the mining company's major operations in South America and the sale announcement of the company's US shale operations, respectively (Hume and Sanderson, 2017; Reuters, 2017).

However, as the decisions evolve, the Australian mining company begins to present the same pattern verified in the mining company Vale where the decisions have no significant negative variation in its CAR[*i*]. It is in the last two developments that, interestingly, our findings show that another deadline extension and the conclusion of the Federal Prosecutor's Office's action lead to a positive and significant effect for BHP Billiton. This behavior suggests that given the negative expectation created by the initial terms of the Public Civil Action, the terms of its end were evaluated as beneficial to the mining company. The final agreement established the immediate extinction of a R$ 20 billion fine - which was also associated with the action during the process - and the suspension of the original R$ 155 billion fine.

These results illustrate well how the same institutional response produces a distinct effect on the market over time. Initially, we observe a negative shock caused by the opening of the Public Civil Action, but next, we note the market losing sensitivity given the action's developments. It can be noted that much of the immediate price reactions spotted nationally and internationally in the 1st decision were due to fear that a harsh and coordinated punishment from the Federal Prosecutor's Office (the highest public prosecutor body in the Brazilian judicial system) would take place against the companies. However, the prosecution process proved to move slower than expected (we noticed that the next decision only comes out on January 17, 2017, almost a year after the 1st decision was reported), which could have informed stock owners of a Brazilian judicial system much less driven to seek reparation for the victims and damages than originally expected.

Another explanation for a series of non-significant and even positive reactions to the decisions on Mariana`s case - as the mining company BHP Billiton's returns record - is to take into account that most of these decisions refer to deadline extensions granted by the authorities so that companies could present their reparation proposal without facing any

[10] We decide to perform the t-test and the rank-sum test - the latter relaxing more the assumptions of variance and normal distribution - since the non-parametric test is less influenced by deviations from normality which can characterize high data frequency (BROWN; WARNER, 1985).

Table 2
Assessing the impact of the dam failure on the comparative mining companies.

	Mount Gibson		Atlas		Rio Tinto		MMX		Cleveland-Cliffs	
Event window	*Parametric test*	*Nonparametric test*	*Parametric test*	*Nonparametric test*	*Parametric test*	*Nonparametric test*	*Parametric test*	*Nonparametric test*	*Parametric test*	*Nonparametric test*
(−3;+3)	0.017	0.536	0.045	2.345	-0.015	-1.397	0.540 * **	4.309 * **	0.036	-0.157
	(0.5652)	(0.5920)	(0.1380)	(0.0190)	(0.6478)	(0.1624)	(0.0005)	(0.0000)	(0.6769)	(0.8754)
(0;+3)	0.029	0.859	0.054	2.014	-0.031	-1.610	0.523 * **	3.212 * **	0.053	0.142
	(0.4558)	(0.3904)	(0.1687)	(0.0441)* **	(0.4952)	(0.1075)	(0.0103)	(0.0013)	(0.6376)	(0.8874)

Notes: This table reports mining companies' CAR from the control group within symmetrical and asymmetrical intervals surrounding Mariana's dam collapse. Individually, abnormal returns are estimated, through a Fama-French three-factor model, in the range of 756–10 trading days before the event date - estimation window - and in the range of 3 trading days prior to the event to 3 trading days after the event – event window. We chose to dismiss 10 trading days that separate the control window from the event windows as a procedure to reinforce the behavior of the two periods to be isolated. The columns display the statistics of the parametric (t-test) and nonparametric (rank-sum). The null hypothesis will test whether the abnormal return (CAR) is zero in correspondence to the event, against the alternative that it is different from zero. P-values (parametric test) and z-value (nonparametric test) in parentheses. * ** $p < 0.01$.

Table 3
Assessing Justice effect's impact.

	VALE S.A.		BHP Billiton	
Judicial decisions	Parametric test	Nonparametric test	Parametric test	Nonparametric test
	(−1, +1)	(−1, +1)	(−1, +1)	(−1, +1)
1st	− 0.529 * **	− 2.784 * **	− 0.377 * **	− 2.992 * **
	(0.0002)	(0.0054)	(0.0001)	(0.0028)
2nd	-0.118	-1.530	-0.166	-1.653
	(0.4048)	(0.1261)	(0.0864)	(0.0982)
3rd	-0.117	-1.530	− 0.192 * **	-1.854
	(0.4097)	(0.1261)	(0.0480)	(0.0638)
4th	-0.189	-1.698	− 0.198 * **	-1.899
	(0.1825)	(0.0895)	(0.0410)	(0.0576)
5th	-0.027	-1.229	-0.184	-1.775
	(0.8513)	(0.2190)	(0.0572)	(0.0759)
6th	-0.031	-1.235	-0.081	-1.237
	(0.8287)	(0.2170)	(0.4025)	(0.2160)
7th	-0.035	-1.245	-0.086	-1.256
	(0.8060)	(0.2131)	(0.3747)	(0.2093)
8th	-0.101	-1.482	-0.043	-0.876
	(0.4748)	(0.1383)	(0.6562)	(0.3809)
9th	-0.034	-1.242	-0.022	-0.647
	(0.8126)	(0.2141)	(0.8241)	(0.5177)
10th	0.025	-1.005	0.159	1.986 ***
	(0.8613)	(0.3148)	(0.1003)	(0.0471)
11th	0.161	1.387	0.206 ***	2.115 ***
	(0.2552)	(0.1653)	(0.0339)	(0.0345)

Notes: This table reports mining companies' CAR in an interval (−1; +1) surrounding each of the 11 main Federal Prosecutor's Office decisions. Individually, abnormal returns are estimated, through a Fama-French three-factor model, in the range of 756–10 trading days before the event date - estimation window - and in the range of 3 trading days prior to the event to 3 trading days after the event – event window. The columns display the statistics of the parametric (t-test) and nonparametric (rank-sum) tests. The null hypothesis will test whether the abnormal return (CAR) is zero in correspondence to the event, against the alternative that it is different from zero. P-values (parametric test) and z-value (nonparametric test) in parentheses. *** $p < 0.01$.

late fees. Finally, on June 25, 2018, a final deal was closed among Samarco, its shareholders, and the Brazilian Federal Prosecutor's Office. The terms companies had to comply with in order to have the R$ 155 billion fine suspended was largely seen as mild by civil society organizations and the communities directly affected by the dam collapse in the Mariana region. For those, the companies` financial proposal was incompatible with the need for full reparation of those affected.

Finally, as a robustness exercise, we conducted a 'placebo' experiment by selecting the days around November 5, 2014. This date corresponds to returning one year before Mariana's dam collapse. Therefore, the new test aims to capture any seasonality that may be present in this period of the year and which, reasonably, would be influencing the significant variation found in Table 4. As we can observe, the results demonstrate that, in general, no significant variations are occurring in this same period of the year for both mining companies. It is even possible to verify, through the nonparametric test, that Vale has a positive and significant CAR in (−3, + 3) around the date. Hence, gathering this result with the observed behavior of the control mining companies (Table 2), the hypothesis of a merely spurious relationship between the findings of our study is weakened.

Table 4
Placebo effect.

	VALE		BHP Billiton	
Event window	*Parametric test*	*Nonparametric test*	*Parametric test*	*Nonparametric test*
CAR				
(−3, +3)	0.097	2.207 ***	0.060	1.959
	(0.0535)	(0.0273)	(0.0617)	(0.715)
(0,+3)	0.088	1.526	0.056	1.383
	(0.1877)	(0.1271)	(0.1905)	(0.1667)

Notes: Falsification exercise of the cumulative abnormal return (CAR) reported by mining companies one year before the event. The columns display the statistics of the parametric (t-test) and nonparametric (rank-sum). The null hypothesis will test whether the abnormal return (CAR) is zero in correspondence to the event, against the alternative that it is different from zero. P-values (parametric test) and z-value (nonparametric test) in parentheses. * ** $p < 0.01$.

6. Concluding remarks

This study has evaluated the relationship between companies involved in environmental disasters and the stock market reaction to this involvement. We focused on one of the most relevant Brazilian socio-environmental disasters: the Samarco's dam failure on November 5, 2015, in Mariana, in the state of Minas Gerais. Based on an event study approach, we found evidence of a negative impact on the abnormal returns (CAR) of the two Samarco's parent companies, the Brazilian Vale and the Australian BHP Billiton, while a similar effect was not observed in a set of comparative companies (Atlas Iron, Mount Gibson Mining Iron, Rio Tinto, MMX Mineração e Metálicos, and Cleveland-Cliffs). These results help us understand how the mining companies ultimately being involved in the dam's collapse failed to anticipate the event (news informed at $t + 1$ only affected the prices at $t + 1$ onwards), and also how value losses primarily reflect their expected future legal penalties.

In order to better understand how legal penalties originated from the Mariana dam collapse affects the companies, another strategy we followed was to investigate whether the market reacted negatively to the Brazilian authorities' procedures in penalizing the mining companies involved in the disaster. Our results illustrate well how the same institutional response produces a distinct effect on the market over time. Initially, we observe a negative shock caused by the opening of the Public Civil Action, but next, we note the market losing sensitivity given the action's developments – mostly beneficial to the companies as deadline extensions and ultimately the ending of a R$ 155 billion fine. And, finally, in its outcome, we concluded that whether for the long period until the conclusion of an agreement and/or the positive expectation concerning the terms in which the negotiation was closed, the market no longer reacts negatively in response to the authority's legal proceedings. In this period, it is even possible that the market receives the information on the legal developments with optimism - as the mining company BHP Billiton's returns record.

As discussed by Carpentier and Suret (2015), our results stress the importance of a solid institutional response following a disaster, encouraging the market to also perform as an agent penalizing the involvement of companies in such events. This paper does suggest that the coordination time spent by the Brazilian authorities to follow a more objective line of action, in addition to the continuous deadline extensions granted for the mining companies were interpreted as positive signals by the market. Our findings point out a reduction in the expectation that a severe and agile punishment would truly take place after Mariana's disaster, which raises concern on the punishment capacity Brazilian institutions can penalize companies operating in Brazil's mining sector.

CRediT authorship contribution statement

T.P. Assis: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Software, Data curation, Investigation. **F.F.Cordeiro:** Concpetualization, Methodology, Supervision, Validation. **L.C. Schiavon:** Concpetualization, Methodology, Supervision, Validation.

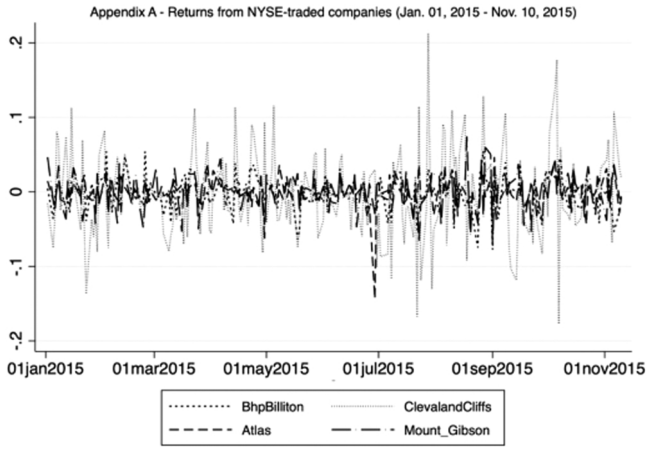
Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in the paper

Data Availability

Data will be made available on request.

Appendix



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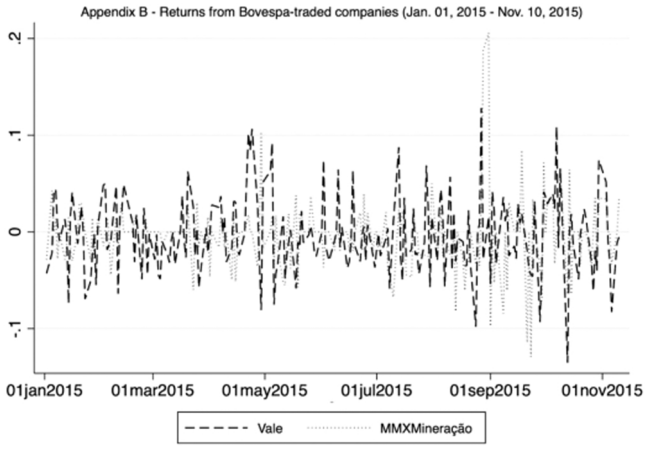

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Appendix C. - Pearson`s correlation NYSE-traded companies (Jan 01,2015 - Oct 30, 2015)

	BHP Billiton	Atlas	Mount Gibson	Cleveland Cliffs
BHP Billiton	1			
Atlas	0.3004 **	1		
Mount Gibson	0.3024 **	0.2883 **	1	
Cleveland Cliffs	0.4334 **	0.1799 **	0.0513	1

Note: Pearson's correlation of the NYSE-traded mining companies' returns. ** $p < 0.05$

Appendix D. - Pearson`s correlation Bovespa-traded companies (Jan 01,2015 - Oct. 29, 2015)

	Vale
MMX Mineraç ão	0.1530 *

Note: Pearson's correlation of the Bovespa-traded mining companies' returns. ** $p < 0.05$

Appendix E. - Adjusted EBITDA of NYSE-traded companies for the first semester of 2014

BHP Billiton	Rio Tinto	Cleveland Cliffs	Atlas Iron	Mount Gibson
US$12,300,000,000	US$544,000,000,000	US$656,000,000	US$125,000,000	US$73,200,000

Appendix F. - Adjusted EBITDA of Bovespa-traded companies for the first quarter of 2014

Vale	MMX Mineraç ão e Metálicos
US$ 4100,000,000	US$ (208,000,000)

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