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**Impactos dos Acidentes Ambientais de Mariana e Brumadinho no Preço das  
Ações da Mineradora Vale S.A.**

*Impacts of the environmental accidents in Mariana and Brumadinho on the share  
price of Mineradora Vale S.A.*

*Impactos de los accidentes ambientales en Mariana y Brumadinho en el precio de  
las acciones de Mineradora Vale S.A.*

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**PALAVRAS-CHAVE**

Impacto Ambiental,  
Estudo de Eventos,  
Hipótese do Mercado  
Eficiente.

**Resumo:** Em novembro de 2015, a barragem Fundão, localizada em Mariana (MG), e controlada pelas empresas Vale S.A. e BHP Billiton Brasil, rompeu-se e causou o vazamento de rejeitos industriais. Em janeiro de 2019, a barragem 1 da Mina do Córrego do Feijão, da Vale S.A., localizada em Brumadinho (MG), também se rompeu e despejou no meio ambiente rejeitos de mineração. Incidentes como esses têm diversas consequências na sociedade, e uma delas é a forma com que o mercado financeiro reage a esse tipo de evento. Diante disso, o estudo objetivou avaliar a reação das ações da Vale S.A. no mercado de capitais brasileiro ao rompimento das barragens, através da hipótese dos Mercados Eficientes, em que os preços das ações refletem as informações disponíveis no

mercado. Para isso, foi utilizada a técnica de Estudo de Eventos como método. Os resultados mostram que, em ambos os casos, as ações da Vale S.A. foram impactadas de forma negativa pelos acidentes ambientais, sofrendo quedas nas suas cotações no curto prazo, se recuperando no longo prazo. Comparando os dois resultados, o acidente de Brumadinho acarretou uma queda no preço das ações mais acentuada, porém o Ibovespa não a acompanhou como fez no caso de Mariana.

#### **KEYWORDS**

*Environment Impact, Event Study, Efficient Market Hypothesis.*

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**Abstract:** *In November 2015, the Fundão dam owned by mining company Samarco, located in Mariana (MG), and controlled by the companies Vale S.A. and BHP Billiton Brasil, failed and caused the leakage of industrial tailings. In January 2019, dam 1 of the Mina do Córrego do Feijão, owned by Vale S.A. in Brumadinho (MG), also failed and dumped millions of m<sup>3</sup> of mining tailings into the environment. Incidents like these have several consequences for society, and one of them is the way the financial market reacts to this type of event, especially in the case of a company that has shares on the stock exchange. Given this, the study evaluated the Vale S.A. reaction to the accidents, in the Brazilian capital market. The Efficient Markets Hypothesis was used as a theoretical basis. As a method, we used an event study. Results showed that, in both cases, Vale S.A.'s shares were negatively impacted by environmental accidents and suffered a drop in their prices in the short term and recovery in the long term. Comparing the results, the Brumadinho accident led to a more accentuated fall in the price of shares, however, the Ibovespa did not follow it as it did in the case of Mariana.*

#### **PALABRAS CLAVE**

*Impacto Ambiental, Estudio de Eventos, Hipótesis de Mercado Eficiente*

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**Resumen:** *En noviembre de 2015, la represa de Fundão, propiedad de la minera Samarco, ubicada en Mariana (MG), y controlada por las empresas Vale S.A. y BHP Billiton Brasil, rompió y provocó la fuga de relaves industriales. En enero de 2019, la presa 1 de la Mina Córrego do Feijão, de propiedad de la minera Vale S.A., ubicada en la ciudad de Brumadinho (MG), también se rompió y arrojó millones de m<sup>3</sup> de relaves mineros al medio ambiente. Incidentes como estos tienen varias consecuencias para la sociedad, y una de ellas es la forma en que el mercado financiero reacciona ante este tipo de evento, tratándose de una empresa que cotiza acciones en bolsa. Ante eso, el estudio tuvo como objetivo evaluar la reacción de Vale S.A. en el mercado de capitales brasileño al colapso de las represas. Los resultados muestran que, en ambos casos, las acciones de Vale S.A. fueron impactadas negativamente por accidentes ambientales, sufriendo una caída en sus precios en el corto plazo, recuperándose en el largo plazo. Comparando los dos resultados, el accidente de Brumadinho provocó una caída más acentuada en el precio de las acciones, pero el Ibovespa no lo acompañó como lo hizo en el caso de Mariana.*

## Introduction

In the last decades, several environmental accidents happened in Brazil and around the world. Among them, we mention the rupture of the São Francisco dam in 2007, controlled by the former Mineração Rio Pomba Cataguases, in Mirai/MG (G1, 2015), which spilled 2 billion liters of mud; the explosion of the Deepwater Horizon oil rig, operated by BP in the Gulf of Mexico, in 2010 (Varela & Milone, 2014), which killed 11 people and was the worst spill in the oil industry; and the leak of thousands of barrels of oil during the operation of the US company Chevron, in the Bacia de Campos/RJ, in 2011 (CBN, 2016). In addition to these, there are accidents involving Vale S.A. dams in Mariana and Brumadinho.

On November 5, 2015, in the district of Bento Rodrigues, municipality of Mariana, Minas Gerais, the Fundão dam of the mining company Samarco S.A., controlled by the companies Vale S.A. and BHP Billiton, ruptured and caused the leakage of about 60 million m<sup>3</sup> of industrial waste mud (Araújo et al, 2018). This incident caused the death of 19 people, in addition to harming water courses, arable land, economic activities, and the biodiversity of the Rio Doce State Park (MG). At the time, it was considered one of the biggest environmental accidents in Brazil and the world.

About 3 years later, on January 25, 2019, dam 1 of the Córrego do Feijão Mine, owned by the mining company Vale S.A., located in the city of Brumadinho, in the metropolitan region of Minas Gerais, also ruptured and spilled into the environment about of 13 million cubic meters of mining tailings (Barcellos et al, 2019). This accident was also considered one of the biggest environmental accidents in the world, in addition to being the biggest

accident at work ever recorded in Brazil, causing more than 250 deaths and destroying the fauna and flora of areas that were affected by the collapse in the city, which contributed part of the Atlantic Forest biome (Viezorkesky et al, 2020). After this tragedy, Vale S.A. was punished with a fine applied by the Brazilian Institute of the Environment (IBAMA) in the amount of BRL 250 million, in addition to being sued in court for the blocking of funds (Forbes, 2019).

According to Nogueira and Angotti (2011), society has blamed industries for most of the degradation of the environment and, therefore, has started to charge them with greater environmental responsibility. Still, according to the authors, the reputation of companies came to be seen as the most important asset. Environmental disasters negatively affect the reputation of companies.

It is true that accidents of these magnitudes impact several areas present in society and a relevant focus that must be interpreted is the economic/financial one. As the municipalities of Mariana (MG) and Brumadinho (MG) depend heavily on the mining industry, disasters not only involve the mud of tailings that reached the ecosystem, but also the loss of revenue collected, which is reflected in the supply capacity of the essential services (Barcellos et al, 2019). Therefore, it is clear that, in addition to the deaths caused by disasters, there are also external consequences to the place where the event took place. An example within this universe of affected areas is the impact of environmental disasters on the financial market, that is, how this event affects the scenario of the capital market in the country where the tragedy occurred and the stock prices of the companies involved.

In this context, the main objective of this work is to analyze the reaction of the

prices of the shares of the mining company Vale S.A. after the occurrence of two of the biggest environmental tragedies in the country. In particular, the study intends to investigate the response of the capital market after the disclosure of the Mariana (2015) and Brumadinho (2019) disasters.

The research is justified by the need to update the literature on the subject since the events are recent and were not the subject of studies in this joint approach. In addition, society's concern about the environment has become ever greater (Vital et al, 2009). Several companies have been seeking to reconcile the environmental issue with the development of their activities. More and more, shareholders and stakeholders are including good practices concerning the environment, by companies, as criteria for investments and allocation of resources.

Through the event study methodology, we seek to assess the investors response in the Brazilian capital market to tragedies. For this, it investigates the return of shares in the periods of 200 days and 100 days before and after the ruptures of the Fundão dam, in Mariana, and dam 1 of Mina do Córrego do Feijão, in Brumadinho. This allows understanding of the reactions of capital market decision-makers to incorporating (or not) ethical and environmental issues into their business models (Araújo et al, 2018).

In the next section of the study, a literature review will be presented, addressing the theory of the Efficient Market Hypothesis and accounting information, followed by an analysis of the effects of environmental crises on the market. After this section, the methodology will describe the econometric model used in the study of events, moving on to the analysis of the results of the impacts of accidents in the Brazilian capital market. Finally, the article will reveal and analyze

its effects, as well as the observation of the way of disclosure and if there is a pattern of market reaction to accidents.

## **Research theoretical elements**

### **Efficient Market Hypothesis and Accounting Information**

According to Fama (1970), capital markets are fundamental for the economic development of a country by allocating resources available for investment. In addition, they provide signals for the formation of security prices, which must reflect existing information in the economic system at any time. Nobrega (2000) adds that the financial market is also important for allowing the approximation of two agents: the saver, who has excess resources; and the borrower, who is in the opposite situation, that is, the one who needs financial resources to make a certain investment. In this way, investors demand information that enables the evaluation, monitoring, and consideration of the performance of each asset acquired in this market (Nogueira & Angotti, 2011).

Regarding its efficiency, the market presents three degrees and possible classifications: weak, semi-strong, and strong (Takamatsu et al, 2008). The market is efficient in weak form when it completely incorporates information about past security prices into present prices (Nogueira & Angotti, 2011). Fama (1970) argues that the fundamental assumption of the weak form of efficiency is that expected returns under equilibrium conditions are formed from the set of available information, which is fully reflected in prices.

In the semi-strong form, only publicly available information will be reflected in the present price of securities (Nogueira &

Angotti, 2011). Public information is information that becomes known at the same time as it affects the price, that is, it affects it before anyone can negotiate it (French & Roll, 1986). In its strong form, the Efficient Market Hypothesis (EMH) indicates that prices reflect all existing information in the market, including private or privileged information (Nogueira & Angotti, 2011; Castro & Marques, 2013).

In addition to the theory, Fama (1970) also presented how the tests to identify the efficiency of markets should be. To test its weak form, the tests seek to assess how well past returns predict future returns. If a pattern of behavior, investment schemes, or price correlation with any variable is found, it is considered that the market has efficiency in its weak form. Fama (1991) called this test the predictability of returns test (Forti et al, 2009).

For the semi-strong form, the tests seek the speed with which asset prices reflect public information. The faster the price adjustment, the more efficient the market, as it offers less opportunity to obtain abnormal profits consequent on the information. Fama (1991) named this test an event study.

Finally, for the strong form, Forti et al (2009) understand that tests of this type of efficiency seek to detect ownership by some investor or insider of privileged information that is not reflected in prices and whether they could benefit from such information, obtaining abnormal profits. This test was called the private information test.

Later, Fama (1991) decided to improve his theory of the Efficient Market Hypothesis. For him, a market is considered efficient when prices reflect the information available to the point where the benefit generated with this information exceeds the cost of obtaining it.

Furthermore, although the definition established by Fama (1970) is difficult to achieve, there is an advantage in building a standard of comparison to determine the degree of efficiency of the various markets (Romacho & Cidrais, 2007).

According to Cardoso and Martins (2008), the semi-strong form is considered the closest form of market efficiency to reality, since many studies confirm this hypothesis. One of them is that of Forti et al (2009), who compiled data from the main national conferences in the financial area to identify whether the authors of the works accept or reject the weak, semi-strong, and strong forms of the EMH. As a result, the research revealed that 42% of the works accept, while 58% reject the weak form of the HME. 100% of the works reject the strong form of the HME, but, on the other hand, 100% of the works accept the semi-strong form of the HME, corroborating the statement by Cardoso and Martins (2008).

The Efficient Market Hypothesis is based on the assertion that the price of a share reflects the available information about the company that issued it and new information will change its quotation (Marques & Castro, 2013). The authors also carried out a study on the efficiency of the Brazilian market and the impact of disclosing accounting information on companies' stock prices. Through a study of events, considering the disclosure date of the financial statements, the authors concluded that the results reinforced the market efficiency hypothesis in its semi-strong form. This conclusion was reached because most of the financial statements did not significantly affect the prices of securities traded on the stock exchange.

Lopes (2002) argues that the information approach conceives accounting its role as a supplier of information to economic agents. Therefore,



it becomes evident that, over the years, accounting began to exercise the function of informing not only administrators and creditors but also shareholders and investors interested in investing their resources in the company in the financial market, using the statements that the company publishes.

Hendriksen and Van Breda (1999) explain that financial disclosure aims to provide useful information for investors to make decisions. According to the authors, “the disclosure made in the publication of financial information can be defined as the presentation necessary for the optimal functioning of efficient capital markets” (Hendriksen & Van Breda, 1999, p. 511).

Following this line of reasoning, Yamamoto and Salotti (2006) also argue that accounting information must be efficient to help its users' decision-making, and must have qualitative characteristics that allow them to assess the allocation of their financial resources. For information to be efficient, it must be inserted in an equally efficient market, whose definition is explained by the HME.

According to Camargos and Barbosa (2003), an efficient capital market presupposes that information meets legal requirements and the expectations of its participants, so that new information is absorbed quickly, with the consequent adjustment in security prices.

Alves and Borba (2009) studied the relevance of environmental information in making a company's investment decisions. Through qualitative research, 10 of the participants stated that environmental accounting information is highly relevant when making an investment decision. In addition, 3 indicated environmental information as the second most relevant. Nogueira and Angotti (2011) add that “environmental impacts generate repercussions that undermine the

confidence of investors, shareholders, consumers, and other social groups, causing damage to companies” (Nogueira & Angotti, 2011, p. 70).

### **Effects of Environmental Crises on the Market: Empirical Evidence**

Several studies were carried out analyzing the effects of relevant environmental accidents that occurred in the world. Nogueira and Angotti (2011) sought to identify the reaction of the capital market, through the variation of stock returns, to the disclosure of oil spills by companies in the oil sector. The authors selected 30 events from 4 companies in the oil sector: Petrobras, British Petroleum, Chevron, and Shell, between the years 2000 and 2010. The methodology used by the authors to assess the impact on stock prices of oil industries after the announcement of accident environments was the study of events. To estimate the event window, the authors established 11 days, the first 5 days before the accidents and the 5 days after them. The result showed that environmental events have an impact on the value of companies, but information about an oil spill takes a few days to reflect on share prices.

To assess the reaction of government stakeholders and shareholders concerning the oil spill accident in the Gulf of Mexico, involving British Petroleum (BP) in 2010, Varela and Milone (2014) verified how environmental risks of unsuccessful operations can burden companies, both in financial terms and in stock devaluations. For this, the method used by the authors was the single case study, raising the discussion on the theory of stakeholders, describing the accident, collecting data on the effects of the tragedy, and verifying what were the impacts of the actions of the stakeholders involved for BP. As a result,

they found that BP lost 55% of its market value compared to its value on the date of the accident. Furthermore, through statistical analysis, they concluded that the total recovery of BP shares would take around 7 years. Also, “ignoring the socio-environmental risks involved in operations can have unpredictable effects” (Varela & Milone, 2014, p. 14).

In the case of accidents in which the company Vale S.A. was involved, Araújo et al (2018) analyzed the reactions of the Brazilian and Australian capital markets after the environmental accident of the mining company Samarco, a joint venture divided between Vale S.A. and BHP Billiton. After collecting selected data from companies that had shares listed on the Brazilian and Australian stock exchanges, the authors conducted an event study, considering 200 days before and 200 days after the accident. In addition, the authors calculated the systematic risk (beta) to assess variations in the return of companies' shares. As a result, they found that, in the first days after the accident, the shares of Vale S.A. suffered losses, and soon after, after 10 days, the Brazilian market as a whole was affected. However, 60 days after the accident, the effect of instability on the share price was no longer felt. In turn, in the Australian market, the effect became significant only after 50 days.

Still on Vale S.A., Souza et al (2019) aimed to verify the impact of the Brumadinho dam rupture on the shares of companies linked to the mining market traded on Bovespa (currently B3) and to verify how this relates to market assumptions. For this, they used the event study technique and considered a window of events of 51 days (25 days before the accident, and 25 days after the accident). As a result, they verified that, with statistical significance, the rupture of the

Brumadinho dam negatively influenced the stock price of the analyzed companies. According to the study, the shares of Vale S.A. dropped around 25% on the day of the event, but that price remained stable until the end of the window.

Related to the Brumadinho accident, Viezorkesky et al (2020) established, as a research objective, the analysis of the reaction of the prices of the shares of the mining company Vale S.A. after the Brumadinho Dam accident, in addition to observing the impact of this event on the American mining market. In the event study, the time window was set at 200 days before and 200 days after the event date. As a result, the authors found that the accident harmed Vale S.A. share prices, with a drop of 24.52% on the first business day after the event and a reduction of 11.02% in average prices compared to the same previous period. In the American market, the authors concluded that the accident did not affect the American mining market, with only 3 companies out of the 11 selected with a drop in daily returns in the 200 days after the accident.

### **Research methodological elements**

The article is characterized as descriptive in terms of its objective, as it intends to describe aspects of a given population analyzed and establish relationships between variables. In practice, the article seeks to establish a relationship between the two environmental accidents mentioned above and the price of the security in the capital market of the company involved. Furthermore, the article is classified as quantitative. This is because, to achieve the objective of the work, it was necessary to use an econometric methodology.

With regard to procedures, the research is characterized as bibliographical and

documental. The bibliographic research is developed based on material, mainly scientific articles, which will support all phases of the research. According to Nascimento and Sousa (2016), documentary research consists of seeking, reading, evaluating and systematizing evidence to clarify past phenomena, with the aim of obtaining conclusions or explanations for the present. In the study, the documents will be obtained from the websites of the companies and data from the stock exchange.

Finally, it should be noted that the data used are secondary. The collection was carried out through the Economática® platform, which collects balance sheet data from Brazilian companies, CVM, AMBIMA, Bovespa or similar, since 1986. Economática® also states that, to ensure greater reliability, all available data are double-checked.

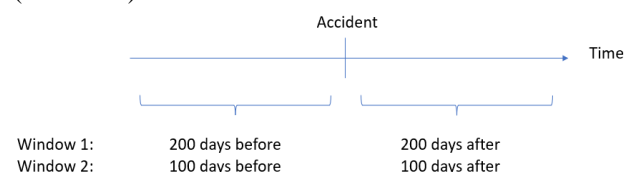
In order to analyze the effects of the accidents in Mariana and Brumadinho, the methodology chosen was the Study of Events, as it is the most appropriate for this purpose, according to the literature. This method consists of verifying the impacts of some specific event on the variable of interest. In this case, the interest lies in studying the influence of environmental disasters on the value of the common shares of Vale S.A., discounting the normal market variation. The preliminary hypothesis is that the events negatively influenced the mining company's shares.

According to Camargos and Barbosa (2003), the event study technique is used to measure the effect of disclosing specific information from a given entity on the price of its shares. Campbell and MacKinley (1997) point out that, assuming that the market is efficient, an event will have an immediate impact on prices.

In addition to determining the event itself, it is important to choose a time

window (Magness, 2008). This window consists of a period before the event, in which the variable of interest is not affected, and after the event (period in which the variable of interest suffers the effects of the event in question). For this study, two distinct windows are considered for each of the events. The first window consists of a period of 200 days before and 200 days after the events. The second window consists of a shorter period, characterized by 100 days before and after the events. The 200-day window was used according to existing literature (Araújo et al, 2018; Vierzorkesky et al, 2020). The 100-day window sought to find an intermediate value between 200 days and 25 days (work by Souza et al, 2019). It is also worth adding that there is no methodology to concretely define the size of a window, leaving it up to the researchers. In schematic terms, Figure 1 illustrates the windows and the event.

Figure 1: Timeline, Windows and the Event (Accident)



Source: Authors' elaboration

Based on Magness (2007), Equation (1) will be used to estimate the 4 models, one with the largest window and the other with the smallest window for each of the disasters.

$$Vale_t = \beta_0 + \beta_1 Ibovespa_t + \beta_2 Accident_t + \beta_3 (Ibov.Ac)_t + \varepsilon_t \quad (1)$$

Where: the subscript  $t$  refers to time, in days; *Vale* is the return, in percentage terms, of the shares of Vale S.A. (VALE3); *Ibovespa* is the return, in percentage terms,



of the Ibovespa index; *Accident* is a binary variable (dummy), which takes value 1 for the day of the event onwards and 0 otherwise (this variable will allow capturing the part of the total return that is attributed to a change in beta at the time of the accident); *Ibov.Ac* is a variable that measures the interaction between the returns of the Ibovespa index after the event;  $\beta$ 's are the parameters to be estimated; and  $\varepsilon$  is the random error term.

It is important to emphasize that for both return variables (*Vale* and *Ibovespa*), the following notation was considered:

$$\frac{(x_t - x_{t-1})}{x_t}$$

To estimate the  $\beta$  parameters, the Ordinary Least Squares (OLS) methodology will be used, also based on Magness (2007). As a preliminary hypothesis, it is expected that the returns on Vale S.A. are smaller after accidents. In practical terms, it is expected that  $\beta_3 < \beta_1$ . For hypothesis testing, Student's t test will be considered. All the mentioned procedures will be done through the Stata14® software.

It is worth emphasizing that it is necessary to prove the stationarity of the variables before the estimation. For this, Dickey-Fuller ADF tests will be applied. Next, one should verify whether, after making the estimates, there is the presence of autocorrelation and heteroscedasticity through the Durbin-Watson and Breusch-Pagan tests, respectively. If the presence of problems is verified, the model must be re-estimated considering corrective measures.

## Presentation and discussion of the results

### Disclosure of Environmental Accidents by the Company

Vale S.A. is a publicly traded company

and is responsible for approximately 13.7% of the composition of Ibovespa, which today is the most important indicator of the stock exchange in Brazil. Vale S.A. operates globally, being the largest producer of iron ore, pellets, and nickel in the world. In addition to mining, the company also operates in the logistics sector and efficiently integrates mines, railways, ships, and ports to transport the ore safely to the customer (Vale, 2023).

One of the purposes of the work was to analyze the forms of disclosure by Vale S.A. about the environmental accidents in Mariana and Brumadinho. For this, data were collected in the investor relations section on the mining company's website, on the website of the Securities and Exchange Commission, and on various journalistic portals on the internet.

When it comes to publicizing Mariana's accident, Vale S.A. published, still in 2015, three Relevant Facts<sup>3</sup> Relevant Facts on the subject, one of which was to address the impact of the accident on production, one just to convene conferences with analysts and investors to discuss the accident, and, finally, one to communicate on a public civil action in which it was summoned, together with Samarco and BHP Billiton, with a request for payment of compensation reaching R\$20 billion. In addition, the mining company also published the accident in its financial statement for the 4th quarter of 2015, highlighting it as a "Relevant Event". In the topic, the mining company detailed the case bringing four approaches, namely: (a) Accounting impacts on the investment resulting from the dam failure; (b) Socio-environmental remediation; (c) Contingencies; and (d) Insurance. The CVM published several articles about the accident on its website, and it is also important to note that the case made headlines in the main newspapers in the

country at the time, which justifies its relevance to society.

In terms of disclosing the Brumadinho accident to the market, a notable difference is the number of communications that Vale S.A. prepared concerning Mariana's accident, the number being much higher in the second accident. This may have been influenced by the fact that Vale has full control of the dam, and therefore has greater responsibility for communicating with the market and its investors. These communications ranged from information about the accident itself, exposing the number of victims of the accident, to the progress of judgments and sanctions suffered by the company during the year. In the financial statement for the 1st quarter of 2019, the accident was a key point, with an exclusive explanatory note for the event, in addition to a point of emphasis previously highlighted by the independent audit. The note referring to the accident is divided into subsections, namely: (a) financial impacts arising from the dam failure; (b) de-characterization of dams; (c) operation stoppages; (d) write-off of assets; (e) agreements; (f) donations and other expenses incurred; (g) contingencies and other legal matters. On the CVM website and in newspapers across the country it was no different, with several reports and announcements about the accident.

### Trajectory of shares in the market

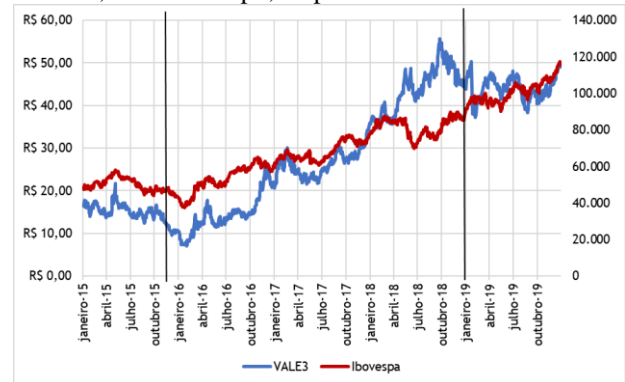
In light of the theoretical basis (Efficient Markets Hypothesis), market agents make use of all disclosed information to make their investment decisions. In particular, much of the attention of investors is focused on Notices to the Market and Material Facts from Vale S.A. In this sense, there is a negative reflection on the company's share price.

The following section discusses these effects on the company's share price.

### Graphical Analysis

Figure 2 shows the evolution of the two time-series used: Vale's share prices, on the left vertical axis, and Ibovespa prices, on the right vertical index. The black lines mark the dates of accidents in Mariana and Brumadinho, respectively.

Figure 2: Evolution of Vale's share price (VALE3), in BRL, and Ibovespa, in points

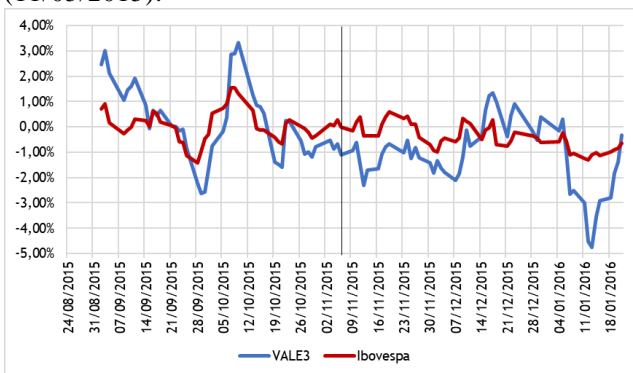


Source: Authors' elaboration based on Economática

In Figure 2, it is possible to notice that Vale's shares fell after both environmental disasters. However, it is worth noting that the fall during the first accident was visually smaller than the second. Moreover, during the first accident, the stock exchange index accompanied the fall, while, in the second disaster, the Ibovespa index was on an upward trajectory. In other words, part of the fall in Vale's share price during the first accident may have been driven by a drop in the market as a whole, and not entirely driven by the environmental accident. On the other hand, during the period of the second accident, Vale moved in the opposite direction to the Ibovespa. As the stock index rose, it was concluded that the main reason behind the fall in the price of Vale S.A. is the environmental accident.

To analyze stock returns, it is interesting to use the 7-day moving average, as it is an indicator that captures a trend. In addition, it also helps to mitigate volatility, which is quite characteristic when it comes to financial market indicators. Figures 3 and 4, below, illustrate the moving averages of percentage changes in Vale and Ibovespa shares. Vertical black lines mark the accidents.

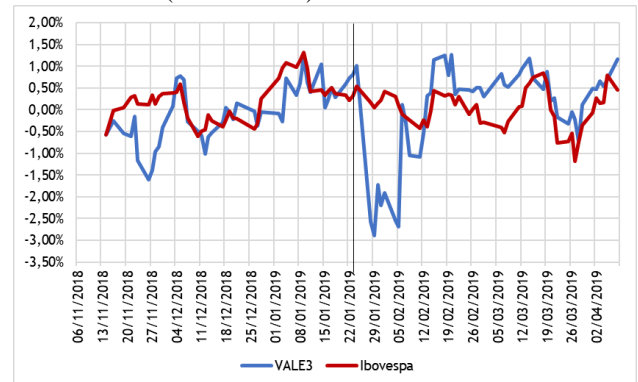
Figure 3: 7-day moving average for percentage changes in Vale and Ibovespa shares 100 days before and 100 days after the accident in Mariana (11/05/2015).



Source: Authors' elaboration based on Economática

In the case of Mariana, the shares of Vale S.A. suffered drops in the first few days, with a price of R\$14.24 on 11/04/2015 (1 day before the accident), and reaching R\$12.31 (Figure 2) a week later, a drop of 13.55%, which resulted in a 7-day moving average for percentage changes of -2.30% on 11/12/2015 (Figure 3). In addition, it was also observed that the Ibovespa was affected, accompanying the falls suffered by the mining company's shares. In the case of the Ibovespa, the 7-day moving average pointed to a devaluation of 0.06%. Thus, it is inferred that the poor performance of Vale S.A. shares, compared to the performance of the Ibovespa, is related to the environmental accident.

Figure 4: 7-day moving average for percentage changes in Vale and Ibovespa shares 100 days before and 100 days after the accident in Brumadinho (01/25/2019).



Source: Authors' elaboration based on Economática

In the case of the Brumadinho accident, it can be seen that the drop in share prices occurred more abruptly and aggressively compared to the fall in Mariana (Figure 2). On 01/24/2019, Vale's shares were worth R\$50.24. On the following business day, Monday, 01/28/2019, the shares closed the trading session quoted at R\$37.92, representing a drop of 24.52% from the previous price.

From the joint analysis of Figures 3 and 4, it is possible to notice that, in the period immediately following the Mariana and Brumadinho disasters, the percentage changes in Vale's shares were always at a lower level than the percentage changes in the Ibovespa. The highlight, however, is the second case, the Brumadinho accident, in which the moving average even indicated a 3% drop in the mining company's share price compared to a variation close to 0% for the Ibovespa. In the case of Mariana, the drop in stock returns was smaller, reaching -2%.

### Econometric Analysis

As these are analyzes involving time series, a preliminary step to the estimates

is to verify the stationarity of the variables. For this, the Dickey-Fuller ADF stationarity test was used. In it, the null hypothesis is that the series is not stationary. The results are shown in Table 1.

Table 1: Stationarity Tests

Variable	Mariana		Brumadinho	
	Statistic	p-value	Statistic	p-value
Vale	-17,504	0,00	-21,314	0,00
Ibovespa	-18,718	0,00	-20,102	0,00

Source: Authors' elaboration

Since all p-values are equal to zero, all null hypotheses are rejected. In this sense, it is possible to state that all series are stationary. Then, it is possible to estimate Equation (1) using Ordinary Least Squares estimators. However, it is necessary to verify the absence of autocorrelation and heteroscedasticity. In this sense, the Durbin-Watson tests were performed for autocorrelation and the Breusch-Pagan tests for heteroscedasticity. Both tests consider a significance level of 5%. The results are displayed in Table 2.

Table 2: Autocorrelation and Heteroscedasticity Tests

Autocorrelation		
	Mariana	Brumadinho
dW (n = 400; k = 4)	1,915	2,104
dU (n = 400; k = 4)	1,856	1,856
Heteroscedasticity		
	Mariana	Brumadinho
Statistic chi2(1)	4,90	56,87
p-value	0,027	0,000

Source: Authors' elaboration

For the Durbin-Watson self-correction tests, the absence of autocorrelation is observed if the following decision rule is met:  $dU < dW < 4 - dU$  (Gujarati & Porter, 2011). Considering the values shown in Table 2, it appears that the dW statistic meets the condition and, therefore, the

presence of autocorrelation is not detected for both cases.

In the case of Breusch-Pagan heteroscedasticity tests, the null hypothesis considers homoscedasticity, that is, constant variance. When analyzing the data in Table 2, the null hypothesis is rejected, thus confirming the presence of heteroscedasticity in both cases. Therefore, it is necessary to correct the problem, since, without homoscedasticity, the Ordinary Least Squares estimator is no longer the best and with minimum variance (Gujarati & Porter, 2011).

In this way, the models of Equation (1) are estimated considering consistent standard errors for heteroscedasticity, developed by Newey and West (1987). Table 3 presents the estimation results, considering the two accidents and the two windows (Figure 1).

Table 3: Estimation Results for Equation (1)

Variable	Mariana		Brumadinho	
	Window 1	Window 2	Window 1	Window 2
Ibovespa	1,625*** (0,1631)	1,59*** (0,216)	0,621*** (0,0978)	0,703*** (0,1387)
Accident	-0,00064 (0,0031)	-0,0012 (0,0046)	-0,00225 (0,0021)	0,00054 (0,0036)
Ibov.Ac	0,07342 (0,2207)	0,03433 (0,2948)	0,5002** (0,00216)	0,49630 (0,38401)
Constant	-0,00015 (0,0021)	0,00051 (0,0028)	0,00118 (0,00136)	-0,00112 (0,00196)
Obs	400	200	400	200
F	76,85	40,24	22,71	13,36
Prob > F	0,000	0,000	0,000	0,000
Robust standard error in parentheses				
* p-value < 0,10; ** p-value < 0,05; *** p-value < 0,01				

Source: Authors' elaboration

Regarding the results obtained in Table 3, it is noted that the signs presented by the variables are following the economic theory since a positive relationship was expected between the variables *Ibovespa* and *Ibovespa.Ac* and Vale's shares, and a relationship negative relationship between the Accident and the return of the mining

company's shares. In this sense, positive returns on the Ibovespa result in positive returns on Vale's shares. Analogously, the negative sign of the Accident variable can be interpreted as resulting in negative returns on the mining company's shares. The only exception was for the *Accident* variable, for Brumadinho, during Window 2, which showed a positive sign. However, it is worth emphasizing that the variable is not statistically significant, that is, in statistical terms, it is equal to zero.

Another relevant factor for the study is to verify the joint significance of the four models presented. For this, the F statistics and their respective p-values are used. Overall, all models are statistically significant, as all p-values are close to zero. In this context, it can be said that the adjustments of the models were adequate.

Finally, an important step is to test the preliminary assumption raised:  $\beta_3 < \beta_1$ . This means that it was expected that the estimated coefficients for the interactive variable (*Ibovespa.Ac*) would be lower than the average returns of the Ibovespa. It is important to point out that all the estimated coefficients for the Ibovespa are statistically significant and the coefficients for the interactive variable did not show statistical significance, except for Window 1 of Brumadinho.

In the case of the Mariana disaster, one can clearly see the confirmation of this hypothesis that  $\beta_3 < \beta_1$ , since the estimated coefficients are higher and statistically significant for the average market returns. Regarding the Brumadinho accident, although the  $\beta_1$  coefficients are higher, the difference in relation to the  $\beta_3$  is smaller. Furthermore, in order to confirm Brumadinho's Window 1, it is necessary to perform a hypothesis test, since both variables are statistically significant. Table 4 indicates the F-test performed.

Table 4: F Test for Brumadinho's Window 1

Null Hypothesis ( $H_0$ )	$\beta_3 = \beta_1$
F (1, 396)	0,17
Prob > F	0,679

Source: Authors' elaboration

The result of the F Test for Window 1 of Brumadinho indicates that the null hypothesis is accepted for a significance level of 5%. In this sense, no statistical evidence is found that the coefficients  $\beta_1$  and  $\beta_3$  are different, however, in general, the events marked by environmental accidents at dams had a negative impact on the return on Vale's shares. These results are valid for the two Windows of the Mariana disaster and Window 2 of Brumadinho.

Finally, it is emphasized that the findings of this work corroborate those found in the literature. Araújo et al (2018), Souza et al (2019), and Viezorkesky et al (2020) also found evidence that environmental accidents had a negative effect on the price of Vale S.A. shares.

## Concluding Remarks

The main objective of this study was to analyze the reaction of the prices of the shares of the mining company Vale S.A. and the Brazilian capital market after the two biggest environmental accidents in Brazil, which occurred in the city of Mariana in 2015, and in the city of Brumadinho in 2019, both in the state of Minas Gerais. As a hypothesis, it was postulated that the accidents would cause a drop in the value of the company's shares, given the Efficient Markets Hypothesis. For this, the daily values of Vale S.A. shares were collected, as well as the Ibovespa index points. Additionally, the research also had intermediate objectives, the first being to analyze how the two accidents were disclosed, and the second to



evaluate similarities and differences in the impacts of accidents on the financial market, and if there was any pattern of behavior.

Through the event study methodology, it was concluded that the two environmental accidents had a negative impact on the actions of Vale S.A. in the Brazilian capital market, confirming the preliminary hypothesis and reaching the objective of the work. It was noticed that the fall during Mariana's accident was smaller than the fall in Brumadinho. Regarding the Ibovespa index, only in the case of Mariana did the index follow the fall of the mining company's bonds. The conclusions found are in line with studies published on the same topic.

More specifically, in the case of Mariana's accident, it was found that the role of Vale S.A. had a drop of 13.55% in one week, representing a weekly moving average of -2.30%, influencing the Ibovespa index, which also fell in the same period. This result is in line with Araújo et al (2018), who also found that Vale's shares suffered losses in the early days.

In the case of Brumadinho, the study revealed that the fall in share prices occurred more abruptly, reaching 24.52% on the first business day after the accident, in addition to a weekly moving average of -2.88%, however, did not have such a large impact on the Ibovespa index, differing from the case of Mariana. The result of this research converges with the results of other previously published studies, such as Cruz et al (2020) and Souza et al (2019).

In the field of disclosures, it was observed that in both cases Vale S.A. published relevant facts and dedicated exclusive explanatory notes to the accidents in the quarterly financial statements for the period of the accidents, to better detail it for the reader of the document. According to the research

survey, it was found that in the case of Brumadinho, the mining company issued a greater number of communications concerning Mariana. As there was more information on the second accident, the negative impact on the company's share price was significantly greater.

Analyzing and compiling the results of previous studies and this present research, it was possible to perceive the existence of a pattern of behavior of the prices of the shares of companies involved in environmental accidents. In all cases studied, the accidents had a negative impact on share prices, resulting in a loss of market value for related companies. This shows the relevance that environmental accidents have not only for society in general but also for the economic and financial scenario. In January 2019, for example, the risk agency Moody's downgraded, on a global scale, the ratings of Vale S.A., in addition to changing the company's outlook to negative. For Moody's, the uncertainties related to the consequences of the environmental disaster impacted the company, with emphasis on litigation, compensation to families, financial liabilities, and class actions against the company. On the balance sheet, the company reported a total effect of BRL 19 billion, leading to a loss of BRL 6.4 billion in the 1st quarter of 2019 (Vale, 2019).

The results found are limited to the two accidents that occurred with the company Vale S.A., making generalizations impossible. On the other hand, the statistical model was based on assumptions supported by research that used the same methodology, whose event and estimation windows were arbitrary to some extent.

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