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DIESELGATE'S EFFECTS ON THE RELATIONSHIP BETWEEN AUTO MANUFACTURERS' ECONOMIC INDICATORS AND SHARE PRICES

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TABLE OF CONTENTS

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ABSTRACT

This paper investigates the effect of a company's environmental violation on the relationship between its share price and value drivers, as well as possible contagion. It examines whether valuation multiples remain stable when a company undergoes a crisis. Is there a structural break between the share prices and value drivers of Volkswagen, BMW, and Daimler following Dieselgate? Value drivers calculated from quarterly financial data and closing share prices are compiled for each company pre- and post-Dieselgate. Linear regressions are formed for each company and value driver. The Chow test detects a break between forward EBITDA and share price for Volkswagen and Daimler. A structural break is found when examining forward EPS and forward dividend per share in BMW's case. This supports the idea of a shift in investor attitudes toward Volkswagen, BMW, and Daimler following Dieselgate. No solid conclusion can be made as to which multiple is most vulnerable. In general, the relationship between financial indicators and share price was weaker following the scandal.

Keywords: Valuation multiples, Dieselgate, economic indicators

INTRODUCTION

On September 18th 2015, Volkswagen receives a notice of violation from the United States Environmental Protection Agency. The document outlines the regulations under the Clean Air Act, intended to limit nitrogen oxide emissions from cars and the health issues they cause. Most critically, the letter details a "switch" implemented in certain Volkswagen vehicles. This switch monitors the environment around the car and reduces the emission control system when it detects it is not being tested (Brooks 2015). Using this, Volkswagen was able to circumvent the restrictions set out by the EPA. This sparked the scandal now known as Dieselgate. By the end of the year, the gravity of Volkswagen's predicament was clear. The initial EPA notice concerned 482 000 cars in the U.S., but Volkswagen later admitted to 11 million cars that had the device. The company set aside 6.7 billion euros for associated costs (Hotten 2015). Volkswagen's share price plummeted fast, losing over 30% of its share price within 5 days of the EPA notice (Snyder, Jones 2015). Nor was the damage limited to Volkswagen alone. Multiple studies have documented the effects of Dieselgate on other companies in the automobile industry.

With increasing attention paid to environmental issues and climate change, companies will be facing increasingly stringent regulations. For the European Union to reach its target of carbon neutrality by 2050, decisive action is required. The car industry has a significant role to play in this change, as car emissions make up 15% of EU carbon emissions (Reducing carbon … 2021). Nor are cars manufacturers performing at their expected level under the regulations, with emissions from new cars having increased in both 2017 and 2019. Car emissions must be reduced significantly to meet the 2050 target (CO2 performance … 2021). The increasing attention from regulators is placing pressure on car manufacturers to meet climate standards. The question arises: are investors concerned with the risks associated with climate change? Signs point to yes. A 2020 survey finds that institutional investors believe climate risks are currently under-priced on markets and that they are aware of the potential negative financial effects of climate risk (Krueger *et al.* 2020). Furthermore, Volkswagen's recent case has shown that markets react quickly and violently to perceived violations and even non-offending companies can be caught in the aftermath.

The research problem tackled in this paper is the relationship between intrinsic value and market value following a crisis. Previous papers have focused on the impact on the share prices of Volkswagen and other companies in the automobile industry. This paper approaches the issue from another angle. Rather than investigating whether share prices were affected, it explores the question: how is the relationship between share prices and value indicators affected by Dieselgate? To answer this question, this paper investigates possible structural breaks in the relationships between the share prices and indicators of intrinsic value of the companies under question. More specifically, the tools used are an ordinary least squares (OLS) regression and a Chow test. Each company's forward earnings per share (EPS), forward dividends per share (DPS), and forward EBITDA are regressed separately against the company's share price. Forward values are used to see whether changes in share price were associated with changes in the companies' financials. It can be argued that structural breaks between forecast share price and economic indicators were due to investors' perceptions of increased risk and the use of forward indicators based on actual data is meant to address this. If investors' perceived risks do not materialise through financial results, then a structural break could indicate a disconnect between expected financial results and actual financial results. This hints at an overreaction in the predictions made by investors. This paper tests two groups of hypotheses: that there are structural breaks in the relationship between Volkswagen's share prices and value indicators, and that there are structural breaks in the relationships between its competitors' share prices and value indicators. A Chow breakpoint test is run on the regression at Q3 2015. This paper examines quarterly data from 2010 to 2019.

The rest of the paper consists of a literature review, methodology, the results, and a discussion. The literature review goes over previous studies on market efficiency, price multiples, and the contagion effect. The final subsection is dedicated to Dieselgate and how the previous topics are relevant to this scandal. Next is the methodology section. This section outlines the statistical methods and software used, as well as the data and its sources. Any issues with the methods and data are described, in addition to the solutions used here. The results section presents graphs of the P/E ratio, dividend yield, and price-EBITDA ratios. The OLS regressions and the Chow test p-values are presented. Where relevant, pre- and post-Dieselgate regressions are also included. Finally, the discussion presents the results in a cohesive manner, along with conclusions.

1. LITERATURE REVIEW

1.1. Dieselgate

Dieselgate had a massive impact on stock markets and it has been a point of interest for researchers, who have studied the event from a variety of angles. Information regarding Volkswagen's misconduct was announced in public as early as 2007, yet it went unacknowledged by investors until the 2015 EPA announcement. Why was there an eight-year delay in investors' responses? The markets' passiveness towards this information has been used as an example of an informational cascade, where the majority of investors do not acknowledge the information held by the few. Instead of reacting to the information regarding Volkswagen's potential failure immediately, investors remained passive, following the lead of the others around them (Griffin, Lont 2018). The response would have occurred years earlier if investors were considering all relevant information when valuing the company.

After the announcement by the Environmental Protection Agency, Volkswagen's share price plummeted, resulting in a 21.6 EUR billion loss in market capitalization by the end of the week—nor was Volkswagen the only company to be affected (Bouzzine, Lueg 2020; Griffin, Lont 2018). In the US market, companies in the automobile industry lost a combined 1.59 billion USD after Dieselgate. Even companies in the supply chain were affected, with three such companies found to have lost 4.88 billion USD in value (Nunes, Park 2016). The magnitude of Volkswagen's infraction was sufficient to make investors wary of non-offending companies, purely for their association with Volkswagen and its industry. On the other hand, Tesla was able to net a positive cumulative abnormal return for 6 days after Dieselgate. Its distance from fossil fuels shielded it from Volkswagen's fallout and it offered an alternative to disillusioned investors (Barth *et al.* 2019).

BMW and Daimler, both more strongly associated with Volkswagen, did not fare as well as Tesla. Bouzzine and Lueg find that the initial EPA announcement causes a significant negative return in

Volkswagen's and Daimler's shares. Nor was the damage limited to that, as BMW and Daimler experienced further negative abnormal returns during subsequent Dieselgate-related announcements (Bouzzine, Lueg 2020). The contagion effect is also visible when examining the betas of the three companies. Dieselgate raised their beta coefficients for a short while, before they fell close to 0 as their correlation with the market was reduced (Čižinská *et al.* 2021). The above results indicate that Dieselgate had a prolonged significant effect on both Volkswagen and its competitors. The following sections explain the background and significance of these events.

1.2. Market efficiency

Before delving into the definition of an efficient market, it is important to understand what motivates people to invest in the first place. What value are investors getting from their investment? Value in an efficient market, as Fama (1970) explains it, is tied to future cash flows. From the point of view of investors, a common simple model states that they look to future dividends for these cash flows. Thus, in the eyes of investors, attractive companies are ones that can offer a steady stream of dividends (Shiller 1980). However, investors in real life may have preferences that are not represented by this theoretical model. For example, some investors may prefer value stocks, where the fundamentals are higher relative to price, over riskier growth stocks, which have potential for higher value over time. These dispositions depend largely on investors' past experiences and behavioural biases (Cronqvist *et al.* 2015). Additionally, investors can be swayed by soft values, such as social responsibility. One study finds that the emotional affect generated by responses to successes in corporate social responsibility increases investors' valuations of the company in question (Elliot *et al.* 2014). Market price may be affected by factors outside of future dividends, causing a deviation from the efficient market price.

Next, what is market efficiency? Fama (1970) explains that capital markets function to allocate resources. His theory of efficient markets is a central tenet of the modern perception of market efficiency. In his paper, an efficient market is defined as one in which prices reflect available information. Efficiency can be split into three categories. Weak form efficiency tests focus on whether current prices are derived from past prices. Semi-strong efficiency testing goes a step further and checks how quickly prices come to reflect information available to the public, such as annual reports, stock splits, etc. Strong-form efficiency tests verify whether some price-relevant information is exclusive to certain groups. In addition to the efficient markets model, past literature

has focused on two specific cases: the sub martingale and random walks models. In short, the sub martingale model implies that given information relevant to the price of a security, the predicted price is equal to or greater than the current price. As an extension, given the same information, it should be impossible to produce a higher return by trading the security, than by buying and holding it. The random walk model, on the other hand, states that price changes must be independent from previous ones and that the distributions of successive changes are identical. (Fama 1970).

There is a wide base of literature in support of market efficiency, but the subject is contested. In a blog post two weeks following the scandal, Damodaran (2015) examines the costs of the scandal to Volkswagen. He estimates that after Dieselgate, the market price of Volkswagen shares was roughly 10% below where it should be and chose to invest in the company (Damodaran 2015). The question arises: Could his choice be profitable? What would lead to such a disconnect between the intrinsic and perceived values of the company? This phenomenon has been studied for decades—a 1978 study found that markets took up to 45 days to adjust to earnings per share announcements (Brown 1978). One study investigated the link between accounting data and investor sentiment during the dot com bubble and the 2007 financial crisis. They found that, prior to the burst of the bubble, equity pricing models based on accounting data suffered from increased errors in periods of high investor sentiment. Similarly, more errors appeared alongside lower sentiment during the 2007 crisis (D'Mello, Gruskin 2013).

These results show that when the pendulum of investor sentiment swings in one direction or the other, share prices are not determined by financial data alone. Even if a drop in share price is warranted by the underlying financials, the drop is not necessarily proportional to the loss in intrinsic value. A similar effect can be found when examining changes in share prices. Stocks that undergo a significant decrease in value tend to demonstrate better returns than other stocks, implying that the price drop was too severe to begin with (De Bondt, Thaler 1985). In the opposite direction, companies whose share price rose suddenly by over 50 percent proceeded to perform 30 percent below the market for the following year (Howe 1986). Rather than rationally weighing the company's performance against its peers and predecessors, investors focus on current perceived successes and failures, then react accordingly.

In a market of perfectly rational actors, such phenomena should be impossible. Economic theory expects investors to make rational choices consistently, a view that is challenged by behavioural

economics and psychology. Take, for example, the regression towards the mean in winners' and losers' portfolios. Over long periods, it is unlikely for companies to maintain exceptionally good or particularly poor performances. However, people match their impression of the initial result to expected future performance, rather than considering the more likely outcome (Kahneman, Tversky 1977). Exacerbating this effect is the tendency to consider singular information over distributional data. Rather than considering the myriad different outcomes companies have had after difficulties, people are prone to focus in on the specific characteristics of the company under question (Kahneman, Tversky 1977; De Bondt, Thaler 1985). As a result, there is a tendency towards overreaction, which is directly visible in share prices. The representativeness heuristic examined in the field of psychology in Kahneman and Tversky's research, was pointed out by De Bondt and Thaler as another possible cause for this overreaction (De Bondt, Thaler 1985).

Mental shortcuts lead people to evaluate data points in terms of how well they fit a larger population, rather than the specifics of the item in question. There is also a tendency to be overly confident in one's evaluations and when making predictions based on them (Tversky, Kahneman 1974). In the language of stocks, this is matching a company's characteristics to the perceived characteristics of a successful or an unsuccessful company, rather than evaluating a company based on its own merits and failures (Tversky, Kahneman 1974). In general, people's ability to make predictions is vulnerable to several biasing factors. It is difficult to determine the trustworthiness of the information available, so mistaken sources are weighted equally with reliable sources. In addition, people prefer consistent, if limited, information over more comprehensive and scattered information. As a result, investors can fall prey to poor information when making their predictions on future price changes (Kahneman, Tversky 1977).

As explained in the beginning of this section, Fama's (1970) theory explains that market price is an accurate indicator of intrinsic value in efficient markets. However, several empirical studies have found events where this does not appear to be true. Justification for these inconsistencies has been found in the field of behavioural economics, which have presented various biases that can complicate evaluating intrinsic value. Investors may be especially prone to these biases during turbulent periods, such as Dieselgate, which can lead to overreaction. Previous research does not indicate with certainty that in the period following Dieselgate Volkswagen's and its competitors' share prices were accurate to their intrinsic value. As valuation multiples are often used for estimating intrinsic value, the next section is dedicated to their exploration.

1.3. Valuation multiples

There are various methods used for valuing companies, each with their own strengths and weaknesses. Broadly speaking, these are split between fundamental and relative valuation methods. Fundamental valuation can be described as the discounting of future cashflows of the company. This includes items such as dividends, residual income, and free cash flow. However, fundamental valuation is vulnerable to distortion if the wrong discount rate is selected, or if cash flows are predicted incorrectly. The calculation of the discount rate is a significant challenge when using this method. Relative valuation, on the other hand, uses price multiples. It functions by multiplying a firm's multiple by its peer group's average ratio between price and that variable. The method poses some challenges in the selection of the peer group and the possible nonlinear relationship between fundamentals and value (Nissim 2013). Nevertheless, due to the relative simplicity of the price multiple method, it is widely used. Among the analysts surveyed by Asquith et al., 99.1% of analysts use price multiples in valuation, while only 12.8% use discounted cash flow. In terms of accuracy, both methods appear to be similarly successful. The same study finds that price multiples set target prices with 48.4% to 55.1% accuracy, depending on the multiple used. Discounting methods reached an accuracy of 52.3% (Asquith *et al.* 2005). In general, price multiples fare better when used on larger companies (Lie, Lie 2002).

Price multiples are a multifaceted tool used by analysts. Some are more commonly used than others. Of the top three valuation methods found by Shahed et al. (2008), two were multiples. The first is price-earnings and the second is EV/EBITDA. Another oft-mentioned multiple, dividend yield, is less common, yet still features in many analysts reports (Shahed *et al.* 2008). In addition to being widely used, price-earnings has been found to be an accurate multiple. One study found that multiples based on a one-year forecast EPS had an average pricing error of -$0.01 when using a peer group of companies in the same industry (Liu *et al* 2002). EV/EBITDA has not had comparable results in terms of accuracy. When compared with other multiples, it ranks beneath price-earnings, yet above book value and sales multiples. However, it is still commonly used by analysts (Shahed *et al.* 2008). An additional attractive feature of the EBITDA multiple is its independence of capital structure, which is useful for drawing comparisons between companies (Lie, Lie 2002). Although EBITDA is often seen in the multiple EV/EBITDA, Liu et al. have found that using equity value instead of enterprise value resulted in better accuracy (Liu *et al.* 2002). Unlike the previous two multiples, dividend yield uses dividends instead of earnings-based

cash flows. It is comparable to the dividend discount method; however, it is the more frequently used of the two (Harbula 2009). For multiples in general it has been found that using forecasted values reduces the amount of pricing errors (Liu *et al.* 2002). As multiples are viewed as indicators of future results, a company's expected future growth has a positive effect on them. Profit multiples also increase with stability of known results and future growth (Harbula 2009). Similarly, several studies have found that valuations based on forecast data are more precise than those based on trailing historical values (Liu *et al.* 2002; Harbula, 2009; Hammel, Hodes 1957).

As mentioned above, value can be seen strictly as a result of fundamentals or as the result of investors' myriad conclusions and preferences. Furthermore, swings in share price can be a sign of consumer overreaction, which would drive perceived value further from intrinsic value. In the wake of the shock caused by Dieselgate alongside the uncertainty regarding future events, investors may well be valuing Volkswagen's fundamentals much differently from before. As a result, one could suspect a shift in the relationship between intrinsic value and perceived value.

H1a: There is a structural break in the relationship between Volkswagen's share price and EPS at Dieselgate.
H1b: There is a structural break in the relationship between Volkswagen's share price and dividends per share at Dieselgate.
H1c: There is a structural break in the relationship between Volkswagen's share price and EBITDA at Dieselgate.

1.4. Contagion effects of environmental violations

Dieselgate is an environmental violation, on the topic of which there have been multiple studies. Their effects have been studied as early as the 1980s, where the successes and failures of environmental management were found to influence company valuation. Since then, multiple event studies have confirmed these results, demonstrating that negative announcements related to environmental performance cause negative abnormal returns (Klassen, McLaughlin 1996; Lundgren, Olsson 2010; Gupta, Goldar 2005; Dasgupta *et al.* 2006). The market pays attention to environmental violations and is quick to punish companies who fail to follow standards. In fact, the effect is pronounced enough that it is not only limited to the offending companies. A study by

Wood et al. finds that from 1984 to 2016, the environmental violations of car manufacturers led to statistically significant negative returns in the general market. Interestingly, this effect is less severe in later cases, but fuel standard violations remain a serious offense (Wood *et al.* 2018).

This potential for negative contagion effects has been studied in the arena of environmental violations, as well as other contexts. In their paper, Laufer and Wang outline the factors that aid contagion: country of origin, industry, organisational type, and positioning. The presence of multiple of the aforementioned factors is a factor in itself (Laufer and Wang, 2018). In Volkswagen's case, other car manufacturers are at immediate risk of contagion, especially its German peers. Indeed, the negative effect on other automobile companies has been widely documented. In examining the many announcements along the timeline of Dieselgate, one study found that Volkswagen only faced statistically significant negative returns as the news of Dieselgate broke and several of the consequent Dieselgate-related events caused negative abnormal returns for Daimler and BMW (Bouzzine, Lueg 2020). Based on these previous findings, this paper hypothesizes that Volkswagen's competitors were subject to contagion due to their proximity to Volkswagen.

H2a: There is a structural break in the relationship between BMW's share price and EPS at Dieselgate.
H2b: There is a structural break in the relationship between BMW's share price and dividends per share at Dieselgate.
H2c: There is a structural break in the relationship between BMW's share price and EBITDA at Dieselgate.
H3a: There is a structural break in the relationship between Daimler's share price and EPS at Dieselgate.
H3b: There is a structural break in the relationship between Daimler's share price and dividends per share at Dieselgate.
H3c: There is a structural break in the relationship between Daimler's share price and EBITDA at Dieselgate.

2. DATA AND METHODOLOGY

2.1. Data

The sample covers the years 2010-2019 and uses quarterly data. Inspired by Bouzzine and Lueg (2020), the companies under study are Volkswagen and its two competitors, Daimler and BMW. The multiples investigated are Price-Earnings, P/EBITDA, and dividend yield. The sample consists of the financial indicators: earnings per share (EPS), EBITDA, and dividends per share (DPS). Data related to earnings is drawn from EIKON, while data relating to dividends per share is taken from the companies' annual and quarterly financial statements. Dividends per share figures use dividends attributable to common shareholders. For the per-share indicators, the figure is calculated using the amount of outstanding shares at the time. It should be noted, that changes in outstanding shares could influence the analysis. However, there are no major changes in outstanding shares aside from some shares being issued by Daimler and Volkswagen in the beginning of the period. To avoid unnecessary complication, this paper opts to use the values given by EIKON without adjusting for changes in outstanding shares.

Additionally, in order to describe movements in price more accurately, forward figures are used rather than trailing figures (Liu *et al.* 2002). Rather than forecasted figures, this paper uses actual forward values. As mentioned previously, Fama's (1970) explanation for such a change in these companies' share price is the intake of new information. Volkswagen's actions could lead to fines and loss of reputation, which would result in decreased profitability. This weakening of its financials would also reduce its intrinsic value. Thus, one expects that the change in share price would be proportional to changes in these indicators, such as future earnings or dividends. An erroneous estimation of the risk and costs associated with Dieselgate could result in a disconnect between the change in indicators and the change in share price. By using using forward indicators based on future results, this paper is able to verify whether the relationship between share price and financial indicators stays constant or whether a disconnect is present at Dieselgate. Such a disconnect would imply overreaction or underreaction on the investors' part.

Table 1 presents descriptive statistics for the forward figures used in the regression analysis. In terms of central tendency, Volkswagen differs from the other two companies. Its mean price is considerably higher, which is accompanied by a larger standard deviation. At this stage, it is not clear whether the larger standard deviation is due to high price alone, or whether Volkswagen's involvement in Dieselgate plays a role. The same effect is seen across all of Volkswagen's financial indicators. However, no variable stands out as having an especially high standard deviation relative to its mean value. Additionally, it should be noted that Daimler's EPS values have been trimmed. The current minimum is 0.36, but the three last quarters of the series included negative quarterly EPS values. Because negative EPS values cannot be used for financial analysis, they have been removed. As a result, Daimler's EPS has 37 observations, while all other samples consist of 40.

Table 1. Descriptive statistics of sample data

	Company	Mean	Median	St. Dev	Min.	Max.
Price	VW	142.7045	142.325	35.9304	69.96	240.05
	Daimler	55.9615	53.935	13.89762	33.63	89.73
	BMW	73.8245	73.975	16.74466	34.18	116.45
EPS	VW	26.863	23.625	8.86313	13.15	47.94
	Daimler	6.5	6.77	1.974915	0.36	9.61
	BMW	8.99	8.86	2.0414	4.98	13.08
EBITDA	VW	33552975	35039500	8311261	19301000	47584000
	Daimler	18362150	18870000	5433789	11074000	26857000
	BMW	15545825	16397500	2627216	10080000	19254000
DPS	VW	3.26725	3.4625	1.280113	0.11	4.8
	Daimler	2.505	2.325	0.755348	0.9	3.65
	BMW	2.7925	2.7875	0.771782	0.8	4

Source: Author's calculations based on data retrieved from Daimler, Volkswagen, and BMW financial reports

2.1. Methodology

To restate, the issue examined in this paper is whether Volkswagen and its peers were valued incorrectly on the market after Dieselgate. This paper approaches the issue through the lens of

intrinsic value. Markets assign certain values to financial indicators, such as earnings per share, dividend per share, and EBITDA. To determine whether the change in value perceived by the market was based on weaker financial results, one can test the relationship between share prices and financial indicators. If there is a change in this relationship following Dieselgate, one can conclude that investors perceive the value of these underlying financial indicators differently after the scandal. The Chow test can be used for this purpose. It verifies whether the coefficients of a linear regression remain stable across two periods. Given a series of observations, it tests whether a significantly better fit can be obtained by splitting the observations into two separate regressions at a pre-determined breakpoint (Chow 1960).

Although this method is useful, it has certain limitations. The number of observations in both pre- and post-Dieselgate periods must be greater than the number of regression coefficients (Rea 1978). Additionally, the variance of error terms in both periods must be equal. Otherwise, the test is less powerful (Toyoda 1974). Nor is heteroskedasticity the only concern, as autocorrelation within the sample can also distort the results of the Chow test (Giles, Scott 1992). These limitations have all been controlled for. First, heteroskedasticity and autocorrelation are controlled for using White's test and the autocorrelation tests in gretl. The results of the heteroskedasticity and autocorrelation tests are displayed in Appendix 1. All heteroskedasticity and autocorrelation were accounted for by adding a one-period lag of closing share price. The resulting models cover the period Q2 2010 to Q4 2019. In the case of BMW, heteroskedasticity remained significant until three lags were used. BMW's model includes data from before 2010, Q3 2009 being its earliest lag. Volkswagen and Daimler use Q1 2010 as the first lag. As a result, the samples have 39 observations each, except for BMW's EPS. As BMW had negative EPS values during the last three quarters of the data set, the data in question was trimmed down to 36 observations. With quarterly observations from a decade of data, the sample is much larger than the three to six regression coefficients used.

For the purposes of this paper, the test will be used to determine whether there was a structural break between certain indicators and market prices of Volkswagen and its competitors after Dieselgate. A separate linear regression model is drawn for each indicator and each company, in the simple form:

$$y_1 = x_1 B_1 + e$$

(Chow 1960). In this paper, x_1 represents the value indicator, B_1 the price multiple, and y_1 the share price. The independent variables also include a lag of the share price, to eliminate serial

correlation. For Volkswagen and Daimler, a one-period lag is used. BMW required three lags to eliminate serial correlation. An example of the Volkswagen EPS regression would be:

$$P_t = EPS_t B + P_{t-1} C + e$$

In the above equation, EPS_t represents forward EPS, P_{t-1} is the lagged share price, and B and C represent their coefficients. The rest of the models are formulated in a similar fashion, except for BMW, which have three lags of the share price.

3. Empirical analysis

3.1. Graphical analysis

Before diving into statistical analysis, this paper presents the price multiples and underlying indicators of Volkswagen, Daimler, and BMW in graphical form. This section aims to get an initial understanding of possible breaks in the relationships between the price multiples and indicators before and after Dieselgate. In addition, any relevant information is used to explain the results of later statistical analysis. Figure 1 presents the forward P/E ratios of Volkswagen, BMW, and Daimler from Q1 2010 to Q3 2019.

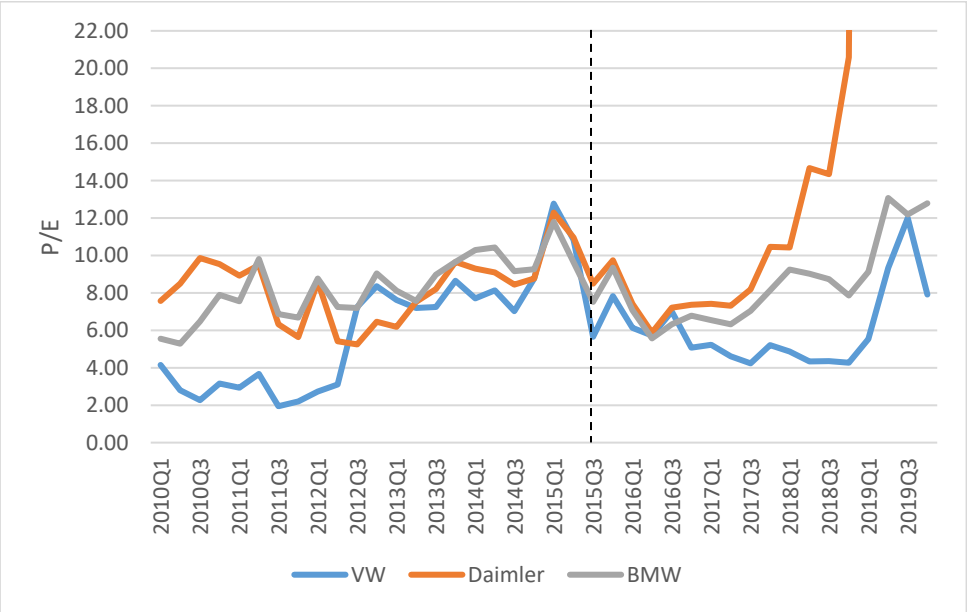

Figure 1. Forward P/E ratio 2010-2019
Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

Figure 1 indicates a possible shift at Q3 2015 for all three companies. Knowing that Volkswagen's share price plummets after Dieselgate, the dip in P/E is due to price change rather than an increase in earnings. Daimler and BMW are also subject to lower valuations, although Volkswagen's predicament is the most pronounced, being the company at the centre of the scandal. Based on this, it appears that after Dieselgate investors are paying lower prices for future earnings than they used to. On the other hand, it could be that investors were more cautious regarding the long-term performance of the companies. To explore this, Figure 2 shows the earnings per share for all three companies.

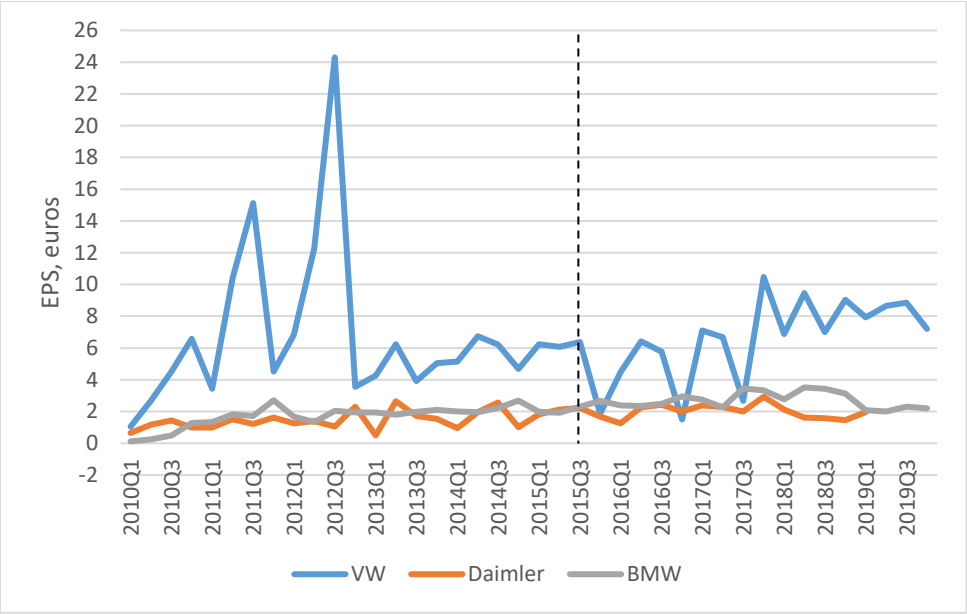

Figure 2. Normalized quarterly EPS 2010-2019
Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

Figure 2 does not indicate a sustained corresponding decrease in EPS following the scandal. While Volkswagen's quarterly EPS is much more volatile in the period after Dieselgate, it recovers by Q1 2018. Afterwards, it attains a higher level than in earlier periods. The P/E ratio does not follow suit, maintaining a slight decline until 2019.

The other two companies do not undergo an equally pronounced period of volatility in terms of earnings per share, with EPS growing at a similar rate as before the scandal. The P/E ratios of both Daimler and BMW are relatively stable prior to Dieselgate, with BMW showing signs of a slight

growth trend. After a drop at Q3 2015, Daimler's P/E climbs rapidly, while BMW's ratio returns to its pre-crisis level. Daimler's EPS becomes very volatile at the end of the period, even after quarters with negative EPS have been trimmed. Nevertheless, the soaring P/E suggests that investors were unprepared for this decreased performance. This could indicate a structural break between Daimler's EPS and share price unrelated to Dieselgate.

Since Daimler and BMW experienced actual lowered EPS towards the end of the period, this could justify the lower P/E ratios and negative investor sentiment. On the other hand, unrelated events (e.g., the Covid crisis) could also have influenced the valuations. To get a more complete understanding of these dynamics, this same analysis is run on alternative financial metrics. Figure 3 presents the forward dividend yield of all three companies.

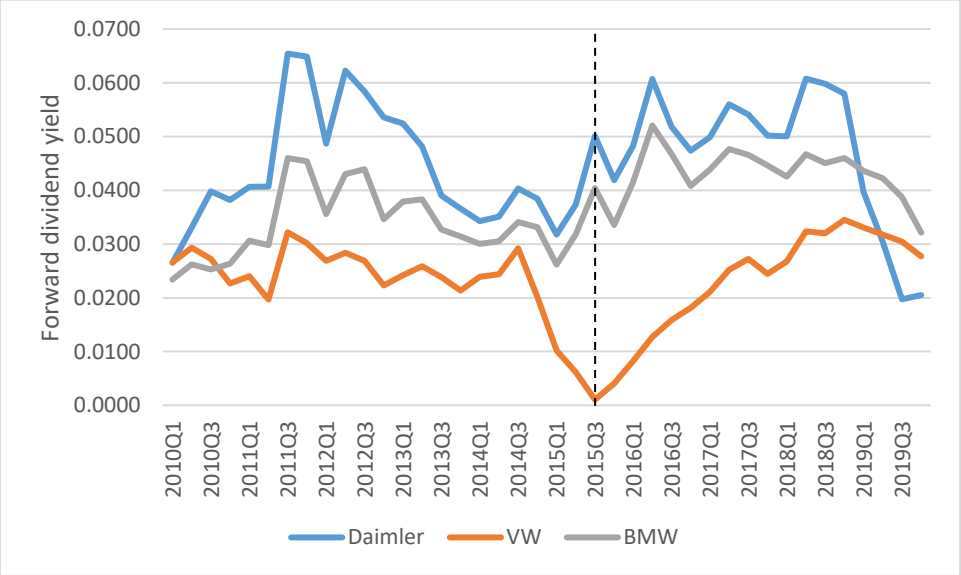

Figure 3. Forward dividend yield
Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

As with its P/E, Volkswagen's dividend yield experiences a substantial change during Dieselgate. As Figure 3 illustrates, dividend yield plummets towards the end of 2014. At Q3 2015, the trend bottoms out, before climbing back up. Volkswagen reaches pre-Dieselgate levels by 2017, after which dividend yield exceeds previous results. When examining the other two companies, a synchronised dip can be seen at Q3 2015. Unlike Volkswagen, its competitors do not experience

a large drop in dividend yield, but the multiple does follow and upward trend until 2018-2019. This is peculiar when considering the quarterly dividends shown in Figure 4.

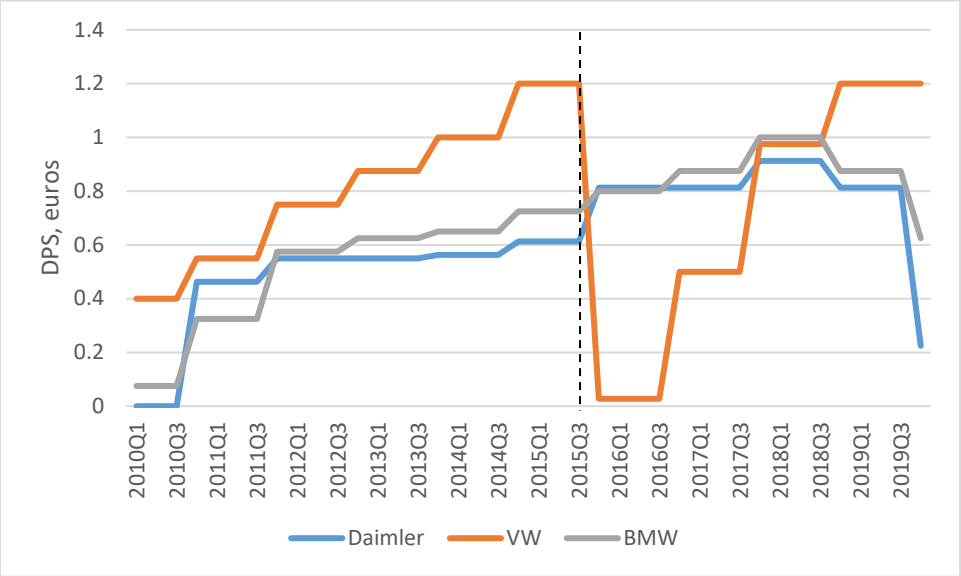

Figure 4. Quarterly dividend per common share, euros
Source: Author's calculations based on data retrieved from Daimler, Volkswagen, and BMW financial reports

As seen in Figure 4, Volkswagen slashes its dividend payouts for four quarters after Dieselgate. Over the four following years, dividends are quickly increased to pre-Dieselgate levels. When comparing this to Volkswagen's forward dividend yield, the rapid decrease in the latter makes sense. Markets did not adjust to the looming lack of dividends, because they did not see it coming. As a result, forward dividend yield plummets ahead of the crisis. The dividend yield takes a long time to recover, seeming to improve as dividends are increased. Pre-scandal, dividend yield had no clear upward trend even as dividends increased, meaning that share prices were increasing proportionally to changes to dividends. The fact that dividend yield does not recover despite increasing dividends per share implies that share prices are increasing slower than dividends during this period. This suggests that investors are valuing Volkswagen's shares lower than previously. However, this phenomenon is weaker after 2019, as dividend yield drifts downwards again. Whether due to improved trust in Volkswagen or an external factor, investors are placing value in future dividends again.

As for Volkswagen's two competitors, their dividends reveal an interesting turn in investor attitudes. Unlike Volkswagen, neither BMW nor Daimler reduce their dividends following Dieselgate. BMW increases its dividend payout at the same even pace as before. Daimler's dividend is increased after Dieselgate, stays unchanged for a year, then increases slightly the year after that. In neither case does the dividend payout appear to be affected by the events of Dieselgate. Nevertheless, dividend yield continues to climb as dividends increase, but share prices do not follow suit. It appears as though investors are wary of the two companies due to their proximity to the scandal, even though their financial performance does not justify such pessimism. This trend persists until Q4 2018, where dividend yield takes a downward turn for all three companies.

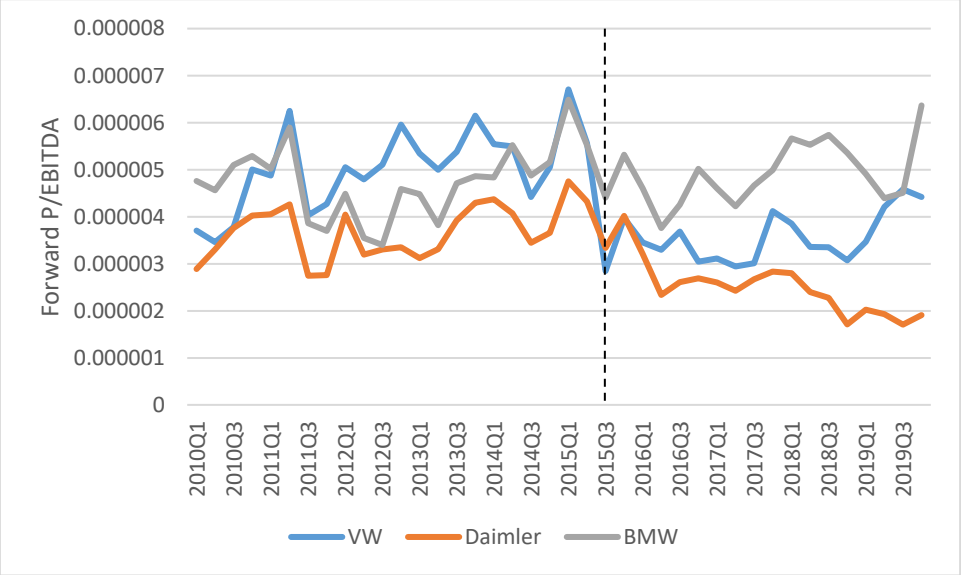

Figure 5. Forward P/EBITDA
Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

In Figure 5, the P/EBITDA ratios are presented. Leading up to Dieselgate, Volkswagen's P/EBITDA has an upward trend. At Q2 2015, the trend takes a sharp turn downwards, although the dip is comparable in size to the drop in Q2 2014. However, the plummeting value in Q3 2015 stands out. After Dieselgate P/EBITDA does not show signs of recovery and it remains at a noticeably lower level than it was in earlier periods. From 2019 onwards there is some sign of improvement, but the multiple does not come close to its pre-Dieselgate value. BMW and Daimler both experience a slight drop in Q3 2015, but the magnitude of the change is small when compared to Volkswagen. BMW's P/EBITDA does not display persistent effects after Dieselgate. Daimler,

on the other hand, has a much lower multiple than before, as well as a downward trend that persists until the end of the period. The underlying quarterly EBITDA are presented in Figure 6 for further analysis.

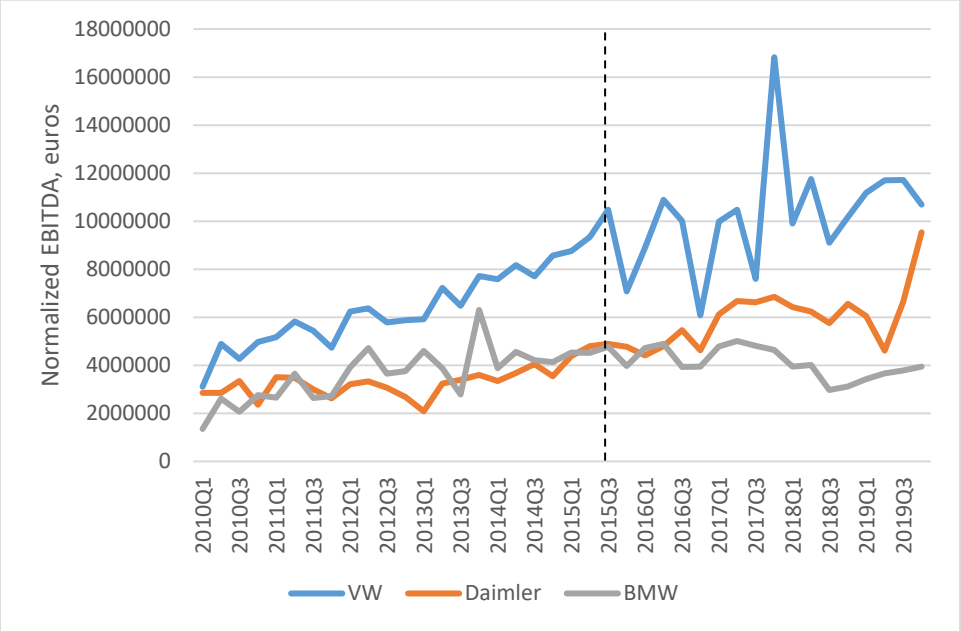

Figure 6 Quarterly normalized EBITDA, euros
Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

As with EPS, Volkswagen's quarterly EBITDA becomes more volatile following Dieselgate, as is shown in Figure 6. Up until Q3 2015, Volkswagen's EBITDA grows steadily without major spikes or troughs. Immediately after Dieselgate, Volkswagen's EBITDA sinks back to its level in 2013. It recovers by Q2 2016, before falling even lower than before. EBITDA continues to be turbulent during the rest of the period. In situations where companies' future performance is uncertain, such as volatile cash flows or earnings, valuation is more difficult. In these cases, investors are more prone to errors, such as overconfidence or representativeness biases (Kumar, 2009). As EBITDA became much more volatile after Dieselgate, it could be that investors were deterred by the difficulty of valuing Volkswagen. This could explain the lower P/EBITDA, especially since EBITDA still had a general upward trend, even if marred by its turbulence.

Daimler and BMW experience no similar troubles in terms of EBITDA. Daimler's EBITDA maintains a gentle upward trend until 2019. As there is no marked change in EBITDA following Dieselgate, the consequent downward trend in P/EBITDA is likely due to changed investor

attitudes. As for BMW, no significant change is immediately visible in EBITDA, or P/EBITDA. EBITDA remains stable during the entire period, nor is there a clear persistent change in P/EBITDA. It appears that aside from the drop in P/EBITDA after Dieselgate, the scandal has not influenced this multiple.

As evidenced by the mixed results above, it is unclear whether Dieselgate had a significant effect on the relationships between the multiples discussed and share prices. There are some shifts and trends that suggest structural breaks in Volkswagen as well as its competitors. To thoroughly investigate the matter, this paper turns to ordinary least squares (OLS) regressions. In the following sections, a Chow test is run using the same companies and indicators to determine whether there is a significant break at Q3 2015.

3.2. Volkswagen

The following section presents the results of the OLS regression. Based on the results in Table 2, it appears that the EPS regression model is somewhat suitable for describing Volkswagen's share prices during this period. All variables are below the 5% significance level, and the overall model has a significance level far below 1%. However, the coefficient of forward EPS is negative, which is unexpected. As investors value earnings growth, EPS should be positively related to share prices (Nissim 2013). It should also be noted that adjusted r^2 is only 51.9%. This regression model is a weak descriptor of share prices. The illogical EPS coefficient and low r^2 could indicate that the EPS predicted by analysts differed from the actual future EPS. The next step is to verify whether a structural break could help explain this result.

Table 2. Volkswagen forward EPS OLS regression 2010 Q2 – 2019 Q4

	Model	Forward EPS	Closing price$_{t-1}$	Intercept
P-value	9.77E-06	0.0387	0.0002	0.0039
Coefficient	-	-0.730745	0.610022	77.766
St. Dev	-	0.340565	0.147027	25.1864
Adjusted r^2	0.519058	-	-	-
Chow p-value	1.67E-02	0.1697	-	-

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

When examining the Chow test values in Table 2, however, no statistically significant break is found. The question remains: why is the EPS coefficient negative? An illogical EPS coefficient and low r^2 could indicate that the EPS predicted by analysts differed from the actual future EPS. The graphical analysis showed that analysts were not prepared for the decline in forwards EPS after Dieselgate. It should also be noted that the graphical analysis showed high volatility in EPS right after the crisis, as well as spikes in EPS at the beginning of the period. As discussed previously, investors are more prone to mistakes when valuing shares in a volatile environment (Kumar 2009). Additionally, profit multiples tend to increase with stability and growth (Harbula 2009). The importance of earnings stability has also been documented in previous studies. Janda finds that increasing earnings volatility leads to higher errors when using multiples-based valuation (Janda 2019). The study in question measured rolling average volatility, while the question at hand concerns future earnings. Nevertheless, these findings support the idea that Volkswagen's volatility led investors to be more cautious when valuing its earnings relative to the situation before Dieselgate.

To confirm that this effect was not limited to Volkswagen's earnings, this paper investigates whether Dieselgate had any significant effect on its other financial multiples. Table 3 displays the regression of forward EBITDA against share price. Much like forward EPS, EBITDA is a poor descriptor of share prices during this period. Although the model p-value is low, EBITDA has a high p-value, making it unsuitable for describing share prices. The adjusted r^2 is low, with the model describing only 49.5% of changes in share price. A Chow test is run to determine whether this ill fit is caused by a break in the data.

Table 3. Volkswagen forward EBITDA OLS regression 2010 Q2 – 2019 Q4

	Model	Forward EBITDA	Closing price$_{t-1}$	Intercept
P-value	1.04E-06	0.3569	0.0002	0.0151
Coefficient	-	3.76285E-7	0.645413	40.1695
St. Dev	-	4.03202E-7	0.158653	15.7439
Adjusted r^2	0.495041	-	-	-
Chow p-value	0.0040667	0.00297304	-	-

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

As shown in Table 3, the forward EBITDA for Volkswagen is an unsuitable descriptor during 2010 Q1 – 2019 Q4. Although the model's overall p-value is low, EBITDA has a high p-value. Nor is the model a suitable descriptor of share prices, as it only describes 49.5% of changes. Unlike the EPS, however, there is evidence of a structural break. According to the Chow test, not only the model, but EBITDA specifically undergoes a structural break after Dieselgate. There is a significant difference between the coefficient that EBITDA has before Dieselgate and after Dieselgate. As with forward EPS, there is a break in the overall model. However, there is also a significant break in forward EBITDA. In other words, the relationship between EBITDA and share prices was significantly altered after Dieselgate. Investors are weighting the indicator differently when evaluating Volkswagen's share price. The question remains: how did the relationship change? This can be answered by running two separate regressions pre-Dieselgate and post-Dieselgate.

Table 4 presents the separate OLS regressions for EBITDA before and after the break. Pre-Dieselgate, the model is not a perfect fit for describing share price changes. The overall p-value is beneath the 5% significance level. The intercept and lagged share price are not significant variables, hinting that the model could be improved for a better fit. Nonetheless, this paper's focus is the forward EBITDA, which performs passably as a descriptor. The model's adjusted r^2 is also high, at 79%. The model becomes unreliable after Dieselgate. The adjusted r^2 plummets to -9.7%, while the model's p-value rises well above the allowed 0.05. Perhaps the most drastic change is in EBITDA, whose p-value shoots up to 0.4889, making it an unusable variable. It appears that the structural break indicated by the Chow test was due to the EBITDA losing its power as an indicator. While investors appear to have used it when setting prices prior to Dieselgate, they are not doing so in the latter half of the period. As with EPS, EBITDA fluctuates after the scandal. Despite the fact that the general trend is mostly unchanged, P/EBITDA was much lower than it was pre-scandal. The OLS regressions suggest that investors were disregarding EBITDA in share valuations, perhaps due to this increased volatility. Instead, investors are turning to other indicators of value, whether financial or non-financial. To investigate the extent of this phenomenon, forward DPS is also analysed.

Table 4. Volkswagen EBITDA OLS regressions pre- and post-Dieselgate

Time period		Coefficient	Standard error	P-value

Q2 2010 – Q2 2015	Intercept	-40.0717	28.3370	0.1744
	Forward EBITDA	5.85472E-6	1.95007E-6	0.0076
	Closing $price_{t-1}$	0.151356	0.203010	0.4656
	Adjusted r^2	0.789951		
	Model p-value	5.32E-9		
Q3 2015 – Q4 2019	Intercept	126.616	44.8841	0.0129
	Forward EBITDA	6.12280E-8	8.62914E-7	0.4889
	Closing $price_{t-1}$	-0.0617726	0.272706	0.8239
	Adjusted r^2	-0.097360		
	Model p-value	0.780627		

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

The DPS model in Table 5 has low descriptive power, yet is it valid. The model only describes 54.5% of changes in share prices, but all variables are beneath the required 5% significance level, as is the model p-value. As indicated by the model, a one-euro change in annual dividends led to a 6.3 euro increase in share price. The positive coefficient fits the discounted dividend model logic, as an increasing stream of dividends is an incentive to pay more for shares (Shiller 1980).

Table 5. Volkswagen forward DPS OLS regression 2010 Q2 – 2019 Q4

	Model	Forward DPS	Closing $price_{t-1}$	Intercept
P-value	9.76E-10	0.0305	0.124405	0.0185
Coefficient	-	6.343	0.643849	32.2078
Standard error	-	2.81569	0.124405	13.0515
Adjusted r^2	0.544974	-	-	-
Chow p-value	5.965E-13	0.50249	-	-

Source: Author's calculations based on data retrieved from Börse Frankfurt, EIKON, and Volkswagen financial reports

The results of the Chow test detect a structural change in the model at Dieselgate, but the relationship between forward DPS and share price does not undergo a significant change. It appears that there is some change in the model due to the scandal, but this change is not in the relationship between dividends and share prices. When considering the results of the graphical analysis, the lack of a structural break is surprising. Dividend yield tumbles following Dieselgate as forward DPS approaches zero yet share prices do not follow suit. Despite this abrupt change in dividend yield, it appears share prices follow the change closely enough not to cause a significant structural break in the relationship between forward DPS and share price. According to this test, investors continue to value dividends the same even after the crisis. This is unexpected, given the results of the graphical analysis. The upward trend in Volkswagen's dividend yield suggests that following Dieselgate, the recovery of share prices was lagging behind the increasing dividends per share. As this behaviour was not present before Dieselgate, some change took place following the scandal. However, the results of the Chow test suggest that this visual observation was not statistically significant.

Within the regressions for Volkswagen, some evidence of structural breaks is present. Not all indicators were similarly affected. To get a more comprehensive understanding of these breaks, the analysis is also done on Volkswagen's two competitors, Daimler and BMW. There is evidence of contagion in previous studies on Dieselgate (Bouzzine, Lueg 2020; Nunes, Park 2016), so it is possible these structural breaks will also appear in their financials.

3.3. Daimler

Table 6 shows that EPS is a significant independent variable for describing share price during the period, as is the model with an alpha well below 5%. The adjusted r^2 of 64.7% hints that the model is not an ideal tool for this purpose, as its descriptive power is limited. Still, it suggests that EPS has a slight positive relationship with price, with the latter increasing 1.05 EUR for a 1 EUR increase in EPS. Based on the initial OLS regression, no immediate issues are visible. Nonetheless, a Chow test is run to detect a structural break.

Table 6. Daimler forward EPS OLS regression 2010 Q2 – 2019 Q4

	Model	Forward EPS	Closing price$_{t-1}$	Intercept
P-value	8.20E-12	0.0846	1.28E-10	0.0437
Coefficient	-	1.05357	0.715225	9.73488
St. Dev	-	0.592538	0.0778106	4.64249
Adjusted r^2	0.647240	-	-	-
Chow p-value	3.61294E-10	0.416046		

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

According to the results of the Chow test, EPS remains a significant descriptor of share prices throughout the Dieselgate scandal. The Chow test for Daimler's forward EPS indicates that this multiple was not significantly affected during Dieselgate. As seen in earlier tests, there is significant change in the overall model, but not in that specific multiple. In Daimler's case, there are no issues with the coefficient being negative. Based on these results, investors use forward EPS consistently when valuing Daimler shares throughout the period.

Table 7 presents the OLS regression for Daimler's forward EBITDA. EBITDA performs poorly as a descriptor of share price for the period 2010 Q1 – 2019 Q4. The overall model has a p-value below 0.01, yet EBITDA's p-value is a high 0.68. While the adjusted r^2 of 63.7% is not wholly unusable, EBITDA does not perform well when describing share prices during the period. However, rather than being a sign of the unsuitability of EBITDA as a descriptor for Daimler, this may instead be a result of a structural break.

Table 7. Daimler forward EBITDA OLS regression 2010 Q2 – 2019 Q4

	Model	Forward EBITDA	Closing price$_{t-1}$	Intercept
P-value	1.64E-14	0.6752	3.40E-12	0.0045
Coefficient	-	9.69E-08	0.766436	11.6573
St. Dev	-	2.29E-07	0.0750061	3.84925
Adjusted r^2	0.636609	-	-	-
Chow p-value	3.029E-04	0.00045424	-	-

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

The Chow test does indeed indicate a significant structural break in both the overall model and EBITDA alone. Investors change their view of EBITDA when valuing Daimler shares after Dieselgate. This break follows the pattern established by Volkswagen as both companies experience a significant structural break between forward EBITDA and share prices. The effects of the break are investigated next, to see whether the EBITDA multiple performs worse after Dieselgate, as it did in Volkswagen's case.

In Table 8, the results of the OLS regressions pre- and post-Dieselgate show a deterioration in EBITDA's relationship to share price. From the beginning of 2010 to mid-2015, the EBITDA model performs well when describing share price. Both forward EBITDA and lagged closing price are significant independent variables. EBITDA's coefficient is 3.65E-6, indicating a positive relationship with Daimler share prices. Most notably, the model has an adjusted r^2 of 81.1%. Overall, it is a useful model for describing movements in share prices. This is not the case post-Dieselgate. The model deteriorates in several ways. While its p-value remains significant, its adjusted r^2 plummets to 35.7%, which is not usable. EBITDA's coefficient becomes negative—an illogical value for EBITDA as it was for EPS. Furthermore, forward EBITDA's p-value shoots up to 0.81. It is no longer a significant variable. Again, investors disregard EBITDA after Dieselgate. As EBITDA was a good descriptor before the scandal, one can conclude that investors have redirected their attention away from this financial indicator. The results of this statistical test support the observations in the graphical analysis. Daimler's P/EBITDA falls after Dieselgate and remains lower than it was before. Daimler's EBITDA does not become more volatile nor is it diminished following the scandal. EBITDA itself does not provide an explanation for its decreased value in the eyes of investors. The cause may lie with its competitor. As with Volkswagen, the structural break led to a previously strong indicator of share prices being disregarded by investors. Daimler's result indicates contagion between Volkswagen and its competitors.

Table 8. Daimler EBITDA OLS regressions pre- and post-Dieselgate

Time period		Coefficient	Standard error	P-value
Q2 2010 – Q2 2015	Intercept	-16.0444	7.07977	0.0360
	Forward EBITDA	3.65210E-6	8.34117E-7	0.0004

	Closing $price_{t-1}$	0.346245	0.112244	0.0064
	Adjusted r^2	0.810850		
	Model p-value	2.63E-11		
Q3 2015 – Q4 2019	Intercept	30.8128	35.3771	0.3975
	Forward EBITDA	-2.55045E-7	1.05701E-6	0.8126
	Closing $price_{t-1}$	0.575879	0.189419	0.0083
	Adjusted r^2	0.356540		
	Model p-value	0.000949		

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

Table 9 presents the OLS regression results for Daimler's forward DPS. The overall model is significant with a p-value well below 0.05. Nor is its r^2 especially low, with a value of 64.2%. However, its main issue lies with the DPS variable. Its p-value is 0.1376, well above the permitted 0.05. As it stands, DPS is not a valid descriptor of share prices for the whole period.

Table 9. Daimler forward DPS OLS regression 2010 Q2 – 2019 Q4

	Model	Forward DPS	Closing $price_{t-1}$	Intercept
P-value	5.66E-14	0.1376	1.53E-09	0.0035
Coefficient	-	2.12198	0.711541	11.1618
St. Dev	-	1.39724	0.0885956	3.56521
Adjusted r^2	0.642267	-	-	-
Chow p-value	5.141E-06	0.32471	-	-

Source: Author's calculations based on data retrieved from Börse Frankfurt, EIKON, and Daimler financial reports

According to the Chow test, the relationship between DPS and Daimler's share price is not significantly affected by Dieselgate. There is a structural break in the model itself, hinting at a change in the effects of the other uncaptured variables or the lagged closing price. However, it

appears that DPS is not a main tool used by the market to value Daimler shares during this period. This statistical observation is supported by the graphical analysis. Even though dividends only increase a considerable amount in the beginning of the period and after Dieselgate, dividend yield fluctuates on its own in the interim. There is some similarity when comparing Daimler's dividends per share to Volkswagen. There is no structural break at Dieselgate for either company. In Daimler's case, however, the dividends per share model is invalid, while Volkswagen's is still useable, despite its low r^2. These results suggest that the models are not well specified as is. Regardless, no structural break is evident in either.

3.4. BMW

This section continues the analysis of possible contagion effects with Volkswagen's other competitor, BMW. Table 10 presents BMW's full-period forward EPS regression. The model has a low p-value and its r^2 of 67.1% is also a good sign. However, the EPS variable's p-value is 0.1617, too high to be significant. Although neither Volkswagen nor Daimler experienced structural break between EPS and share price, this could be a sign of one.

Table 10. BMW forward EPS OLS regression 2010 Q2 – 2019 Q4

	Model	Forward EPS	Closing $price_{t-1}$	Closing $price_{t-2}$	Closing $price_{t-3}$	Intercept
P-value	4.81E-11	0.1617	6.80E-5	0.0418	0.0019	0.0150
Coefficient	-	0.865592	0.572614	-0.265271	0.404931	14.8517
St. Dev	-	0.605080	0.126226	0.125431	0.119945	5.79643
Adjusted r^2	0.670683	-	-	-	-	-
Chow p-value	0.000249346	0.000211283	-	-	-	-

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

The Chow test confirms that there is a structural break at Dieselgate, both in the overall model and in forward EPS specifically. This is surprising, as there was no break in EPS for the previous two companies. While the number of companies to make definitive conclusions about patterns in structural breaks, this hints at a characteristic that makes companies more prone to breaks related to certain indicators. Previous literature has found evidence that may support this theory. As

pointed out by Bouzzine and Lueg, Daimler and Volkswagen both feature diesel vehicles and commercial vehicles as a core tenet of their product portfolio, which leads to a similar business structure. Crucially, Daimler witnessed more severe abnormal returns than BMW after Dieselgate (Bouzzine, Lueg 2020). Investors could be valuing these companies differently based on their characteristics.

Additionally, the previous OLS regressions between share prices and forward EPS proved to be poor models. In Volkswagen's case, the EPS coefficient was negative and in Daimler's case, EPS was an insignificant variable. It may be that BMW is simply a better fit for the simple forward EPS OLS regression approach than the other two companies. In this case, the Chow test could be capturing a break in BMW that went undetected in Volkswagen and Daimler's cases due to an ill-fitting model. In any case, this test confirms a structural break between BMW's share price and forward EPS. Although it is beyond the scope of this paper, a separate analysis dedicated to structural breaks in EPS and share price would be insightful.

Based on the data in Table 11, the forward EPS model is less accurate after Dieselgate. The model is valid, with a p-value of 7.09E-9 and a high adjusted r^2 of 79.1%. Forward EPS has a positive relationship with share price and a coefficient of 7.4. The model becomes worse after Dieselgate. The model remains significant based on its p-value, but the adjusted r^2 plummets to 37.7% EPS remains a significant variable and the effect EPS has on share price decreases to 1.48 euros per one unit change in EPS. There are still invalid variables among the lagged share prices. Referring to the forward EPS in Figure 2, BMW experienced slightly more volatile EPS towards the end of the period, although there was no jarring change in EPS immediately following Dieselgate. There was, however, major fluctuation in forward P/E, which means share prices are changing independent of EPS. Again, it appears that investors are relying much less on EPS when valuing BMW's shares after Dieselgate.

Table 11. BMW forward EPS OLS regression pre- and post-Dieselgate

Time period		Coefficient	Standard error	P-value
Q2 2010 – Q2 2015	Intercept	-30.2706	21.4670	0.1777
	Forward EPS	7.40375	3.32226	0.0405

	Closing $price_{t-1}$	0.315783	0.152462	0.0549
	Closing $price_{t-2}$	-0.224854	0.153859	0.1633
	Closing $price_{t-3}$	0.529748	0.169854	0.0066
	Adjusted r^2	0.791505		
	Model p-value	7.09E-9		
Q3 2015 – Q4 2019	Intercept	31.1587	11.9063	0.0213
	Forward EPS	1.48720	0.582961	0.0241
	Closing $price_{t-1}$	0.295270	0.286232	0.3211
	Closing $price_{t-2}$	-0.218555	0.174979	0.2337
	Closing $price_{t-3}$	0.322648	0.128998	0.0265
	Adjusted r^2	0.376630		
	Model p-value	0.001333		

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

BMW's result diverges from the pattern established by Volkswagen and Daimler. The other two companies showed no signs of a significant structural break between EPS and share price. There are, however, some similarities between the EPS figures of Volkswagen and BMW. As established in the graphical analysis, Volkswagen's EPS is much more volatile after the scandal. BMW's EPS figure also appears to fluctuate more post-Dieselgate. Similarly, BMW's P/E ratio is lower than it used to be. While the volatility in Volkswagen's figures did not lead to a structural break, in BMW's case investors were more wary and the value assigned to EPS was diminished. As a result, BMW experienced a significant structural break between its EPS and share prices. It should also be noted that Volkswagen's EPS model had issues despite the lack of a structural break. BMW's

result supports the possibility that there is a break between Volkswagen's EPS and share price, but that the model used is not sophisticated enough to portray the relationship accurately.

Next, the BMW analysis is continued for EBITDA. Table 12 presents the full-period regression for forward EBITDA and share price. Forward EBITDA is decent descriptor of BMW's share prices. The model is significant and describes 68.2% of changes in share price. For the whole period, all variables except the intercept are valid. Previous breaks have been evidenced by an insignificant variable or a negative coefficient. In BMW's case, neither problem is present. EBITDA's p-value is low and the coefficient is positive. A Chow test is run to confirm that no statistically significant break is present.

Table 12. BMW forward EPS OLS regression 2010 Q2 – 2019 Q4

	Model	Forward EBITDA	Closing $price_{t-1}$	Closing $price_{t-2}$	Closing $price_{t-3}$	Intercept
P-value	2.30E-10	0.0260	2.47E-5	0.0415	0.0021	0.2505
Coefficient	-	1.01128E-6	0.555030	-0.256894	0.391622	8.48114
St. Dev	-	4.34453E-7	0.113768	0.121274	0.117651	7.25459
Adjusted r^2	0.682095	-	-	-	-	-
Chow p-value	0.0973813	0.43563	-	-	-	-

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

BMW's overall EBITDA OLS regression do not show signs of a significant structural break. Investors weigh BMW's EBITDA consistently when deciding on BMW share prices. Again, this shows that BMW's results differ from Volkswagen and Daimler. It should be noted that the full-period for BMW is a solid descriptor of share prices. This deviation from the pattern of breaks does not appear to be due to a mis-specified model. Another explanation could be that BMW's investors did not value EBITDA as much as they did for Volkswagen and Daimler, which might explain the lack of a break. However, BMW's EBITDA coefficient lies between those of Volkswagen and Daimler rather than below them, meaning that EBITDA's effect on BMW's share prices is not drastically lower. In the graphical analysis, BMW's quarterly EBITDA did not stand

out from the other two. While Volkswagen's EBITDA fluctuated and Daimler's EBITDA continued its growth, BMW's EITDA remained mostly steady for the latter half of the period. As BMW's EBITDA does not appear to be the root of this lack of a break, this result suggests that company profiles could affect the likelihood of breaks. Before finishing with the analysis, BMW's forward DPS is analysed to explore this pattern.

Table 13 shows the OLS regression for BMW forward DPS. This model is a poor descriptor of BMW's share prices for the full period. The model has a low p-value and an adjusted r^2 of 66.1%. However, the negative forward DPS coefficient is problematic. As explained earlier, these indicators should have a positive relationship with share prices, as they indicate increasing value for investors. Furthermore, its p-value is negative. These suggest a break in the relationship between BMW's dividends and share price. A Chow test is used to confirm this.

Table 13. BMW forward DPS OLS regression 2010 Q2 – 2019 Q4

	Model	Forward DPS	Closing $price_{t-1}$	Closing $price_{t-2}$	Closing $price_{t-3}$	Intercept
P-value	1.21E-11	0.8339	5.21E-5	0.0612	0.0044	0.0002
Coefficient	-	-0.639418	0.615050	-0.251155	0.430348	18.5161
St. Dev	-	3.02594	0.132932	0.129732	0.140851	4.42525
Adjusted r^2	0.661465	-	-	-	-	-
Chow p-value	9.18132E-5	0.0434144	-	-	-	-

Source: Author's calculations based on data retrieved from Börse Frankfurt, EIKON, and Daimler, Volkswagen, and BMW financial reports

As suspected, both the model and forward DPS experience a significant structural break. At this point, the relationships between BMW's indicators and share prices are behaving completely differently from Volkswagen and Daimler's. BMW has experienced a break in the EPS and dividend variables, but none in EBITDA. BMW's dividend policy seemed untouched by Dieselgate and they kept rising gradually after the scandal. When comparing to the other two companies, Volkswagen's dividends plummeted, while Daimler's dividends were raised sharply in 2016. The fact that Daimler and Volkswagen have more similarities between their product

portfolios and target markets than with BMW could be an important factor. Perhaps investors were concerned by Volkswagen and Daimler's increased exposure to diesel regulations or the more commercial target market of these companies, as noted by Bouzzine and Lueg (2020). Still, dividend yield spiked in BMW's case as it did for Daimler. This break could be the result of investors disregarding forward DPS when valuing shares, as was the case with previous breaks. The next step is to examine the two separate regressions to determine whether this is the case.

Table 14 shows that forward DPS becomes a better descriptor of share prices after Dieselgate. The overall model is valid and describes 76% of changes in share prices before Dieselgate. However, the fit of the model is likely due to the one and three period lagged prices, which are the only valid variables aside from the intercept. Forward DPS has a p-value well above what is allowed by the 5% significance level, in addition to a negative coefficient. After Dieselgate, there are mixed changes in the model. While its overall p-value remains low, the adjusted r^2 plummets to 40.1%. However, forward DPS improves as a descriptor. In the second regression, it becomes a significant variable. Furthermore, its coefficient is now positive, which matches the logic of the multiple. As with Volkswagen and BMW, there is reason to suspect that this simple model is not capturing the full effect dividends have on share price. Regardless, one can conclude that forward DPS improved as a descriptor after the scandal. There is some logic behind this change. As stated by Shiller, investors are thought to be looking for dividend-based income when buying shares (Shiller 1980). In times of uncertainty and volatility they may turn to familiar indicators of value such as the dividend. Unlike EPS and EBITDA, dividends per share are a direct and clear indicator of the income a shareholder will receive during the coming year, which may appear less risky.

Table 14. BMW forward DPS OLS regressions pre- and post-Dieselgate

Time period		Coefficient	Standard error	P-value
Q2 2010 – Q2 2015	Intercept	15.1800	5.71619	0.0173
	Forward DPS	-7.36747	5.78286	0.2209
	Closing $price_{t-1}$	0.506684	0.123834	0.0009
	Closing $price_{t-2}$	-0.105496	0.169770	0.5431
	Closing $price_{t-3}$	0.746049	0.206048	0.0023
	Adjusted r^2	0.759863		
	Model p-value	6.39E-9		
Q3 2015 – Q4 2019	Intercept	16.9044	15.5042	0.2954
	Forward DPS	9.15049	3.31398	0.0162
	Closing $price_{t-1}$	0.248805	0.227913	0.2948
	Closing $price_{t-2}$	-0.204392	0.159666	0.2229
	Closing $price_{t-3}$	0.330373	0.144806	0.0400
	Adjusted r^2	0.401151		
	Model p-value	0.001045		

Source: Author's calculations based on data retrieved from Börse Frankfurt, EIKON, and BMW financial reports

Although the indicator becomes significant, the model itself is still weak, able to describe only 40% of movements in price. For Volkswagen and Daimler, the full-period forward DPS model is

either a weak or an insignificant descriptor of share prices and does not undergo a significant break. This hints that as a simple model, dividend per share may not be a sufficient descriptor of share price for this industry. Nevertheless, the current results imply that forward DPS may be a preferred indicator of value in times of uncertainty. Further investigation is needed to confirm whether this effect can be found using a more precise model and the whether it exists in specific cases.

CONCLUSION

Although there is evidence of breaks in the sample, no straightforward pattern has emerged. When examining Volkswagen and Daimler, the results are similar. Of the indicators studied, only the relationship between EBITDA and share price undergoes a significant break. DPS has a stable coefficient, as does EPS. Based on this evidence, it appears that investors value EBITDA differently before and after Dieselgate. The same effect is seen in Daimler's financials. EBITDA is a valid descriptor of share price for Daimler before the scandal, but not after. In BMW's case, the EBITDA regression model is a poor descriptor of prices for the full period, but no statistically significant structural breaks are found. The only statistically significant breaks are related to BMW's forward EPS and DPS.

The combination of graphical analysis and Chow tests gives insight into possible causes behind the breaks. First of all, one should note the role of volatility in Volkswagen's financial indicators following Dieselgate, which could have affected the behaviour of its price multiples. As for Volkswagen's competitors, the graphical analysis does not show evidence of the same kind of volatility. Regardless, there were statistically significant breaks in both Daimler and BMW's models. Based on these results, it appears that the causes behind Volkswagen's breaks are not the same as those behind BMW and Daimler's breaks. While investors may have been wary of Volkswagen's volatile financial indicators, these results imply that investors' changed opinion of the competitors' indicators was a result of contagion.

Based on the seemingly random pattern of structural breaks, multiples appear to be company-specific with regards to their relationship with market prices and cannot easily be standardized. Yet, there are still some patterns to be found. As mentioned earlier, the companies' target market and product portfolio could play a role in which indicators undergo breaks. In addition, the forward EPS model may require further investigation. Although no statistically significant break was found for Volkswagen, forward EPS had a negative coefficient. As stated before, this result is not

logically sound and it hints at some issue with the model—misspecification, a break which was not statistically significant, but distorted the coefficient, or a mix of the two. As the current EPS model was not a significant descriptor of Daimler's share prices either, there is considerable interest in exploring the EPS indicator with a better specified model.

Interesting patterns emerge when examining the relevance of indicators before and after their breaks. In all cases bar one, the structural break led to a worse performance of the indicator as a descriptor of share price. It appears that the market places less value on the aforementioned multiples after the scandal. This could be a mistake caused by uncertainty or a decision to prioritise other measures of value. On the other hand, BMW's forward DPS became a significant descriptor of share price following Dieselgate. This hints at investors turning to this traditional measure of value in the wake of Volkswagen's scandal. Further investigation is needed to confirm whether this effect can be found using a more precise model and the whether it exists in specific cases.

In summary, several points can be taken away from this paper. There is evidence of structural breaks in the relationships between the price multiples studied and the share prices. Based on the direction of the change, the price multiples have a decreased effect on share prices after the scandal. Investors and analysts using these multiples to determine firm value should be wary of this possibility following periods of upheaval. Whether wary of volatile financials or some other risk, investors changed their valuation of underlying financials. In the data studied, all multiples that were strong descriptors of share prices became less reliable after the scandal. Based on these results, it is beneficial to rely on multiple methods of valuation instead of price multiples alone. Further studies could investigate whether valuation models with several multiples are shielded from structural breaks.

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Appendices

Appendix 1. Heteroskedasticity and autocorrelation values

Table 15. White's test and autocorrelation test results

	Volkswagen			Daimler			BMW		
	Forward EPS	Forward EBITDA	Forward DPS	Forward EPS	Forward EBITDA	Forward DPS	Forward EPS	Forward EBITDA	Forward DPS
White's test	0.243214	0.281245	0.0623159	0.853876	0.321748	0.318897	0.433267	0.397031	0.34609
Autocorrelation	0.501138	0.408378	0.0772981	0.195349	0.142803	0.175721	0.413025	0.463948	0.429653

Source: Author's calculations based on data retrieved from Börse Frankfurt and EIKON

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