The Impact of Volkswagen Dieselgate on the Taiwanese Automotive Market

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September 28, 2021

Abstract

We investigate the effects of 2015 Volkswagen diesel emissions scandal in the Taiwanese new car market. Using a difference-in-differences empirical strategy and administrative data on new car registrations, we find that quarterly sales of Volkswagen fell by more than 20% in self-use market. But sales of Volkswagen quickly recovered after one year. In B2B market, business buyers did not respond to the emissions scandal. For collective reputation, we do not find evidence of spillovers to other German brands, indicating that environmental concerns in Taiwan did not extend to other brands within the same country.

JEL Codes: D12, L14, L62, Q53

Keywords: environmental consciousness, automobile, reputation, business buyer, Volkswagen emissions scandal

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1 Introduction

In the past two decades, consumers have been increasingly more concerned with environmental issues such as climate changes and pollution. Environmentally sound products are favored by more consumers despite higher prices.[1] On the other hand, failing to meet environmental regulations could result in adverse market reactions. Understanding the extent to which consumers respond to an environmental violation is relevant and important for both policy makers and corporations.

In September 2015, the Environmental Protection Agency (EPA) in the U.S. served a notice of violation of the Clean Air Act on Volkswagen Group as the VW group had programmed a software to intentionally lower emissions in laboratory testing. The sudden announcement of EPA and extensive media coverage of VW Dieselgate make it an ideal natural experiment to consumer environmental consciousness since VW advertised its diesel cars as "clean diesel", and claimed that diesel engines are both environment-friendly and fuel efficient. As a result, buyers with stronger environmental conciousness would immediately respond to this environmental fraud. In this paper, we exploit the exogenous shock and estimate the impacts of the scandal on new vehicle sales for different types of buyers.

We consider the setting of new car market in Taiwan since the administrative data distinguishes buyer types, self-use buyers and business buyers, due to tax purposes. Using a difference-in-differences (DD) identification strategy and event study approach on quarterly brand-level new car registrations, our empirics address several questions about heterogeneous environmental preferences, collective reputation, and declining preferences for diesel cars. First, we provide descriptive evidence that popularity of diesel cars in Taiwan has diminished considerably after VW Dieselgate. But the declining trend was less obvious for business passenger diesel cars. Second, we find that the scandal led to 23% to 44% decrease in

[1] See https://www.tetrapak.com/content/dam/tetrapak/publicweb/gb/en/sustainability/documents/Tetra-Pak-Consumer-Environmental-Trends.pdf

Volkswagen sales. However, the sales recovered after one year. On the other hand, business buyers did not respond to the scandal given that our estimates in B2B passenger car market are close to zero and insignificant. Third, we find no evidence of spillovers from collective reputation damage as consumers may associate German auto brands together. Fraudulent behavior resulting in environmental concerns by one of the members may jeopardize overall collective reputation. However, our results show that sales of two other German auto manufacturers, BMW and Mercedes-Benz, are unaffected by the scandal.

This paper is related to studies on the consequences of VW emission scandal. Previous studies using data from used-car market find negative impacts on transaction prices (Strittmatter and Lechner, 2020; Che et al., 2020; Ater and Yoseph, 2021). Among these studies, Ater and Yoseph (2021) further show that the volume of transactions also dropped, and the decrease mainly came from private sellers. Using new vehicle sales in the U.S., Bachmann et al. (2021) perform both reduced-form and structural analyses to separate substitution effects and spillover effects from VW Dieselgate. To the best of our knowledge, our study is the first to investigate heterogeneous responses from different types of buyers in the context of VW Dieselgate.

Our findings about differential responses from self-use and business buyers to environmental fraud provide policy implications. In order to induce environment-friendly consumption behaviors, extra incentives are needed for business buyers since they are less responsive to environmental concerns. The results also add to the literature on heterogeneous environmental preferences (Bollinger and Gillingham, 2012; Jacobsen et al., 2013; Wagner, 2016). In particular, Wagner (2016) corroborates the existence of heterogeneous environmental preferences and finds different sensitivities in gasoline price and excise tax elasticities.

Finally, our paper contributes to the literature on collective reputation. Built on theoretical work from Tirole (1996), empirical studies often exploit exogenous shocks to identify externalities from collective reputation (Freedman et al., 2012; Bai et al., 2021; Bachmann

et al., 2021). Our results are closely related to reduce-form estimates in Bachmann et al. (2021) since we both use VW Dieselgate to identify spillovers on German auto makers. However, unlike Bachmann et al. (2021), we do not find negative impacts on German car manufacturers. The discrepancies could be reconciled by empirical findings in Hammond (2013) and Bai et al. (2021), which suggest more established individual reputation can shield from negative shocks on individual reputation or collective reputation.

The remainder of the paper is organized as follows. In the next section, we introduce the background of VW Dieselgate. Section 3 describes the data. In Section 4, we present our empirical strategy. Section 5 analyzes heterogeneous buyer responses and examines colletive reputation spillovers. The final section draws conclusions. We provide additional tables and figures in the Appendix.

2 Background

2.1 Dieselgate

Dieselgate is one of the largest industrial scandals in the history. Before the scandal, VW car had been known for its fuel efficiency on diesel engines. In Europe, diesel vehicles account for a significant portion of new vehicle sales because of fuel efficiency and low carbon dioxide emissions.[2] Consumers even regard diesel as clean energy compared to gas because of VW diesel engine. However, Volkswagen Group had added a defeat device to its diesel engine EA 189 since 2008. The emission control system on EA 189 can function properly in laboratory emission tests. To everyone's surprise, the defeat device shuts down the capacity of the emission system while on the road to achieve better fuel efficiency. As a result, the diesel engine emit way more nitrogen oxides and suspended particulates than emission standards.

International Council on Clean Transportation (ICCT) conducted a project to collect

[2] See: https://www.statista.com/statistics/425113/eu-car-sales-share-of-diesel-engines-by-country/

emission data from 15 different vehicles. In this project, scientists from West Virginia University took charge of vehicles includes Passat, Jetta, and BMW X5. During road tests, they found that nitrogen oxides (NOx) emitted by VW vehicles were higher than regulatory standards by 10 to 40 times. ICCT and West Virginia University then issued a warning to the California Air Resources Board (CARB) and the U.S. Environmental Protection Agency(EPA) regarding the test results of VW diesel vehicles. On September 18, 2015, EPA published a research report accusing the VW Group of cheating.

The report shows that the fraud affected numerous models of cars with EA 189 diesel engines in Volkswagen Group during 2009 to 2015. On September 21, VW stock price plunged 16.7%, with a market value loss of more than 25 billion euros. 11 million vehicles were involved worldwide. In addition, VW Group has to face a penalty of $15.3 billion in the US, of which 10 billion compensates car owners, 2.7 billion for research environmental compensation, 2 billion for zero emissions, and the other 600 million for compensation required by other states. These penalties do not even include the cost of fines and recall costs in other countries. After this scandal, the CEO of the VW group resigned on September 23, 2015. As of September 27, 2015, the representative of Volkswagen and Audi owners filed at least 34 class actions in the U.S. and Canada, accusing VW of breach of contract.

2.2 Dieselgate in Taiwan

In 2015, diesel vehicles only accounted for 3.6% of total number of passenger cars in Taiwan.[3] However, Environmental Protection Administration in Taiwan immediately reacted to this event. Shortly after September 18, 2015, EPA in Taiwan sent a letter asking Audi Volkswagen Taiwan Co., Ltd to explain this scandal and perform random inspections of GOLF 1.6 TDI without warning. The test results were not exactly the same as those issued by the U.S.

[3] Total number of passenger cars was 6,666,006, and the number of diesel cars was 239,168. For more information, please see https://stat.thb.gov.tw/hb01/webMain.aspx?sys=100&funid=11100

Environmental Protection Agency since diesel vehicles sold in Taiwan were all EU-specific vehicles. Emissions systems were designed are based on the EU's emissions standards (EURO 5). However, the results still show huge discrepancy between road test and laboratory test.[4] On October 20, a total of 18,716 cars, including Audi, Volkswagen, and ŠKODA, were affected.[5] After clarifying the problem, Taiwan's EPA approved VW's recall plan on January 14, 2016, and began to recall all affected vehicles in stages from March 2016.

3 Data

In this study, we focus on passenger cars.[6] The data is publicly-available data from Directorate General of Highways.[7] It provides a monthly panel of the number of new car registrations from every manufacturer. Moreover, as Vehicle License Plate Tax and Fuel Tax are levied according to engine displacement and purpose of usage, the data also distinguishes types of owners: self-use, or business.[8] Business owners are specifically referred to taxi drivers, leasing firms, or transportation companies. The market share of business passenger vehicles is around 11% to 12% of the whole passenger car market. Figure 1 shows the annual sales of Volkswagen in self-use and business market respectively. Despite differences in sales, the market shares for VW in the two markets are roughly the same, around 3% to 4%. Looking at sales and market shares in 2015 and 2016, we find small drop in the self-use market but no obvious change in the business market. However, the descriptive annual sale

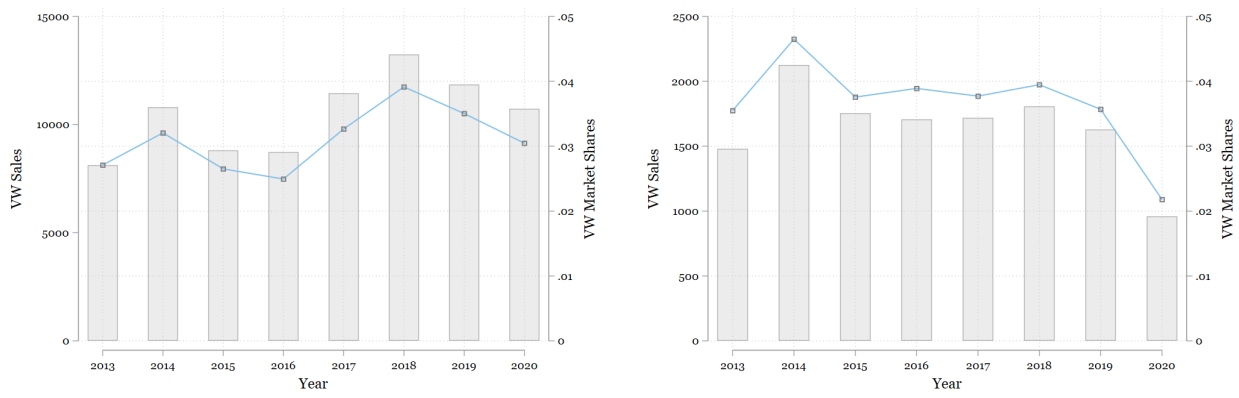
[4] Unfortunately, regulations in Taiwan did not include road tests with portable emissions measurement system (PEMS) due to uncontrollable factors on the road. However, the results of the affected GOLF 2.0 models using PEMS measured by Taiwan's EPA are comparable to those conducted by West Virginia University.

[5] We present detailed numbers across car models in Table A1. The information is also available on https://mobile.epa.gov.tw/VW/VWqa.aspx.

[6] A passenger car is defined as a vehicle with no more than nine seats and a maximum mass less than 3.5 tonnes.

[7] See https://stat.thb.gov.tw/hb01/webMain.aspx?sys=100&funid=11100

[8] See https://law.moj.gov.tw/LawClass/LawAll.aspx?pcode=G0340095 and https://law.moj.gov.tw/LawClass/LawAll.aspx?pcode=K0040007



(a) Self-use vehicle **(b) Business vehicle**

Figure 1: VW sales and market shares

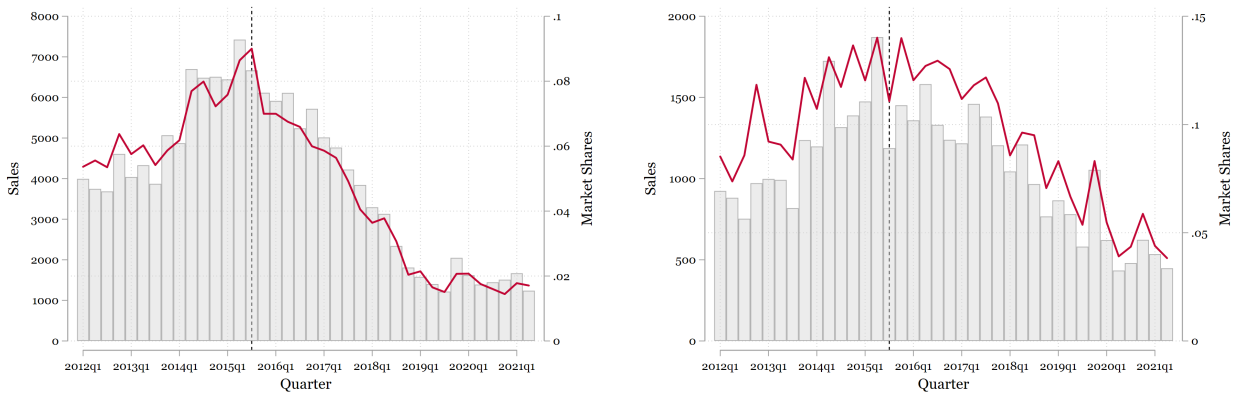
Notes: The two figures focus on new passenger cars only. We calculate market shares for self-use and business market separately. The data is publicly available on https://stat.thb.gov.tw/hb01/webMain.aspx?sys=100&funid=11200.

trends can be affected by multiple confounding factors. For the empirical analyses in later sections, we aggregate the data into brand-quarter level.[9]

Since the affected vehicles are all diesel cars, we first provide descriptive evidence of heterogeneous consumer responses to new diesel vehicles in Figure 2. In self-use market, Figure 2a shows that shortly after September 2015, popularity of diesel vehicles fades quickly. There are noticeable drops in both sales and market shares after the peak in 2015 while diesel vehicles were getting more and more popular in the previous years. As of 2020, self-use diesel vehicles only account for less than 2% of new vehicle sales, and there is no sign of recovery.[10] In contrast, Figure 2b exhibits a moderate declining trend with no significant change around 2015 and 2016. The two figures suggest strong responses from self-use buyers, and less responsive behavior from business buyers. The descriptive findings also motivate

[9] We do not use monthly panel since VW and other German brands are selling imported cars, which are subject to sea freight market conditions. Using monthly sale data may include volatilities which cannot be capture by the empirical models.

[10] We believe that the emission scandal has altered consumers' perspectives toward diesel cars in terms of environmental concerns. It may also open up the door for electronic vehicles.



(a) Self-use diesel vehicle **(b) Business diesel vehicle**

Figure 2: Declining Trends for Diesel Cars

Notes: The two figures focus on new passenger cars only. The data is publicly available on https://stat.thb.gov.tw/hb01/webMain.aspx?sys=100&funid=11200.

more sophisticated empirical analyses on affected auto manufacturers.

4 Empirical Strategy

This section describes our empirical models used to estimate the impact of VW Dieselgate on new vehicle sales for relevant brands. In Section 4.1, we first introduce a difference-in-differences (DD) specification, challenges to identifying assumptions, and our strategies. Section 4.2 presents an event study model which allows us to look into the evolution of relative sale differences over time while controlling for time-invariant brand differences and time-varying common shocks to all auto makers in the market.

4.1 Difference-in-Differences Specification

Equation (1) is our baseline difference-in-differences specification, which compares the sales of treated auto brands to the sales of other untreated brands before and after fourth quarter

in 2015.[11]

$$y_{jt} = \beta \cdot \text{VW Dieselgate}_j \times \text{POST}_t + \gamma_j + \delta_t + \epsilon_{jt} \tag{1}$$

y_{jt} is the natural logarithm of quarterly sales of new vehicles for brand j in quarter t; VW Dieselgate$_j$ is a dummy variable for treated brands. POST$_t$ is also a dummy variable that equals one if t is in the follow-up period, i.e. between Q4 2015 and Q3 2016. Finally, γ_j and δ_t are brand fixed effects and quarter fixed effects. The two-way fixed effects controls for time-invariant brand-level unobserved heterogeneities and prevailing market conditions, such as seasonality or changes in fuel prices, common to all brands. Standard errors are clustered at brand-level to allow for arbitrary serial correlation in ϵ_{jt} within brand j over time. β is the coefficient of interest since it captures the impact of VW Dieselgate on treated auto manufacturers relative to untreated brands.

Identification in the difference-in-differences strategy requires the parallel trends assumption, in which sale trends would be the same for both affected and unaffected auto brands in the absence of the scandal. Unfortunately, this identifying assumption is untestable. However, we would check the pre-treatment balance between treated and untreated brands even though the pre-treatment similarities do not necessarily imply parallel counterfactual trends.[12]

Another threat to our DD design is potentially invalid control groups. In the context of auto market, instead of being untreated, control group units could be "contaminated" by substitutions to non-VW cars. That is, potential buyers of VW cars would switch to other alternatives, close substitutes from other auto makers, due to the scandal. The substitution behavior would bias our estimates, potentially leading to more negative estimates. In order to overcome this concern, we select domestic auto makers as our preferred control group since domestic cars and imported cars may not be close substitutes. The idea is that VW

[11] We define the fourth quarter in 2015 as the time of the event since the scandal took place on September 18, 2015, which was close to the end of third quarter in 2015.

[12] We will conduct the pre-trend checks with event study model, which will be described in Section 4.2.

and other affected auto brands are imported cars, which are subject to 17.5% import tariffs. Moreover, the tariff gets compounded by commodity tax and sales tax, leading to significant differences in tax payable.[13] The final prices are much higher for imported than those for domestic cars. Consumers considering a VW car may switch to other imported brands but unlikely to consider domestic cars as they are not in same price segment.[14] To strengthen our arguments about control group selections, we calculate and plot cumulative abnormal returns (CAR) after VW Dieselgate for four publicly trading local auto makers. In Figure A1, we do not find patterns of gains over time or systematic trends for four firms, indicating that, at least from stock market's perspective, these domestic firms were not benefiting from the event.

4.2 Event Study Specification

In addition to difference-in-differences analyses, we also present an event study model in Equation (2) to investigate the dynamics of treatment effects after the scandal, as well as the comparable outcome dynamics before treatment. This empirical specification complements the previous analyses as DD estimates essentially summarize the effects across all post-scandal quarters using one single indicator variable. The event study model use the same two-way fixed effects equation except that it includes indicators in every quarter for the treated.

$$y_{jt} = \alpha + \sum_{\tau=-q}^{-2} \beta_\tau D_{j\tau} + \sum_{\tau=0}^{m} \beta_\tau D_{j\tau} + \gamma_j + \delta_t + \epsilon_{jt} \tag{2}$$

[13] Specifically, take a 2,000 c.c. imported car for example. Consumers pay 17.5% of import tariff, 30% of commodity tax, and 5% of sale tax. Multiply all these taxes: $1.175 \times 1.3 \times 1.05 - 1 = 60.4\%$. Domestic cars do not have to pay import tariff. As a result, the tax burden for a a 2,000 c.c domestic car is: $1.3 \times 1.05 - 1 = 31.2\%$.

[14] In 2015, MSRP of Golf 1.2 TSI was NT$ 898,000 while MSRP of Toyota Corolla Altis 1.8 and Toyota Vios 1.5 were NT$ 646,000 and NT$ 519,000 respectively.

$D_{j\tau}$ is an interaction term between VW Dieselgate$_j$ and $\mathbf{1}(t - t_j^* = \tau)$. Both are indicator variables. VW Dieselgate$_j$ is one for treated brand, and zero for other untreated brands. Binary variable $\mathbf{1}(t - t_j^* = \tau)$ indicates the number of quarters away from scandal, t_j^*. Typically, the baseline omitted category is the quarter prior to the event, where $\tau = -1$. Each estimate of β_τ, compared to the prevailing difference in the omitted base period, captures the differences in outcome variable between treated and control brand at quarter τ, the number of quarters away from the event quarter. If sales of treated and untreated auto manufacturers were trending similarly prior to VW Dieselgate, we expect to find estimates of β_τ before the event, $\tau \leq -2$, to be small and insignificantly close to zero. Estimates of β_τ after the event, $\tau \geq 0$, provide intertemporal dynamics for treated brands, which allows us to distinguish between transitory shock and persistent shock.

5 Empirical Results

In Section 5.1, we first investigate whether different types of buyers responded differently to VW Dieselgate under various specifications for robustness. Section 5.2 provides results on collective reputation, in which we use two other German auto brand as treatment group. We compare our results to those in Bachmann et al. (2021) and offer potential drivers of different findings.

5.1 Heterogeneous Responses

Table 1 reports the estimation results from Equation (1) using sales in self-use passenger car market. Column 1 and 2 use all available auto brands. Column 2 and 4 additionally control for brand-specific linear time trends. The DD estimates of -0.241 and -0.444 indicate statistically significant 24% to 44% decreases in quarterly sales of self-use VW cars after the scandal. Using indigenous auto brands as control group (Column 3 and 4), we obtain

Table 1: Dieselgate's effect on self-use Volkswagens buyers

	(1)	(2)	(3)	(4)
VW Dieselgate×POST	-0.241**	-0.444***	-0.233***	-0.338***
	(0.113)	(0.127)	(0.037)	(0.085)
Brand Fixed Effect	Yes	Yes	Yes	Yes
Quarter Fixed Effect	Yes	Yes	Yes	Yes
Time Trend	No	Yes	No	Yes
Observations	200	200	64	64
R-squared	0.840	0.915	0.979	0.985

Note: This table shows the regression results for Equation (1). Dependent variable is the natural logarithm of quarterly sales for individual brands. The baseline period and the follow-up period both include four quarters. We also exclude auto brands with average quarterly sales less than 300. Column (1) and (2) use all available brands are control groups. Column (3) and (4) use only domestic auto manufacturers as control groups. Standard errors in parentheses are robust and clustered at brand level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

slightly different but still statistically significant estimates of -0.233 and -0.338, implying 23% to 34% drop in sales for Volkswagens.[15] The estimates in smaller magnitude are expected as substitution behavior may cause downward bias in DD estimates. Using control group units which are not close substitutes to VW cars partly remove the downward biases.

The estimation results from B2B passenger car market, presented in Table 2, indicate smaller and insignificant impact on business buyers. In Column 1 and 3, in which we do not add linear time trends, the DD estimates are 0.0395 and 0.0731 respectively, which are qualitatively different from corresponding DD estimates in Table 1. After adding linear time trends, the estimates become negative but still statistically insignificant. The obvious contrast in DD estimates implies heterogeneous consumer responses in a way that self-use buyers are more responsive to VW Dieselgate while business buyers are somewhat indifferent to the scandal.

To explore pre-trend similarities and long-term dynamics for the effects of VW Dieselgate

[15] We conduct the same estimation for auto brands, Audi and ŠKODA, within VW Group. However, the results, presented in Table A2, are mixed and most estimates are not significant since Audi and ŠKODA have much smaller market shares than VW.

Table 2: Dieselgate's effect on business Volkswagens buyers

	(1)	(2)	(3)	(4)
VW Dieselgate×POST	0.0395	-0.107	0.0731	-0.196
	(0.063)	(0.112)	(0.137)	(0.259)
Brand Fixed Effect	Yes	Yes	Yes	Yes
Quarter Fixed Effect	Yes	Yes	Yes	Yes
Time Trend	No	Yes	No	Yes
Observations	136	136	56	56
R-squared	0.942	0.958	0.955	0.967

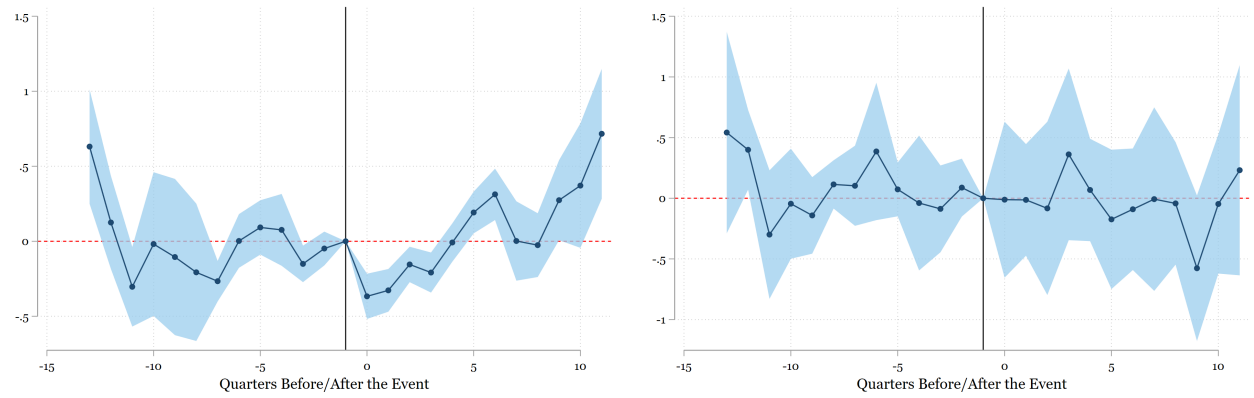
Note: This table shows the regression results for Equation (1). Dependent variable is the natural logarithm of quarterly sales for individual brands. The baseline period and the follow-up period both include four quarters. Column (1) and (2) use all available brands are control groups. Column (3) and (4) use only domestic auto manufacturers as control groups. Standard errors in parentheses are robust and clustered at brand level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

on VW sales, we estimate Equation (2) and plot estimated coefficients, β_τ, along with their 95% confidence intervals in Figure 3. In Figure 3a, we focus on self-use passenger car market. The estimated pre-treatment coefficients are close to the horizontal zero line, implying similarities pre-trends in logarithm of sales. For post-treatment estimates, we observe immediate and sharp drop at $\tau = 0$, the first quarter after VW Dieselgate. However, the magnitudes of the negative estimates get smaller after the first quarter, and turn positive after a year. This evolution of treatment effects indicate that the shock caused by VW Dieselgate is transitory not permanent.[16]

Figure 3b plots estimates of β_τ in Equation (2) for B2B new vehicle market. In sharp contrast to Figure 3a, estimates in Figure 3b are fairly close to zero before and after the treatment. Furthermore, this pattern seems to last for more than two years.[17] The visualization of event study estimates is consistent with DD results in Table 1 as we find no significant negative impact on VW sales of vehicle in B2B market.

[16] Figure 3a points out the importance of event study as the different lengths of follow-up periods in our DD set-up may lead to estimates with opposite signs.

[17] This rules out the explanation of long-term contracts with VW leading to non-responsiveness.



(a) Self-use buyer **(b) Business buyer**

Figure 3: Common pre-trends and intertemporal dynamics

Notes: Figure 3 plot estimated coefficients β_τ from Equation 2 and specification in for self-use new vehicle sales, Figure 3a, and business new vehicle sales, Figure 3b.

Our results of heterogeneous responses from self-use and business buyers complement findings in Ater and Yoseph (2021) as they find large drop in transactions for private sellers and negligible for non-private sellers, leasing firms and companies, in used-car market. In Ater and Yoseph (2021), they argue that in the used-car market increased adverse selection due to VW Dieselgate raised potential buyers' concerns about reliability of VW used cars, and non-private sellers can better alleviate informational frictions through warranties or long-term relationships than individual sellers. The mechanism may not hold for new vehicle market since both self-use and business buyers are facing the same VW seller.

We claim that the discrepancy could be driven by differences in environmental consciousness. Individual consumers, or households have significant willingness-to-pay for clean air (Luechinger, 2009, 2010; Giovanis, 2019) since air pollution has negative impacts on physical conditions, as well as mental health and happiness (Zhang et al., 2017). Business buyers, including taxi drivers, leasing firms, and transportation companies, on the other hand, are more concerned about fuel economy, maintenance costs and reliability. VW Dieselgate was essentially an environmental fraud, which did not affect other aspects, such as safety, relia-

bility, or fuel efficiency. Environmental risks from extra emissions caused by a defeat device are probably not of first order importance for these business buyers.

The findings offer policy implications to related environmental-friendly programs in a sense that uniform responsiveness cannot be expected due to different levels of environmental awareness, especially for business buyers. Extra incentives are required for business buyers since they do not share the same level of environmental concerns as regular individuals or households.

5.2 Collective Reputation

Our DD estimates of spillover effect from VW Dieselgate are reported in Table 3. Two German auto manufacturers, i.e. BMW, and Mercedes-Benz, are in treatment groups. Panel A uses data from self-use buyers while Panel B focus on business buyers. We do not find any statistically significant estimate across various specifications and selections of control group. Meanwhile, most estimates are positive. The result suggest that the scandal did not impose notable externalities on other German auto makers in the Taiwanese auto market.

To make our empirical results directly comparable to those in Bachmann et al. (2021), in which they find negative and significant spillover effects on German auto manufacturers, we estimate a DD specification using monthly panel and the same dependent variable 12-month log sales growth, i.e. $\ln(\text{sales}_{jt}) - \ln(\text{sales}_{jt-12})$. Our results in Table 4 are qualitatively different from Table 1 in Bachmann et al. (2021) as we find positive and insignificant DD estimates for German auto makers in column (1). In column (2), we separately estimate the effects for BMW and Mercedes-Benz. Both estimates still have the same positive sign.

Why did consumers respond different to collective reputation in a sense that environmental concerns caused by VW did not extend to BMW and Mercedes-Benz in Taiwan? We argue that the existence of collective reputation relies on relative reputation levels. Specifically, externalities from collective reputation only apply to less established firms. In Taiwan

Table 3: Dieselgate's effect on German Auto Makers

	(1)	(2)	(3)	(4)
Panel A: Self-use				
German Auto Maker×POST	0.0667	-0.150	0.069	-0.031
	(0.144)	(0.138)	(0.086)	(0.083)
Brand Fixed Effect	Yes	Yes	Yes	Yes
Quarter Fixed Effect	Yes	Yes	Yes	Yes
Time Trend	No	Yes	No	Yes
Observations	192	192	72	72
R-squared	0.840	0.915	0.971	0.982
Panel B: Business				
German Auto Maker×POST	0.102	0.170	0.123	0.060
	(0.109)	(0.150)	(0.161)	(0.267)
Brand Fixed Effect	Yes	Yes	Yes	Yes
Quarter Fixed Effect	Yes	Yes	Yes	Yes
Time Trend	No	Yes	No	Yes
Observations	128	128	64	64
R-squared	0.943	0.959	0.953	0.966

Note: This table shows the regression results for Equation (1). Dependent variable is the natural logarithm of quarterly sales for individual brands. The baseline period and the follow-up period both include four quarters. We also exclude auto brands with average quarterly sales less than 300. Column (1) and (2) use all available brands are control groups. Column (3) and (4) use only domestic auto manufacturers as control groups. Standard errors in parentheses are robust and clustered at brand level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

VW sales were ranked outside top 10 brand during 2014 to 2016 while BMW and Mercedes-Benz stay in top 10 or even top 5.[18] The differences in sales were also tremendous, ranging from 30% to 50%. It is safe to say BMW and Mercedes-Benz have more established reputation than Volkswagen. Therefore, consumers do not attribute environmental concerns from VW to other two auto brands. On the other hand, in the U.S., three German auto makers, BMW (15th), Mercedes-Benz (13th), and Volkswagen (14th) were selling very similar numbers of vehicle, around 2% market shares, in 2014 and 2015.[19] While these German auto man-

[18] We provide detailed market shares and rankings from 2014 to 2016 in Table A3.
[19] See: https://www.goodcarbadcar.net/usa-auto-sales-brand-results-2015-calendar-year/

Table 4: Dieselgate's effect on German Auto Makers

	(1)	(2)
German×Post-Scandal	0.219	
	(0.171)	
BMW×Post-Scandal		0.124
		(0.156)
MERCEDES-BENZ×Post-Scandal		0.315*
		(0.156)
Year-Month Fixed Effects	Yes	Yes
Brand Fixed Effects	Yes	Yes
R-squared	0.409	0.409
N	840	840

Note: Sample period spans from September 2012 to December 2016. Brands with VW Group, VW, Audi, Skoda, and Porsche, are excluded from the sample. We also exclude auto brands with average monthly sales less than 100. Standard errors in parentheses are robust and clustered at firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

ufacturers are not consumers' preferred auto brands in the U.S. and the market shares are extremely close, BMW and Mercedes-Benz could be vulnerable to negative shocks on "German Engineering". Our claim is related to Bai et al. (2021), in which the authors investigate interaction between collective and individual reputation, and find that young and small firms are more vulnerable to shock on collective reputation. In similar vein, not only damage on collective reputation, Hammond (2013) compares market responses to similar safety recalls, damage on individual reputation, of Toyota and Audi, and finds stronger negative effects for less established brand, Audi, and negligible effects for more established brand, Toyota. Our results corroborates that more established individual reputation can shield brands from negative shocks.

6 Conclusion

This paper addresses consumer heterogeneities and spillovers from an environmental scandal. Specifically, we study the direct effect of VW Dieselgate on VW's quarterly sales for two types of buyers, self-use and business. Using Taiwanese auto registration data, we find noticeable but transitory drops in self-use vehicle sales. Self-use buyers are more responsive to the fraudulent scandal while no evidence indicating change in behavior for business buyers are found. Empirical results complement existing studies of VW Dieselgate by shedding lights on heterogeneous environmental awareness. Differential programs based on consumer types can be designed to induce better policy outcomes. We further investigate spillovers from damage on collective reputation. Our results show that other German auto makers are not affected by the shock, suggesting that more established individual brand reputation can be exempt from damage of collective reputation.

Our empirical strategies are limited to reduced-form analyses using brand-level sale data. More sophisticated structural models cannot be estimated using sale data alone. As a results, we cannot investigate direct impacts on diesel and gasoline cars, substitutions between car models, or long-term effects on choice of auto energies. Studies on the interplays with taxes, energy prices, and consumer preferences can be valuable and relevant not only to the literature but also to energy and environmental policies in Taiwan. We leave them to future research as more detailed data may be available.

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Online Appendix

A Additional Tables and Figures

Table A1: Number of Vehicle Affected by VW Dieselgate

Brand-Model	Model Year	Number of Affected Cars
AUDI		2,396
A6	2012-2014	702
A4	2009-2015	324
A3	2009-2013	146
Q5	2013-2016	965
Q3	2012-2014	259
VW PC		12,041
POLO	2011	1
TOURAN	2011-2015	3,294
GOLF 6	2008-2013	2,667
PASSAT	2013-2016	1,153
CC	2010-2016	292
GOLF PLUS	2010-2013	817
TIGUAN	2008-2016	2,494
SHARAN	2014-2015	1,323
VW CV		3,116
CADDY	2010-2016	3,019
AMAROK	2011-2012	97
ŠKODA		1,163
OCTAVIA	2010-2015	375
SUPERB	2010-2015	523
YETI	2011-2015	265
Total		18,716

Note: Source: https://mobile.epa.gov.tw/VW/VWqa.aspx

Table A2: Dieselgate's effect on Audi and Skoda

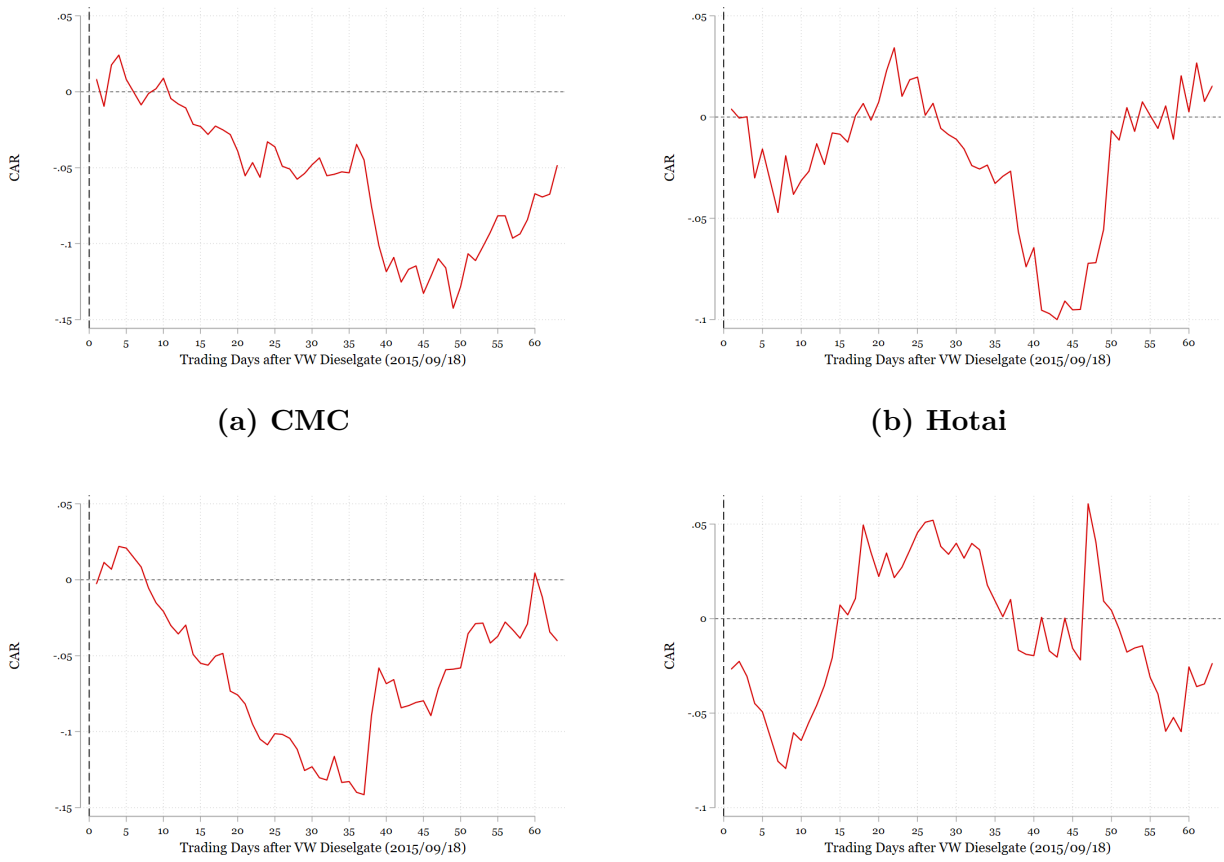
	(1)	(2)	(3)	(4)
Panel A:				
VW Group×POST	0.194	0.204	-0.203	-0.0269
	(0.293)	(0.297)	(0.155)	(0.135)
Brand Fixed Effect	Yes	Yes	Yes	Yes
Quarter Fixed Effect	Yes	Yes	Yes	Yes
Time Trend	No	No	Yes	Yes
Observations	256	72	256	72
R-squared	0.902	0.979	0.948	0.992
Panel B:				
Audi×POST	-0.176	-0.167***	-0.326**	-0.150
	(0.111)	(0.0366)	(0.121)	(0.0839)
Skoda×POST	0.565***	0.575***	-0.0795	0.0963
	(0.111)	(0.0366)	(0.121)	(0.0839)
Brand Fixed Effect	Yes	Yes	Yes	Yes
Quarter Fixed Effect	Yes	Yes	Yes	Yes
Time Trend	No	No	Yes	Yes
Observations	256	72	256	72
R-squared	0.903	0.987	0.948	0.992

Note: This table shows the regression results for Equation (1). Dependent variable is the natural logarithm of quarterly sales for individual brands. The baseline period and the follow-up period both include four quarters. Column (1) and (3) use all available brands except VW as control groups. Column (2) and (4) use only domestic auto manufacturers as control groups. Standard errors in parentheses are robust and clustered at brand level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Taiwanese Auto Sales Brand Rankings

	2014 Market Shares	2015 Market Shares	2016 Market Shares
TOYOTA	32.8%	31.5%	31.4%
NISSAN	12.3%	11.0%	10.8%
HONDA	6.4%	7.3%	6.9%
FORD	6.3%	5.6%	4.8%
MITSUBISHI	5.6%	5.4%	5.4%
MERCEDES-BENZ	5.0%	5.7%	6.3%
BMW	4.4%	5.1%	4.8%
LUXGEN	4.3%	4.0%	4.1%
MAZDA	3.9%	5.5%	6.0%
HYUNDAI	3.9%	3.1%	3.1%
LEXUS	3.5%	3.3%	3.9%
VOLKSWAGEN	3.4%	2.8%	2.6%
SUBARU	1.5%	1.9%	1.9%
AUDI	1.3%	1.3%	1.1%
VOLVO	1.2%	1.3%	1.1%
Others	4.2%	5.1%	5.6%

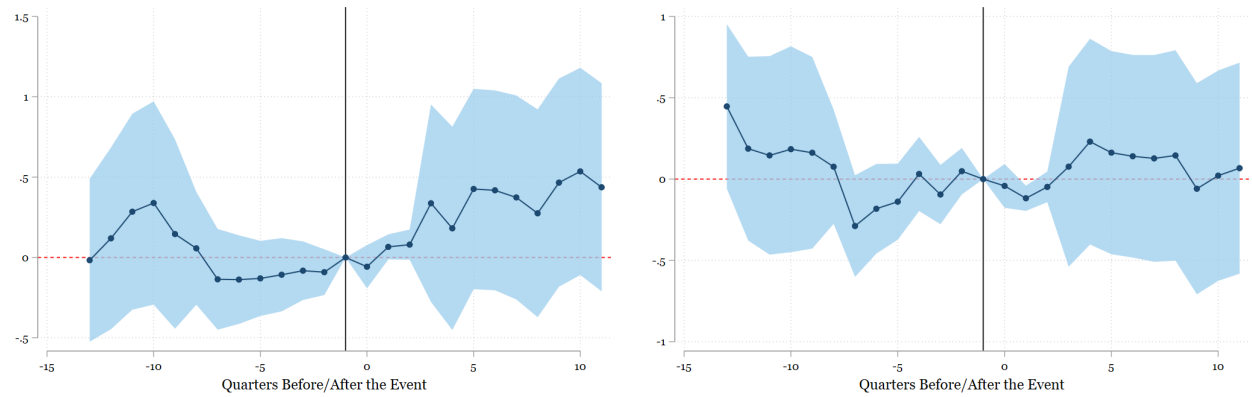
Note: This table shows top auto makers' market shares of new vehicle sales in 2014, 2015, and 2016. The numbers only come from self-use passenger vehicle registrations.



(a) CMC **(b) Hotai**

(c) Sanyang **(d) Yulong**

Figure A1: Cumulative Abnormal Returns after VW Dieselgate



(a) MERCEDES-BENZ **(b) BMW**

Figure A2: Pre-trends and post-event dynamics for German auto manufacturers

Notes: Two figures plot estimates from Equation 2 using all other auto brands except VW as control groups.