# Do Lenders Price the Brown Factor in Car Loans? Evidence from Diesel Cars

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**Abstract**

The transition to a green economy strongly depends on the existence of appropriate economic incentives for agents. The loan market for car purchases is a paradigmatic example in this respect, as different lenders may set credit conditions which may discourage or support the purchase of high-emission vehicles. Using car loan-level data, we study whether captive and independent banks adjust their lending terms and conditions in response to different shocks to the perceived environmental quality and the usability of diesel vehicles. Focusing on the impact of the diesel emissions scandal in the automobile sector in 2015 and on local policy changes regarding circulation restrictions due to air pollution, we find that bank lending particularly by captive banks may further reinforce the market and regulatory failures that led to extensive levels of pollution by the automobile sector.

## 1. Introduction

An important academic and policy debate in recent years has been exploring the role of the banking sector in the transition to a green economy. Despite the public commitments towards sustainability and the negative implications of transition risk for their balance sheets, credit institutions still provide large amounts of credit and sometimes at favorable conditions to highly polluting firms and activities (De Haas and Popov, 2023; Bolton and Kacperczyk, 2021; Degryse et al., 2023; Delis et al., 2023). Also, it has been argued that some banks may do so due to potential conflicts of interest, for instance due to the legacy positions towards existing firms or industries (Degryse et al. 2022), which may limit the possibility for banks to properly incorporate transition risks in their bank lending decisions.

In this paper, we investigate the incentives of different types of financial intermediaries to price the pollution factor in setting bank lending conditions. For this purpose, we exploit the empirical setting of consumer credit for car loans, to finance the purchase of cars with different levels of pollution, diesel versus petrol cars. The empirical setting of consumer credit for cars provides important insights for various reasons. First, a large share of households purchases cars using bank loans, so that – particularly for consumers subject to financing constraints - the credit conditions set by lenders may be highly relevant for the choice of the vehicles by consumers. Second, in the car markets, the disclosure of pollution levels or the introduction of circulation restrictions may raise uncertainty about future value of cars, and then also affect the value of the collateral provided in car loans. Third, the car loan market is characterized by the presence of two types of financial intermediaries, captive lenders and independent banks, whereby captive banks are subsidiaries of large car manufacturers. As different intermediaries could be subject to different incentives due to their ownership, we explore whether and how different types of financial intermediaries react to environmental shocks affecting the car markets.

Various events and reports in recent years have shown that diesel cars cause serious health and environmental problems, worsening the perception about the environmental performance of diesel cars. In particular, when the diesel emissions scandal revealed the actual levels of pollution generated by diesel vehicles, car purchasers were discouraged from buying the diesel cars of the affected brands, due to the negative effect of this fraud on consumer decisions, while developing concerns also for other brands due to collective reputation externalities (Bachmann et al., 2022; Hasan et al., 2023). Also circulation restrictions limiting the possibility to use diesel cars in highly polluted urban areas may significantly reduce the willingness of consumers to purchase diesel cars and affect the collateral value of these cars in the resale market.

Banks operating in the car loan market set credit conditions which - in addition to the incentives from the vehicle prices, as set by the manufacturers - may discourage or support the purchase of cars (Grunewald et al., 2020). This concerns also the loans for the purchase of high-polluting diesel vehicles. In this paper, using loan-level data for used cars, we explore whether banks adjust lending price and terms in response to different shocks to the perceived environmental quality of diesel vehicles in the resale market.

A shock to the perceived environmental quality of diesel cars affects the usability prospect of these vehicles, potentially leading to an oversupply in the used-car market, with significant implications on their prices. This results into uncertainty about the future resale values of these vehicles, suppressing collateral value. This also implies higher credit risk for the loans financing the purchase of affected cars. Therefore, a bank is expected to tighten lending terms and conditions to account for deteriorated collateral/resale value. This reduction in collateral value would affect potentially all lenders. In addition, other incentives may be specific to car manufacturer-owned captive banks, due to the vertical integration between production and finance. When manufacturers are also lenders, they internalize the dynamic implications of their own production and sales (Barron et al., 2008; Benetton et al., 2022).

In this context, uncertainties and risks related to the purchase and collateralization of used diesel cars would erode also the future profits of a car manufacturer, given that the current production of cars will eventually be sold in the used car market. Hence, the price of new cars reflects rational expectations about the resale market (Bulow, 1986; Gavazza et al., 2014). When environmental shocks create uncertainty about the future value of diesel cars, captive financial intermediaries may have the incentive to apply more attractive loan conditions, in order to support car value.

To investigate how the environmental risk of diesel vehicles is priced in the loan contracts between banks and borrowers, we examine the impact on bank credit conditions of shocks to the perceived environmental quality of diesel engines or to the actual circulation possibility of diesel cars. To study these effects we rely on the quasi-natural experiments provided by the diesel emissions scandal in the automobile sector in 2015, as well as by local policy shocks in the form of circulation restrictions due to air pollution, as triggered by actual pollution levels. We use loan-level data on car loans for the purchase of used cars, for loans originated in France, Germany, Spain and Italy from 2006 to 2018, and available from European Data Warehouse. Overall, we find that captive banks adjust loan conditions in a more favorable way for the purchase of diesel cars versus petrol cars, to support the sales of the vehicles produced by their own parent carmakers; while independent consumer banks charge stricter credit conditions after environmental shocks for the loans financing diesel cars relative to captive banks.

Captive banks apply more favorable lending conditions – relative to independent banks - via higher loan-to-value ratios (LTV) and lower interest rates for used diesel cars; they do so to affect borrowers' willingness to take a loan and purchase a car, as well as their assessment of cars' longevity after environmental shocks. However, different shocks affect differently the perception of consumers about the longevity of these cars - hence how long a car is expected to be usable. The diesel emission scandal has raised awareness over the true higher levels of pollution emitted by diesel cars, but this disclosure has not implied per se immediate constraints on the usability of these cars. On the other hand, local circulation restrictions – introduced to address the high levels of local pollution - reduce immediately the actual possibility to use the cars subject to these restrictions. These differences are relevant also for the risk assessment by credit institutions and for the determination of the credit conditions applied to the loans for the purchase of diesel cars relative to petrol cars.

In general, given the large presence of captive banks in the car loan market, financing terms reflect the underlying risk from the diesel engine technology less than what would be expected. This is the case for the diesel emissions scandal, as the empirical evidence shows a favorable adjustment of the loan terms and conditions applied by captive banks to the loans for diesel cars, but no significant change for the credit conditions by independent banks. On the other hand, following the introduction of the circulation restrictions, captive banks do not change credit conditions, while independent banks tighten them for the loans to diesel cars. Actual or expected changes in circulation regulation affect the usability of diesel cars and the credit risk assessment of financial intermediaries more strongly than the diesel emissions scandal, inducing lenders to account for the true cost of polluting diesel technology in financing terms.

Our paper makes two main contributions. First, it relates to the role of bank lending in the green transition in presence of information frictions between creditors and borrowers. We provide evidence of conflict of interests that may distort banks' assessment and pricing of transition risks, which are due to the ownership of different financial intermediaries. Captive lenders may set credit conditions which may support the purchase of high-emission vehicles, as they are linked to car manufacturers due to the vertical integration between production and finance within the same parent group. Second, our paper exploits shocks to the environmental risk of diesel cars to investigate the effects on bank lending conditions in the car loan market. Indeed, the auto sector faces rising credit risks due to carbon transition as fossil fuel-based engines technologies will be stranded; this process concerns diesel cars even more quickly than petrol cars, but it may be delayed if captive lenders pursue also other objectives and incentives relevant for the parent manufacturer group.

The rest of this paper is structured as follows. Section 2 reviews the main literature and provides some background on car pollution. In Section 3, we elaborate on the economic intuition underlying the relationship between environmental shocks and bank lending incentives and behavior. In Section 4 we discuss our dataset. In Section 5 we describe the empirical strategy and we present the results of our empirical analysis. In Section 6 we conclude summarizing our results and their implications.

## 2. Related Literature and Background

### 2.1 Literature

Our work is closely linked to the recently growing literature on the role of banks in the green transition, both in corporate lending, and in household credit. Banks do not produce hazardous chemicals or discharge toxic pollutants into the air, land, or water. However, through their lending practices banks are inextricably linked to economic activities that may degrade the natural environment (Accetturo et al., 2022). In the context of the emergence of more stringent climate policies, environmental risks could have significant impact on banks' portfolios and therefore should be accounted for. Much of this literature has focused on how banks incorporate environmental risk factors in their decisions to extend new credit (loan amounts and conditions) and in the management of their existing loan portfolios (Beyene et al., 2021; De Haas & Popov, 2020; Degryse et al., 2023; Houston & Shan, 2022; Kacperczyk & Peydró, 2022).

An important area of focus has been research that highlights the potential conflict of interests of banks as a key underlying reason for their continued financing of polluting activities. For example, there might be increased cross-border lending in response to higher climate policy stringency in home countries (Benincasa et al., 2021; Laeven & Popov, 2021). Moreover, banks are less likely to finance innovation as it is more efficient for them to acquire information on mature technologies compared to newer technologies (Brown et al., 2017; Ueda, 2004). In the context of the green transition, banks may face reduced incentives to finance innovative projects, if new technologies may reduce the value of their legacy exposures to brown assets or activities (Degryse et al., 2022). Our paper contributes to this literature by examining the conflict of interest that captive banks, vis-à-vis independent banks, might be subject to, and how it might impact the way environmental shocks are addressed.

Second, our paper is related to the literature on the lending behavior of captive financial intermediaries. When manufacturers are also lenders, credit approval process considers both the profit from providing a loan and the profit from selling the product that is acquired through the captive loan. Several empirical and theoretical papers have examined the differential performances of banks and finance companies in credit markets (Barron et al., 2008; Bodnaruk et al., 2016; Brennan et al., 1988; Murfin & Pratt, 2019). Some studies explore the effects of financial shocks and of sales incentives on loan terms and conditions under vertical integration (Benetton et al., 2022; Ramcharan and Yao, 2022). Other papers analyze the response of banks and non-banks to increased competition, and in particular the lending expansion by non-banks in consumer credit markets to riskier borrowers at the extensive margin (Gissler et al., 2020).

Third, this paper relates to the literature on the car market as well as the related market for consumer credit. A large share of households purchase cars using either bank credit or other type of asset-based lending and so readily available credit continues to push car sales. The literature on loan intermediation in auto markets shows the importance of credit conditions on car loans for auto sales, particularly for borrowers subject to credit constraints (Adams et al., 2009; Johnson et al., 2014). In this context, financial shocks affecting the funding conditions of consumer lenders may have significant real economy implications, by tightening lending conditions for car loans and reducing car sales (Benmelech et al., 2017; Ramcharan et al., 2016). Other studies investigate the role of search frictions in consumer loan markets (Argyle et al., 2022), the consumer response to exogenous variations in credit terms (Argyle et al., 2021), or the importance of monthly payments in consumer installment debt (Argyle et al., 2020). This paper establishes a clear connection between the environmental shocks affecting the automotive industry and the lending terms and conditions in the loan market to finance the purchase of these cars.

## 2.2 Background on car markets and pollution

The transport sector is second only to the energy industry in greenhouse gas emissions and one of the main contributors to air pollution. The move towards less energy consumption and stricter pollution control has emerged as an issue of growing prominence not only from a consumer perspective, but also for policymakers, as governments have set timelines to phase out fossil-fuel vehicles.

Air pollution refers to the release of pollutants into the air-pollutants which are detrimental to human health and the planet as a whole.[1] The automobile sector – as a main contributor to air pollution – poses a major threat to climate as well as to health. A major source of traffic related air pollution is diesel exhaust. Diesel and petrol engines are both internal, intermittent combustion engines. However, per liter, diesel contains more energy than petrol and the vehicle's engine combustion process is more efficient, adding up to higher fuel efficiency and lower $CO_2$ emissions when using diesel. The reverse side of the coin is the harmful diesel exhaust that is a hazard for the environment and human health. While diesel cars produce lower $CO_2$ emissions relative to petrol cars, diesel emissions are significantly more damaging to health. Moreover, expected greenhouse gas savings initiated by the shift to diesel cars have been overestimated while toxic $NO_x$ emissions of diesel cars have been grossly underestimated (Cames & Helmers, 2013). This threatens the value of polluting diesel cars. If car owners and governments care about emissions, we expect the car market to react to news about the emissions of cars. In fact, environmental concerns are increasingly driving consumer choices, implying that the automobile sector will be strongly affected by an increasing incorporation of air quality and climate change in policy development. Most governments have already set timelines to phase out fossil-fuel vehicles. While extant literature shows that the consumption of environmentally harmful products can have significant costs for consumers, how this process is mediated by banks remains an open question that this paper aims to address.

[1] According to the WHO, air pollution is the biggest environmental risk for non-communicable diseases in Europe. Higher air pollution concentrations increase the risk for cardiovascular and respiratory disease, cancer, and adverse birth outcomes, and also are associated with higher death rates. Each year air pollution is responsible for nearly seven million deaths around the globe. Nine out of ten human beings currently breathe air that exceeds the WHO's guideline limits for pollutants.

The financing of environmentally harmful products can also be costly for banks. A shock to the resale value of diesel cars translates into higher credit risk, ultimately affecting the financial sector's profits if car prices are not stabilized. Lenders active in the car sector are vulnerable to a drop in used-car prices after a surge in risky loans. Their undiversified business models would suggest that the transition risk is particularly pronounced for captive banks if the car manufacturer they are tied to is slow to adapt to less-polluting technologies.

## 3. Empirical Predictions

Following the diesel emission scandal and the introduction of low-emission zones, we expect the used-car market to react to the new information about the emissions of cars or about their actual usability. Firstly, the durability of the exhaust system could significantly decline after retrofitting, thus increasing maintenance costs. Secondly, we would expect car owners who care about the emissions of their cars to react to the new information about the emissions of cars. The shocks to the perceived environmental quality have, in fact, caused short-term positive supply effects on the used car-market as well as a negative impact on the price (Strittmatter & Lechner, 2020; Ater and Yoseph, 2022). In this section, we discuss the intuition behind the prediction of how consumer finance and captive banks react to a change in the perceived environmental quality of the underlying cars.

The current value of a consumer loan extended by a bank to a car purchaser is equal to the value of the sum of interest payments, loan installments, and the resale value in the used-car market in the case of default. When the value of cars declines due to revealed bad environmental quality, some borrowers may default on their car loans, leaving lenders with losses. Loan losses rise also because recoveries in the event of default are lower. If a shock to the perceived environmental quality of cars leads to a surplus of used cars and to a consequent drop in their resale value, lenders who set loan conditions balance the potential revenue from interest charges against the risk of default and the reduced value of the collateral (Stroebel, 2016). Similarly, lenders may require higher down payments, which results in lower loan-to-values (LTVs) as a consequence, to ensure good re-payment capacity and lower loan losses.[2]

[2] Shocks reducing the collateral value available to banks may raise credit constraints for borrowers and reduce the amount and the maturity of extended bank credit, also with real effects. See for instance Cerqueiro et al. (2013).

Captive banks would also be subject to potential considerations about the reduction in the value of the collateral; but, in addition, they internalize the dynamic implications of the production and sales of new cars for their own parent manufacturers (Benetton et al., 2022). Consumer uncertainty related to the purchase and resale of used diesel cars can erode future profits of a car manufacturer. This is because the current production of cars will eventually reach the used car market; so the price of new cars reflects rational expectations about the resale market (Bulow, 1986; Gavazza et al., 2014). New information about the environmental performance of diesel cars increases the expectation that there might be restrictions implemented affecting the usability of diesel cars. Following the discussed environmental shocks, consumers who want to buy a diesel car cannot be sure that the quality in terms of product and price depreciation will meet expected standards, leading to an oversupply of these cars in the used-car market. Car manufacturers' choice to grant attractive financing terms provides an opportunity for manufacturer to reduce concerns about product and price depreciations (Pike et al., 2005). This suggests that when the manufacturer maximizes its profit with respect to not only the production output but also loan conditions, the subsidiary captive bank would be able to charge lower interest rates and grant higher LTV ratios relative to independent banks post-environmental shocks, despite the potential risks associated with the usability and price depreciation of the cars (Barron et al., 2008; Murfin & Pratt, 2019).

## 4. Data

Our main dataset comprises car loans securitized by European banks and captive lenders. These data are available through the European Data Warehouse (EDW) which is a centralized European platform that collects, validates and makes available loan-level data for the underlying loan pools of Asset-Backed Securities (ABS), for different asset classes. Issuers of ABSs eligible as collateral for repo borrowing with the Eurosystem are required to quarterly report loan level information on the composition and the performance of their securitized loan portfolios in a detailed and standardized format set by the ECB (Ertan et al., 2017). Since then, European Data Warehouse has established its role as the main securitization repository in the European Union, as now the loan-level data should be reported to a recognized repository for all securitization transactions issued in the EU.

Figure 2 shows the market share of diesel vehicles in new car registrations across time. The share of diesel vehicles used to be over 50% but is clearly in a decreasing trend. We apply the following filters to the retrieved EDW data. We only consider loans for the purchase of used cars not for commercial use, amortizing car loans, and loans originated between 2006 and 2018 in Germany, Italy, France, and Spain. Most importantly, we require each car underlying a loan to be identifiable according to brand-model and fuel type. The choice between a petrol versus a diesel car as a key factor in a consumer's decision when purchasing a car is central to our identification strategy. The fuel type is identified based on the naming convention used for each model by the car brand in the EDW dataset. Car brands and models are included in the dataset only if the engine type (diesel or petrol) can be indubitably identified. Ultimately, we consider the car models of the brands: Alfa Romeo, Audi, BMW, Citroën, Dacia, FCA, Peugeot, Renault, SEAT, Škoda, and Volkswagen. Our final dataset consists of a total of 781,033 loan contracts with European banks from 2006 to 2018.

Table 1 describes the dependent variables as well as all potential covariates. Table 2 provides an overview of car loan and borrower characteristics. The average interest rate is 7.5%, the loan term 55 months and the loan-to-value (LTV) ratio 63%. The sample is restricted to cars used by households, whereby almost 60% of the borrowers are known to be employed and 15% pensioners. The average primary income of borrowers is at EUR 27,000. 75% of car loans have been provided by captive banks. The dataset includes a notable number of observations for captive intermediaries of large carmakers, like BMW Bank, FCA Bank, PSA Banque, RCI Banque, Toyota Kreditbank, Volkswagen Bank.

## 5. Empirical Analysis

### 5.1. Diesel Emission Scandal

We first focus on the diesel emission scandal of 2015. Since market participants did not expect the information revealed by this fraud event, the resulting decline in the observable environmental quality of diesel cars produced by the affected car brands is a quasi-experimental exogenous shock to the used-car market. On 18 September 2015, the US Environmental Protection Agency (EPA) issued a notice of violation of the Clean Air Act to German car producer Volkswagen Group. The notice was based on the allegation that the car producer had intentionally programmed turbo-charged direct injection (TDI) diesel engines to activate certain emission control systems only during laboratory testing. The manipulation had the obvious aim of bypassing the diesel emission standards. Diesel cars have been emitting four to seven times more $NO_2$ in on-road driving than in type approval tests. VW has admitted that about 11 million cars worldwide, including eight million in Europe, have been fitted with the so-called defeat device. The scandal had sizeable effects on consumer decisions and on the registrations of Volkswagen cars, particularly in Germany, with some heterogeneity across groups in relation to the perception of corporate fraud (Hasan et al., 2023).[3]

When the diesel emission scandal first emerged in 2015, analysts said it was likely that other car makers were also cheating tests (Bachmann et al., 2022). After the US EPA issued notices of violation first to VW in September, a second notice for Porsche and Audi was issued in November 2015. Other authorities started investigations into other car brands. In 2016 German authorities launched investigations into luxury car makers Porsche and Daimler for allegedly cheating emissions tests and French authorities raided Renault and PSA Peugeot Citroën headquarters. Others, such as Fiat Chrysler and Nissan were also hit by similar allegations in 2017. Figure 1 illustrates the timeline along which the different car brands were directly affected by the scandal. The emissions manipulations led to the eruption of a proper global scandal that has exposed high number of dirty diesel cars on the roads.

The diesel emission scandal had a strong impact on the consumer perception about the environmental quality of diesel cars and then on consumer decisions, even more strongly in the market for used cars. As in the seminal study by Akerlof (1970), the uncertainty on product quality can increase information asymmetries and have pervasive effects via adverse selection in the market for used cars. Ater and Yoseph (2022) provide evidence of a drop in the number of transactions involving used VW-manipulated cars, and of a fall in the resale price of these cars, due to lower willingness-to-pay and adverse selection. Also Strittmatter and Lechner (2020) find that after the scandal the supply of used VW diesel vehicles increased to a larger extent for vehicles with high probability of manipulation. Bachmann et al. (2022) document a spillover effect from the scandal also to the non-VW German auto manufacturers, via a drop in consumer valuations of vehicles and a reduction in annual sales.[4]

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[3] Hasan et al. (2023) provide evidence on the heterogeneity in consumer decisions due to differences in enforcement culture. They find that new registrations of VW cars decline significantly in German counties with a high share of Protestants following the VW scandal, due to the negative effects of corporate fraud on consumer preferences.

[4] The perceived longevity of cars is an important factor to determine their prices in the resale market. Also shocks affecting the ability of carmakers to provide complementary goods and services, like maintenance, spare parts or warranties, may have indirect effects on the prices of used cars in the resale market (Hortaçsu et al., 2013).

Consumers were affected twofold by these developments. First, they faced a financial disadvantage as the collateral values of diesel cars might have declined due to the uncertainty on their environmental quality. Moreover, they were exposed also to the additional risk of restrictions for the use of diesel vehicles in city centers, further compromising the value of their diesel cars. Overall, the ownership of diesel cars was less attractive as their use might have been limited. Especially in Europe, the prices for diesel cars dropped as customers feared regulatory changes and the future of these cars was not certain. This scandal had spillover effects also on financial markets, including the stock and bond prices of Volkswagen competitors and suppliers (Barth et al., 2022), as well as the pricing of European auto asset-backed securities, backed by loans for car purchases (Hachenberg et al., 2018).

### *5.1.1. Empirical strategy: Comparing pre- and post-diesel emission scandal*

Our empirical approach is based on comparing pre- and post-Dieselgate. In a first step, we group loan observations by borrower's income group, region, car model, and fuel type. We then follow Bertrand et al. (2004) and Khwaja and Mian (2008) and collapse our panel into two sub-periods around the diesel emission scandal. The sub-periods include one year before and one year after the event in order to account for seasonality patterns in the car market (Einav et al., 2013). The diesel emissions scandal started with the investigation on Volkswagen cars in September 2015. While this generated extensive media coverage from the beginning, the individual automotive makers were subject to specific investigations at different points in time (see Figure 1). As the disclosure events affecting the individual automotive makers are salient to consumers, in the baseline specification we use brand-specific dates for the diesel emission scandal, which is whenever a brand was accused of illegal behavior.

Our empirical approach focuses on loans financing cars of the same model, where loans differ in the fuel type of the purchased cars, and then in the car exposure to the Dieselgate shock. In first-differenced data, we compare how lending conditions change for loans underlying diesel cars relative to loans for petrol cars. Grouping loan observations by income group, region, car model, and fuel type before differencing, allows us to compare very similar loans both in terms of underlying car characteristics (car model) and in terms of borrower characteristics (income group, region). In this way, we ultimately compare loans - for similar cars and borrowers - financing the purchase of diesel and non-diesel cars. Further, the differencing specification produces standard errors that are robust to concerns of autocorrelation and we have additionally clustered standard errors. The empirical model is the following:

$$\Delta \text{Interest Rate}_{\text{model,bank,region,income,fuel}} = \beta\text{Diesel} + \gamma\text{Controls} + \mu_{\text{model}} + \mu_{\text{bank,region}} + \mu_{\text{brand,income}} + \varepsilon_{\text{model,bank,region,income,fuel}} \quad \text{Eq. 1}$$

Where $\Delta \text{Interest Rate}_{\text{model,bank,region,income,fuel}}$ is the change in interest rate between the year before September 2015 and the year after the brand specific diesel-emission disclosure event, within the groups defined by car model, fuel type, borrower's region and income group. The same applies when the LTV is the dependent variable. Diesel takes on the value 1 if the car is a diesel, and 0 if it is a petrol car. The specification includes a vector of control variables: the change in the average loan-to-value and the loan term, as well as the pre- brand-specific diesel emission scandal average income, by the model-bank-region-fuel type groups. In addition, standard errors are clustered at the model-fuel level. $\mu_{\text{model}}$ represents car model fixed effects; $\gamma_{\text{bank,region}}$ represents bank-region and $\delta_{\text{brand,income}}$ brand-income group fixed effects. ε it is the error term.

#### 5.1.2. *Empirical results: Comparing pre- and post-diesel emission scandal*

Table 3 and Table 4 present the summary statistics of loan conditions pre- and post-diesel emission shock for all used diesel and petrol car loan observations, for which all variables required for the grouping by income group, region, car model and fuel type are available. We further report a t-test to identify statistically significant differences between pre- and post-shock.

Table 3 shows the summary statistics separated by diesel and petrol subsamples. Overall, the differences between pre and post sub-periods are larger for the diesel subsample. Interest rate at origination decreases by 90 basis points (bps) for the diesel subsample, while the average LTV ratio increases by 4.5 percentage points (pp). Over the same time horizon, the interest rate on the loans for petrol cars decreases to a lesser extent (by 50 bps), while the average LTV ratio even decreases (by 3.3 pp).

Separating loans granted by captive banks from those granted by independent banks (Table 4) provides further insights on loan condition policies relevant to our hypothesis that captive banks support the sale of cars produced by their own manufacturing group. The average contract terms and lending standards for captive and independent banks differ significantly. Cars for which captive banks and independent banks provide financing may differ in terms of usage, as captive banks may be more likely to provide loans for newer used cars, due to an imbalance between supply and demand of new cars unsold. On average, captive lenders offer relatively worse financing conditions (higher rate, lower maturity, lower loan-to-value) because they are likely targeting a segment of the buyer population that is less likely to obtain bank credit (Barron, et al., 2008). After the diesel emission scandal, loan conditions applied by captive banks for loans to purchase cars of their own brands change more strongly in favor of the borrower.

The results for the models in Eq.1 with interest rate and loan-to-value as dependent variable are reported in Table 5 and Table 6, respectively. In the first specification, we include only the full set of fixed effects and the average primary income pre-event, while in the second we additionally include ΔLoan term and, respectively, Δ LTV (for Table 5) and Δ Interest rate (for Table 6) as controls. In the third specification we only include car models which are available in our sample both with a petrol engine and with a diesel engine in order to better account for potentially unobserved car characteristics. The number of observations decreases consequently for this specification. In the fourth specification, we consider only loan observation groups if the lender is a captive bank. In the final column, we present the findings only for non-captive banks.

We find an average negative effect of the diesel emission scandal on interest rates, by 17 bps for the overall sample of loans (Table 5, Col. 2). This effect is even stronger, with a reduction by 25 bps, when we conduct the analysis only for the car models which are available in our sample both with a petrol engine and with a diesel engine (Col. 3). Importantly, this decrease in lending rates is driven by the captive bank subgroup. While Column 4 shows a decrease in interest rates of about 25 basis points for captive bank loans, no similar change can be observed in Column 5 for the subsample of loans provided by independent banks. Economically, our coefficients indicate that, after the diesel emission scandal, borrowers of captive banks would have to pay 3-4 percent less in the annual interest rate. Given that auto loan borrowers may be liquidity constrained and sensitive to even small changes in monthly payments, this could potentially be an effective way to stimulate consumption (Adams et al., 2009; Argyle et al., 2020; Attanasio et al., 2008).

To observe whether banks tighten credit limits via other loan characteristics, we look at the impact of the diesel emission scandal on loan-to-value ratios (Table 6). Captive banks increase loan-to-value of diesel cars by 1-2 percentage points relative to petrol cars. On average, for the overall sample of loans, we find an increase in the LTV by 0.98 pp (Col. 2). This effect is even larger (1.28 pp), when considering only the car models available in our sample with both a petrol engine and a diesel engine (Col. 3). In fact, when we consider the two subsamples for different types of financial intermediaries, the effect is driven by the lending conditions of captive banks, as a strong and significant increase in the LTV is observed only for the loans provided by captive banks (1.48 pp).

These results are consistent with the prediction that after the environmental shocks - reducing the longevity of used diesel cars and then accelerating their price depreciation - captive banks charge lower interest rates and grant higher LTVs relative to independent consumer banks. When banks do not anticipate a higher risk of restrictions on diesel vehicles after the emissions scandal, captive banks have an additional incentive to provide more attractive loan conditions to support the sale of new cars.

After the diesel emission scandal, there were two possible scenarios. Either regulatory bodies and governments would feel the pressure to take a stricter stance on diesel fuel. Or regulations in the main European markets could remain unaffected by the scandal. Overall, the results seem to be more consistent with the expectation towards a somewhat rebounding diesel market. In fact, diesel cars still enjoyed favorable tax treatment compared with petrol, despite being the main cause of the air pollution crisis in European cities, and even if emission tests are still being watered down to provide automotive manufacturers with additional lead-time.

To summarize, the increased transparency - due the diesel emission scandal - on the true pollution caused by diesel engines does not seem to lead independent banks to price the higher credit risk of the loans; potentially, because they did not anticipate that the diesel emission scandal could have triggered higher risk of restrictions for diesel vehicles. At the same time, with the expectation of a potential recovery of the diesel market, captive banks had the incentive to provide more attractive credit conditions for loans to purchase diesel cars, possibly to increase the probability of sales for the cars of their own manufacturers.

## 5.2. Local Circulation Restrictions

The diesel emission scandal has revealed that exhaust levels produced by diesel cars are significantly higher than their formal test emissions. However, this new information about the true environmental or health risks of diesel vehicles does not necessarily trigger lending policies internalizing this cost; in fact, while independent banks do not seem to adjust their lending conditions, captive banks apply more favorable conditions for loans to diesel cars.

If so, we explore whether the setting of binding restrictions for the circulation of diesel vehicles may provide more effective incentives for lenders and borrowers to account for the environmental challenge of harmful diesel engine exhaust. For this purpose, we investigate the effects of the introduction of low emission zones on the lending conditions for car loans to purchase diesel versus petrol cars.

While monitoring pollution levels, over recent years governments have increasingly implemented a range of strategies to reduce traffic volumes and then ambient air pollution, such as low emission zones (LEZ) and pedestrianization. In the European Union, Low Emission Zones (LEZ) are signposted areas where access of vehicles is regulated, typically banning high-emitting vehicles from entering the zone altogether. These zones use Euro standards to regulate cars.[5] Low-emission zone rules usually only apply to diesel-powered passenger cars, other than to trucks and coaches.

Usually, to leave citizens with enough time to adjust, LEZs are phased in step by step. Figure 3 provides an overview of the phase-in of low emission zones in Germany and indicates which Euro norm standards were required at the respective stages. Also, Table 7 provides a list of all the low-emission zones introduced in Germany, with the indication of the district and of the municipality. We conduct our analysis on the introduction of low-emission zones for Germany because low emission zones are prevalent in German cities during our observation

[5] Along with the Ambient Air Quality Directives, the EU legislation sets emission standards for vehicles. Before a new vehicle model is placed on the EU market, it should be certified that it complies with pre-defined requirements for environmental performance. In accordance with the mutual recognition principle, once approved by the national authority of one EU Member State, the model can be sold in all other EU Member States. As regards the environmental performance of internal combustion engine vehicles, and in particular, the emissions of air pollutants from such vehicles, the EU has been adopting successive (and increasingly stringent) specific rules (Euro standards) since the 1990s. From 1993 on new cars had to fulfill Euro 1, from 1997 on Euro 2, from 2001 on Euro 3, from 2006 on Euro 4, from 2011 on Euro 5, and from 2015 on Euro 6.

period, compared to other EU countries, and to rely on a homogeneous framework regulating the process for their institution.

*5.2.1. Empirical strategy and results: Comparing pre- and post-low emission zone introduction*

To identify the effects of the introduction of the low emission zones and compare the ex-ante and the ex-post, we again follow the approach by Bertrand et al. (2004) and collapse our data into a pre- and post-treatment period. Before first differencing, we group loan observations by borrower's income group and district, car model and fuel type. Hence, the grouping procedure is more granular as we additionally require that the loans grouped together are from the same district.

We estimate the following model as in Equation 2:

$$\Delta \text{ Interest Rate}_{\text{model,bank,district,income,fuel}} = \beta \text{Diesel} + \gamma \text{Controls} + \mu_{\text{model}} + \mu_{\text{district}} + \mu_{\text{bank,region}} + \mu_{\text{brand,income group}} + \varepsilon_{\text{model,bank,district,income,fuel}} \quad \text{Eq. 2}$$

Table 8 presents summary statistics for loan characteristics before and after the introduction of low emission zones. In the period since the introduction of low emission zones, we note only relatively small statistically significant changes in loan characteristics.

Table 9 presents the results for the estimation of Equation 2 with interest rate and loan-to-value as dependent variables. The first two columns present the results for the subset of loans that have been granted by captive banks.[6] The last two columns present the results for the subset of loans provided by independent banks. In all specifications we include the full set of covariates and fixed effects.

The results show that independent banks charge higher interest rates after the introduction of LEZs by approximately 12 basis points. For captive banks we do not observe a significant change in loan conditions in any direction. This suggests that, after the introduction of circulation restrictions for diesel cars, independent banks internalize the additional credit risk of loans for the purchase of used diesel cars by applying more stringent loan pricing conditions. Captive banks do not adjust their lending conditions, also due to the counteracting incentives

[6] Due to the limited number of observations after the grouping of loan observations, we cannot present separate results for the loans of captive banks financing only the purchase of cars produced by other manufacturer groups.

of the collateral damage and of the captive financing. But importantly, compared to the evidence from the diesel emissions scandal, they do not relax their lending conditions.

## 5.3. Local Pollution Levels

Where air pollution is high there is big regulatory and public interest to reign in traffic pollution. In various jurisdictions, public authorities are also subject to stringent requirements for public disclosure of pollution levels towards citizens.[7] In countries using low-emission zones, the public disclosure of the recorded pollution levels may be relevant in view of the future introduction of new low-emission zones, if a given threshold for pollution level is surpassed in areas previously not subject to LEZ restrictions. In this case, the surpassing of this threshold may anticipate the future setting of LEZs, although this process may require some time for a complex decision-making process.

High pollution levels may imply a high risk associated with diesel cars, due to the future potential restrictions to the use of these vehicles. If so, health and environmental hazards of air pollution might justify an increase in the credit risk for loans to purchase cars with diesel engines. If loan markets were to price this risk and discipline borrowers' behavior, car loan conditions should internalize the assessment of the increased credit risk associated with diesel engines. We explore local pollution levels and analyze the potential manifestation of health and environmental hazard on the pricing of the resulting credit risk.

### *5.3.1. Empirical strategy and results: Local pollution-levels*

For the empirical analysis, we use local measures of $NO_2$-levels in Germany as main explanatory variable. We conduct this analysis in connection with the previous study on the introduction of low emission zones, given that high $NO_2$-levels may trigger corrective measures which could then affect the usability particularly of diesel cars. We analyze whether - and to what extent - banks financing car purchases internalize the potential effects of pollution levels above maximum threshold in setting lending terms and conditions for auto loans. Based on the EU legislation, we consider the event of trespassing the threshold of $NO_2$ annual mean value

[7] These disclosure requirements are based on environmental right-to-know laws (Sarokin & Schulkin, 1991)

limit of 40 μg/m³, as this should trigger policy actions by local authorities. We estimate the following difference-in-differences model:

$$\text{Interest rate}_{model,bank,region,income,fuel} = \beta_0 + \beta_1 \text{Diesel} + \beta_2 (> NO_2\ 40\ \mu g/m^3) + \beta_3 \text{Diesel x } (> NO_2\ 40\ \mu g/m^3) + \gamma \text{Controls} + \mu_{model} + \mu_{year} + \mu_{district} + \pi_{bank,region} + \mu_{brand,income} + \varepsilon_{model,bank,region,income,fuel} \quad \text{Eq. 3}$$

where (> $NO_2$ 40 μg/m³) is a dummy equal to one for loans extended to borrowers in German districts where the $NO_2$ annual mean value limit of 40 μg/m³ has been surpassed the past year, and zero otherwise. The coefficient $\beta_2$ captures the average interest rate in the post period. The main coefficient of interest $\beta_3$ captures the effect of passing the threshold on the lending conditions for diesel car loans. The control group of petrol cars is not exposed to the $NO_2$ threshold and to the implied potential policy change, given that petrol engines barely produce $NO_2$ and that the potential restrictions from excessive $NO_2$ levels would not apply to petrol cars.

Table 10 presents the results. Columns 1-3 and 4-6 respectively report estimates for interest rate and LTV as dependent variables. Each column differs in terms of lender subgroup: 1) captive banks providing financing for own-brand cars; 2) captive banks providing financing for cars produced by other manufacturers; and 3) independent banks. All specifications include the following full set of fixed effects: model, year, district, bank-region, brand-income group. Standard errors are clustered at the model-fuel type and at the district level.

Separating the captive bank sub-sample into loans for car brands of the same manufacturer group (as the bank) and loans for cars of other producers allows us to investigate whether a captive bank provides more attractive loan conditions to support car sales of its own brand or to dispose more widely of their existing stock of used cars. We observe that, following the surpassing of the critical $NO_2$-level, captive banks increase the lending rates for diesel car models of other producers by 20 bps, to a larger extent than independent banks (11 bps). Yet, we find no evidence of such effects for the loans to finance cars of the same manufacturing group. This is consistent with the evidence for the introduction of the low emission zones, as observed for the overall loan portfolio of captive banks.[8]

Therefore, despite a potential decrease in the collateral value of diesel cars, captive banks prefer not to tighten credit conditions for used cars of their own brands, while they do so only for cars of other groups. Although not statistically significant, our findings for the specifications with LTV as dependent variable are aligned with our findings with regards to interest rates. Overall, independent banks are more likely to price the increased risk stemming from diesel cars relative to captive banks. This seems to confirm the incentive of captive banks to support the primary market profits of the parent manufacturers rather than the sales of used car stocks.

## 6. Conclusions and Implications

The transition to a green economy strongly depends on the existence of appropriate incentives for economic agents, including financial intermediaries. We investigate how different types of credit institutions – captive and independent – price the pollution factor when setting credit conditions for loans to finance the purchase of used cars. We distinguish cars with diesel versus petrol engines, due to the mounting evidence on the stronger negative impact of diesel cars on environment and health. As this threatens the longevity and the usability of diesel cars – and to the extent that lenders may perceive the use of diesel engines as a relevant risk factor - banks should adjust their loan conditions for these risks more so if car loans are originated in areas more vulnerable to the hazard of air pollution.

In this paper, using loan-level data for auto loans, we estimate the effect of different shocks to the perceived environmental quality of diesel vehicles on bank lending conditions for car loans. Financed cars are used as collateral, which makes it ideal to investigate the impact of an increased risk of devalued diesel technologies.

The diesel emission scandal has raised awareness over the high levels of pollution emitted by all diesel vehicles from a wide range of carmakers. However, the increased transparency on the environmental performance of these cars does not seem to be sufficient for

[8] In fact, the used cars sold by car dealers are much more frequently from the same manufacturer group and more rarely from other carmakers. This is evident also in the different number of observations for loans by captive banks in Table 10: Col. 1 (4) for cars of the same group; Col. 2 (5) for cars of other groups.

banks to disincentivize the consumption of high-emission vehicles. Despite the uncertainty related to the diesel engines underlying car loans, banks overall have not been discouraged from supporting the purchase of diesel vehicles. In fact, captive banks have further decreased interest rates and increased loan to value ratios to support diesel car purchases.

In this context, the introduction of binding circulation restrictions creates stronger incentives to price the pollution factor related to diesel vehicles in the credit conditions for car loans. After the institution of low emission zones, independent banks increase interest rates for loans to diesel cars relative to petrol cars. Moreover, independent banks charge higher interest rates on loans for diesel cars in areas with high local air pollution. Hence, even in presence of high levels of pollution and under the introduction of low emission zones, captive banks provide relatively more attractive lending terms compared to independent consumer banks. This analysis provides insights on whether direct regulation setting actual constraints on the usability of diesel cars may be more effective in providing appropriate incentives to price the risk of high-emission vehicles.

These results suggest that the bank lending behavior – particularly by captive banks - may interfere with the green transition of the automotive sector and may further enforce the market and regulatory failures that led to extensive levels of pollution by the transportation sector. These findings are relevant in face of today’s increasingly stringent EU limits car emissions driving bans, and in light of the future phase-out of internal combustion engine vehicles.

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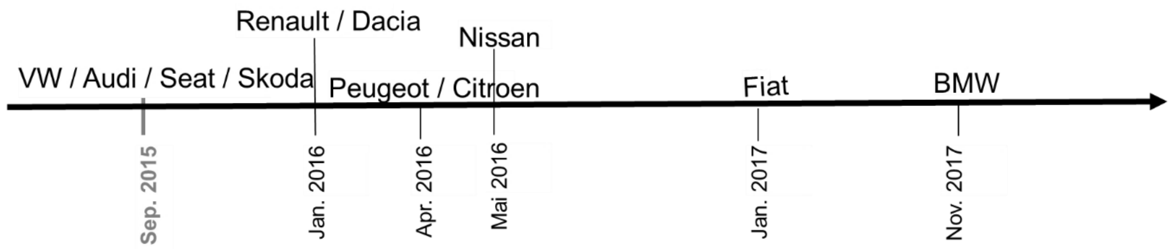
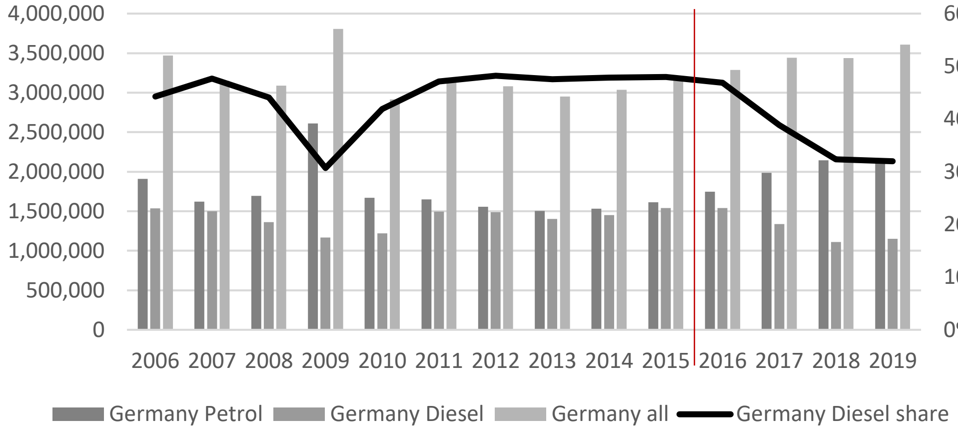
*Figure 1. Diesel emission scandal timeline by brands*




*Source: own illustration*

Figure 2. New registrations of passenger cars by fuel type in Germany




*Source: own illustration based on Eurostat data*

Figure 3. Implementation of low emission zones introductions in Germany

| Level | **Level 1 LEZ** | **Level 2 LEZ** | **Level 3 LEZ** |
|---|---|---|---|
| Diesel | Euro 2 or Euro 1 + particle filter | Euro 3 or Euro 2 + particle filter | Euro 4 or Euro 3 + particle filter |

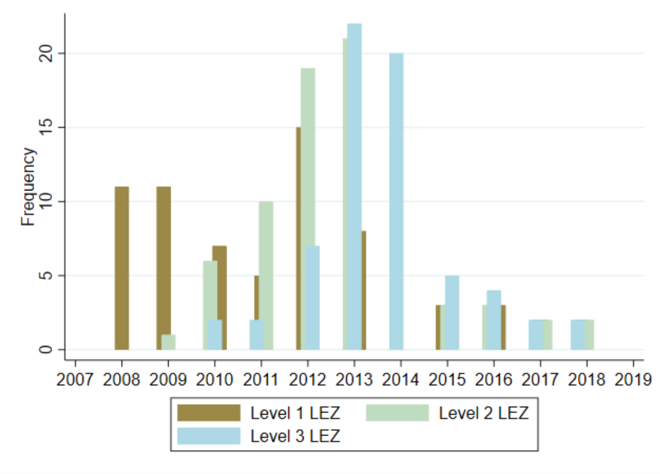


Table 1. Overview variables

| Variable | Description | Source |
|---|---|---|
| *A. Dependent variables in main specifications* | | |
| Interest rate | Current interest rate (%) | EDW |
| Loan term | Original contractual term | EDW |
| Loan-to-value | Original loan amount over car value | EDW |
| In arrears | Indicator variable equal to 1 if the borrower has ever been in arrears on the loan | EDW |
| *B. Other loan characteristics* | | |
| Down payment | Amount of deposit/down payment at origination | EDW |
| Car value | Car value at origination | EDW |
| *C. Explanatory variables: Bank characteristics* | | |
| Firm size | Log of total firm assets | FitchConnect |
| Market-to-book ratio | The ratio of the market value of assets to the book value of assets | FitchConnect |
| Tangibility | The ratio of tangible assets to total assets (multiplied by 100) | FitchConnect |
| Leverage | The ratio of total debt to total assets (multiplied by 100) | FitchConnect |
| Profitability | The return on equity | FitchConnect |
| *D. Explanatory variables: Borrower characteristics* | | |
| Region | The region where the borrower is located at loan origination | EDW |
| Primary income | Primary borrower underwritten gross annual income | EDW |
| Employment status | Different dummies indicating the employment status of borrower (employed, self-employed, student, pensioner, unemployed) | |
| *E. Explanatory variables: Car characteristics* | | |
| Brand | Brand name of car | EDW |
| Model | Model of car | EDW |
| Car classification | As defined by the European Commission | EDW |
| Used car | Indicator that equals 1 if the car was used at the time of origination | EDW |

Table 2. Summary statistics

This table reports the number of observations, the standard deviation, mean, median, minimum, and maximum, of the main variables used to estimate the regression specification. The variables are defined in Table 1 and the sample period is 2006-2018.

| | N | sd | mean | min | max |
|---|---|---|---|---|---|
| Interest rate (% per annum) | 781,033 | 2.349 | 7.544 | 0 | 15 |
| Primary income (EUR) | 691,663 | 1.015e+06 | 27,571 | 0 | 8.400e+08 |
| Loan term (months) | 781,036 | 16.34 | 55.32 | 4 | 147 |
| Down payment amount (EUR) | 780,875 | 36,675 | 6,145 | 0 | 2.090e+07 |
| Loan-to-value (%) | 780,732 | 35.21 | 62.89 | 0 | 455 |
| Car valuation (EUR) | 577,357 | 5,586 | 14,072 | 900 | 1.100e+06 |
| In arrears (binary) | 781,045 | 0.204 | 0.043 | 0 | 1 |
| Captive bank | 781,045 | 0.4324 | 0.7509 | 0 | 1 |
| Countries (binary) | | | | | |
| Germany | 781,045 | 0.457 | 0.298 | 0 | 1 |
| France | 781,045 | 0.497 | 0.553 | 0 | 1 |
| Spain | 781,045 | 0.308 | 0.106 | 0 | 1 |
| Italy | 781,045 | 0.204 | 0.0436 | 0 | 1 |
| Employment status (binary) | | | | | |
| Employed | 781,045 | 0.491 | 0.596 | 0 | 1 |
| Unemployed | 781,045 | 0.110 | 0.0122 | 0 | 1 |
| Self-employed | 781,045 | 0.237 | 0.0600 | 0 | 1 |
| Student | 781,045 | 0.0720 | 0.00522 | 0 | 1 |
| Pensioner | 781,045 | 0.357 | 0.150 | 0 | 1 |
| Legal-entity | 781,045 | 0.0843 | 0.00716 | 0 | 1 |

Table 3. Summary statistics pre and post diesel emission scandal, diesel vs. petrol

This table reports the average loan characteristics in both periods, pre- and post- the brand-specific diesel emission scandal for both diesel and petrol car loans provided by captive and independent banks. A t-test is used to identify statistically significant differences across the pre and post sub-periods. The left side of the table reports the characteristics for loans that have diesel cars underlying while the right side describes the average loan characteristics for loans that have petrol cars underlying. The sub-periods consist of one year before September 2015 and respectively one year after the brand-specific diesel emission scandal event.

| | diesel | | | | | | petrol | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pre | | post | | Δ | | pre | | post | | Δ | |
| Loan characteristics | mean | sd | mean | sd | b | t | mean | sd | mean | sd | b | t |
| Interest rate | 7.65 | 2.2 | 6.75 | 2.31 | 0.90*** | (71.1) | 6.46 | 2.19 | 5.96 | 2.32 | 0.50*** | (23.69) |
| Loan term | 54.06 | 16.01 | 55.39 | 16.09 | -1.33*** | (-14.74) | 54.36 | 19.61 | 55.4 | 18.36 | -1.04*** | (-5.83) |
| LTV | 60.49 | 34.6 | 64.91 | 34.08 | -4.42*** | (-22.98) | 75 | 33.49 | 71.66 | 33.52 | 3.34*** | (10.61) |
| Down payment amount | 6654.51 | 6106.8 | 6149.16 | 5950.25 | 505.36*** | (14.97) | 4239.85 | 4561.37 | 4968.49 | 5111.56 | -728.64*** | (-16.00) |
| Observations | 72611 | | 56583 | | | | 22477 | | 22749 | | | |

Table 4. Summary statistics pre and post the diesel emission scandal, captive vs. independent banks

This table reports the average loan characteristics in both periods, pre- and post- the brand-specific diesel emission scandal for diesel car loans provided by captive and independent banks. A t-test is used to identify statistically significant differences across the pre and post sub-periods. The left side of the table reports the characteristics for loans provided by captive banks while the right side describes the average loan characteristics for loans provided by independent banks. The sub-periods consist of one year before September 2015 and respectively one year after the brand-specific diesel emission scandal event.

| | captive banks | | | | | | independent banks | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pre | | post | | Δ | | pre | | post | | Δ | |
| Loan characteristics | mean | sd | mean | sd | b | t | mean | sd | mean | sd | b | t |
| Interest rate | 8.29 | 1.91 | 7.26 | 2.23 | 1.03*** | -76.04 | 5.61 | 1.78 | 5.21 | 1.79 | 0.40*** | (19.62) |
| Loan term | 52.98 | 13.83 | 54.12 | 13.38 | -1.15*** | (-13.14) | 57.56 | 21.2 | 59.23 | 21.95 | -1.66*** | (-6.77) |
| LTV | 51.29 | 31.44 | 55.97 | 31.17 | -4.68*** | (-23.21) | 90.15 | 26.81 | 92.08 | 27.5 | -1.93*** | (-6.24) |
| Down payment amount | 7704.37 | 6226.52 | 7115.55 | 6124.43 | 588.81*** | -14.81 | 3268.99 | 4185.25 | 3211.67 | 4188.88 | 57.31 | (1.20) |
| Observations | 55424 | | 42576 | | | | 17187 | | 14007 | | | |

Table 5. Dieselgate pre and post interest rate

The table reports coefficients and standard errors (in parentheses). The dependent variable is Δ Interest rate. We define all variables in Table 1. Estimation method is OLS with standard errors clustered by model-fuel type. The sample consists of amortizing loans for used cars for individual customers issued in DE, ES, IT, FR. The sub-periods before first differencing are the year before September 2015 and the year after brand specific diesel-emission scandal. The observations are collapsed by car model, lender bank, region and fuel type.

| | All banks | | | Captive bank | Independent banks |
|---|---|---|---|---|---|
| | | | Same diesel petrol models | | |
| Dependent variable: Δ Interest rate | (1) | (2) | (3) | (4) | (5) |
| Diesel-dummy | -0.310*** | -0.172*** | -0.227*** | -0.250*** | -0.0231 |
| | (0.0986) | (0.0524) | (0.0487) | (0.0616) | (0.0563) |
| Δ Loan-to-value | | 0.0203*** | 0.0167*** | 0.0131*** | 0.0345*** |
| | | (0.00173) | (0.00278) | (0.00202) | (0.00168) |
| Δ Loan term | | 0.0650*** | 0.0579*** | 0.0937*** | 0.0261*** |
| | | (0.00253) | (0.00457) | (0.00319) | (0.00214) |
| Primary income | -4.47e-07* | -5.88e-08 | -9.15e-07** | -4.74e-07** | 5.06e-09 |
| | (2.50e-07) | (6.18e-08) | (3.77e-07) | (2.12e-07) | (1.85e-08) |
| Constant | -0.650*** | -0.506*** | -0.480*** | -0.618*** | -0.465*** |
| | (0.0697) | (0.0405) | (0.0394) | (0.0490) | (0.0424) |
| Observations | 20,530 | 20,530 | 9,390 | 11,870 | 8,648 |
| R-squared | 0.185 | 0.750 | 0.718 | 0.792 | 0.772 |
| Model FE | YES | YES | YES | YES | YES |
| Bank X Region FE | YES | YES | YES | YES | YES |
| Brand X Income-quartile FE | YES | YES | YES | YES | YES |
| Model X Fuel type clustered SE | YES | YES | YES | YES | YES |

*** p<0.01, ** p<0.05, * p<0.1

## Table 6. Dieselgate pre and post loan-to-value

The table reports coefficients and standard errors (in parentheses). The dependent variable is Δ Loan term. We define all variables in Table 1. Estimation method is OLS with standard errors clustered by model-fuel type. The sample consists of amortizing loans for used cars for individual customers issued in DE, ES, IT, FR. The sub-periods before first differencing are the year before September 2015 and the year after brand specific diesel-emission scandal. The observations are collapsed by car model, lender bank, region and fuel type.

| | All banks | | | Captive bank | Independent banks |
|---|---|---|---|---|---|
| | | | Same diesel petrol models | | |
| Dependent variable: Δ Loan-to-value | (1) | (2) | (3) | (4) | (5) |
| Diesel-dummy | -1.551 | 0.982** | 1.286*** | 1.483** | 0.0407 |
| | (1.115) | (0.424) | (0.486) | (0.601) | (0.537) |
| Δ Interest rate | | 2.432*** | 2.264*** | 1.704*** | 4.754*** |
| | | (0.206) | (0.391) | (0.251) | (0.231) |
| Δ Loan term | | 1.078*** | 1.090*** | 1.097*** | 0.978*** |
| | | (0.0131) | (0.0216) | (0.0201) | (0.0129) |
| Primary income | -5.88e-06* | -3.34e-07 | -2.26e-06 | -2.94e-06*** | -1.93e-07 |
| | (3.27e-06) | (6.64e-07) | (1.48e-06) | (7.07e-07) | (3.35e-07) |
| Constant | -2.768*** | 0.276 | 1.053** | 0.772 | 0.682 |
| | (0.823) | (0.381) | (0.448) | (0.537) | (0.442) |
| Observations | 20,530 | 20,530 | 9,390 | 11,870 | 8,648 |
| R-squared | 0.184 | 0.829 | 0.814 | 0.797 | 0.880 |
| Model FE | YES | YES | YES | YES | YES |
| Bank X Region FE | YES | YES | YES | YES | YES |
| Brand X Income-quartile FE | YES | YES | YES | YES | YES |
| Model X Fuel type clustered SE | YES | YES | YES | YES | YES |

*** p<0.01, ** p<0.05, * p<0.1

Table 7. Area and introduction date of low emission zones in Germany

| **District** | **Municipality** | **Introduction LEZ** |
|---|---|---|
| Stuttgart | Stuttgart | 01.03.2008 |
| Böblingen | Herrenberg | 01.01.2009 |
| Esslingen | Wendlingen | 02.04.2013 |
| Ludwigsburg | Pleidelsheim | 01.01.2013 |
| Rems-Murr-Kreis | Urbach | 01.01.2012 |
| Heilbronn | Heilbronn | 01.01.2009 |
| Heilbronn | Ilsfeld | 01.03.2008 |
| Heidenheim | Heidenheim | 01.01.2012 |
| Ostalbkreis | Schwäbisch Gmünd | 01.03.2008 |
| Karlsruhe | Karlsruhe | 01.01.2009 |
| Karlsruhe | Pfinztal | 01.01.2010 |
| Heidelberg | Heidelberg | 01.01.2010 |
| Mannheim | Mannheim | 01.03.2008 |
| Pforzheim | Pforzheim | 01.01.2009 |
| Enzkreis | Mühlacker | 01.01.2009 |
| Freiburg im Breisgau | Freiburg | 01.01.2010 |
| Rottweil | Schramberg | 01.07.2013 |
| Reutlingen | Reutlingen | 01.03.2008 |
| Tübingen | Tübingen | 01.03.2008 |
| Zollernalbkreis | Balingen | 01.04.2017 |
| Ulm | Ulm | 01.01.2009 |
| München | München | 01.11.2008 |
| Regensburg | Regensburg | 15.01.2018 |
| Augsburg | Augsburg | 01.07.2009 |
| Neu-Ulm | Neu-Ulm | 01.11.2009 |
| Berlin | Berlin | 01.01.2008 |
| Bremen, | Bremen | 01.01.2009 |
| Darmstadt | Darmstadt | 01.11.2015 |
| Frankfurt am Main | Frankfurt am Main | 01.11.2008 |
| Offenbach am Main | Offenbach | 01.01.2015 |
| Wiesbaden | Wiesbaden | 01.02.2013 |
| Limburg-Weilburg | Limburg a.d. Lahn | 31.01.2018 |
| Marburg-Biedenkopf | Marburg | 01.04.2016 |
| Region Hannover | Hannover | 01.01.2008 |
| Osnabrück | Osnabrück | 04.01.2010 |
| Düsseldorf | Düsseldorf | 15.02.2009 |
| Duisburg | Duisburg | 01.01.2012 |
| Essen | Essen | 01.01.2012 |
| Krefeld | Krefeld | 01.01.2011 |
| Mönchengladbach | Mönchengladbach | 01.01.2013 |
| Mülheim an der Ruhr | Mülheim an der Ruhr | 01.01.2012 |
| Oberhausen | Oberhausen | 01.01.2012 |
| Remscheid | Remscheid | 01.01.2013 |
| Wuppertal | Wuppertal | 15.02.2009 |
| Mettmann | Langenfeld | 01.01.2013 |
| Rhein-Kreis Neuss | Neuss | 15.02.2010 |
| Wesel | Dinslaken | 01.07.2011 |
| Aachen | Aachen | 01.02.2016 |
| Bonn | Bonn | 01.01.2010 |
| Köln | Köln | 01.01.2008 |
| Aachen | Eschweiler | 01.06.2016 |
| Rheinisch-Bergischer Kreis | Overath | 01.11.2017 |

| | | |
|---|---|---|
| Bottrop | Bottrop | 01.01.2012 |
| Gelsenkirchen | Gelsenkirchen | 01.01.2012 |
| Münster | Münster | 01.01.2010 |
| Recklinghausen | Herten | 01.01.2012 |
| Bochum | Bochum | 01.01.2012 |
| Dortmund | Dortmund | 01.01.2012 |
| Hagen | Hagen | 01.01.2012 |
| Herne | Herne | 01.01.2012 |
| Siegen-Wittgenstein | Siegen | 01.01.2015 |
| Mainz | Mainz | 01.02.2013 |
| Leipzig | Leipzig | 01.03.2011 |
| Halle (Saale) | Halle (Saale) | 01.09.2011 |
| Magdeburg | Magdeburg | 01.09.2011 |
| Erfurt | Erfurt | 01.11.2012 |

Table 8. Summary statistics pre and post the introduction of low emission zones

This table reports the average loan characteristics in both periods, pre-and post the district-specific introduction of low emission zones in Germany. A t-test is used to identify statistically significant differences across the pre and post sub-periods. The sub-periods consist of 2 years before the introduction of the low-emission zones and respectively two years after.

| | Pre | | Post | | Δ | |
|---|---|---|---|---|---|---|
| | mean | sd | mean | sd | b | t |
| Interest rate | 5.99 | 1.54 | 6.09 | 1.51 | -0.09** | (-3.17) |
| Loan term | 58.7 | 20.15 | 57.7 | 20.91 | 1.00* | -2.51 |
| Loan-to-value | 87.06 | 28.47 | 87.03 | 28.93 | 0.03 | -0.05 |
| Down payment amount | 3088.96 | 3961.31 | 3111.88 | 3944.56 | -22.93 | (-0.30) |
| Car valuation | 11738.4 | 4084.37 | 11651.58 | 4195.8 | 86.83 | -0.62 |
| Observations | 4275 | | 6803 | | | |

Table 9. Pre and post introduction of low emission zones (LEZ)

This table contains OLS estimated coefficients for Equation 2. The dependent variable in Column 1 and 3 is the interest rate and in Column 2 and 4 is the loan-to-value of the loans in the analyzed sample. The term "Diesel" is a dummy indicating if the loan is granted to finance the purchase of a diesel vehicle. Estimations include the other loan characteristics, the primary income of the borrower as well as the employment status of the borrower. The sample consists of amortizing loans for used cars extended to individual customers in Germany. The sub-periods include 2 years before the introduction of the low-emission zones and respectively two years after. The observations are collapsed by car model, lender banks, borrower's income and region, and fuel type.

| | Captive banks | | Independent banks | |
|---|---|---|---|---|
| Dependent variables: | Δ Interest rate | Δ Loan-to-value | Δ Interest rate | Δ Loan-to-value |
| | (1) | (2) | (3) | (4) |
| Diesel-dummy | 0.0518 | -0.832 | 0.122** | 0.0865 |
| | (0.0590) | (0.945) | (0.0599) | (0.708) |
| Δ Interest rate | | 7.156*** | | 6.017*** |
| | | (0.359) | | (0.244) |
| Δ Loan term | 0.0477*** | 0.595*** | 0.0220*** | 0.873*** |
| | (0.00218) | (0.0391) | (0.00181) | (0.0202) |
| Δ Loan-to-value | 0.0322*** | | 0.0381*** | |
| | (0.00164) | | (0.00158) | |
| Primary income | -3.10e-05*** | -0.000181*** | -3.17e-05*** | -4.24e-05* |
| | (5.49e-06) | (5.82e-05) | (6.39e-06) | (2.36e-05) |
| Constant | 0.652*** | 2.526** | 0.759*** | 2.005*** |
| | (0.0811) | (0.967) | (0.134) | (0.756) |
| Observations | 2,509 | 2,509 | 4,276 | 4,276 |
| R-squared | 0.911 | 0.899 | 0.869 | 0.916 |
| Model FE | YES | YES | YES | YES |
| Bank X District FE | YES | YES | YES | YES |
| Brand X Income-quartile FE | YES | YES | YES | YES |
| Model X Fuel type clustered SE | YES | YES | YES | YES |

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 10. Local pollution levels

This table contains OLS estimated coefficients for Equation 3. The dependent variable in Column 1-3 is the interest rate and in Column 4-6 is the loan-to-value of loan observations. The term "> $NO_2$ 40 µg/m³" is a dummy indicating if the $NO_2$ threshold of has been surpassed and "Diesel" is a dummy indicating if it is a diesel vehicle that is underlying a loan. Estimations include the other loan characteristics and primary income of the borrower as well as employment status of the borrower. NO2 µg/m³ is scaled by 1000 for better readability.

| **Dependent variable:** | **Interest rate** | | | **Loan-to-value** | | |
|---|---|---|---|---|---|---|
| | Captive | | Independent | Captive | | Independent |
| | Own | Other | | Own | Other | |
| (> $NO_2$ 40 µg/m³) | 0.0937* | -0.0496 | -0.0883** | 0.997* | 2.529** | 0.989** |
| | (0.0504) | (0.0901) | (0.0375) | (0.592) | (1.147) | (0.402) |
| Diesel | -0.0409* | -0.178*** | 0.0730*** | -1.057 | 1.777* | 1.781*** |
| | (0.0240) | (0.0607) | (0.0257) | (0.870) | (0.961) | (0.684) |
| (> $NO_2$ 40 µg/m³) X Diesel | -0.00988 | 0.202** | 0.109*** | 0.0108 | -0.180 | -0.358 |
| | (0.0334) | (0.0810) | (0.0308) | (0.530) | (1.131) | (0.433) |
| Constant | 4.914*** | 4.299*** | 5.399*** | 28.93*** | 56.42*** | 42.44*** |
| | (0.118) | (0.243) | (0.0390) | (1.368) | (3.695) | (1.096) |
| Controls | YES | YES | YES | YES | YES | YES |
| Model FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| District FE | YES | YES | YES | YES | YES | YES |
| Bank X Region FE | YES | YES | YES | YES | YES | YES |
| Brand X Income-quartile FE | YES | YES | YES | YES | YES | YES |
| Model X Fuel type clustered SE | YES | YES | YES | YES | YES | YES |
| District clustered SE | YES | YES | YES | YES | YES | YES |
| R-squared | 0.449 | 0.507 | 0.331 | 0.245 | 0.526 | 0.318 |
| Observations | 33,079 | 2,855 | 106,315 | 33,079 | 2,855 | 106,315 |

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

# Appendix

## Table A1. Brand and model used cars

This Table reports the number of amortization car loan observations with a maturity larger than 1 by brand and model. Brands included are: ALFA ROMEO, AUDI, BMW, CITROEN, DACIA, FIAT, PEUGEOT, RENAULT, SEAT, SKODA, and VW. Car models are included if the frequency is larger than 100.

| | **Freq.** | | **Freq.** | | **Freq.** |
|---|---|---|---|---|---|
| **ALFA ROMEO** | | DS4 | 5,576 | Kadjar | 446 |
| 147 | 509 | DS5 | 2,902 | Koleos | 1,240 |
| 159 | 1,103 | Xsara Picasso | 757 | Laguna | 1,181 |
| Brera | 102 | **DACIA** | | Latitude | 105 |
| GT | 219 | Duster | 2,557 | Megane | 6,447 |
| Giulietta | 1,255 | Lodgy | 542 | Modus | 824 |
| MiTo | 717 | Logan | 278 | Scenic | 4,651 |
| Spider | 149 | Sandero | 2,122 | Twingo | 803 |
| **AUDI** | | **FIAT** | | Wind | 182 |
| A1 | 1,779 | 500 | 550 | **SEAT** | |
| A3 | 8,966 | 500L | 307 | Altea | 2,671 |
| A4 | 4,697 | Bravo | 571 | Cordoba | 175 |
| A5 | 2,270 | Croma | 391 | Exeo | 1,188 |
| A6 | 3,318 | Freemont | 297 | Ibiza | 2,468 |
| A7 | 216 | Panda | 171 | Leon | 8,826 |
| A8 | 422 | Punto | 398 | Toledo | 338 |
| Q3 | 644 | Tipo | 138 | **SKODA** | |
| Q5 | 1,730 | Ulysse | 199 | Fabia | 3,466 |
| Q7 | 1,143 | **PEUGEOT** | | Octavia | 3,261 |
| TT | 270 | 1007 | 1,400 | Rapid | 594 |
| **BMW** | | 107 | 812 | Superb | 1,060 |
| 1 Series | 9,470 | 108 | 2,548 | Yeti | 2,400 |
| 2 Series | 242 | 2008 | 17,183 | **VW** | |
| 3 Series | 15,814 | 206 | 8,828 | Eos | 1,124 |
| 4 Series | 146 | 207 | 54,411 | Golf | 15,240 |
| 5 Series | 10,082 | 208 | 46,515 | Jetta | 734 |
| 7 Series | 659 | 3008 | 32,215 | Passat | 5,516 |
| X1 | 1,001 | 307 | 10,960 | Phaeton | 408 |
| X3 | 2,592 | 308 | 61,307 | Polo | 4,998 |
| X5 | 1,244 | 4007 | 1,603 | Scirocco | 158 |
| X6 | 366 | 4008 | 957 | Sharan | 2,283 |
| **CITROËN** | | 406 | 236 | Tiguan | 5,232 |
| C1 | 2,942 | 407 | 14,723 | Touareg | 281 |
| C2 | 3,520 | 5008 | 15,906 | Touran | 11,247 |
| C3 | 40,799 | 508 | 13,904 | | |
| C3 Picasso | 17,183 | 607 | 1,752 | | |
| C4 | 96,003 | 807 | 4,259 | | |
| C5 | 25,386 | RCZ | 2,545 | | |
| C6 | 1,500 | **RENAULT** | | | |
| C8 | 3,649 | Captur | 2,653 | | |
| DS3 | 11,449 | Clio | 7,412 | | |

## Table A2. Brand and car Segment used cars

This Table reports the number of amortization car loan observations with a maturity larger than 1 by brand and vehicle category. The classification is based on the passenger car classification defined by the European Commission. A: mini cars, B: small cars, C: medium cars, D: large cars, E: executive cars, F: luxury cars, S: sport cars, J: SUV, M: Multi-purpose cars. (https://www.eafo.eu/knowledge-center/european-vehicle-categories)

| | **Freq.** |
|---|---|
| **ALFA ROMEO** | |
| executive cars | 1,211 |
| medium cars | 1,764 |
| small cars | 717 |
| sport cars | 479 |
| **AUDI** | |
| executive cars | 3,538 |
| large cars | 6,979 |
| luxury cars | 442 |
| medium cars | 8,993 |
| small cars | 1,781 |
| sport cars | 271 |
| sport utility cars | 3,534 |
| **CITROËN** | |
| executive cars | 4,402 |
| large cars | 25,386 |
| medium cars | 101,579 |
| mini cars | 6,462 |
| multi purpose cars | 21,589 |
| small cars | 52,297 |
| **DACIA** | |
| medium cars | 278 |
| multi purpose cars | 542 |
| small cars | 2,122 |
| sport utility cars | 2,564 |
| **FIAT** | |
| large cars | 391 |
| medium cars | 797 |
| mini cars | 1,028 |
| multi purpose cars | 265 |
| small cars | 398 |
| sport utility cars | 297 |
| **PEUGEOT** | |
| executive cars | 1,752 |
| large cars | 28,863 |
| medium cars | 72,292 |
| mini cars | 3,360 |
| multi purpose cars | 20,165 |
| small cars | 109,758 |
| sport cars | 2,545 |
| sport utility cars | 51,958 |
| **RENAULT** | |
| executive cars | 105 |
| large cars | 1,181 |
| medium cars | 6,450 |
| mini cars | 803 |
| multi purpose cars | 7,395 |
| small cars | 8,418 |
| sport utility cars | 1,240 |
| **SEAT** | |
| large cars | 1,188 |
| medium cars | 9,164 |
| multi purpose cars | 2,767 |
| small cars | 2,643 |
| **SKODA** | |
| executive cars | 1,060 |
| medium car | 594 |
| medium cars | 3,261 |
| small cars | 3,466 |
| sport utility cars | 2,416 |
| **VW** | |
| large cars | 5,516 |
| luxury cars | 408 |
| medium cars | 16,140 |
| multi purpose cars | 13,530 |
| small cars | 4,998 |
| sport cars | 1,282 |
| sport utility cars | 5,513 |

## Table A3. Diesel emission scandal timeline

| | |
|---|---|
| **June 2007** | The EU introduces regulation that bans defeat devices and Member States have a standing obligation to police and enforce this ban. |
| **2011** | The European Commission's Joint Research Centre finds that the levels of harmful nitrogen dioxide (NOx) emissions exceed the EU levels by up to 14 times in different car models while testing exhaust emissions under gas under real road operating conditions (Weiss et al., 2011) |
| **October 2014** | A study conducted by the International Council on Clean Transportation (ICCT) reveals excessive emission volumes in several **VW** cars sold in the US (Franco et al., 2014) |
| **September 2015** | The US Environmental Protection Agency accuses **VW** of duping diesel emissions tests using "defeat devices"<br>Volkswagen admits to installing software designed to reduce emissions during lab tests in 11 million diesel engines worldwide.<br>**VW** shares plunge by 40 percent in two days. |
| **November 2015** | EPA issues second Notice of Violation for **Audi** and **Porsche**. |
| **January 2016** | Headquarter of **Renault** was raided by French fraud investigators. |
| **February 2016** | the EPA issues a notice of violation to **Fiat ChryslerAutomobiles (FCA)** alleging that over 100,000 model year 2014, 2015, and 2016 diesel SUVs and trucks had software that allowed them to exceed NOx pollution limits. |
| **April 2016** | Headquarter of **PSA Peugeot Citroen** was raided by French fraud<br>**Daimler** investigates its certification process for diesel exhaust emissions in the United States at the request of the Justice Department. |
| **May 2016** | South Korean authorities accused **Nissan** of using a defeat device for manipulating emissions data for the British-built Nissan Qashqai. Nissan denies the accusation. |
| **July 2016** | German authorities launched investigations into luxury car makers \ **Porsche** and **Daimler** for allegedly cheating emissions tests. |
| **January 2017** | the EPA issues a notice of violation to **Fiat Chrysler Automobiles (FCA)** alleging that over 100,000 model year 2014, 2015, and 2016 diesel SUVs and trucks had software that allowed them to exceed NOx pollution limits. |
| **March 2017** | **Nissan** vehicles tested by Which? were found to produce 0.81 g/km NOx compared to the 2009 European emission standards Euro 5 legal limit of 0.18 g/km. |