

Do Lenders Price the Brown Factor in Car Loans?

Evidence from Diesel Cars

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Abstract

The transition to a green economy and the reduction of air pollution strongly depend 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 air pollution by the automobile sector.

1. Introduction

An important academic and policy debate in recent years has been raised on 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 banks' balance sheets, credit institutions still provide large amounts of credit and often 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 be subject to potential conflicts of interest, for instance due to the legacy positions towards polluting 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 purchases; we examine the credit conditions applied to loans for different car types, namely diesel versus petrol cars, as producing different levels of air pollution. The empirical setting of consumer credit for cars provides interesting 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 vehicles by consumers. Second, in the car markets, the disclosure of the pollution levels produced by car models or the introduction of circulation restrictions for certain vehicles may raise uncertainty about the future value of these cars, and then also affect the value of the collateral pledged 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, while independent consumer banks are part of large banking groups operating in multiple credit markets. As different intermediaries may be subject to different incentives due to their ownership structure, we examine whether and how different types of financial intermediaries respond to environmental shocks affecting the car markets.

We also explore different intensity of the pollution factor, as we are comparing loans extended for diesel cars relative to petrol cars. Indeed, 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 has revealed the actual levels of pollution generated by diesel vehicles, car purchasers have been 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). Moreover, 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 then negatively affect the collateral value of such vehicles in the resale market.

Banks operating in the car loan market determine 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 applies also to the purchase of high-polluting diesel vehicles, even more for used cars, as they may require further maintenance and retrofitting due the potential defects of their exhaust systems and therefore may be subject to quicker depreciation. 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, reducing their collateral value. This also implies higher credit risk for the loans financing the purchase of the affected cars. Therefore, a bank may be expected to tighten lending terms and conditions to account for deteriorated collateral or resale value (Cerqueiro et al., 2016 and 2020). This decrease in the 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 encourage the sales of these vehicles and to support their 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, Italy and Spain from 2006 to 2018, and available from European Data Warehouse. Overall, we find that - after environmental shocks affecting diesel cars - 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 - relative to captive banks - for the loans financing diesel cars.

Captive banks apply more favorable lending conditions – relative to independent banks - via lower interest rates and higher loan-to-value ratios (LTV) in consumer credit for used diesel cars; they do so to affect borrowers' willingness to take a loan and purchase a diesel car 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 diesel 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 set 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. Similar results are observed when considering, rather than the actual circulation restrictions, the pollution levels observed in local areas, which may prelude to future restrictions for highly polluting 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 discussion on the role of bank lending in the green transition, in presence of information asymmetries and 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 technologies for fossil fuel-based engines 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, 2023; Degryse et al., 2023; Houston & Shan, 2022; Kacperczyk & Peydró, 2022).

An important area of focus is the potential existence of conflicts of interests by 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, 2023). 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, the credit approval process considers both the profit from providing a loan, and the profit from selling the product that is acquired through captive loans. 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 car markets as well as on consumer credit markets. 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

Air pollution refers to the contamination of air with pollutants, which are substances detrimental to human health and to the planet as a whole.¹ The transport sector is one of the main contributors to air pollution, as well as to greenhouse gas emissions. Within road transportation, passenger cars are the largest source of air pollution, more than trucks.

A major component 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, implying higher fuel efficiency and lower carbon dioxide (CO₂) 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, due to the emissions of other toxic substances, like nitrogen oxides (NO_x).

While diesel cars produce lower CO₂ emissions relative to petrol cars, diesel emissions of nitrogen dioxide (NO₂) are significantly more damaging to health. Moreover, expected greenhouse gas savings initiated by the shift to diesel cars have been overestimated while toxic

¹ According to the World Health Organization (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 are also 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.

NO₂ 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 actual emissions of cars. In fact, environmental concerns are increasingly driving consumer choices, as the use of environmentally harmful products can have significant costs for consumers. Also, the automobile sector has to increasingly incorporate air quality and climate change considerations due to policy developments. For instance, various governments have introduced restrictions to the circulation of highly polluting vehicles and have set timelines to phase out fossil-fuel vehicles. Overall, 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.

However, how this process is mediated by banks remains an open question that this paper aims to address. The financing of environmentally harmful products can be costly also for banks. A shock to the resale value of diesel cars translates into higher credit risk, ultimately affecting the profits of car lenders if car prices are not stabilized. Lenders active in the car sector are vulnerable to a drop in used car prices after the extensive provision of car 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 environmental shocks used in our analysis, namely the diesel emission scandal and the introduction of the low emission zones, we expect the used car market to react to the new information about the true emissions of cars or about their actual usability. Firstly, the durability of the exhaust systems could significantly decline after retrofitting, thus increasing maintenance costs. Secondly, we would expect car owners who care about the environmental impact of their cars to react to the new information about the true emissions caused by 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 resale price of the affected car models (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 have more incentives to 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 revenues from interest charges against the risk of default and the reduced value of the collateral (Stroebel, 2016); if so, they may apply higher interest rates to address the higher credit risk of these loans. 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

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). In fact, 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). In this context, new information about the environmental performance of diesel cars increases the expectation that there might be restrictions implemented affecting the usability of diesel cars. Also, following the above environmental shocks, consumers who may consider the purchase of a diesel car cannot be sure that the quality of the product will meet expected standards and so may fear a quick price depreciation, 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 quality and price depreciation (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 may have the incentive to charge lower interest rates and grant higher LTV ratios relative to independent banks after environmental

² Shocks reducing the collateral value available to banks may induce banks to increase lending rates and tighten credit limits. Moreover, the shocks to collateral – by raising credit constraints for borrowers - may reduce the amount and the maturity of the extended bank credit, also with real effects. See Cerqueiro et al. (2020, 2016).

shocks, despite the potential risks associated with the usability and the 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 refinancing operations 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; Klein et al., 2020). Since then, the European Data Warehouse has established its role as the main securitization repository in the European Union; as of now, based on regulatory requirements for securitization, 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. In countries like Germany, the share of diesel vehicles used to be over 50% but now it 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 carmaker, as reported 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 27,571. 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 the 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 the German car producer Volkswagen Group (VW). 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 NO₂ in on-road driving than in type approval tests. VW has admitted that about eleven 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 depending on the cultural perception of corporate fraud (Hasan et al., 2023).³

When the diesel emission scandal first emerged in 2015, analysts considered as likely that also other car makers were cheating the emission tests (Bachmann et al., 2022). After the US EPA issued notices of violation first for 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

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.

and Daimler for allegedly cheating emissions tests and French authorities inspected 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

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 became less attractive as their use could have been limited. Especially in Europe, the prices for diesel cars dropped as customers feared regulatory changes and the future of these vehicles 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).

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).

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 and region, car model and fuel type. We then collapse our panel into two sub-periods around the diesel emission scandal following the approach proposed by Bertrand et al. (2004) and used also in other studies, like Khwaja and Mian (2008). 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 borrower's income group and 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:

$$\begin{aligned} \Delta \text{Loan Conditions}_{\text{bank,district,income,model,fuel}} & \qquad \qquad \qquad \text{Eq. 1} \\ &= \beta \text{Diesel} + \gamma \text{Controls} + \mu_{\text{model}} + \mu_{\text{bank,region}} + \mu_{\text{brand,income}} \\ &+ \varepsilon_{\text{bank,region,income,model,fuel}} \end{aligned}$$

Where $\Delta \text{Loan Conditions}_{\text{bank,region,income,model,fuel}}$ is the change in the loan conditions charged by a given bank 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 loan-level outcome variable for lending conditions

can be: either the interest rate, or the loan-to-value (LTV). 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, as computed for the groups defined by model, fuel type, bank and region. In addition, standard errors are clustered at the model-fuel level. μ_{model} represents car model fixed effects; $\gamma_{\text{bank,region}}$ represents bank-region fixed effect and $\delta_{\text{brand,income}}$ brand-income 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 borrower's income group and 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. The 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 manufacturing groups. The average contract terms and lending standards for captive and independent banks differ significantly. Cars for which captive and independent banks provide financing may differ in terms of previous usage, as captive banks may be more likely to provide loans for used cars with no or limited previous consumption, due to potential 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 to loans for the purchase of used cars 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 Δ Loan 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 loans by independent 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 23 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). 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 (1.29 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 increase the demand for diesel cars and to support the sales of new cars of their own manufacturers.

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 favorable conditions for loans to purchase used diesel cars, to limit the depreciation of their resale value and possibly to encourage the sales of new cars from 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 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 norm 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 they are prevalent in German cities during our observation period, compared to other EU countries, and to rely on a homogeneous regulatory framework disciplining 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 collapse our data into a pre- and post-treatment period following the approach by Bertrand et al. (2004). Before first differencing, we group loan observations by borrower's income group and district, car model and fuel type. Hence, the grouping

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 onwards, new cars had to fulfill Euro 1, from 1997 Euro 2, from 2001 Euro 3, from 2006 Euro 4, from 2011 Euro 5, and from 2015 Euro 6.

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:

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

where $\Delta \text{Loan Conditions}_{\text{bank,district,income,model,fuel}}$ is the change in the loan conditions charged by a given bank, comparing the two years before the district-specific introduction of the low-emission zone and the two years after, within the groups defined by car model, fuel type, borrower's district and income group. As for the diesel emissions scandal, the analyzed variables for loan conditions are the interest rate and the loan-to-value ratio.

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. 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 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.

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.

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 Moreover, in countries with low emission zones, the public disclosure of the recorded pollution levels may be relevant also 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 the threshold may anticipate the future setting of LEZs, although this process may require some time for the (potentially complex) decision-making process.

We address the potential concern that the introduction of a low emission zone might not be completely exogenous due to this timeframe dimension. Therefore, we exploit the measurement of the local pollution levels and we investigate the conditions applied to car loans for diesel vs. petrol cars before and after the first recording of pollution levels above the maximum threshold. In this way, we can compare the evidence from the introduction of the low emission zones with the results of the analysis based on the actual pollution levels.

To give the intuition, higher pollution levels may imply higher risk for 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 credit risk for car loans.

5.3.1. Empirical Strategy and Results: Local Pollution Levels

For the empirical analysis, we use local measures of nitrogen dioxide (NO₂) as the key explanatory variable to measure air pollution levels. We exploit data on NO₂ levels observed in individual measuring stations across Germany (around 600 stations) from 2008 to 2018 and reported as annual averages in µg/m³ (micrograms per cubic meter) by the German

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

Environment Agency (Umweltbundesamt – UBA).⁸ High NO₂-levels may trigger corrective measures which could then affect the usability particularly of diesel cars. Based on the EU legislation, we consider the event of trespassing the threshold of NO₂ annual mean value limit of 40 µg/m³, as this would require policy actions by local authorities.

We analyze whether - and to what extent - banks financing car purchases internalize the potential effects of pollution levels above the maximum threshold, while setting lending terms and conditions for auto loans, namely interest rates and loan-to-value ratios. We estimate the following regression model:

$$\begin{aligned} \text{Loan Conditions}_{\text{bank,district,borrower,model,fuel}} = & \beta_0 + \beta_1 \text{Diesel} + \beta_2 (> \text{NO}_2 \text{ } 40 \text{ } \mu\text{g}/\text{m}^3) + & \text{Eq. 3} \\ & \beta_3 \text{Diesel} \times (> \text{NO}_2 \text{ } 40 \text{ } \mu\text{g}/\text{m}^3) + \gamma \text{Controls} + \mu_{\text{model}} + \mu_{\text{year}} + \mu_{\text{district}} + \mu_{\text{bank,region}} + \\ & \mu_{\text{brand,income}} + \varepsilon_{\text{bank,region,income,model,fuel}} \end{aligned}$$

where the dependent variable is the interest rate or the loan-to-value in individual car loans extended by a bank to a borrower in a district to purchase a car model. (> NO₂ 40 µg/m³) is a dummy equal to one for the loans extended to borrowers in German districts where the NO₂ annual mean value limit of 40 µg/m³ (micrograms per cubic meter) has been surpassed the past year, and zero otherwise. The coefficient β₂ captures the average interest rate in the post period. The main coefficient of interest β₃ captures the effect of passing the threshold in a district on the lending conditions for the diesel car loans to borrowers in that district. The control group of petrol cars is not exposed to the NO₂ threshold and to the implied potential policy change, given that petrol engines barely produce NO₂ and that the potential restrictions from excessive NO₂ 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 loan-to-value 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,

⁸ The information about the exact location of individual measuring stations allow to link these data to the data at the district level as used in the analysis on low emission zones.

brand-income group. Standard errors are clustered at the model-fuel type and at the district level.

In this analysis, we explore the observations for the individual loan contracts, instead of grouping them. The reason for this is of practical nature so that - for the loans by captive banks – we can compare the loans to purchase cars of their own carmaker and of other carmakers. Separating the loans of captive banks into loans for car models of the same manufacturer group and 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 of the existing stock of used cars. We observe that, following the surpassing of the critical NO₂-level, captive banks increase the lending rates for diesel car models of other producers by 20 bps; while we find no evidence of such effects for the loans to finance diesel cars of the same manufacturer.⁹ At the same time, independent banks increase the lending rates charged to loans for diesel cars by 11 bps. Our results for the specifications with the loan-to-value ratio as dependent variable, although not statistically significant, are aligned with our findings with regard to interest rates.

Overall, the results of the analysis for the actual pollution levels are consistent with the evidence for the introduction of low emission zones, as observed for the loan portfolios of captive and independent banks. In fact, 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, and to a relatively large extent, for cars of other groups. Overall, independent banks are more likely to price the increased risk stemming from used 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

⁹ 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.

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 accordingly. This would hold even more so if car loans are originated in areas more vulnerable to the hazard of air pollution, and where the use of diesel cars may be subject to current or future restrictions.

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 used 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 banks to disincentivize the consumption of high-emission vehicles. Despite the uncertainty related to diesel engines, banks overall have not been discouraged from supporting the purchase of diesel vehicles when setting credit conditions for car loans. 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 higher local air pollution. Hence, even in presence of high levels of pollution and under the introduction of low emission zones, captive banks do not restrict lending conditions for used diesel cars, unless for those produced by other manufacturers. 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 for car

emissions and driving bans, and in light of the future phase-out of internal combustion engine vehicles.

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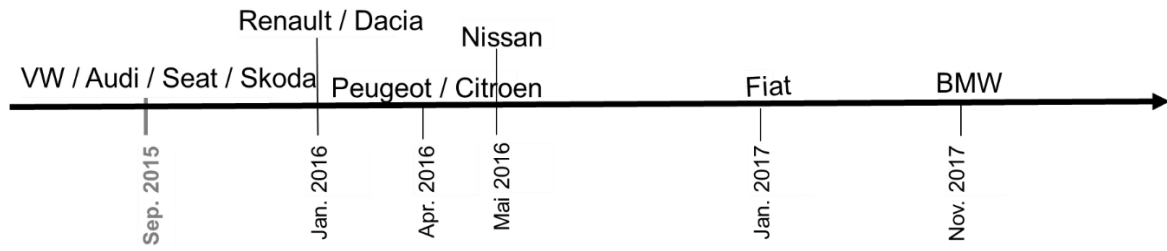
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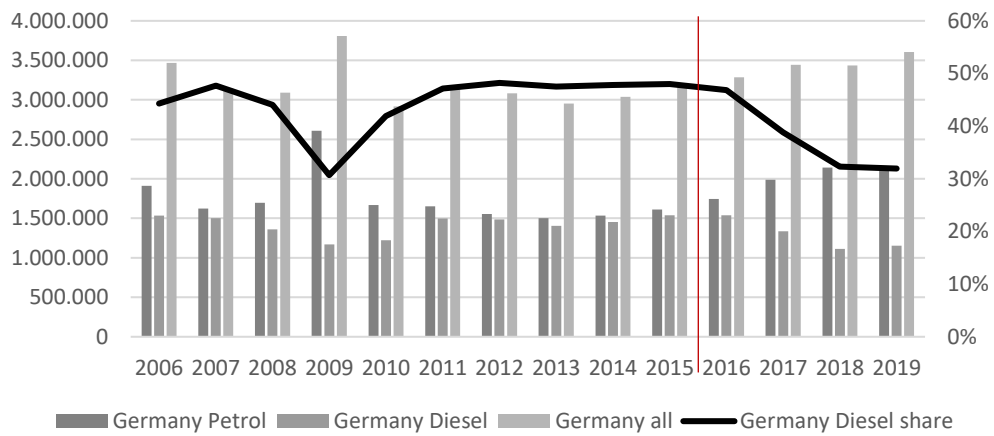
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Figure 1. Diesel Emission Scandal Timeline by Car Brands



Source: own illustration

Figure 2. New Registrations of Passenger Cars by Fuel Type in Germany



Note: The variable on the LHS axis indicates the number of registrations in Germany for petrol, diesel and all cars. The variable on the RHS axis denotes the share of diesel cars out of total cars in car registrations.
 Source: own illustration based on Eurostat data

Figure 3. Implementation of Low Emission Zones 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

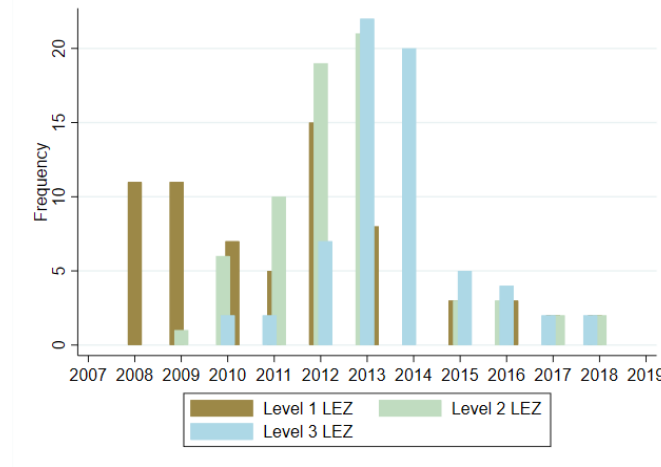


Table 1. Overview Variables

Variable	Description	Source
<i>A. Dependent variables in main specifications</i>		
Interest rate	Current interest rate (%)	EDW
Loan-to-value	Original loan amount over car value	EDW
<i>B. Other loan characteristics</i>		
Down payment	Amount of deposit/down payment at origination	EDW
Car value	Car value at origination	EDW
Loan term	Original contractual term	EDW
<i>C. Explanatory variables: Borrower characteristics</i>		
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)	EDW
<i>D. Explanatory variables: Car characteristics</i>		
Brand	Brand name of car	EDW
Model	Model of car	EDW
Car classification	As defined by the European Commission	EDW
Used car	Indicator equal to 1 if the car was used at the time of the loan origination	EDW

Table 2. Summary Statistics

This table reports the number of observations, the standard deviation, the mean, the minimum and the 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 Cars

This table reports the average loan characteristics before and after the brand-specific diesel emission scandal – as applied by all banks (captive and independent) - to the loans for, respectively, diesel and petrol car loans. A t-test is used to identify statistically significant differences between the pre and post sub-periods. The left-hand side of the table reports the characteristics of loans for diesel cars while the right-hand side describes the average loan characteristics of loans for petrol cars. The sub-periods consist of one year before September 2015 and respectively one year after the brand-specific diesel emission scandal event.

Loan characteristics	diesel						petrol					
	pre		post		Δ		pre		post		Δ	
	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 for Diesel Car Loans, Captive vs. Independent Banks

This table reports the average loan characteristics before and after the brand-specific diesel emission scandal for diesel car loans, as provided by – respectively - captive and independent banks. A t-test is used to identify statistically significant differences between the pre and post sub-periods. The left-hand side of the table reports the characteristics for loans provided by captive banks while the right-hand 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.

Loan characteristics	captive banks						independent banks					
	pre		post		Δ		pre		post		Δ	
	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) for the estimation of the effects of the brand-specific diesel emissions scandal on credit conditions for loans to diesel vs. petrol cars, as in Equation 1. 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, as extended to individual customers 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 lender bank, borrower's region and income quartile group, car model and fuel type.

Dependent variable: Δ Interest rate	All banks			Captive bank	Independent banks
	(1)	(2)	Same diesel petrol models (3)	(4)	(5)
Diesel-dummy	-0.310*** (0.0986)	-0.172*** (0.0524)	-0.227*** (0.0487)	-0.250*** (0.0616)	-0.0231 (0.0563)
Δ Loan-to-value		0.0203*** (0.00173)	0.0167*** (0.00278)	0.0131*** (0.00202)	0.0345*** (0.00168)
Δ Loan term		0.0650*** (0.00253)	0.0579*** (0.00457)	0.0937*** (0.00319)	0.0261*** (0.00214)
Primary income	-4.47e-07* (2.50e-07)	-5.88e-08 (6.18e-08)	-9.15e-07** (3.77e-07)	-4.74e-07** (2.12e-07)	5.06e-09 (1.85e-08)
Constant	-0.650*** (0.0697)	-0.506*** (0.0405)	-0.480*** (0.0394)	-0.618*** (0.0490)	-0.465*** (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

Robust standard errors in parentheses

*** 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) for the estimation of the effects of the brand-specific diesel emissions scandal on credit conditions for loans to diesel vs. petrol cars, as in Equation 1. The dependent variable is Δ Loan-to-Value. 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, as extended to individual customers 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 lender bank, borrower's region and income quartile group, car model and fuel type.

Dependent variable: Δ Loan-to-value	All banks			Captive bank	Independent banks
	(1)	(2)	Same diesel petrol models (3)	(4)	(5)
Diesel-dummy	-1.551 (1.115)	0.982** (0.424)	1.286*** (0.486)	1.483** (0.601)	0.0407 (0.537)
Δ Interest rate		2.432*** (0.206)	2.264*** (0.391)	1.704*** (0.251)	4.754*** (0.231)
Δ Loan term		1.078*** (0.0131)	1.090*** (0.0216)	1.097*** (0.0201)	0.978*** (0.0129)
Primary income	-5.88e-06* (3.27e-06)	-3.34e-07 (6.64e-07)	-2.26e-06 (1.48e-06)	-2.94e-06*** (7.07e-07)	-1.93e-07 (3.35e-07)
Constant	-2.768*** (0.823)	0.276 (0.381)	1.053** (0.448)	0.772 (0.537)	0.682 (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

Robust standard errors in parentheses

*** 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, before and after the district-specific introduction of low emission zones in Germany. A t-test is used to identify statistically significant differences between 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 the results for the estimation of the effects of the introduction of low emission zones on credit conditions applied to loans for diesel vs. petrol cars, as in Equation 2. The dependent variable in Column 1 and 3 is the change in the interest rate and in Column 2 and 4 is the change in the loan-to-value of the loans in the analyzed sample. Estimation method is OLS with standard errors clustered by model-fuel type. The term “Diesel” is a dummy indicating if the loan is granted to finance the purchase of a diesel vehicle. Estimations include 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 lender banks, borrower’s income and district, car model and fuel type.

Dependent variables:	Captive banks		Independent banks	
	Δ Interest rate (1)	Δ Loan-to-value (2)	Δ Interest rate (3)	Δ Loan-to-value (4)
Diesel-dummy	0.0518 (0.0590)	-0.832 (0.945)	0.122** (0.0599)	0.0865 (0.708)
Δ Interest rate		7.156*** (0.359)		6.017*** (0.244)
Δ Loan term	0.0477*** (0.00218)	0.595*** (0.0391)	0.0220*** (0.00181)	0.873*** (0.0202)
Δ Loan-to-value	0.0322*** (0.00164)		0.0381*** (0.00158)	
Primary income	-3.10e-05*** (5.49e-06)	-0.000181*** (5.82e-05)	-3.17e-05*** (6.39e-06)	-4.24e-05* (2.36e-05)
Constant	0.652*** (0.0811)	2.526** (0.967)	0.759*** (0.134)	2.005*** (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 reports the results for the estimation of the effects of the surpassing of the NO₂ threshold in individual German districts on the credit conditions for loans to borrowers in those districts, for diesel vs. petrol cars, as in Equation 3. The dependent variable in Column 1-3 is the interest rate and in Column 4-6 is the loan-to-value for individual loan contracts. The term (>NO₂ 40 µg/m³) is a dummy indicating if the NO₂ threshold has been surpassed and “Diesel” is a dummy indicating if the car loan is provided for a diesel vehicle. Estimation method is OLS with standard errors clustered by model-fuel type and by district. Estimations include the other loan controls, the primary income of the borrower as well as the employment status of the borrower.

Dependent variable:	Interest rate			Loan-to-value		
	Captive		Independent	Captive		Independent
	Own	Other		Own	Other	
(> NO ₂ 40 µg/m ³)	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/m ³) 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 observations for amortized car loans with a maturity longer than one year by brand and model. Brands included are: Alfa Romeo, Audi, BMW, Citroën, Dacia, FCA, Peugeot, Renault, SEAT, Škoda, and Volkswagen. 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 observations for amortized car loans with a maturity longer than one year by brand and vehicle category. The classification is based on the passenger car categories as 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.		Freq.		Freq.
ALFA ROMEO		FIAT		SEAT	
executive cars	1,211	large cars	391	large cars	1,188
medium cars	1,764	medium cars	797	medium cars	9,164
small cars	717	mini cars	1,028	multi purpose cars	2,767
sport cars	479	multi purpose cars	265	small cars	2,643
AUDI		small cars	398	SKODA	
executive cars	3,538	sport utility cars	297	executive cars	1,060
large cars	6,979	PEUGEOT		medium car	594
luxury cars	442	executive cars	1,752	medium cars	3,261
medium cars	8,993	large cars	28,863	small cars	3,466
small cars	1,781	medium cars	72,292	sport utility cars	2,416
sport cars	271	mini cars	3,360	VW	
sport utility cars	3,534	multi purpose cars	20,165	large cars	5,516
CITROËN		small cars	109,758	luxury cars	408
executive cars	4,402	sport cars	2,545	medium cars	16,140
large cars	25,386	sport utility cars	51,958	multi purpose cars	13,530
medium cars	101,579	RENAULT		small cars	4,998
mini cars	6,462	executive cars	105	sport cars	1,282
multi purpose cars	21,589	large cars	1,181	sport utility cars	5,513
small cars	52,297	medium cars	6,450		
DACIA		mini cars	803		
medium cars	278	multi purpose cars	7,395		
multi purpose cars	542	small cars	8,418		
small cars	2,122	sport utility cars	1,240		
sport utility cars	2,564				

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 (NO ₂) emissions exceed the EU levels by up to 14 times in different car models while testing exhaust gas emissions 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 using "defeat devices" to comply with diesel emissions tests Volkswagen admits that it had installed softwares designed to reduce emissions during lab tests in 11 million diesel engines worldwide. 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 subject to inspections by French fraud investigators.
April 2016	Headquarter of PSA Peugeot Citroen were inspected by French fraud investigators. In the US, Daimler was requested by the Department of Justice to investigate its certification process for diesel exhaust emissions.
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 US EPA issued a notice of violation to Fiat Chrysler Automobiles (FCA) alleging that over 100,000 models of diesel SUVs and trucks produced in the years from 2014 to 2016 exceeded NO ₂ pollution limits despite softwares controlling for emissions during tests.
March 2017	Nissan vehicles were found to produce NO ₂ levels above the legal limit foreseen for the 2009 EU emission standards Euro 5.