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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 lenders may set credit conditions which may discourage or support the purchase of high-emission vehicles. Using car loan-level data we study whether banks adjust their lending terms and conditions in response to different shocks to the perceived environmental quality 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

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. 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 and resulting in uncertainty about the future resale values of these vehicles. After the diesel emissions scandal, car purchasers were discouraged from buying the diesel vehicles of the affected brands, due to the negative effect of this fraud on consumer decisions (Hasan et al., 2022), while at the same time they developed concerns also for other brands due to collective reputation externalities (Bachmann et al., 2022).

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 longevity perspective of these vehicles, with significant implications on their prices. This suppresses collateral value and 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. A unique characteristic of the car loan market is that it features two types of lenders: car manufacturer-owned captive banks and independent consumer finance banks. 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. 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 supporting 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 find that captive banks adjust loan conditions in a more favorable way for the purchase of cars produced by their own parent carmakers, in order to incentivize the sales of these vehicles. On the other hand, 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 via higher loan-to-value ratios (LTV) and lower interest rates for used cars after environmental shocks; they may be incentivized to do so to affect borrowers' willingness to take a loan and purchase a car as well as their assessment of cars' longevity. However, the impact of the two types of shocks on the perceived longevity of these cars - hence how long a car is expected to be usable - is different. 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, high local pollution levels and local circulation restrictions 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 market for car loans, financing terms might still be less reflective of the underlying risk from the diesel engine technology than what would be expected. This is particularly visible 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 contrary, 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 impact 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 to the literature. First, it relates to the literature on bank lending practices in the green transition in the presence of information frictions between creditors and borrowers. We suggest potential conflict of interests that may distort banks' integration of transition risks. This is relevant because the auto sector faces rising credit risks due to carbon transition as fossil fuel-based engines technologies will be stranded. Second, our paper exploits shocks to the environmental risk of diesel cars to explain the different lending behavior of independent consumer banks and captive banks in the car loan market.

The rest of this paper is structured as follows. Section 2 reviews the main literature and provides institutional background on diesel car financing. In section 3, we elaborate on the economic intuition underlying the relationship between lenders' expected profit and environmental shocks. In section 4 we discuss our data set. In section 5 we provide an overview of the empirical strategy and results. In section 6 we conclude summarizing our results and their implications.

2. Related Literature and Background

Policy increasingly signals that the financial sector should be a driving force in achieving global sustainability agendas. Lending institutions, such as 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 commercial activity that degrades the natural environment (Gray & Bebbington, 2022; Sarokin & Schulkin, 1991). Credit conditions have a significant influence on auto sales. 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. Literature on loan intermediation in auto markets shows that vehicle purchases typically account for an outsized share of the contraction in economic activity during a recession, in part because a concurrent tightening in auto lending conditions makes car purchases less affordable for many households (Benmelech et al., 2017; Johnson et al., 2014). Adams, Einav, and Levin (2009) show that liquidity-constrained auto loan consumers are sensitive to monthly payments but also depended on other contract terms besides the interest rate, such as the loan term and down payment.

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.

The financing of environmentally harmful products can also be costly for banks. A shock to diesel cars residual values 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.

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[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.

3. Empirical Predictions

In this section, we discuss the intuition behind two predictions of how consumer finance and captive banks react to a change in the perceived environmental performance of loan underlying cars.

A consumer finance position consists of the value of interest payments and loan installments and the collateral value in the case of default. When the value of cars declines due to revealed bad environmental performance, some borrowers will default on their car loan, leaving lenders with losses. Used car prices determine the value of the collateral backing the loan. Even if the number of defaults would not change, declining used car prices hence collateral values would cause loan losses to rise because recoveries in event of default are lower. When lenders set the interest rate, they trade off the revenue from interest charges with the loss in the event that bad environmental performance results in shorter productive lives and hence faster depreciation (Stroebel, 2016). Similarly, lenders offer higher down payments/lower loan-to-values (LTVs) to face less loan losses.

Captive banks additionally internalize the dynamic implications of the production and sales of new cars (Benetton et al., 2022). Borrower uncertainties related to the purchase and collateralization of used diesel cars erodes future profits of a car manufacturer. This is because the current production of cars will reach the used car market; the price of new cars reflects rational expectations about the resale market. New information about the environmental performance of diesel cars increases the expectation that there will be restrictions implemented affecting the longevity of diesel cars. If car manufacturers do not anticipate a big impact on the productivity of used cars and if there is information asymmetry between lenders and borrowers, car manufacturers have an incentive to signal high future resale values of used cars to ultimately preserve rents from selling new cars.

In this context, captive finance can be viewed as a contractual solution to information problems concerning product quality. Following environmental shocks, consumers who want to buy a diesel car cannot be sure that the quality in terms of product longevity and price depreciation will meet expected standards. This uncertainty can be reduced if car manufacturers can provide guarantees (Pike et al., 2005). The car manufacturers' choice to grant attractive financing terms provides an opportunity for manufacturer to reduce concerns about product quality. If the impact on environmental performance on productivity is high, captive banks will be limited by the default boundary. Murfin and Pratt (2019) show that captive finance affects the price of tomorrow's new (and used) durable goods because it helps manufacturers to commit to ex-post actions that support the price of goods. Based on this, we explore the distinct but closely related idea that lower depreciation rates on captive-financed cars are driven by higher ex-ante quality of captive-backed cars which manifests in longer productive lives and hence slower depreciation (Murfin & Pratt, 2019). Based on the considerations above, we formulate the following empirical predictions:

Prediction 1. Captive banks charge lower interest rates and grant higher LTV ratios relative to independent banks post environmental shocks that may negatively impact the productivity - in terms of longevity and consequent price depreciation - of used diesel cars.

Prediction 2. By offering high LTVs and low interest rates for used cars, captive banks signal ex-ante high product quality, hence high resale values. Loan terms convey information about future product quality

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 asset class specific loan-level data for Asset-Backed Securities (ABS) transactions. Banks that use their ABS for repo borrowing with the Eurosystem are required to quarterly report loan level information on the structure and performance of their securitized loan portfolios in a detailed and standardized format set by the ECB (Ertan et al., 2017). Figure 1 shows the market share of diesel 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 loans or leases 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 identification is derived from car brand's model naming convention in the EDW dataset. Car brands and models are only included if diesel as well as petrol engines can be indubitably identified. Ultimately, we consider the car models of the brands: ALFA ROMEO, AUDI, BMW, CITROËN, DACIA, FIAT, PEUGEOT, RENAULT, SEAT, SKODA, and VW. Our final dataset consists of a total of 781,033 loan contracts with European banks from 2006 up 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 ratio 63%. The used car sample is restricted to consumer use cars 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. In comparison, the net income per capita in the European Union in 2020 was 27.73 USD. 43% of car loans have been provided by captive banks, whereby the captive banks for which we have notable number of observations belong to BMW, FCA, PSA, RCI, and TKG.

5. Results

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 incident, the resulting decline in observable environmental quality of diesel cars of affected car brands is a quasi-experimental exogenous shock to the used-car market (Strittmatter & Lechner, 2020). 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 due to the cultural perception of corporate fraud (Hasan et al., 2022).[2]

[2] Hasan et al. (2022) 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.

When the diesel emission scandal first emerged in 2015, analysts said it was likely other car makers were also cheating tests (Bachmann et al., 2022). After EPA issued notices of violation first to VW in September a second notice for Porsche and Audi was issued in November 2015. Following suit 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 have also been hit by similar allegations in 2017. Figure 2 illustrates the timeline along which the different car brands were implicated. The emissions manipulations led to the eruption of a proper global scandal that has exposed high number of dirty diesel cars on the roads. Consumers were hit by the diesel emission scandal twofold. First, they faced a financial disadvantage as the cars' collateral values might have declined. Second, they were exposed to additional risk of restrictions on diesel vehicles in city centers further compromising the value of their diesel cars. Especially in Europe, the prices for diesel cars dropped as customers fear political changes and the future of these cars was not certain. Ownership of diesel cars was less attractive as their use might have been limited. 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, car model, region, 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 consist of one year before and one year after the event in order to account for seasonality patterns in the car market (Einav et al., 2013). For the public, the scandal was a surprise in September 2015, and it immediately generated extensive media coverage. However, individual automotive makers are salient to consumers, enabling us to use in the baseline model brand-specific dates for the diesel emission scandal, which is whenever a brand was accused of illegal behavior.

Our empirical approach focuses on loans for underlying cars of the same model, where the loans differ in their exposure to the Dieselgate shock. In first-differenced data, we compare how lending conditions change for loans underlying diesel cars relative to less affected petrol cars. Grouping loan observations by income group, car model, region, and fuel type before differencing, allows us to compare very similar diesel and non-diesel cars which further captures potential differences in the underlying car characteristics. 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:

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

Where $\Delta \text{Interest Rate}_{\text{model,bank,region,fuel}}$ is the change in interest rate between the year before September 2015 and the year after brand specific diesel-emission scandal within the groups defined by car model, bank, region, and fuel type. The same applies for 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 controls consisting of the change in average loan-to-value and loan term as well as pre-brand-specific diesel emission scandal average income also by the model-bank-region-fuel type groups. In addition, standard errors are clustered at the bank-model level. μ_{model} represents car model fixed effects; $\gamma_{\text{bank,region}}$ represents bank-region and $\delta_{\text{brand,income group}}$ 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, car model, region, 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 almost one percentage point for the diesel subsample while the average LTV-ratio decreases by 4.5 percentage points. On the other hand, petrol cars in the post-period have a higher valuation while less down payment is required.

Separating loans granted by captive banks from those granted by independent banks (Table 4) provides further insights in 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 differ in terms of usage, with captive banks more likely to provide loans for newer used cars due to a supply and demand imbalance 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 provided by captive banks to their own in-house car brands change much stronger 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 Interest rate,Δ LTV and ΔLoan term respectively as controls. In the third specification we only include car models which are available in our sample both with a petrol engine as well as 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 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. This 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 of Table 5 for the subsample of loans provided by independent banks. Economically, our coefficients indicate that post diesel emission scandal borrowers would have to pay 3-4 percent less in annual percentage rate. Given that auto loan borrowers are 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 LTVs (Table 6). Captive banks increase loan-to-value of diesel cars by 1-2 percentage points relative to petrol cars.

These results are consistent with Prediction 1 in that post environmental shocks that may negatively impact the productivity - in terms of longevity or price depreciation - of used diesel cars negatively, captive banks charge lower interest rates and grant higher LTVs relative to independent consumer finance banks. When banks do not anticipate that the diesel emission scandal would trigger a higher risk of restriction on diesel vehicles, captive banks have an additional incentive to provide more attractive loan conditions to support the sale of new cars. Post-diesel emission scandal there are really two scenarios possible. Either regulatory bodies and governments feel the pressure to take a stricter stance on diesel fuel. Or regulations in the main European markets remain unaffected by the scandal. Overall, the results seem to be more consistent with expectation towards a somewhat rebounding diesel market. In fact, diesel cars are still enjoying favorable tax treatment compared with petrol, despite being the main cause of the air pollution crisis in Europe's cities and emission tests are still being watered down through politics to provide automotive manufacturers with additional lead-time.

To summarize, increased transparency on diesel engines' true pollution in the context of the diesel emission scandal, does not seem to lead to independent banks and individuals to make decisions that can benefit the environment and society. Potentially, because they did not anticipate that the diesel emission scandal would trigger a blanket higher risk of restrictions on diesel vehicles. While the expectation might be that the diesel market will recover, the impact on the probability of sales is more immediate, warranting captive banks to provide more attractive credit.

5.2. Local pollution levels

Where air pollution is high there is big regulatory and public interest to reign in traffic pollution. Following the diesel emission scandal of 2015, local governments have increasingly implemented a range of strategies to reduce traffic volumes, such as low emission zones (LEZ) and pedestrianization. These interventions have been accompanied by initiative at the EU level aimed at improving air quality via an EU-wide monitoring network.3

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[3] European Union policy on air quality aims to develop and implement appropriate instruments to improve air quality. In this context, the directive foresees an EU-wide monitoring network that measures ambient air pollution mainly from the pollutants NO_x and PM, and hence provides reliable, credible and comparable information on air quality. Surpassing limit values set by the Directive for the monitored pollutants should trigger corrective actions. The annual mean NO_2 concentration does should not exceed 40µg/m^3. There is a EU-wide monitoring network – which now includes more than 4'000 monitoring stations with more than 16'000 sampling points – that measures specific pollutants for which the Ambient Air Quality Directives sets limit values.

Therefore, high pollution levels may imply a high risk associated with diesel cars. Market discipline would imply that the borrower's behavior is sustainable because car loan conditions would indicate the assessment of the increased credit risk associated with diesel engines. Health and environmental hazards of air pollution translate into credit risk for car loan that have underlying diesel engines. Looking at local pollution levels allows us to analyze the impact of the manifestation of health and environmental hazard and the resulting credit risk.

5.2.1. Empirical strategy and results: Local pollution-levels

For the empirical identification, we rely on local measures of NO_2-levels in Germany as main explanatory variable. High NO_2-levels may trigger corrective measures which then in return could affect the product quality in terms of longevity and price deprecation of cars with fossil fuel combustion engines. To test the impact of local pollution levels on loan characteristics, we begin by estimating the following Difference-in-Difference model:

$$\text{Interest rate} = \beta_0 + \beta_1 \text{Diesel} + \beta_2 (> NO_2\ 40\ \mu g/m^3) + \beta_3 \text{Diesel x} (> NO_2\ 40\ \mu g/m^3) + \gamma \text{Controls} + \mu_{model} + \mu_{year} + \mu_{district} + \pi_{bank,region} + \mu_{brand,income\ group} + \varepsilon_{model,bank,region,fuel} \quad \text{Eq. 2}$$

($> NO_2$ 40 $\mu g/m^3$) is an indicator that equals one for loans attached to districts in Germany where the NO_2 annual mean value limit of 40 $\mu g/m^3$ has been surpassed the past year, and zero otherwise. The coefficient β_2 captures the average interest rate in the post period, and the interaction coefficient β_3 captures the important Difference-in-Difference effect. The control group of petrol cars is unexposed to the NO_2 level and implicated potential policy change given that petrol engines barely produce NO_2 and are unaffected by low emission zones.

Table 7 contains 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 cars, 2) captive banks providing financing for competitor cars, 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 district level.

Separating the captive bank sub-sample into loans for car brands that belong to the same manufacturer group as the bank and loans for cars of a competitor brands allows us to investigate whether a captive bank provides more attractive loan condition in order to support new car sales or to get rid of their existing stock of used cars. We observe that captive banks increase interest rates for competitors' diesel car models following the surpassing of the critical NO_2-level to a larger extent than independent banks. Yet, we find no evidence of such effects related to cars that the captive supports. Although not statistically significant, our findings for the specifications with LTV as dependent variable are aligned with our findings with regards to interest rates. Independent banks are more likely to price the increased risk stemming from diesel cars relative to captive bank counterparts. We suggest that this observation is related to captive banks incentive to support car manufacturers primary market profits rather than the sale of used car stocks.

5.3. Local Emission Restrictions

Diesel emission scandal and wide-spread measurements of pollution-levels have revealed that exhaust levels were significantly higher than their formal test emissions. Because this new information about the true environmental or health risks of diesel does not necessarily trigger lending policies internalizing this cost, the materialization of concrete restrictions for diesel vehicles may be required. To examine this, we next pose the question whether the implementation of low emission zones can be more effective for creating appropriate economic incentives for lenders and borrowers to account for the environmental challenge of harmful diesel engine exhaust.

In the European Union, a key policy measure to reduce ambient air pollution is the implementation of Low Emission Zones (LEZ), signposted areas where access of vehicles is regulated, typically banning high-emitting vehicles from entering the zone al- together. These zones use Euro standards to regulate cars.4 Usually, to leave citizens with enough time to adjust, LEZ are phased in step by step. Figure 3 provides an overview of the phase in of low emission zones in Germany and of which Euro norm standards are required at the respective

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[4] Along with the Ambient Air Quality Directives, EU type-approval 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 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.

stages. Low-emission zone rules usually only apply to diesel-powered passenger cars, other than to trucks and coaches.

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

We again follow Bertrand, Duflo, and Mullainathan (2004) and collapse our data into a pre- and post-treatment periods. Before first differencing, we group loan observations by income group, car model, district, and fuel type. Hence, the grouping procedure is more granular as we additionally require that the loans grouped together are from the same district. This analysis is limited to Germany because low emission zones are only prevalent in German cities during our observation period.

We estimate the following same model as in Equation 2:

$$\Delta \text{ Interest Rate}_{\text{model,bank,district,,fuel}} = \beta\text{Diesel} + \gamma\text{Controls} + \mu_{\text{model}} + \mu_{\text{district}} + \mu_{\text{bank,region}} + \mu_{\text{brand,income group}} + \varepsilon_{\text{model,bank,region,fuel}} \quad \text{Eq. 3}$$

Table 9 presents summary statistics for loan characteristic variables pre and post 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 10 presents the results of the estimations for Equation 3 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. Due to lack of observations after the grouping of loan observation by model, bank, district, and fuel type, we are not able to present separate results for only the captive bank loans that are not produced by the same manufacturer group. The last two columns present the results for the subset of loans. In all specifications we include the full set of covariates and fixed effects. The estimations show that independent banks charge higher interest rate post 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.

6. Conclusion and Implications

The transition to a green economy strongly depends on the existence of appropriate economic incentives for agents. There is mounting evidence on the adverse impact of diesel cars on environment and health. As this threatens the productivity of diesel cars - to the extent that lenders perceive diesel 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 car loan data, we estimate the effect of different shocks to the perceived environmental quality of diesel vehicles on bank lending conditions. Car loans provide a useful setup to study this question. Financed cars are used as collateral, which makes it ideal to investigate the impact of an increased risk of devalued diesel technologies. Our main results suggest that bank lending may interfere with the phasing out of fossil fuel vehicles via the used car market and may further enforce the market and regulatory failures that led to extensive levels of pollution by the transportation sector. Our findings on the effects of the diesel emission scandal have highlighted that increased transparency on the environmental performance of cars may not be sufficient to regulate the consumption of high-emission vehicles in the context of bank finance. The diesel emission scandal raised awareness over the higher levels of pollution emitted by all diesel-powered vehicles from a wide range of car makers. Despite, the increased transparency on the environmental risks and uncertainty related to diesel engines underlying car loans, banks were overall not discouraged from supporting the purchase of diesel vehicles. In fact, OEM-owned captive banks have further decreased interest rates relative to petrol vehicles to additionally support diesel car purchases. Further, only independent banks' interest rates are sensitive to the local air pollution. Hence, even in the face of high levels of pollution and consequent low-emission zones introductions captive banks provide more attractive lending terms compared to independent consumer banks. Examining the impact of the introduction of low-emission-zones that target NO_2 and other pollutants in high-traffic areas, provides insights whether direct regulation impacting the consumption of diesel cars may be more effective than a market-based approach in providing appropriate prices that reflect the risk of high-emission vehicles.

These findings are relevant in face of today's increasingly stringent EU limits car emissions and driving bans as well as future technologies such as electric and hybrid drives that threaten diesel engines viability. Overall, this work brings to the forefront the question of the role of banks in the context of de-dieselization efforts.

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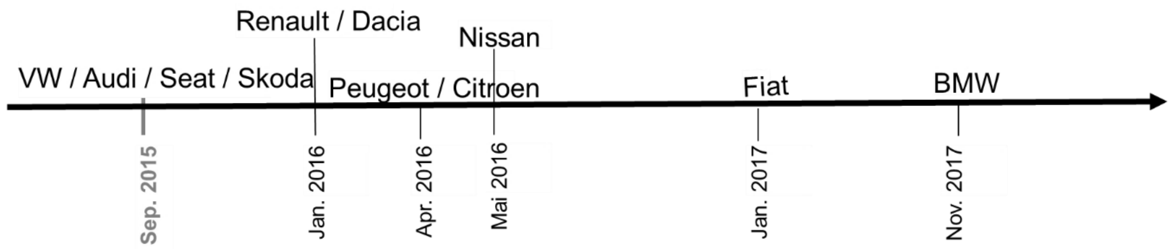
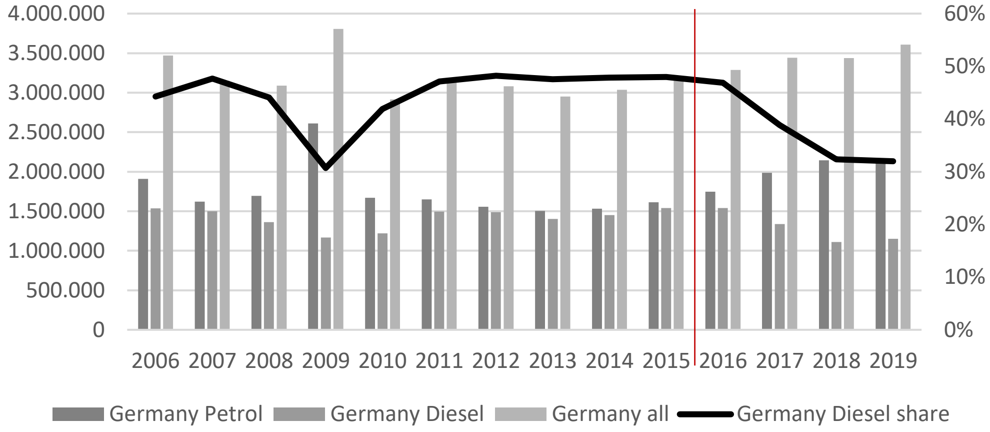
Figure 1. Diesel emission scandal timeline by brands



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

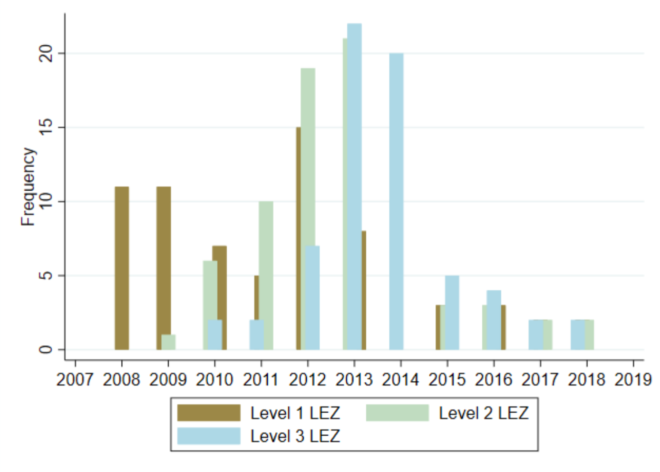


Table 1. Overview variables

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		129194		22477		22749		45226	

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		98000		17187		14007		31194	

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. Local pollution levels

This table contains OLS estimated coefficients for Equation 2. 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

Table 8. 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 9. 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		11078	

Table 10. Pre and post introduction of low emission zones (LEZ)

This table contains OLS estimated coefficients for Equation 3. The dependent variable in Column 1 and 3 is the interest rate and in Column 2 and 5 is the loan-to-value of loan observations. The term "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. The sample consists of amortizing loans for used cars for individual customers issued in DE. The sub-periods consist of 2 years before the introduction of the low-emission zones and respectively two years after. The observations are collapsed by car model, lender banks, 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)	(4)	(5)
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

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

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.		**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 (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" Volkswagen admits to installing software 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 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 **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.

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