THE EFFECT OF INFORMATION ON MARKET ACTIVITY: EVIDENCE FROM VEHICLE RECALLS

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Abstract—We evaluate the effect of vehicle recalls on vehicle transactions in the second-hand market. Using a rich data set of Dutch vehicle registrations, we exploit the quasiexperimental variation in recalls across nearly identical cars. We find strong heterogeneities across market segments: transactions increased for cars with lower listed price or with defects, and decreased for those with higher price or no defects. Based on our theoretical model, this suggests that recalls increase sorting in low-end markets, yet exacerbate adverse selection in high-end markets. Our results shed light on the effect of information arrival in markets subject to uncertainty and information asymmetries.

I. Introduction

INFORMATION availability about product characteristics plays a fundamental role in the correct functioning of markets. In particular, purchasing decisions about expensive durable goods, such as vehicles or household appliances, involve complex considerations about product quality, which is information not always known in advance, or easily observed, by consumers.

Uncertainty about product quality can be mitigated by measures such as quality certifications and mandatory disclosures. A particular type of information disclosure are product recalls due to safety reasons. Recall procedures are in place for a wide range of products, including food, chemical products, textiles, electronics, machinery, furniture, cosmetics, toys, and motor vehicles. For durable goods such as cars, where the defect typically involves one specific component, the product is usually not replaced or reimbursed, but instead repaired for free.

In the automotive market, vehicle recalls are often considered an adverse signal of vehicle quality. Recalls of passenger vehicles are also extremely common. In 2019 alone, the U.S. National Highway Traffic Association registered 743 recall episodes due to vehicle defects, which affected over 34 million vehicles (NHTSA, 2019), while the European Commission recorded 510 vehicle recall occurrences in the EU, each of which often involved multiple models (European Commission, 2020). Though most recall episodes are not widely reported upon, the largest ones generate substantial media attention. Prominent examples are the Volkswagen emission and Takata airbag scandals, which jointly led to the recall of over 50 million vehicles worldwide.

These recalls create concerns with owners of the affected vehicles regarding the reliability of their vehicle, as well as its potential resale value. Yet, despite their widespread occurrence, the effect of recalls on the recalled vehicle and the used-vehicle market has been strikingly understudied. Analyzing the effect of recalls on the used-vehicle market is particularly relevant as for many households a car is the second most expensive durable owned. These cars are actively traded, with the used-vehicle market substantially exceeding the primary market in volume.[1]

In this paper, we are interested in analyzing the effect of the recall announcement on the used car market. Because the recall is triggered by the discovery of a potential safety risk or defect in a group of vehicles, and said defect is explained in the recall description, the announcement itself is akin to other types of quality certifications (such as product reviews or certain product quality labels).

We use a difference-in-differences methodology to assess the effect of recalls on the used car market, focusing primarily on resale rates. We additionally consider the effect of recalls on the depreciation factor (defined as the ratio of used-vehicle asking price to new-vehicle listed price) of vehicles offered in the used-car market. Due to its unexpected nature, a recall constitutes an information shock to both sides of the market. As such, the effect of the recall on the used-car market offers an insight into the effect of the arrival of (negative) information about product quality in markets subject to substantial uncertainty and information asymmetries.

For this empirical assessment, we consider vehicle recalls in the context of the Dutch used-car market. In the Netherlands, detailed vehicle-level information on recalls is readily available to, and commonly accessed by, both buyers and sellers. Owners of a recalled vehicle are informed of the recall by letter, while several government and commercial search engines offer information about current and/or past recalls of specific vehicles to prospective buyers. The vast majority of recalls are due to mechanical problems that pose serious security risks to the driver or passengers. Still, while in the Netherlands a recalled vehicle can be repaired free of charge, owners have no obligation to do so, and may continue to use or sell their vehicle without taking any action.

As we show using a stylized model of the used-car market, the effect of an adverse signal about vehicle quality on resale rates is not immediate. The model captures two primary rationales for trade in the used-car market. The first is sorting, which is driven by differences in the willingness to pay for quality across consumers. Consumers who put a high value

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[1]In the United States, the volume of trade in the used-vehicle market exceeds the new-vehicle market by a factor of 2.5 (Automotive, 2018). In the Netherlands, this is about a factor of 4 (CBS, 2019).

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on quality will tend to buy new vehicles, and act as sellers on the market for used vehicles. They sell to consumers with a low valuation for quality, who prefer the cheaper, lower-quality, used vehicles over the more expensive new cars. The second rationale for trade is adverse selection: used-vehicle sellers have private information about quality, which makes them more inclined to sell especially if this private information indicates that the vehicle quality is low.

The arrival of negative information about vehicle quality affects vehicle transactions through the same two channels. First, the information shock can lead to increased sorting; vehicle sellers value quality more than buyers, and will thus be more inclined to sell. As such, the arrival of information about the quality of the vehicle allows for an improved match of the vehicle to a specific user. Second, the novel information may affect the information asymmetry between buyer and seller. Insofar as a recall leads the buyer to adjust their expectation of the privately observed quality downward, it will reduce the likelihood of a transaction taking place. Taken together, our theoretical framework points out that the effect of an information shock on trade is ex ante ambiguous; our empirical analysis will provide insight into which mechanism dominates.

Our analysis uses the Dutch vehicle registration database, which includes detailed vehicle-level information on vehicle characteristics, registration changes, and recalls for the entire Dutch vehicle fleet of about 9 million vehicles. The precise classification of the vehicles in our database allows us to adopt an identification strategy that relies on a difference-in-differences strategy exploiting the quasiexperimental variation in the occurrence of recalls *within* groups of almost identical cars. We group vehicles by version, following official EU regulation for vehicle classification. By this regulation, all cars belonging to the same version must be identical in terms of manufacturers, chassis, engine, body style, and other fundamental characteristics; only differences in minor features such as color and options are allowed. Yet, while vehicles within a version are virtually identical in terms of core characteristics, they might still exhibit differences due to differences in the assembly process, such as a different production cycle, plant location, or supplier of the vehicle's components. For this reason, recalls are issued at the vehicle level, and for a specific version, only a subset of vehicles may be recalled. This feature, in combination with a large sample of vehicles, allows us to control for version-level vehicle characteristics that we do not observe in our data. Additionally, we are able to control for characteristics of recalled cars of a specific version that we do not observe in our data (such as options), and for unobserved version-specific time trends.

We find that during the first 6 months from the announcement of a recall, the vehicle resale probability decreases, while, depending on the specification, it increases or remains stable afterwards. The effect over the entire sample period is negative, but not statistically significant across all specifications. When considering different market segments, we identify substantial heterogeneity in the response to vehicle recalls. Vehicles in the high-end used-vehicle market, as proxied by high listed price, no past defects, and high vehicle brand reliability, tend to experience a decrease in resales following a recall. This is contrary to the effect for inexpensive vehicles and vehicles with defects, where we identify an increase in resales due to the recall. Using an ancillary data set of a large Dutch vehicle marketplace, we do not find an effect of recalls on the depreciation rate of vehicles offered for sale.

Our results are suggestive of recalls affecting the used-car market through both increased sorting and a reinforcement of adverse selection. The heterogeneity in our results indicates that for cheap, unreliable vehicles, the sorting effect is dominant. The reduction in transactions of high-quality used vehicles, however, suggests that for those vehicles, the announcement of a recall primarily reinforces adverse selection and thereby need not improve market efficiency.

Our paper is strongly complementary to Tadelis and Zettelmeyer (2015), who show that in car auctions the disclosure of information to prospective buyers increases auction revenues and the number of transactions when the information disclosed is new. Contrary to our analysis, Tadelis and Zettelmeyer (2015) only capture the effect of increased information on the demand-side of the market; their experimental design forestalls any supply-side response to the mitigation of the information asymmetry. We instead analyze a setting where the announcement of a recall is new to both sides of the market, and all market participants may respond to this new information about the quality of the recalled vehicle. Furthermore, we consider the overall vehicle market, as opposed to vehicles sold exclusively through an auction. The different setting implies a different mechanism by which sales might increase following negative information about the vehicle: in Tadelis and Zettelmeyer (2015) it is buyers that are able to better identify the auction of the vehicle that reflects their quality preferences; in our case, used-vehicle owners have a relatively higher valuation for quality compared to buyers, and they decide to sell once they realize that their car quality is lower than previously thought. As such, our analysis highlights that subtle differences in the institutional setting, the market segment, and the type of information revealed can matter greatly for the effect of product quality disclosures on secondary vehicle markets.

As highlighted above, despite the common occurrence of vehicle recalls, their effects on the secondary vehicle market remain understudied; we were able to identify only a limited number of contributions, each focusing on the effects of a large, high-profile recall episode. Hartman (1987) finds that the 1981–1985 GM safety recalls negatively affected used-car prices. Hammond (2013) estimates a negative, albeit small and temporary, effect of the 2009–2010 Toyota safety recall on used-vehicle prices. The more recent work by Strittmatter and Lechner (2020) and Ater and Yosef (2022) explores the effects of the Volkswagen "dieselgate" scandal on used-car markets in Germany and Israel, respectively. Strittmatter and Lechner (2020) establish an increase in the supply of

Volkswagen diesel vehicles following the scandal, as well as a reduction in the asking price of those vehicles. Ater and Yosef (2022) similarly find a reduction in resale prices of used Volkswagen vehicles following the scandal, yet they identify a reduction in the number of transactions.

Our contribution to this literature is twofold. First, we consider the effect of recalls generally, rather than the effect of a single highly publicized episode. Second, our empirical approach relies on the quasiexperimental variation in recalls within the same vehicle versions. As such, we capture the effect of the recall on the recalled vehicle itself, filtering out any possible spillover effects to other brands or models or to nonrecalled cars of the same model, as well as any version-specific trends in resales that might be correlated with the occurrence of a recall. This contrasts past literature, which collectively assesses the effect of recalls by adopting a more aggregated approach, comparing across broader vehicle categories such as brands, fuel type, or year of manufacture.

More generally, by shedding light on how consumers may translate information about product safety into market decisions, our paper contributes to a broader literature that evaluates consumer responses to product recalls. Recent contributions to this literature are Freedman et al. (2012), who analyze the spillover effect of a series of toy recalls on new toy sales, and Ferrer and Perrone (2017), who perform a detailed assessment of consumer demand responses following a major food safety crisis. Related contributions that consider the effects of recalls on the *primary* vehicle market are Rhee and Haunschild (2006), Liu and Shankar (2015), and Bachmann et al. (2023). Rhee and Haunschild (2006) and Liu and Shankar (2015) establish that consumers respond more negatively to recalls for brands with a strong quality reputation. Additionally, Bachmann et al. (2023) consider the Volkswagen scandal. They identify an adverse reputation spillover in response to the scandal, as well as a substitution of new-vehicle demand away from diesel and Volkswagen vehicles.

Finally, this paper contributes to the broader literature on the impact of quality certification and other information disclosure mechanisms on consumer choice. Past empirical research in this area considers a variety of sectors, including vehicles (Lewis, 2011), buildings (Eichholtz et al., 2013), home improvement (Farronato et al., 2020), appliances (Houde, 2018), restaurants (Jin & Leslie, 2003), online marketplaces (Elfenbein et al., 2015), and financial markets (Seira et al., 2017). Theoretical work focuses on both the implications of having a disclosure mechanism in place, as well as the effect of the arrival of new information within this context (Daley & Green, 2012). Akin to our setting, Kessler (2001) and Levin (2001) specifically explore situations in which also the seller has incomplete information about quality. Within this literature, our work provides further insight into how the arrival of information about quality affects market activity.[2]

The remainder of the paper is structured as follows. Section II provides the institutional background of the Dutch used-vehicle market and recalls. Section III puts forward a stylized theoretical framework of the arrival of information about vehicle quality and resale decisions. The data and empirical approach are discussed in sections IV and V, respectively. Results are presented in section VI. Section VII concludes.

II. Institutional Background

This section will briefly set out the institutional context of the Dutch used passenger car market and vehicle recalls.

A. *The Used-Car Market in the Netherlands*

The used-car market in the Netherlands is very active: in 2017, out of the 8.2 million cars in that country, about 2 million changed owners during that year (CBS, 2019). Compared to many other countries, the market is also strikingly transparent. Vehicles are typically advertised in dedicated online marketplaces, where detailed information regarding the main vehicle characteristics is reported. Prospective buyers can also use the vehicle license plate number to obtain detailed information on car characteristics, past inspection results, as well as any recalls. This information is available for free either directly through the search engine of the Netherlands vehicle registration authorities (RDW), or through one of several websites who offer a "license plate check." It is common practice to access these resources prior to purchasing a vehicle; the RDW reports that every month, its vehicle registration database is accessed 12–30 million times (RDW, 2018). Following a vehicle transaction, the new-vehicle owner is required to register the vehicle in his or her name. A change in ownership can be registered online, or at one of nearly 2000 post offices and car dealerships across the country, and is effective immediately.

B. *Vehicle Recalls*

As stipulated by EU law, when a common defect that involves the risk of physical injury has been identified, vehicle producers and distributors (henceforth, distributors) have the obligation to notify authorities, inform consumers, recall the product, and offer a free repair (European Parliament, 2001; RDW, 2020).[3]

Vehicle owners are informed about a recall by letter. This letter typically specifies the type of defect, associated risk, and instructions to arrange an appointment to repair the defective part. The repair is free of charge, yet there is no requirement for the vehicle to be repaired to remain in circulation

[2]Additionally, there exists a literature that considers the effect of indirect information disclosure through auction design on auction revenue (Milgrom & Weber, 1982; Cho et al., 2014). Contrary to this literature, our paper focuses primarily on transactions and considers a market setting where information is disclosed by a third party.

[3]Recalls are typically first initiated in the country of manufacturing; national transport authorities subsequently notify other EU institutions through the "Rapid Alert System." The Netherlands does not have any major vehicle manufacturers, and very few recalls originate from there.

or be traded on the used-car market.[4] Since 2012, in an effort to increase transparency about vehicle recalls, the RDW publishes online (i) a recall registry searchable by vehicle brand and model, (ii) information on open (nonfixed) recalls searchable by license plate, and (iii) a database of vehicle characteristics and current status (open or closed) of each recall by license plate. The recall information provided typically includes a short description of the defect, the part involved, the potential risk, and the procedures towards receiving the free repair. Using RDW data, several commercial "license plate check" websites offer vehicle-level information on open recalls free of charge, and in certain cases also closed recalls, either for free or for a small fee. As such, both buyers and sellers have ready access to information about vehicle recalls, and a newly issued recall can be considered an information shock for all market parties.

III. Theoretical Framework

To formalize and assess the potential effects of the recall information shock on the secondary vehicle market, this section puts forward a stylized framework of a market for durable goods. The framework builds on the models presented in Hendel and Lizzeri (1999) and Peterson and Schneider (2017). In Hendel and Lizzeri (1999), heterogeneous preferences for quality induce trade in consumer durables, such as cars. Asymmetric information about vehicle quality, however, creates adverse selection, which reduces, but never eliminates, trade in this market. Peterson and Schneider (2017) build on this approach by considering two dimensions of quality, one symmetrically observed and one observed only by the seller. They establish a positive relationship between observable quality and the degree of adverse selection, and provide empirical evidence for this result.[5]

We take a similar approach by assuming that part of the vehicle quality is ex ante unobserved. We consider two types of unobserved quality. First, information about vehicle quality may be asymmetric; it is fully observable to the current vehicle owner, but not to the prospective buyer. Akin to Hendel and Lizzeri (1999) and Peterson and Schneider (2017), this implies that the vehicle market features adverse selection. The second type of unobserved quality is symmetric: at the time of trade, neither the current owner nor the vehicle seller can observe its realization.

This setup allows us to distinguish two potential channels through which new information about vehicle quality might affect the used-car market. For the current vehicle owner, the information shock is "news" only if it is a credible signal about the symmetrically unobserved part of vehicle quality. The prospective buyer, however, might additionally respond to the information shock by updating her expectation of the asymmetrically observed part of vehicle quality.

The specific information shock we consider are vehicle recalls. Vehicle recalls tend to be associated with lower overall vehicle quality.[6] We then establish that the effect of a recall on resales depends on which of the channels described above is most important.

The model is as follows. We consider a discrete-time economy with infinitely lived households. Households derive utility from the consumption of a durable good, henceforth referred to as a "car" or "vehicle." Per-period utility of a household reads $u = \theta q - s$, where θ is a preference parameter, q is the quality of the car the households owns, and s denotes net vehicle spending. Households can consume at most one vehicle each period; if a household does not own a vehicle, $q = 0$. Future utility is discounted by a factor $\beta \in (0, 1)$. Households have heterogeneous preferences for vehicle quality. More specifically, we assume there exists a unit mass of households with a high valuation for quality θ_H, and a larger than unit mass of households with low valuation for quality θ_L, with $0 < \theta_L < \theta_H$.

Vehicles last for two periods and have zero scrappage value. If a household decides to buy a new vehicle, it uses it for the first period. At the end of the first period, the household must decide to either use the vehicle for one more period, or sell it on the used-car market. New cars are homogeneous, with quality q^n. We refrain from explicitly modeling the supply of new cars, and instead take the new car price, p^n, as exogenous, and we assume that in every period, a sufficient number of cars are available for households to buy. The quality of a used car is given by

$$q^u = b + c + d, \tag{1}$$

where b, c, and d denote the realizations of random variables distributed according to distributions $f_B(b)$, $f_C(c)$, and $f_D(d)$, with support $[\underline{b}, \bar{b}]$, $[\underline{c}, \bar{c}]$, and $[\underline{d}, \bar{d}]$, respectively. We assume that used cars are of positive, albeit lower, quality than new cars: $q^n > q^u > 0$.[7]

Equation (1) separates used-vehicle quality into three components: b, c, and d. Each component differs in observability. The first component, b, is fully observable to both the buyer and the seller. It captures verifiable vehicle characteristics, such as model and make, but also mileage and any visible wear and tear. The second component, c, is fully observable to the current owner, but not to the buyer. As such, it captures characteristics that can be observed only after a (short) period of use. This includes early prevalence of defects, and also the quality of the engine. The third component, d, is realized only

[4] As a consequence, many cars are never repaired. In the Netherlands, this rate is between 10% and 20%. Similar, and higher, rates can be found internationally: In the United States, for instance, about a third of recalled vehicles remain unrepaired (NHTSA, 2017), while in the UK shares of 47% percent have been reported (Daily Mail, 2017).

[5] See also Peterson and Schneider (2014) for empirical evidence for the simultaneous presence of sorting and adverse selection in the used-car market.

[6] For instance, using U.S. data, the automotive research firm iSeeCars (2018) established a negative correlation between recall rates and vehicle reliability ratings. In our data, vehicles that have been subject to recalls in the past are more likely to be recalled again (see section IV).

[7] A sufficient condition for this is $\bar{b} + \bar{c} + \bar{d} < q^n$ and $\underline{b} + \underline{c} + \underline{d} > 0$.

at the start of the second period; at the time of vehicle sale, neither the buyer nor the seller observes the value of d. We interpret d as capturing any defects or parts of the vehicle quality that are hard to anticipate and will be revealed only after long periods of use, such as a poor gearbox.

Once a vehicle is in use, it may be recalled. Such a recall may reveal information about c and d. We assume that the recall, if anything, is considered an adverse signal about vehicle quality; the conditional expectation of c and d is weakly lower in the presence than in the absence of a recall. This is formally expressed by $\mathbb{E}[c|\text{I} = 1] \leq \mathbb{E}[c|\text{I} = 0]$ and $\mathbb{E}[d|\text{I} = 1] \leq \mathbb{E}[d|\text{I} = 0]$, where $\mathbb{E}[\cdot]$ is the expectations operator and I is an indicator equal to 1 if the vehicle has been subject to a recall, and zero otherwise.[8] We assume that all households can observe this information signal. Below we discuss the resulting equilibrium in the used-car market and the effect of a recall on the likelihood that a vehicle will be sold on this market; we refer the reader to appendix B.1 for a more detailed discussion of the household decisions and resulting equilibrium. For expositional purposes, this solution takes the distributions $f_C(c)$ and $f_D(d)$ as independent of b, and assumes that, conditional on I, c and d are independently distributed.

From the above, the following objects are primitives: (i) household preferences θ_L and θ_H; (ii) new vehicle price and quality, p^n and q^n; and (iii) used vehicle quality distributions $f_B(b)$, $f_C(c)$, and $f_D(d)$. The equilibrium objects considered below are (i) used vehicle price $p^u(b, \text{I})$; (ii) conditional expectation of c, $C(b, \text{I})$; and (iii) the expected welfare of a new vehicle for a high-valuation household, V_H^n.

A. *Equilibrium*

We consider the equilibrium with an active market for used vehicles, in which (i) only high-valuation households purchase new vehicles, and use this vehicle for one or two periods; and (ii) low-valuation households purchase any used vehicles high-valuation households decide to sell.[9] A high-valuation vehicle owner is willing to sell their vehicle after a first period of use whenever the expected utility from using the vehicle for a second period, and purchasing a new vehicle thereafter, is equal to or below the expected utility of selling the vehicle and purchasing a new vehicle instead. This is the case if

$$\theta_H[b + c + D(\text{I})] + \beta V_H^n \leq p^u(b, \text{I}) + V_H^n, \tag{2}$$

where $D(\text{I}) \equiv \mathbb{E}[d|\text{I}]$ is the expectation of d conditional on I, $p^u(b, \text{I})$ is the used-vehicle price of a vehicle with quality realization b and recall signal I, and $V_H^n > 0$ denotes the expected welfare a high-valuation household derives from purchasing a new vehicle.

From equation (2) one directly observes that for a given $p^u(b, \text{I})$, the lower the realization of c is, and the lower the expectation of d, the more likely the vehicle owner is willing to sell. As stated above, low-valuation households never buy new cars. This implies their alternative to buying a used car is buying no car ($q = 0$). Then, as there exist more low-valuation households than high-valuation households, the equilibrium used-car price will be such that low-valuation households are indifferent between these two alternatives. This gives an equilibrium $p^u(b, \text{I})$ equal to the willingness-to-pay of the low-valuation households:

$$p^u(b, \text{I}) = \theta_L[b + C(b, \text{I}) + D(\text{I})], \tag{3}$$

where $C(b, \text{I}) \equiv \mathbb{E}[c|b, \text{I}]$ is the expectation of c conditional on the realization of I, and the observation that the seller is willing to offer a car with observable quality b on the market. We can then combine equations (2) and (3) to establish that the vehicle will be traded on the used-car market if the following condition is satisfied:[10]

$$(\theta_H - \theta_L)[b + c + D(\text{I})] + \theta_L[c - C(b, \text{I})] \leq (1 - \beta)V_H^n. \tag{4}$$

Equation (4) highlights two rationales for trade in the used-car market. The first rationale is sorting. Used-vehicle sellers have a higher marginal willingness to pay for quality than buyers ($\theta_H > \theta_L$). A low expected quality realization $b + c + D(\text{I})$ then implies that sellers are more likely to be willing to sell the vehicle, as this allows them to upgrade to a new vehicle with higher expected quality. Through this process, the lowest-quality used vehicles will be used by low-valuation households, with high-valuation households retaining the relatively higher-quality used cars. The second rationale is adverse selection. The buyer's expectation of c, $C(b, \text{I})$, might deviate from its actual value. Whenever the realization of c is low relative to $C(b, \text{I})$, the actual quality of the vehicle is lower than the buyer's expectation. In this situation, the owner will be particularly inclined to sell the vehicle. Of course, the converse is also true. If c is high relative to $C(b, \text{I})$, buyers are willing to pay less than the "true" value of the vehicle, and consequently vehicle owners are less inclined to sell.

Now suppose that in equilibrium, some, but not all, vehicles are sold on the used-car market, that is, there exist cars for which equation (4) is satisfied, and some for which it is not. A recall will then affect the market through those same two channels. First, a recall may lead both buyers and sellers to adjust their expectation of d downward. This is the case whenever $D(1) < D(0)$. Then, the recall information shock will induce increased sorting on the used-car market, and correspondingly increase the likelihood that a transaction will take place. The reduction in D following a recall may have an additional, indirect, effect through $C(b, \text{I})$, as the drop in

[8]The recall might also be correlated with b, yet, as b is fully observed, it will not reveal any new information about b.

[9]Appendix B.1 specifies the assumption we make on p^n that ensures this equilibrium exists.

[10]Determining the equilibrium on the vehicle market additionally requires solving for $C(b, \text{I})$. In appendix B.2, we do so for a specific distribution $f_C(c)$.

$D(\mathrm{I})$ implies that for given b, sellers will be willing to sell vehicles with a higher asymmetrically observed quality c. Knowing that higher-level c vehicles are offered on the market for recalled cars, buyers assign a higher expectation of c to such a car: $C(b, 0) < C(b, 1)$. While the drop in D reduces the used-vehicle price [see equation (3)], this indirect effect on $C(b, \mathrm{I})$ increases the buyer's willingness to pay for the vehicle and thus the vehicle price, thereby reinforcing the positive effect of the recall information on vehicle transactions. All in all, the sorting channel predicts an increase in vehicle transactions following a recall, with an ambiguous net effect on the vehicle price.[11]

Second, the recall may directly affect the buyer's expectation of c, $C(b, \mathrm{I})$. More specifically, vehicles with low asymmetrically observed quality may more likely be subject to a recall. In this case, $C(b, 0) > C(b, 1)$, and buyers will expect a car with observable quality b to have a lower asymmetrically observed quality c if the car has been subject to a recall. Such a change in expectations following the recall will reduce the buyer's willingness to pay, reduce the vehicle price, and in turn reduce the likelihood that the vehicle is traded on the used-car market.

This second channel highlights that in the presence of information asymmetries, the recall may lead to *reduced* trade in the recalled vehicle. It is relevant to note that those vehicles that are most likely no longer traded due to a recall are those for which the recall leads to an *increase* in information asymmetries. This can be observed as follows. Consider equation (4), and suppose that for a given b and I, sellers with different c are active on the market, such that, for some cars, the buyer's expectation of c, $C(b, \mathrm{I})$, deviates from its actual value. Suppose also that the average quality c is lower on the market for recalled than nonrecalled vehicles: $C(b, 0) > C(b, 1)$. Then following the recall, condition equation (4) is most likely no longer satisfied for the highest c vehicle sold in the absence of a recall; if so, the corresponding owner will now refrain from selling the vehicle. For this vehicle, $c > C(b, 0)$. Then as $C(b, 0) > C(b, 1)$, the recall increases the information asymmetry between the buyer and "marginal" seller.[12]

Proposition 1 below summarizes the effect of a recall on the likelihood a vehicle is resold:

Proposition 1. *Consider a vehicle at the end of a first period of use, with a given realization of b and c. If* $D(0) - D(1) < [C(b, 0) - C(b, 1)]\theta_L/(\theta_H - \theta_L)$*, then this vehicle is less likely sold on the used-car market if it has been subject to a recall than if is has not been recalled. If* $D(0) - D(1) = [C(b, 0) - C(b, 1)]\theta_L/(\theta_H - \theta_L)$*, a recall does not affect the likelihood that the vehicle is sold on the used-car market, while if* $D(0) - D(1) > [C(b, 0) - C(b, 1)]\theta_L/(\theta_H - \theta_L)$*, a recall increases the likelihood the vehicle is sold on the used-car market.*

Proof. Follows from equation (4). □

The remainder of the paper focuses on estimating the effect of a recall on the resale likelihood, as well as prices. Proposition 1 and the preceding discussion will aid us in interpreting our empirical results. More specifically, it provides us with a decomposition of the channels through which the arrival of information about vehicle quality may affect transactions. As such, it allows us to assess whether a recall primarily affects the market by allowing for increased sorting, or causes more owners to refrain from selling their vehicles by affecting underlying information asymmetries.

In our empirical analysis, we estimate the effect of recalls both for the market as a whole, as well as different segments of the market. The latter analysis acknowledges that, in reality, vehicle quality is multidimensional, and consumers have heterogeneous preferences across these many dimensions, as well as different levels of income and risk aversion. For these reasons, the vehicle market is strongly segmented; a luxury BMW 7-series car attracts a very different subset of consumers than the compact Nissan Micra.

In the empirical estimation, we differentiate between "high-end" and "low-end" segments based on measures of the new-vehicle listed price, past defects, and brand reputation. There is no immediate reason to expect that the net effect of recalls is uniform across these segments. Rather, when one reinterprets the model as one of a single market segment,[13] Proposition 1 signals that the adverse selection channel, which operates through $C(b, \mathrm{I})$ and reduces resales, is less influential in a segment where the preference gap between buyers and sellers is relatively large (high θ_H/θ_L). Similarly, a recall may be considered a stronger signal about individual vehicle quality in some segments than others; in the model, this can be captured by a stronger correlation between recalls and low quality c and d for those segments. It is not ex ante clear whether such a signal is likely stronger or weaker for a high-end segment. For instance, a recall may be more surprising to both buyers and sellers if the car has a strong reputation. Simultaneously, a strong reputation may mitigate the extent to which market participants update the perception of vehicle quality after the arrival of recall information.[14]

Finally, it is important to highlight that the discussion above assumes that a recall is considered an adverse signal of vehicle quality. This is the conventional assumption, and consistent with the negative effects of recalls on new-vehicle sales and firm stock market value identified in the literature (Rhee & Haunschild, 2006; Hammond, 2013). We cannot

[11]The example in appendix B.2 shows that this effect can indeed go both ways.

[12]Depending on how "noisy" the recall information shock is, this increase in information asymmetries may be more or less common. For instance, the marginal vehicle will never be recalled if recalls only affect the lowest-quality c vehicles.

[13]By doing so, one would implicitly assume that the segments are independent; that is, the equilibrium in one segment can be analyzed separately from decisions in another segment.

[14]There exists evidence that establishing a brand reputation through advertising can mitigate the adverse customer response after "bad news" (Barrage et al., 2020). Rhee and Haunschild (2006), however, document that high-reputation automakers experience larger declines in market share following a recall.

rule out, however, that in some instances, a recall is instead perceived positively. For instance, a well-managed recall may be interpreted as the manufacturer putting care into ensuring continued satisfaction with its customers. If indeed recalls are perceived as a positive signal for vehicle quality, the above theoretical implications are opposite: it would lead to reduced transactions through the sorting channel, and increased transactions through a mitigation of adverse selection.

IV. Data Description

A. *Data Sources*

For our analysis we use registration data collected by RDW. We consider passenger car registration data from November 2017 to March 2019. For each vehicle, we have information on the license plate, ownership changes, date of first registration, and detailed information on a wide range of vehicle characteristics. Additionally, we know the type, variant, and version of each vehicle, which allows us to distinguish between different groups of vehicles belonging to the same brand or model. Vehicles within the same version are identical in most of the vehicle characteristics, with the exception of minor traits (e.g., color) or accessories.

We complement the registration data with data from the RDW recall registry, which includes all recalls since 2012. For each recall, we know the date the recall was issued by the manufacturer and RDW, and the date of notification of car owners. The registry reports also the number of vehicles recalled in the Netherlands and worldwide, a classification of the risk from the defect (serious, average, low), the vehicle part that is considered defective, and the method through which the recall was communicated to the vehicle owner. Our final data set is thus in a panel format, where for each vehicle-month we observe whether the car changed owner and whether a recall was issued.

B. *Market Share and Recalls by Manufacturer*

While the Dutch passenger car fleet includes a wide range of brands, there are six dominant manufacturers: Volkswagen, Opel, Peugeot, Renault, Ford, and Toyota.[15] These manufacturers all have market shares exceeding 6%, and collectively account for about half of the total vehicle fleet (see figure A1 in appendix A). The remaining top 20 brands are primarily Asian and European, with individual market shares between 1% and 5%.

Some manufacturers issue more recalls than others. Figure A2 in appendix A displays for the major manufacturers the share of registered vehicles that has been recalled at least once between November 2017 and March 2019. We observe that during this period, Mitsubishi and Toyota recalled the greatest proportions of their vehicle fleet, 42% and 32%, respectively. These high shares can mostly be attributed to the unusually expansive and continuing Takata airbag recall.

C. *Characteristics of Vehicle Recalls*

A vehicle recall is a very common occurrence. From November 2017 to March 2019 we observe 896 recall episodes, which jointly involved 957,572 vehicles. This amounts to about 9.47% of vehicles ever in circulation during that period. If we additionally consider earlier recalls, we find that 1,957,581 vehicles, or 19.37% of the fleet, has been recalled at least once. We estimate that the unconditional probability that a car will eventually be recalled is about 32% (see appendix A).

The number of recalled vehicles varies noticeably over time (upper panel of figure 1), both in absolute terms and as a share of the size of the fleet in that particular month. On average, we observe a monthly recall rate of about 0.59%, which amounts to about 51,000 vehicles each month.

Further information about recalls in the Netherlands is provided in appendix A. This appendix also presents evidence that vehicles that have already been recalled once have a higher probability to be recalled again compared to cars with no past recalls (see figures A5–A7). This observation lends support to our assumption that the occurrence of a recall represents a negative signal about general vehicle quality.

D. *Vehicle Resales*

In our sample period, ownership changes are frequent: on average, 2.78% of the vehicle fleet changes owner in a given month. In our sample period, we record a total of 4,246,779 ownership changes.[16]

The bottom panel of figure 1 shows the share and the total number of resales over time. We observe relatively high resale rates from January 2018 through March 2018. This is likely explained by changes in new-vehicle registration taxes becoming effective as of January 2018. Towards the end of our sample period, the rate of monthly resales is fairly stable between 2.5% and 2.9%

V. Empirical Strategy

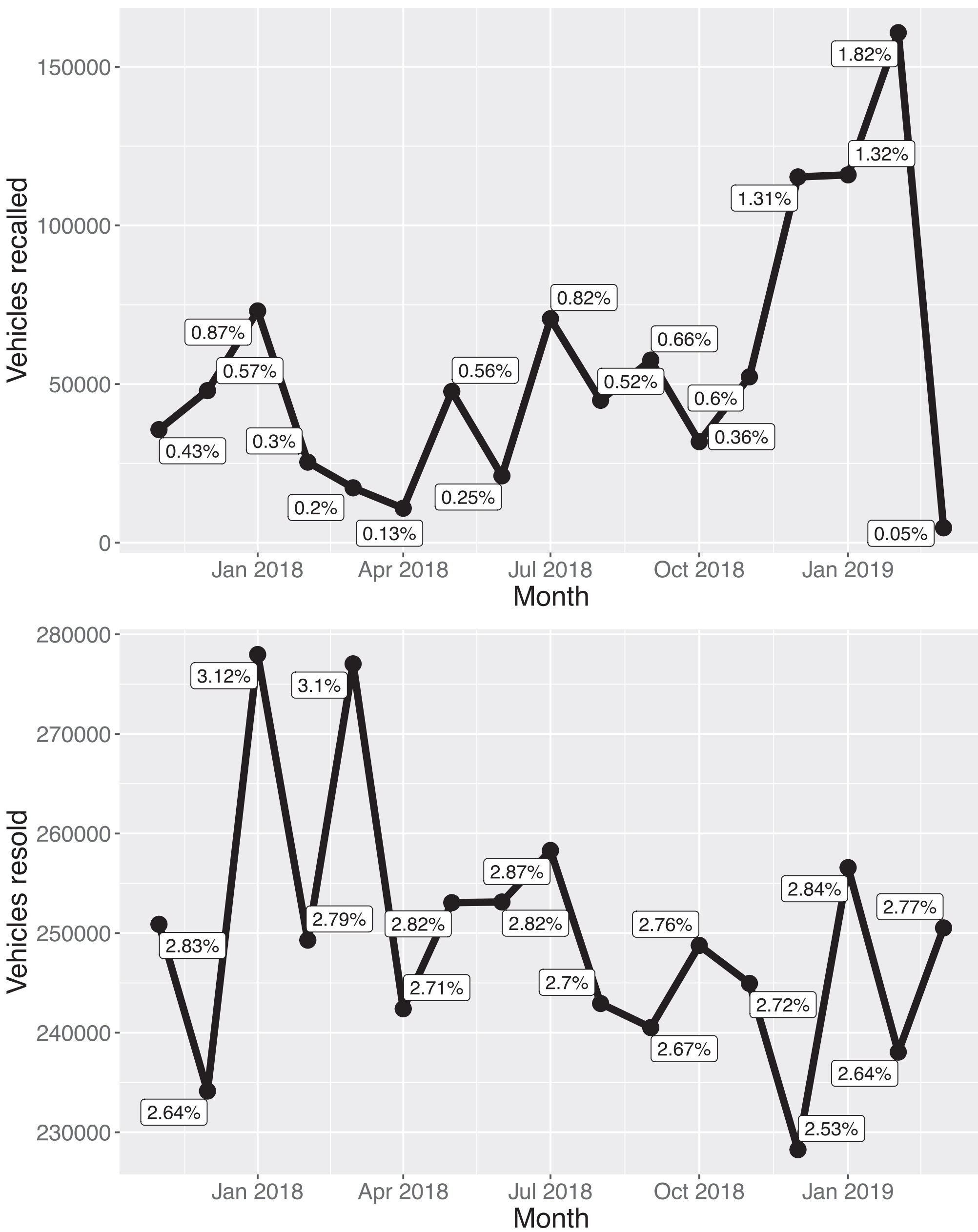
A. *Identification*

In this section, we introduce the econometric methodology used for the main analysis. Any identification strategy of the causal effect of vehicle recalls on vehicle resales must take into account why recalls occur in the first place. If recalls were a random event, we could simply compare differences

[15] In the remainder, we will use the terms "brand" and "manufacturer" interchangeably.

[16] Although in the text we use the terms "ownership changes" and "resales" interchangeably, we cannot verify that each ownership change corresponds to an actual transaction. It is possible that ownership changes very close in time are simply the result of administrative changes within a dealer. In our analysis, we find that our results are robust to excluding ownership changes that occur soon after the previous one (3 months, 6 months, and 12 months).

Figure 1.—Number and Share of Vehicles Recalled and Resold Per Month



in resales before and after their occurrence. However, vehicle recalls are unlikely to happen randomly; they might be correlated with other (in)visible characteristics and brand-model reputation. For instance, cars from a certain brand might be more likely to be recalled because the manufacturer paid less attention to product quality in general.[17] Similarly, for specific vehicle models, recalls may be correlated with other problems, such as poor driving experience and performance, or higher overall maintenance costs.

This issue would normally be addressed through a difference-in-differences framework, comparing recalled cars to a group of nonrecalled cars belonging to a different brand or model, or with different baseline characteristics (such as fuel type). This approach would correctly identify the effect of a recall on vehicle sales if the timing of a recall is uncorrelated with other time-varying characteristics of the recalled vehicle. However, one can imagine situations where this assumption might not be true. For instance, if recalls are symptoms of more general issues with vehicle reliability, defects susceptible to a recall likely appear around the same time a vehicle starts needing more repairs or experiences worse

[17] There is indeed anecdotal evidence on the correlation between vehicle defects and broader flaws in the production process. A report to the GM board of directors about the vehicle recall due to faulty ignition system underlines general issues within the company: "*While GM heard over and over from various quarters* [. . .] *that the car's ignition switch led to moving stalls* [. . .] *nobody took responsibility.* [. . .] *A critical factor in GM personnel's initial delay in fixing the switch was their failure to understand, quite simply*, how *the car was built.*" (Valukas, 2014).

performance. In other words, general vehicle quality might decline faster for recalled cars than nonrecalled cars.

Therefore, a simple approach that consider changes in resales between different brands or models might also capture broader brand- or model-specific time-varying characteristics that are correlated with the timing of the recall and affect the resale probability and prices. In an ideal setting, to ensure that the parallel trend assumption between recalled and nonrecalled cars holds, we would compare two groups of identical cars, of which only one received a recall. Our identification strategy mimics this approach by exploiting the variation in resales between recalled (treatment) vehicles and nonrecalled (control) vehicles belonging to the same *version*. As defined by EU regulation, and further explained below, vehicles belonging to the same version must be identical in all main vehicle characteristics. As such, we are able to mitigate concerns that, within a version, recall occurrence is correlated with the characteristics of the vehicle.

We consider this approach of using the EU vehicle classification system, where vehicle versions are defined in accordance with directives composed and executed by industry experts, preferable to an alternative approach wherein we ourselves would define an "equivalent vehicle" based on observables. To our knowledge, we are the first to exploit the EU vehicle system classification as part of the identification strategy. This strategy is facilitated by the highly disaggregated and rich nature of the Dutch vehicle registration data. Further information about how vehicle versions are defined in the EU classification system is provided below.

B. *Vehicle Version and EU Classification*

Before a specific vehicle can be sold on the European market, vehicle manufacturers are required to obtain an approval. Approvals are classified according to well-defined categories of vehicle type, variant, and version (European Parliament, 2007). Vehicles of the same type are identical in the following aspects: manufacturer, fundamental characteristics of chassis/floor pan, and power plant (e.g., internal combustion/electric/hybrid). Within the same variant, vehicles must also be identical in terms of body style, engine working principle, number and arrangement of cylinders, and axles, while only limited variation in engine power and engine size is permitted. Finally, vehicles belonging to the same *version* are also identical in terms of engine power and size, gear, fuel consumption, seats, and emissions. Thus, within a version, vehicles are close to identical, except for certain optional characteristics, such as color, upgraded interior trim pieces, or additional safety packages.

Although, in principle, two vehicles manufactured many years apart could belong to the same version, this rarely occurs. Rather, due to the rapid technological progress and intense competition in the vehicle sector, the dispersion in vehicle age within the same version is small: we find a mean difference between the first- and last-sold vehicle within a particular version of 274 days, and a median difference of 190 days. As consumers generally understand that different generations of a specific vehicle can be of different quality, and will not consider vehicles that greatly differ in age as "equivalent vehicles," we consider this an advantageous feature of using the version classification to identify very similar cars.

It is relevant to highlight that the same commercial name is typically used for several vehicle versions, or even variants or types.[18] Vice versa, manufacturers nearly always advertise all vehicles belonging to the same version under the same commercial name in the market of sale. As the specific version classification is not communicated to the consumer other than through the vehicle certificate, vehicle owners are unlikely to be aware of this information.

C. *Variation in Recalls and Sample Used*

Our empirical strategy allows us to identify the effect of receiving information about a recall on the probability of vehicle resale only if there exists sufficient variation in recalls across different vehicles belonging to the same version, that is, if within the same version some vehicles are recalled and some are not. Our data show this is the case: up to March 2019, 78% of versions never had a vehicle recalled, while for 12% of versions, all vehicles had been subject to a recall. Our identification strategy thus relies on exploiting variation in recalls in the remaining 18,789 versions (8.93% of all versions in the sample), as these contain both recalled and nonrecalled vehicles.

There are several potential explanations for why out of two seemingly identical vehicles, one may be subject to a recall and the other may not. Vehicles from the same version might have been produced in different plants, in different production cycles, and for these or other reasons have components from different suppliers. Then any variation in the production process across plants or cycles, or simply a poor batch of supplies, may cause variation in recalls within vehicle versions.[19] This is similar to what occurs for recalls in the food industry, where typically only specific batches or serial numbers of the same product are withdrawn from the market. Because there exists such variation in the need to recall vehicles within the same version, recalls are issued and registered at the level of specific vehicles.

The main data set we use in our analysis includes 7,852,875 vehicles and 202,637 versions. This data set includes only vehicles that have either not been recalled or have been recalled only once; this ensures we have a clear date of the start of the treatment. We exclude also very old vehicles, typically registered for the first time before 2000, for which our data

[18]For example, the same commercial name "Ford Focus Wagon 1.6 Ecoboost Titanium 150PK" can belong both to type approval "e13*2007/46*1138*00" and "e13*2007/46*1138*03."

[19]Communication with the Dutch regulatory authority confirmed this is a credible hypothesis.

Table 1.—Summary Statistics by Vehicle Version, Recalled, and Nonrecalled Vehicles

	Average		
	Nonrecalled	Recalled	T-test
List price	53,052.06	53,510.21	0.449
Num. seats	5.06	5.05	0.633
Num. doors	4.26	4.26	0.804
Num. cylinders	4.20	4.23	0.205
Engine displacement	1,875.24	1,890.00	0.190
Mass empty vehicle	1,444.94	1,444.64	0.944
Mass on road	1,544.94	1,544.64	0.945
Max. mass allowed	2,088.43	2,086.02	0.664
Age (months)	45.70	48.26	0.000

Test of equality of means for averages of recalled and nonrecalled vehicles within the same version. The values reported are the averages of the mean values for recalled and nonrecalled vehicles within each version, and the *p*-value of the *t*-test. Only versions with both recalled and nonrecalled vehicles are considered.

set does not specify the type-variant-version classification. Finally, there is a very small number of vehicles that disappear from the sample within our sample period. This could be because the vehicle has been scrapped or because it has been stolen. Because we are not able to distinguish between these two causes, we drop those observations.[20]

D. Summary Statistics and Illustrative Evidence

Table 1 presents several summary statistics for recalled and nonrecalled vehicles. Specifically, we compare vehicle characteristics, new-vehicle listed price, and age of recalled and nonrecalled vehicles belonging to the same versions by reporting average values of within-version means. In most cases, there is no statistically significant difference between recalled and nonrecalled vehicles. We do, however, observe a small difference in vehicle age (3 months). As it takes time to identify defects that may trigger a recall, this difference may be mechanical; it could also signal that cars in earlier production cycles are more susceptible to recalls.

We present some illustrative evidence regarding the effect of recalls on resales in the form of an event study graph. To construct this graph, we calculate the unweighted average of the share of resales within a version for each month, separately for cars that have been recalled between November 2017 and March 2019 and cars that have not. We assign a placebo recall for nonrecalled cars using the modal date of recall for recalled vehicles belonging to the same version.

The resulting event study graph is presented in figure 2. On the horizontal axis, the zero marks the month in which the recall has been issued. Before the recall is issued, we observe very similar dynamics for recalled and nonrecalled vehicles. After the recall, however, we see a large drop in resales for recalled cars. Overall, the event study graph offers compelling evidence of the presence of an effect of recalls on vehicle resales.

Figure 2 also indicates a slight decline in the resale of nonrecalled vehicles after the occurrence of the recall. A possible explanation, supported also by the findings of Freedman et al. (2012), is the presence of spillover effects, where the recall affects nonrecalled cars of the same version.[21] While the presence of such spillovers does not affect the validity of our identification strategy, we briefly explore this hypothesis in appendix C and conclude that spillover effects are plausible within narrow vehicle categories.

E. Econometric Specification

We begin our analysis with a baseline difference-in-differences specification to estimate the effect of vehicle recalls on vehicle resales:

$$Resold_{ijt} = \alpha + \beta RecalledPost_{it} + \gamma Recalled_i + \delta Age_{it} + \zeta DSale_{it} + \eta_t + \theta_j + u_{ijt}. \quad (5)$$

The dependent variable $Resold_{ijt}$ is equal to 1 if vehicle i changed ownership registration in year-month t, and equal to 0 otherwise. Each vehicle belongs to version j. Our treatment indicator, $RecalledPost_{it}$, has value 1 if a car has been recalled at time t or before, and 0 otherwise. Variable $Recalled_i$ is an indicator for the car having been recalled at any point in time up to March 2019, which is the last date of observation in our data set. This indicator controls for any compositional differences between ever recalled and never recalled vehicles. We also control for the age of the car in years, Age_{it}, and the time in years since the last registration change, $DSale_{it}$. Additionally, we include year-month fixed effects η_t and version fixed effects θ_j.

We estimate equation (5) using a linear probability model. Thus, our coefficient of interest β measures the effect of a recall on the probability of a vehicle to be sold in a given month.

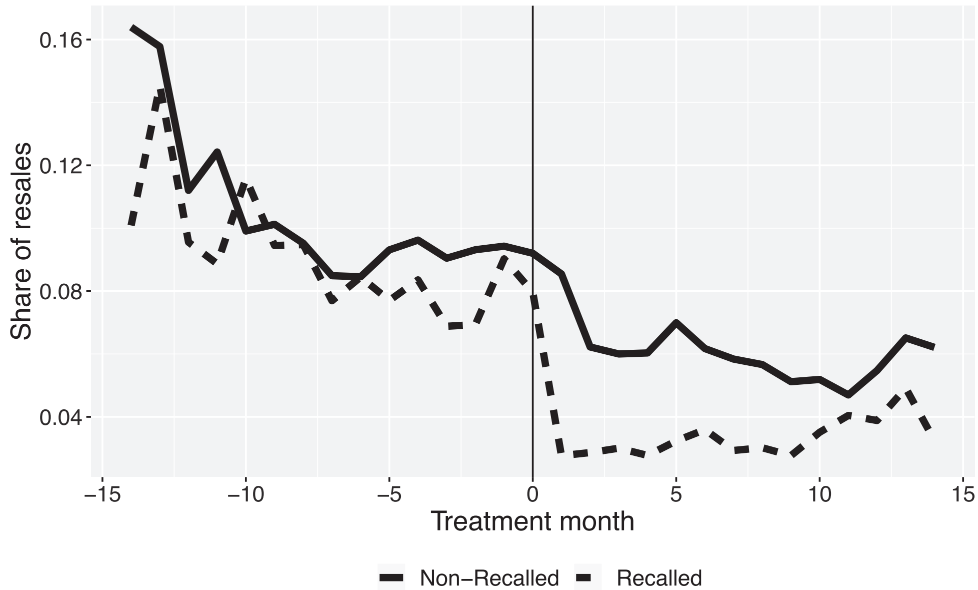
Table 1 shows that there are no difference between recalled and nonrecalled vehicles within a version in terms of new-vehicle listed price and other observable physical characteristics. In our specification, variable $Recalled_i$ controls for systematic differences between recalled and nonrecalled cars in characteristics influencing resale incidence (for instance, the presence of a specific option in recalled cars but not in nonrecalled cars). Yet, one might be concerned that these differences in characteristics might vary across different versions. To address this concern, we include an interaction between the version fixed effects and the indicator on whether the car has been recalled or not at any point in time before the end of March 2019. We refer to this set of fixed effects in the paper as *version-recall* fixed effects.

Trends in the secondary vehicle market may vary across market segments. In addition, a large recall, such as the Takata

[20] In the Netherlands, most vehicles get exported towards the end of their lifetime rather than scrapped. We retain exported vehicles in our sample until the date of export.

[21] Such effects can occur if the recall affects the reputation of a group of similar vehicles, regardless of whether these vehicles have been recalled or not.

FIGURE 2.—EFFECT OF VEHICLE RECALLS ON RESALES: RECALLED AND NONRECALLED VEHICLES



Difference-in-differences event study graph. The vertical axis displays the unweighted average resale share by version. The horizontal axis displays the distance in months from the occurrence of the recall. Data include only versions with both recalled and nonrecalled vehicles, and with a recall issued between November 2017 and March 2019. Placebo recall starting date for nonrecalled vehicles is based on the modal recall date of the recalled vehicles within the same version.

airbag recall, might worsen the overall reputation and desirability of a particular brand or a model, regardless of whether a specific vehicle has been actually recalled or not. Any of these spillover effects would be captured by our coefficient of interest if they are correlated with the timing of a recall. To account for this, and improve the robustness of our identification strategy, we add a set of *version-time* fixed effects to the baseline specification equation (5).[22]

Following the discussion above, we estimate the four different specifications. These are (i) the baseline specification equation (5), which includes only version and time fixed effects; (ii) a specification with version-recall and time fixed effects; (iii) a specification with version-time fixed effects; and (iv) a specification with both version-recall and version-time fixed effects. Specification (iv) is our preferred specification and can be represented as follows:

$$Resold_{ijrt} = \alpha + \beta RecalledPost_{it} + \delta Age_{it} + \zeta DSale_{it} + \phi_{jr} + \psi_{jt} + u_{ijrt}, \quad (6)$$

where the subscript r represents whether the car is ever recalled or not, ϕ_{jr} are version-recall fixed effects and ψ_{jt} are version-time fixed effects.

The different specifications exploit different sources of variation in recalls in the data. In particular, for the estimation of β, our preferred specification (iv) relies only on vehicle versions with a recall occurring during our sample period from November 2017 to March 2019, and for which only a subset of cars has been recalled. Hence, our identifying assumption for specification (iv) is that in the counterfactual scenario of no recalls, within a vehicle version, the evolution of resales over time would have been the same for recalled and nonrecalled vehicles. To provide evidence for the validity of this assumption, we perform a parallel trend test for all four specifications. For specification (iv), this parallel trend test requires us to estimate the following:

$$Resold_{ijrt} = \alpha + \sum_{d} \beta_d Recalled_i * TtR_d + \delta Age_{it} + \zeta DSale_{it} + \phi_{jr} + \psi_{jt} + u_{ijrt}, \quad (7)$$

where TtR_d represents the time distance (per three months) from the occurrence of the recall. Here, $d = -4, -3, \ldots + 3$, with 0 being the first three months after the recall and -1 being the omitted category.[23] Then, whenever the estimated TtR_d is significantly different from zero for $d < 0$, the parallel trend assumption is violated.

VI. Results

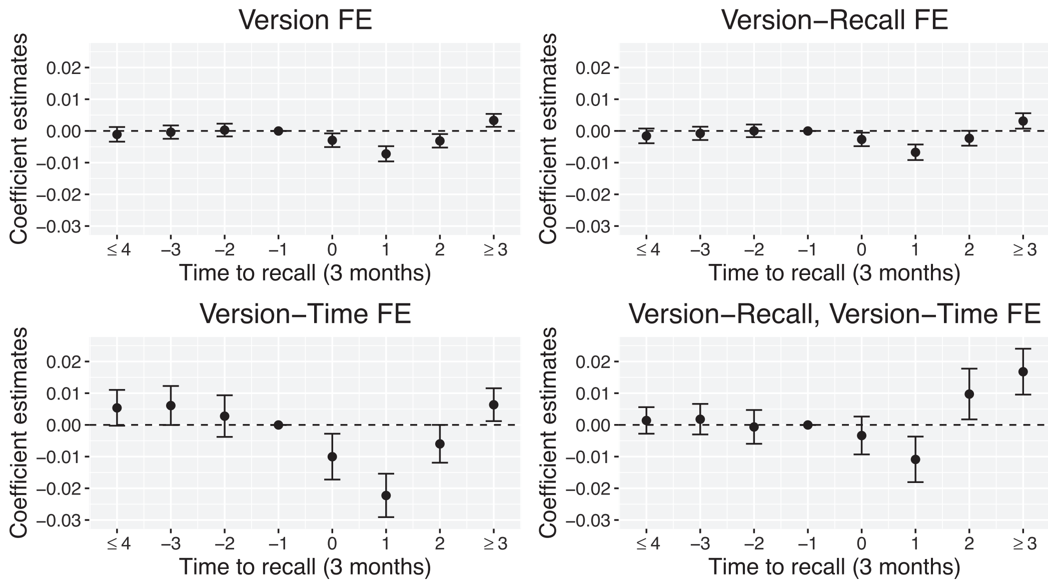
A. Parallel Trend Test

The results of the parallel trend tests are presented in figure 3. It shows that, prior to the recall, there is no statistically significant difference in resale rates between vehicles that are recalled and vehicles that remain nonrecalled (95%

[22] Version-time fixed effects also account for any policy changes that impact some versions more than others, and capture any effects of the recall on overall brand, model, or version reputation.

[23] We group in a unique category all vehicles observed more than 9 months before the recall, and we do the same for vehicles observed more than 9 months after the recall.

FIGURE 3.—PARALLEL TREND TEST



Results from the parallel trend test [equation (7)]. The horizontal axis shows the time (in units of 3 months) since the start of the recall (time 0). Each coefficient represents the change in probability of a resale occurring during each 3 month time period. Time period −1 is the omitted coefficient. The four panels show the results from using different groups of fixed effects. Standard errors at the vehicle type-time level. The bars represent 95% confidence intervals.

confidence level).[24] In our preferred specification (iv) with version-recall and version-time fixed effects, we find no evidence of pretrends.

Following the recall, we observe a significant decline in resales in the second quarter postrecall, followed by no effect or an increase afterwards. For specifications (iii) and (iv), the magnitude of this effect is larger, while qualitatively the main conclusions are unchanged.[25]

These results show that a recall leads to a delay in resales. A potential explanation for this is that owners prefer to repair the vehicle prior to offering it for sale. Illustrative evidence regarding resale trends for repaired and unrepaired vehicles, however, fails to lend support to this hypothesis (see appendix E for an analysis).

B. *Overall Results*

Our estimation results for the overall effect of a recall on resales are presented in table 2. We present the results for specifications (i)–(iv), starting from the baseline model (i) described in equation (5) up to our preferred model (iv) as given by equation (6). The coefficient RecalledPost captures the change in the monthly resale probability of treatment (recalled) vehicles, compared to control (nonrecalled) vehicles, following the recall. To provide a comparison, the average monthly resale probability for control vehicles is 3.31%. All estimations show an overall decline in resales following the recall. However, the coefficient of interest is not statistically significant for specifications (iii) and our preferred specification (iv).

TABLE 2.—OVERALL EFFECT OF RECALLS

	(i)	(ii)	(iii)	(iv)
RecalledPost	−0.0022***	−0.0030***	−0.0006	−0.0013
	(0.0007)	(0.0009)	(0.0012)	(0.0022)
Recalled	−0.0047***		−0.0063***	
	(0.0007)		(0.0011)	
Version-Recall FE	No	Yes	No	Yes
Version-Time FE	No	No	Yes	Yes

Results from specifications (i)–(iv) with a linear probability model. The dependent variable is an indicator for whether the car has been resold in a given period. Coefficient *RecalledPost* identifies the change in monthly resale probability due to a recall. Coefficient *Recalled* controls for time-invariant compositional differences in resales between recalled and nonrecalled cars. The total sample size is 126,698,699 observations for 7,852,875 unique vehicles. Standard errors are clustered at the vehicle type-time level.

This lack of a significant effect need not imply that market participants ignore the recall, or that the recall does not provide additional information on vehicle quality; the theoretical framework established that the overall effect of recalls on resales can go either way. In particular, our model highlights that recalls can improve sorting and thus increase vehicle transactions. Simultaneously, however, a recall might change the buyer's expectation of the asymmetrically observed vehicle quality, which can reduce transactions.

As argued in section III, considering the vehicle market as a whole may disguise important heterogeneities across vehicle market segments. Below, we consider such heterogeneities. In particular, we analyze whether the effect of a recall differs across segments in which vehicles are grouped according to "baseline quality." Because there exists no single objective measure of baseline vehicle quality, we instead consider three different proxies. These are (i) new-vehicle listed price, (ii) history of defects identified during mandatory

[24]Under specification (iii) with version-time fixed effects, TtR_{-3} is significantly different from zero (90% confidence level) 6 to 9 months prior to the recall (see bottom left quadrant). The remaining pretrend coefficients are not significant at the 10% level.

[25]In appendix D, we show that our results are not driven by only a few large recalls.

inspections, and (iii) a brand reliability score. These proxies all capture slightly different dimensions of vehicle quality. For instance, the vehicle listed price can be considered an indicator of the expected quality of a new model or version, while the inspection results may more accurately reflect the recent conditions of the specific vehicle.

C. *Results by New-Vehicle Listed Price*

The vehicle price is the first obvious candidate for a proxy for vehicle quality: previous studies have shown a positive correlation between listed price and the various dimensions of vehicle quality, such as comfort, efficiency, safety, and reliability (McCarthy, 1996). As such, listed price can be considered a broad measure for vehicle quality at the beginning of the vehicle's lifetime, with high-priced vehicles simultaneously targeting a distinct demographic as compared to low-priced vehicles. Information about the listed price is readily available to buyers through the RDW database, even for older cars.

We split the sample of used vehicles into two parts according to the vehicle's real listed price (2016 EUR) when purchased new. We adopt a threshold value of 30,000 EUR (sample median), and we estimate the effect of a recall on resales separately for each of the two vehicle price categories. Differences in price within version are limited; all vehicles belonging to the same version typically also belong to the same price group.[26] The identification strategy and regression specification are the same as in the main results in table 2.

Table 3 presents the results by price category. Panel A shows the effect of a recall for cheaper vehicles, while panel B shows the effect for more expensive vehicles. Under our preferred specification, less expensive vehicles experience an overall increase in resale probability of 1.08 percentage points following a recall, while expensive vehicles see a decline in resale probability of 1.32 percentage points.

D. *Effect of Recalls by Inspection Defects*

While the listed price can be considered to broadly reflect the quality of the vehicle when new, it provides little indication of the evolution of quality over time, nor does it identify the "lemons" within the vehicle pool. Poor maintenance routines or intensive vehicle use can, for instance, affect the quality of a car, and consequently the type of consumers willing to buy such a vehicle. Similarly, whether a vehicle belongs to a "poor batch" is only revealed over time. To obtain a measure of vehicle-specific quality after the first registration, we consider the results from the Dutch mandatory vehicle inspections.

Like in other European countries, in the Netherlands vehicles are subject to a regular mandatory inspection. This

[26]If we observe cars of a version with prices both above and below 30,000 EUR, we treat them as part of a different version.

TABLE 3.—RESULTS BY REAL VEHICLE LISTED PRICE, SEPARATE REGRESSIONS

	(i)	(ii)	(iii)	(iv)
Panel A: Price < 30K EUR				
RecalledPost	0.0043***	0.0046***	0.0034*	0.0108***
	(0.0008)	(0.0009)	(0.0018)	(0.0041)
Recalled	−0.0086***		−0.0080***	
	(0.0009)		(0.0018)	
Panel B: Price ≥ 30K EUR				
RecalledPost	−0.0078***	−0.0096***	−0.0056**	−0.0132***
	(0.0015)	(0.0016)	(0.0022)	(0.0030)
Recalled	−0.0041***		−0.0056**	
	(0.0015)		(0.0022)	
Version-Recall FE	No	Yes	No	Yes
Version-Time FE	No	No	Yes	Yes

Results from specifications (i)–(iv) with a linear probability model, for two separate subsamples of vehicles with a real listed price below 30K EUR (panel A) and vehicles with a real listed price of 30K EUR or more (panel B). The dependent variable is an indicator for whether the car has been resold in a given period. Coefficient *RecalledPost* identifies the change in monthly resale probability due to a recall. Coefficient *Recalled* controls for time-invariant compositional differences in resales between recalled and nonrecalled cars. For panel A the total sample size is of 51,637,432 observations for 3,227,084 unique vehicles (9.52% of versions with within-variation in recalls). For panel B the total sample size is of 28,005,073 observations for 1,835,556 unique vehicles (11.08% of versions with within-variation in recalls). Standard errors are clustered at the vehicle type-time level.

inspection, referred to as the APK, often reveals defects that must be fixed before the car is allowed back on the road. APK inspectors are required to communicate results to the RDW. In an effort to improve transparency on the market, the RDW publishes these results through its standard channels. As such, the APK results constitute a freely available vehicle-specific signal of current vehicle quality. In the remainder of the paper, we will consider a vehicle with a recent history of defects as one belonging to a lower-end vehicle quality segment.

The first mandatory APK test is due 4 years after the first vehicle registration, and is subsequently repeated every 1–2 years depending on the age of the vehicle. To ensure that all cars considered had at least one inspection, we restrict the sample to vehicles that are 4 years or older. We then run the analysis separately for two groups: cars that had no defects during their last inspection, and cars that had one or more defects. The results are presented in table 4.

Results from table 4 are in line with those obtained in the analysis using listed price: higher-quality vehicles (no APK defects) experience a reduction in resale probability as a consequence of the recall, whereas resales for lower-quality vehicles (one or more defects found during the inspection) increase.

E. *Effect of Recalls by Reliability Score*

The final segmentation we consider is based on the 2017 manufacturer reliability score from the Consumentenbond, the main Dutch consumer association. The Consumentenbond surveys Dutch vehicle owners on whether their vehicle had a defect in the previous year. If so, it then asks the respondent to specify which part was affected, and whether the defect prevented them from driving, allowed them to drive but

TABLE 4.—RESULTS BY APK INSPECTION DEFECTS, SEPARATE REGRESSIONS

	Panel A: No defects			
	(i)	(ii)	(iii)	(iv)
RecalledPost	−0.0010**	−0.0012**	−0.0041***	−0.0140***
	(0.0004)	(0.0005)	(0.0008)	(0.0020)
Recalled	−0.0075***		−0.0046***	
	(0.0004)		(0.0007)	
	Panel B: One or more defects			
	(1)	(2)	(3)	(4)
RecalledPost	0.0015***	0.0017***	0.0014***	0.0016**
	(0.0002)	(0.0003)	(0.0005)	(0.0008)
Recalled	−0.0005*		−0.0004	
	(0.0003)		(0.0004)	
Version-Recall FE	No	Yes	No	Yes
Version-Time FE	No	No	Yes	Yes

Results from specifications (i)–(iv) with a linear probability model, for two separate subsamples of vehicles with no defects found during the last APK inspection (panel A) and with one or more defects found (panel B). The dependent variable is an indicator for whether the car has been resold in a given period. Coefficient *RecalledPost* identifies the change in monthly resale probability following a recall. Coefficient *Recalled* controls for time-invariant compositional differences in resales between recalled and nonrecalled cars. For panel A the total sample size is of 28,245,023 observations for 2,302,428 unique vehicles (7.40% of versions with within-variation in recalls). For panel B the total sample size is of 70,107,490 observations for 4,522,001 unique vehicles (5.40% of versions with within-variation in recalls). Standard errors are clustered at the vehicle type-time level.

TABLE 5.—RESULTS BY BRAND RATING, SEPARATE REGRESSIONS

	Panel A: Brand rating below 7			
	(i)	(ii)	(iii)	(iv)
RecalledPost	−0.0017	−0.0026*	0.0007	0.0055
	(0.0011)	(0.0015)	(0.0014)	(0.0035)
Recalled	−0.0035***		−0.0062***	
	(0.0011)		(0.0014)	
	Panel B: Brand rating equal to or above 7			
	(i)	(ii)	(iii)	(iv)
RecalledPost	−0.0017*	−0.0028***	−0.0001	−0.0082***
	(0.0009)	(0.0010)	(0.0021)	(0.0025)
Recalled	−0.0072***		−0.0083***	
	(0.0010)		(0.0021)	
Version-Recall FE	No	Yes	No	Yes
Version-Time FE	No	No	Yes	Yes

Results from specifications (i)–(iv) with a linear probability model, using two separate subsamples of vehicles with a brand reliability rating below 7 (panel A), and a rating of 7 and higher (panel B). The dependent variable is an indicator on whether the car has been resold in a given period. Coefficient *RecalledPost* identifies the change in monthly resale probability due to a recall. Coefficient *Recalled* controls for time-invariant compositional differences in resales between recalled and nonrecalled cars. For panel A the sample size is of 68,396,306 observations for 4,234,740 unique vehicles (8.73% of versions with within-variation in recalls). For panel B the sample size is of 51,541,966 observations for 3,192,213 unique vehicles (8.84% of versions with within-variation in recalls). Standard errors are clustered at the vehicle type-time level.

required immediate maintenance, or if maintenance could be postponed. Based on the survey results, the Consumentenbond construct a reliability score from 5 to 9 for the 24 main vehicle brands.[27] The manufacturer reliability score can be considered a measure of the amount of maintenance the car would likely need in the future, and as such a measure of brand reputation. There exists substantial heterogeneity in the reliability of cars across manufacturers and vehicle makes. To capture this heterogeneity, we split our sample into two groups: cars with a low brand reliability rating (below 7), and cars with a high rating (7 or higher).

Under our preferred specification with version-recall and version-time fixed effects, the results in table 5 show evidence of a decrease in resale rates following a recall for cars of brands with a high reliability rating. This result is consistent with the previous results considering alternative dimensions of quality. For cars of brands with a low reliability rating, the coefficient is positive, but not significant, and it does not seem robust across the different specifications.

The analysis using brand reliability thus offers less robust evidence in favor of heterogeneous responses to recalls than the analysis using real listed prices or vehicle inspection defects. A possible explanation for this is that the reliability ratings by Consumentenbond are less salient to both buyers and sellers, as they are not included in the report produced on the government or private licence plate search engines. Obtaining the brand rating instead would require the consumer to check either the Consumentenbond report directly or a news article reporting on it.

[27]Recent scores can be found at www.consumentenbond.nl/test/auto-fiets-reizen/automankementen. We use the scores published in November 2017, and thank the Consumentenbond for sharing these data with us.

All in all, our results indicate substantial heterogeneities in the implications of vehicle recalls across market segments: following a recall, resales of high-end vehicles fall, while resales of low-end vehicles (weakly) increase. In light of our theoretical framework, our findings suggest that recalls primarily lead to increased sorting in the lower end of the vehicle market. Instead, for the high-end vehicles, exacerbation of the information asymmetries seems to dominate the sorting effect, explaining why the resale probability decreases.

Further analysis indicates that these heterogeneous effects of recalls are likely driven by recalls associated with more fundamental vehicle components (such as safety equipment, engine, or brakes). In our view, this means that recalls perceived as more serious by the market elicit a stronger reaction, both in terms of the sorting effect and the adverse selection effect. Further details can be found in appendix F, where we also establish that the heterogeneous effect of recalls cannot be attributed to differences in recall "types" across high- and low-end vehicles.

In our interpretation of the results of the analysis, we maintain the conventional assumption that recalls constitute a negative signal about the quality of the recalled vehicle. Yet, one could argue that, if managed well, recalls might improve the perception of the quality of the specific vehicle and/or the overall brand. As our empirical strategy controls for version-specific time trends, any positive or negative change in brand reputation does not affect our results. Even though we are not aware of literature evidence that establishes that a recall is regularly considered a positive signal of the quality of a specific recalled car, we cannot rule out this possibility. Further research would be required to assess whether such "positive recalls" could serve as an alternative explanation for the observed negative effect of recalls on resales in the higher-end market segments.

F. *Effect on Depreciation Factor*

So far, our analysis has focused on the effect of the recall on the probability that a vehicle will be resold. Beyond the resale likelihood, recalls may also affect prices on the used-car market. Here again the theoretical framework signals that the direction of this effect is not immediate. More specifically, while the recall unambiguously decreases resale prices through the adverse selection channel, it has an ambiguous effect on the used-vehicle price through the sorting channel. Hence, the net effect of recalls on used-vehicle prices is theoretically ambiguous, and remains an empirical question.

To assess the effect of recalls on used-vehicle prices, we use data on used-vehicle asking prices from one of the largest online marketplaces active in the Netherlands, from May 2018 through the end of our sample period of March 2019. We then adopt the same empirical strategy as for the analysis of the recall probability to estimate the effect of recalls on the ratio of the asking price and the real listed price. We provide further details about our data set and estimation strategy in appendix G.

Results are presented in table G.1 in appendix G. Our results show small and generally insignificant effects of recalls on vehicle depreciation rates. In this appendix, we additionally perform separate regressions by market segment, analogous to tables 3, 4, and 5. We do not find evidence of systematic heterogeneity in the price response across market segments.

VII. Concluding Comments

Over the past years, several large vehicle recall episodes have made newspaper headlines. Yet, despite this substantial attention to recalls by the media and general public, the effect of recalls on vehicle markets remains understudied. In this paper, we shed light on this topic by considering the effect of vehicle recalls in the context of the Dutch secondary vehicle market, focusing on the effect on resale rates.

At first glance, our results do not seem to justify the substantial media attention, and consumer discontent, vehicle recalls evoke: for our preferred specification, we find no significant effect of recalls on resale rates and vehicle depreciation rates. These overall effects, however, disguise substantial heterogeneities, both in time and across market segments. For the first 6 months following a recall, resale rates tend to decline; depending on model specification, they remain constant or increase afterwards.[28] Higher-end vehicles are more likely to experience a decrease in resale rates following a recall, while we find evidence for an increase in resale rates for the cheaper and lower-quality market segments.

We argue that recalls constitute an example of new information arrival in the used-vehicle market. This information may increase resales through increased sorting, or reduce resales by exacerbating preexisting adverse selection problems. As such, the reduction in resales identified for high-quality vehicles may signal that the arrival of negative information about vehicle quality may reduce market efficiency in this market segment.

Past research on vehicle recalls has generally assessed the effect of a single, high-profile, recall episode (Ater & Yosef, 2022; Strittmatter & Lechner, 2020). Our analysis, however, establishes substantial heterogeneity in the effect of recalls across time and market segments. Thus, our results highlight that one should exercise caution with making general claims based on single-event studies, as insights may not generalize across vehicle segments and recall episodes.

[28] Such temporary, or reversal of, effects are more commonly identified in the literature on vehicle sales. For instance, the literature on the 2009 "Cash vs Clunkers" stimulus program (Mian & Sufi, 2012; Li et al., 2013; Hoekstra et al., 2017), found a full reversal of the immediate positive response in vehicle sales to temporary vehicle subsidies within one year.

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