AI AT THE WHEEL:

THE EFFECTIVENESS OF ADVANCED DRIVER ASSISTANCE SYSTEMS

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Abstract. Automakers' introduction of advanced driver-assistance system (ADAS) technologies based on artificial intelligence raise longstanding questions of whether they improve safety and whether the government should mandate their adoption in all new vehicles. We address those issues using a trim-level dataset of automobiles, which appears to be the first of its kind. We find that ADAS technologies reduce all accidents by over 50% and fatal accidents by nearly two thirds. Notwithstanding those considerable benefits, we argue against mandating those safety technologies because drivers are adequately informed about the benefits of and have equal access to ADAS technologies.

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1. Introduction

The automobile industry has long been criticized for paying inadequate attention to motorists' safety and for complaining that safety does not sell. However, since Ford Motor Company mass produced the Model T more than a century ago, the automobile industry has also introduced significant vehicle safety improvements such as headlights, automatic windshield wipers, shatterproof glass, improved braking, advances in body structure, collapsible steering columns, and occupant safety devices.

Government policies also have sought to improve automobile safety by requiring motorists to have a valid driver's license, prohibiting driving under the influence of alcohol or drugs, setting and enforcing speed limits, and requiring vehicles to satisfy National Highway Traffic Safety Administration (NHTSA) safety standards. In some cases, federal regulators have mandated that certain new safety improvements such as seat belts and dual front airbags be installed in all new vehicles while states have passed mandatory seat belt use laws.[2]

A long line of research, however, has questioned both the justification for and effectiveness of government automobile safety policies because consumers' voluntary adoption of vehicles with new safety devices may promote safety more efficiently and because drivers may adjust their behavior when new safety technologies are installed in their vehicle. For example, Thaler and Rosen (1976) and Mannering and Winston (1987) found that although federal law in 1968 required seat belts to be installed in all vehicles except buses, many motorists eschewed their safety benefits based on a rational cost-benefit assessment of the time and bother costs to fasten seat belts and their effect on reducing the probability of a fatal accident. Peltzman (1975) argued that even when seat belts were fastened, motorists reduced their technological effectiveness by driving faster to reduce travel time, thereby maintaining their exposure to accident risk. Winston, Maheshri, and Mannering (2006) found that motorists' increase in risky driving behavior appeared to offset the initial effectiveness of airbags.

Beginning in the late 2000s, automakers have steadily installed advanced driver-assistance systems (ADAS) based on artificial intelligence in their vehicles. In model year 2010, roughly 10% of vehicle make-models had ADAS available at some trim level; by model year 2018 that share had increased to 53%.[3] ADAS consists of a suite of safety features that assist in both the

[2] Government highway expenditures also have been used to improve the safety of the road system.
[3] A vehicle's trim includes powertrain options, aesthetic features, and comfort amenities as well as safety technology.

forward dimension (automatic emergency braking and adaptive cruise control), and the lateral dimension (lane departure warning and blind spot collision prevention).[4] ADAS is standard for some vehicle makes, models and trims, optional for other makes, models and trims, and unavailable for the remaining makes, models and trims. ADAS distinguishes itself from other automobile safety features because it assists the driver by making its own decisions in response to safety threats in real highway travel settings, such as automatically braking to avoid a collision. Hence, ADAS affords a far greater degree of substitutability for driver attention than other safety features do. In addition, unlike safety features such as seat belts and airbags that required government intervention before they were installed in all vehicles, ADAS has thus far been voluntarily installed in vehicles by automakers and selected by motorists through their choice of vehicle and trim.

The recent adoption of ADAS motivates our interest in assessing its effectiveness at reducing accident risk in practice—that is, after accounting for all behavioral responses of drivers to the installation of those features in their vehicles and after accounting for the fact that most vehicles on the road are not ADAS equipped. Our assessment is further motivated by Congress's apparent dissatisfaction with the progress of motorists' adoption of ADAS in their vehicle choices. Following Congress's order, NHTSA (2023a) proposed requiring all new passenger cars and light trucks to be equipped with automatic emergency braking systems, an important component of ADAS, with the requirement going into effect three years after the rule is adopted.[5] It is therefore of interest to shed light on whether this proposed requirement is justified.

The primary empirical challenge to identify the causal effect of a new technology on auto safety is that the adoption of the technology is non-random. Our analysis meets this challenge by exploiting a novel source of plausibly exogenous variation in the availability of ADAS. In a standard approach, the effect of ADAS would be identified only under the assumption that a driver's propensity to purchase an ADAS-equipped vehicle was uncorrelated to their attitudes toward safety and their driving abilities (perhaps conditional on some small set of observable driver characteristics). This is unlikely to be the case. In our approach, we leverage the fact that

[4] Except for adaptive cruise control, ADAS features engage autonomously because they are often enabled by default.
[5] Under the proposed rule, all new vehicles would be required to have a version of automatic emergency braking that is "much more effective at much higher speeds." Specifically, all cars would need to be able to stop and avoid contact with a vehicle in front of them when traveling up to 62mph; vehicles traveling as fast as 37mph would need to come to a complete stop to avoid hitting pedestrians; and braking systems would be required to detect pedestrians and cyclists at night.

ADAS became available at different times for different trim levels (notably within vehicles of the same make and model).[6] We therefore identify the causal effect of ADAS on accidents under the weaker assumption that drivers did not systematically opt for higher trim level vehicles solely because of the availability of ADAS. Intuitively, this assumption is likely to be satisfied because vehicles with different trim levels vary in many dimensions and offer dozens of appealing features, many of which are related more to comfort and aesthetics than to safety. Empirically, we provide a variety of evidence in support of this assumption.

We implement our empirical strategy by using a novel panel dataset of all accidents in Texas from 2010-2018, which involved vehicles that are defined at the calendar year-model year-make-model-trim level. To the best of our knowledge, this is the first paper to use a trim-level dataset in an analysis of automobile safety. We combine the accident histories of all registered vehicles in Texas from 2000 to 2018 with a panel dataset that we construct that identifies the availability of ADAS-related safety features in all vehicles that were sold at all trim levels over this period. These two data sources are merged via a specialized matching procedure that decodes the precise trim level of a vehicle from its Vehicle Identification Number (VIN).

We find that even after accounting for drivers' behavioral responses to its availability, ADAS is highly effective at improving automobile safety: it reduces accidents by over 50% and fatal accidents by roughly two thirds. By significantly reducing the probability of motorists being involved in all types of accidents and in fatal accidents, ADAS is more effective at enhancing motorists' safety than other features such as seat belts and air bags.[7]

Given the remarkable efficacy of ADAS and the fact that federal policymakers mandated the installation of seat belts and air bags in all vehicles, it is natural to ask whether policymakers should mandate the installation of ADAS in all vehicles to further reduce the private and social costs of accidents. However, we caution against such a policy without clear evidence of external benefits to other motorists that are likely to be implausibly large.[8] Our caution is informed by three important pieces of evidence. First, motorists are informed about the benefits of ADAS

[6] Wåhlberg and Dorn (2023) assess the effectiveness of vehicle electronic stability control (ESC) on fatal crash rates, but they do not compare cars' safety performance with and without ESC.
[7] See https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811882.pdf and https://injuryfacts.nsc.org/motor-vehicle/occupant-protection/seat-belts
[8] The policy also could be justified by supplemental evidence that private costs have been reduced by a substantial decrease in the price of ADAS to consumers, or evidence of improvements in autonomous automotive technology that dramatically increases the effectiveness and consumers' perceived benefits of ADAS.

because, on average, they appear to be willing to pay for their significant installation costs. Second, access to ADAS is equitable and does not appear to be affected by supply-side distortions. Third, the external benefits from mandating ADAS in all cars are unlikely to significantly increase their overall benefits. Thus, the mandate's burden on motorists who must bear an installation cost of ADAS that exceeds their private valuation of those safety features' benefits takes on considerable importance.

2. Estimating the Efficacy of ADAS

The staggered rollout of the availability of ADAS over time and across different automobile makes, models and trims generates temporal and cross-sectional variation in registered vehicles' safety features that enables us to identify the causal effect of ADAS on accident risk. In most safety analyses, a vehicle type, which we index by i, is defined as a combination of make and model. However, within a make-model combination in our analysis, some vehicles (e.g., luxury editions) may have ADAS and others (e.g., standard editions) may not. We therefore expand the definition of vehicle type as a combination of make, model and trim, where trim levels as defined in the data section are indexed separately by j.

Crucial to our analysis is that the availability of ADAS for a given vehicle make and model may vary over time because it is not available in earlier model years of some vehicles, but it is available in later model years. Moreover, some vehicle makes and models may never have ADAS available during our sample period. Let y index the model year of a given vehicle type. Then, our treatment variable, the availability of ADAS, which we denote by the dummy variable S_{yij}, varies at the model year, make-model, and trim level.

For each vehicle in each calendar year of our sample, we observe the vehicle's model year, type (make-model), trim level, whether it was involved in an accident, and if so, the accident severity (ranging from property damage only to a fatal accident). We denote by t the calendar year, which will generally differ from the model year, of a specific year in a vehicle's accident history. Because we are interested in the effect of a treatment that occurs at the vehicle level, we aggregate accident outcomes to the model year-type-trim-calendar year level and denote by A_{yijt} the total number of accidents of a given severity that vehicles yij had in year t.

Our panel is distinctive because it contains two different temporal dimensions: model year y and calendar year t. Although the outcome varies over the calendar year dimension, the treatment varies only over the model year dimension y—older models of a vehicle type that were untreated remain untreated even if newer models of that type are treated. Hence, a different treatment variable may be observed at a given $t \geq y$. We exploit the variation in the treatment variable within vehicle type and across trim, model years and calendar years to identify the causal effect of ADAS on accidents.[9]

In table 1, we illustrate the organization of our data for a single vehicle type, the Acura MDX, using the calendar year as the primary temporal dimension for the sample period of 2000 to 2019.[10] The Acura has three trim levels that we denote as Low (L), Medium (M), and High (H), each characterizing the period that they were equipped with ADAS. Vehicles with a low trim level were never equipped with ADAS during our sample period; vehicles with a medium trim level were equipped with ADAS in model year 2018 but not before that calendar year; and vehicles with a high trim level were equipped with ADAS in 2015 but not before that calendar year. The three different trim levels of Acura MDX's on the road during our sample period enable us to define our treated vehicles as Acura MDX's of high (and/or medium) trim levels that include ADAS. Our untreated or control vehicles are Acura MDX's that did not include ADAS.[11]

Specification

Following previous safety research (e.g., Maheshri and Winston (2024)), we model accidents A_{yijt} in a Poisson regression framework as[12]:

$$A_{yijt} = exp\left(\beta\, S_{yijt} + \lambda_{ij} + \lambda_{jt} + \lambda_{it} + \epsilon_{yijt}\right) \ , \qquad (1)$$

[9] Note that our data structure is not ideally suited to a difference-in-differences design because untreated vehicles remain untreated even after future model-year vehicles of the same trim level are treated. For example, when the high trim is treated in a given year, all vehicles of the same trim are not treated, only those vehicles from that year and future model years are treated. Generally, treatment in a DID design would be consistent within the ijt dimension, but the treatment in our data structure is not consistent in that dimension.

[10] Note the model year for vehicles manufactured up to June 2018 will be 2018, but the model year for any of the vehicles in our sample manufactured from July through December in each year (for example, 2015) can be advertised as the next model year. Hence even though our sample period corresponds to 2010-2018, it includes some model year 2019 vehicles.

[11] Because our estimates could be affected by unrelated variation in the safety of different trim levels of never-treated vehicles, we report estimation results with and without never-treated vehicles.

[12] This framework is appropriate because our dependent variable takes on small, discrete, non-negative values (Cameron and Trivedi (1998)).

where S_{yijt} is a dummy variable equal to one if ADAS was available either as standard equipment or purchased through an optional package on vehicle yij in year t and zero otherwise; λ_{ij} are make-model-trim fixed effects; λ_{jt} are trim-calendar year fixed effects; λ_{it} are make-model-calendar year fixed effects; and ϵ_{yijt} is an error term.[13]

The parameter β can be interpreted as the causal effect of the availability of ADAS on selected vehicles on the total number of accidents if $cov(S_{yijt}, \epsilon_{yijt} | \lambda_{ij}, \lambda_{jt}, \lambda_{it}) = 0$. That is, motorists who purchase higher trim vehicles during the first model year that ADAS is made available in those vehicles are not systematically different from the motorists who purchase higher trim vehicles of other model years. Early experiences with autonomous vehicles in controlled testing environments (Blanco, et. al. (2016), Mosquet, Andersen, and Arora (2016)) suggest that ADAS should reduce accidents.

3. Data

We constructed a dataset to analyze the effects of ADAS on all automobile accidents that occurred in Texas from 2010 to 2018 by combining data from two sources: the universe of police accident reports and leading vehicle data aggregators that describe the available safety features in all new vehicle trims introduced during the sample period. To the best of our knowledge this is the first data set at the vehicle trim level that has been used to analyze the efficacy of safety features. We briefly describe the data sources and the procedure we used to merge them here; a more detailed description is available in the online data appendix.

The Texas Department of Public Safety maintains a database of all auto accidents that are reported to police including single and multi-vehicle crashes involving motorists and pedestrians. We obtained access to all police reports filed between 2010-2018. The police reports contain the Vehicle Identification Number (VIN) of every vehicle that was involved in every accident along with information on the severity of the accident.

[13] Data on specific vehicles that were purchased with ADAS as an optional package are not available. However, when a vehicle, defined by make and model, offers ADAS features as an option instead of standard, most consumers who select that vehicle likely purchase the optional ADAS features as well since the entire trim package of a vehicle that offers optional ADAS is usually more expensive than the entire trim package of the same or similar vehicle that does not offer ADAS. Thus, consumers who do not want the optional ADAS features would, in all likelihood, decide to reduce their costs by choosing a similar vehicle without an ADAS option.

We decoded the Vehicle Identification Number (VIN) of every vehicle involved in an accident during our sample period using a commercially available VIN decoder. The decoder identified each vehicle down to the trim level, which is critical to our analysis because different versions of the same vehicle make and model have different features.[14] We then collected detailed information from data aggregators such as TrueCar and MotorTrend by scraping their websites and employing string manipulation techniques to verify the availability of ADAS for every vehicle in our sample. Finally, we used fuzzy string match techniques to link the data on accidents and ADAS safety features. In all, we constructed a panel of annual and fatal accidents from 2010 to 2018 for 5,850 distinct vehicles defined as a unique model year-make-model-trim combination.

4. Results

In table 2, we present estimates of the effects of the availability of ADAS on all accidents and fatal accidents as incidence risk ratios (IRRs) to facilitate interpretation.[15] An IRR greater than 1 corresponds to a positive effect on vehicle accidents, and an IRR less than 1 corresponds to a negative effect on vehicle accidents.

We find that the availability of ADAS reduces the number of accidents of a given vehicle and trim type by nearly 60%, and the effect is statistically significant. We obtain similar results for specifications with and without never-treated vehicles, which suggests that our findings are not an artifact of unrelated variation in safety between different trim levels of never-treated vehicles. Finally, the availability of ADAS reduces fatal accidents by nearly two thirds, which is a large effect.

Heterogeneity

In Figure 2, we present heterogeneous effects of ADAS on all accidents by vehicle weight, price (MSRP), type, and make. ADAS generally has similar effects on those classifications of vehicles, except for trucks and expensive vehicles with an MSRP greater than $65,000. ADAS is notably more effective in Korean and Japanese brands compared with American and European brands. We speculate that this finding reflects the fact that different automakers have

[14] Using the example in table 1, the Acura MDX high level trim is called the Type S Advance, which made ADAS available in model year 2015. The low level is the base trim, which has not made ADAS available.

[15] We did not estimate accident and fatality rates per mile of travel because vehicle miles traveled are likely to be influenced by the adoption of ADAS, which would then confound the distinct effects of ADAS on accidents and fatalities.

independently developed and integrated ADAS technology in their vehicles and have achieved different levels of safety performance.[16] Importantly, these findings are inconsistent with the self-selection of safer drivers into safer vehicles driving our results. If this were the case, we would expect to find systematically larger effects of ADAS in larger and more expensive vehicles instead of only in the small share of vehicles during our sample period with an MSRP exceeding $65,000.

Potential Sources of Bias

There are three potential sources of bias in our analysis. As we have stressed, the main source stems from the fact that a driver's *self-selection* into treatment may be non-random because their ADAS adoption decision may be correlated to their intrinsic safety on the road. If, for example, safer drivers were more likely to adopt ADAS than riskier drivers, then our estimates of β would be biased upwards. Conversely, our estimates of β would be biased downward if riskier drivers were more likely to adopt ADAS than safer drivers. The latter behavior would be more relevant in the case of a safety feature such as ADAS that can compensate for a driver's riskiness, instead of a safety feature such as airbags that does not compensate for a driver's riskiness but engages *after* a vehicle is involved in a collision.

We clarify how our identification strategy specifically mitigates this source of bias by respecifying our empirical model of accidents as:

$$A_{yijt} = exp\left(\sum_{\tau=\pm1\ldots\pm4} \beta^{\tau} \times 1\left(\tilde{y}_{ij} - y = \tau - 1\right) + \text{controls} + \lambda_{ij} + \lambda_{jt} + \lambda_{it} + \epsilon_{yijt}\right), \quad (2)$$

where $\tilde{y}_{ij}$ denotes the model year in which vehicle ij is first equipped with ADAS and $1(\cdot)$ represents the indicator function. The coefficients β^{τ} correspond to the effect of ADAS in τ relative vehicles getting ADAS. Finally, we include $1\left(\tilde{y}_{ij} - y < -4\right)$ and $1\left(\tilde{y}_{ij} - y > 4\right)$ as controls to normalize all effects relative to the model year just prior to treatment (e.g., 2014 for the high trim Acura MDX available in 2015). We estimate this model on the subsample of vehicles that received ADAS at some point in our sample as before; we would expect the IRR associated with β^{τ} for $\tau < 0$ to be equal to 1 if our estimates did not suffer from self-selection, i.e., there should be no treatment effect in model years prior to treatment.

[16] We are unable to estimate precise heterogeneous effects on ADAS on fatalities for many of the vehicle type/weight/MSRP/automaker categories, in all likelihood because of the infrequency of fatal accidents.

We present regression results in an "event-study style" plot in figure 2.[17] There are two potential explanations for the pattern that we find: (1) ADAS reduces the prevalence of accidents by an amount that is quantitatively consistent with the estimates in column 2 of table 1, or (2) drivers systematically switch to ADAS equipped trims only when they are made available, and they avoid higher level trims in earlier model years. We maintain that the second explanation is dubious because higher trim vehicles differ from their lower trim counterparts in a variety of important dimensions, not just in the availability of ADAS. Those dimensions include non-ADAS vehicle safety features, such as side curtain and seat mounted side impact airbags, as well as non-safety features, such as a premium leather collection. (We report a complete list of the non-ADAS and non-safety related trim features that were available for vehicles with high trim, but not for vehicles with low trim in the online data appendix.) The fact that trim choice is influenced by more than just the availability of ADAS lends credence to our first explanation.

Figure 3 provides additional circumstantial evidence against selection bias by showing that over time the safest drivers did not necessarily switch to vehicles that had ADAS. Instead, the crash rate of all drivers who eventually switched to a vehicle with ADAS was quite similar over time. The crash rate of drivers who never switched to a vehicle with ADAS was generally greater over time than the crash rate of drivers who switched to a vehicle with ADAS, but those drivers account for a modest share of drivers in our sample.[18] Finally, our findings of minimal heterogeneity in the effects of ADAS on accidents by vehicle type are also inconsistent with assortative selection of safer drivers into safer vehicles driving our results.

A second potential source of bias stems from the fact that the adoption of ADAS might affect a driver's *behavior* on the road. For example, a driver with ADAS might take more risks while driving, like texting and paying less attention to traffic conditions, which would offset the safety benefits of ADAS. Alternatively, because ADAS features include auditory and visual warnings to drivers when other vehicles are approaching, ADAS may induce drivers to make a

[17] We refer to the plot as "event-study style" because it does not exactly correspond to an event study for the same reason that a difference-in-differences estimation approach is not appropriate in our context. As noted, our data is organized along two time dimensions, calendar year and model year. Accordingly, a given make-model-trim vehicle will contribute different numbers of observations to the estimation of each effect shown in Figure 2. For instance, the 2014 Acura MDX contributes 5 observations to the estimation of the point with -1 model years because ADAS was available in the higher trim calendar years 2014-2018, but the 2016 Acura MDX contributes only 3 observations to the estimation of the point with +1 model years because ADAS was available in higher trim calendar years 2016-2018.

[18] In the future, it would be useful to estimate the effect of the staggered adoption of ADAS-equipped vehicles on the nation's automobile fatalities and insurance costs. The latter will reflect a tradeoff between the lower claims caused by ADAS's reduction in accidents and the higher claims caused by ADAS's increase in the cost of a car and repairs.

safety augmenting response. In any case, given that our interest is to estimate the effect of ADAS on automobile safety in actual driving conditions instead of the controlled environments typically studied by engineers, it is appropriate for any change in drivers' behavior in response to the adoption of ADAS to be incorporated in our estimates. Our estimates of the heterogeneous effects of ADAS by vehicle characteristics did not suggest any systematic changes in certain motorists' behavior in response to adopting ADAS.

The third potential source of bias, which to the best of our knowledge has not received attention in the safety literature, stems from *contamination* of the control group. Specifically, given that treated and untreated vehicles are likely to be periodically involved in accidents with each other, any safety improvement in the treated vehicles, for example, due to the adoption ADAS, also may improve the safety of untreated vehicles. Thus, an estimate of the effectiveness of ADAS safety features—or any other safety features—would be biased downward because it does not account for the positive spillover of safety accruing to vehicles that are not equipped with those safety features.

Although all observational analyses of accident data that are generated when treated and untreated vehicles share the same roadways will be susceptible to contamination bias, the bias is mitigated in our analysis for two reasons. First, the vast majority of vehicles (new and used) on the road during our sample period did not have ADAS available as an option at the time of manufacture.[19] Second, nearly 50% of the fatal accidents in our sample were single-vehicle accidents.

5. Discussion

Our analysis can guide policymakers considering mandates for autonomous safety features in new automobiles. There are three primary justifications for such a mandate: (1) There is a large potential external benefit to people besides the driver from those features, which causes privately optimal and socially optimal vehicle choices to diverge. (2) Individuals are unaware of the benefits (or costs) associated with the choice to include autonomous safety features in their vehicles; thus, they make themselves and possibly others worse off by undervaluing those features. (3) Access to

[19] Slightly more than 25% of all the vehicles in our sample have ADAS.

autonomous safety features is inequitable because of, say, price discrimination through bundling or other supply-side distortions.

Our analysis suggests that although ADAS is extremely effective, it is unlikely that any of the preceding conditions to justify a mandate are met. Of course, it is understandable that policymakers want all motorists and possibly other people to benefit from the most effective automobile safety features to date[20], as supported by ours' and others' findings.[21] However, we argue that the available evidence below does not support policymakers mandating those safety features.

Estimating the external benefits of an automobile safety feature is a challenging empirical problem because it is difficult to determine whether a safety feature could have prevented other people besides the driver from being injured or killed in an accident. Thus, to the best of our knowledge, estimates of such benefits are not available in the literature.[22] It is beyond the scope of this analysis to attempt to estimate the external benefits of ADAS, but contextual evidence suggests that an estimate of those benefits would not significantly increase the large benefits we have already estimated for ADAS.

For example, an implication of the fact that ADAS is a much stronger substitute for driver attention than other automobile safety features is that a large share of the overall benefits of ADAS is likely to be internalized by drivers. We also stress that our estimate of the effect of ADAS on fatal accidents includes any potential external benefits of fatality reduction that are associated with those safety features because the dependent variable in our analysis is specified as the probability of a fatal accident, where the fatality could occur in any vehicle involved or from a pedestrian—that is, our estimates capture the effect of ADAS on fatalities involving non-ADAS equipped vehicles and pedestrians. Generally, the cost of fatal accidents greatly exceeds the cost of nonfatal accidents. The scope of external benefits of ADAS is further limited because roughly one-third of all accidents and one-half of fatal accidents are single vehicle crashes, and 5% of multivehicle accidents involve only vehicles that are equipped with an ADAS.

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[20] We have pointed out that seat belts and air bags cannot prevent a driver from getting into an accident, and we reported evidence in footnote 6 that those safety devices reduce the probability of a fatal accident less than ADAS reduces that probability.

[21] Reviews of studies of autonomous safety features by the Foundation for Traffic Safety (FTS) in its Research Brief provide evidence on the effectiveness of those features.

[22] For example, NHTSA (2023b) assesses the societal impact of motor vehicle crashes but does not attempt to include the external benefits of automobile safety features.

A rough numerical exercise using our results reveals that consumers are reasonably well-informed about the effectiveness of ADAS. To see this, note that the probability of a person dying in a car crash during their lifetime is roughly 1.0%.[23] If a person owns roughly six cars during their lifetime[24], the probability of dying in one of those cars is 0.166%. Based on our estimates in table 2, the probability of dying in those cars is reduced 66%, or becomes 0.055%, if they are equipped with ADAS. Finally, consistent with US Department of Transportation Guidelines during our sample period, assume the value of life for a person is $6 million[25], which implies that a person is willing to pay $60,000 to reduce the probability of dying in a fatal car accident by 1%. Thus, on average, motorists should be willing to pay $6640 (i.e., $60,000 · (0.166-0.055)) for ADAS to be installed in their vehicle, which exceeds the $4248 average cost of installing basic ADAS features but is less than the $7,000 average cost of installing advanced ADAS features.[26]

Of course, under alternative assumptions, one could calculate a different willingness to pay (WTP) that exceeds the average cost of advanced ADAS features or is less than the average cost of installing basic ADAS features. Nevertheless, even those calculations would not suggest that consumers are wildly uninformed about the effectiveness of ADAS. Instead, they underscore the fact that focusing on average WTP masks motorists' heterogeneity. Indeed, even the modest heterogeneous effects of ADAS on accidents that we found suggest people are likely to vary to some extent in their WTP for ADAS. It also appears, in general, that consumers are able to discern the considerable benefits of ADAS to a reasonable degree and that automakers have steadily increased the availability of those safety features on more vehicles because they are able to price them in a manner consistent with their safety benefits, installation costs, and consumers' WTP.

The remaining justification for mandating the installation of ADAS for all cars is that access to them is limited by supply-side constraints. However, as described in the introduction, the availability of ADAS has notably increased over time. In addition, figure 1 in the online appendix shows that the supports of the distributions of manufacturers' suggested retail prices for all ADAS equipped and non-ADAS equipped vehicles in 2019 are nearly identical. Thus, ADAS is generally available at all price points for new vehicles, and consumers can choose from either ADAS equipped or non-ADAS equipped vehicles at all price points.

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[23] https://www.curcio-law.com/blog/odds-of-dying-in-a-car-crash/.
[24] https://www.usedvwaudi.com/blog/2017/11/16/how-many-cars-will-you-go-through-in-one-lifetime.
[25] https://www.theglobalist.com/the-cost-of-a-human-life-statistically-speaking/.
[26] https://www.sbdautomotive.com/post/collision-avoidance-saves-lives-vpp

6. Conclusion

Historically, the introduction of a new vehicle safety feature by automakers has been met with controversy over its technological effectiveness at reducing the probability of fatal and severe injuries, accounting for drivers' behavior, and whether a government intervention could enhance social welfare by making it required in all new vehicles.

We have addressed the first issue empirically in the context of automakers' introduction of ADAS safety features and presented causal evidence that those features have improved automobile safety by significantly reducing the probability of motorists being involved in fatal and nonfatal accidents. Our finding is important because it provides evidence of the benefits of vehicle automation, which could eventually generate social welfare gains in the trillions of dollars from reductions in accidents, congestion, and emissions externalities and from violent altercations from police stops when it evolves in future decades to fully automated operations (Winston and Karpilow (2020), Winston, Yan, and Associates (2024)).

Turning to the second issue, automobile safety policies have not historically been guided by a careful assessment of the costs and benefits of the policy to all members of society. For example, Mannering and Winston (1995) found that, on average, motorists were willing to pay the average cost of installing air bags on their vehicles and that automakers were steadily installing airbags on those vehicles for which motorists were willing to pay the average cost of air bag installation. Nonetheless, in 1998, federal law required that all cars and light trucks sold in the United States have air bags on both sides of the front seat without carefully assessing whether such a requirement was justified on cost-benefit grounds accounting for the welfare loss to motorists who valued air bags less than the cost passed through in higher vehicle prices.

The speed with which ADAS has been introduced is notable and our findings strongly indicate that motorists have benefited from their effectiveness. Notwithstanding those considerable benefits, our analysis casts doubt that government's intervention in the market's adoption of ADAS by mandating them for all vehicles would enhance social welfare. We conclude that such a policy should not be implemented without a better understanding of the external benefits of those safety features and the forces influencing their voluntary adoption.

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Table 1. Example of Data Structure for the Acura MDX

Treated Vehicles			2015 H	2015-2016 H	2015-2017 H	2018 M 2015-2018 H	2018-2019 M 2015-2019 H
Untreated Vehicles	2000-2013 L 2000-2013 M 2000-2013 H	2000-2014 L 2000-2014 M 2000-2014 H	2000-2015 L 2000-2015 M 2000-2014 H	2000-2016 L 2000-2016 M 2000-2014 H	2000-2017 L 2000-2017 M 2000-2014 H	2000-2018 L 2000-2017 M 2000-2014 H	2000-2019 L 2000-2017 M 2000-2014 H
Calendar Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**

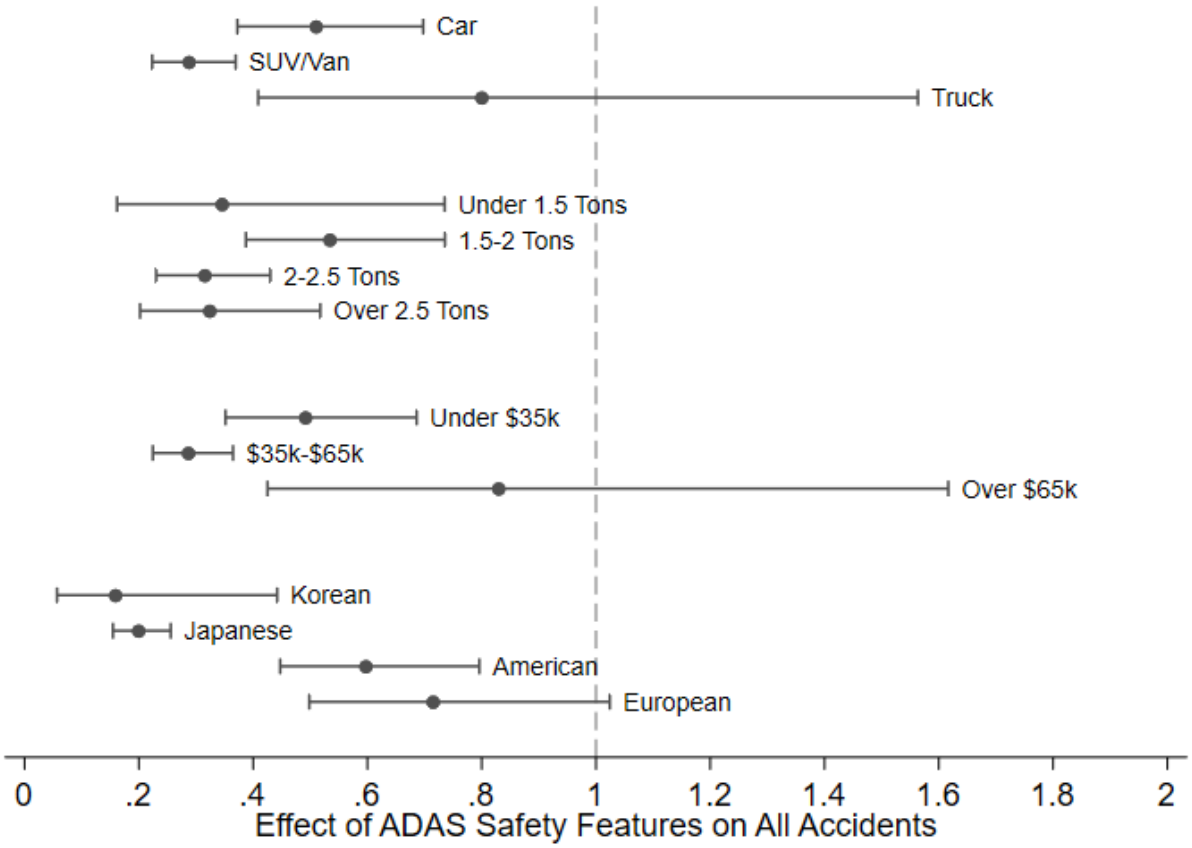
Notes: There are three trim levels for the MDX: L, M and H. Trim level H received ADAS safety features in model year 2015. Trim level M received ADAS safety features in 2018.

Table 2. Effect of ADAS on Accidents and Fatalities

Dependent Variable	Total Accidents		Total Fatalities	
	(1)	(2)	(3)	(4)
ADAS Safety Features Dummy	0.43***	0.42***	0.34**	0.34***
	(0.05)	(0.05)	(0.13)	(0.13)
Make-Model-Trim (ij) FEs?	Y	Y	Y	Y
Trim-Calendar Year (jt) FEs?	Y	Y	Y	Y
Make-Model-Calendar Year (it) FEs?	Y	Y	Y	Y
Include Never Treated Vehicles?	Y	N	Y	N
Pseudo R-squared	0.60	0.60	0.09	0.07
Number of observations	33,491	9,530	4,773	809
Mean of Dependent Variable	3.09	2.10	0.01	0.01

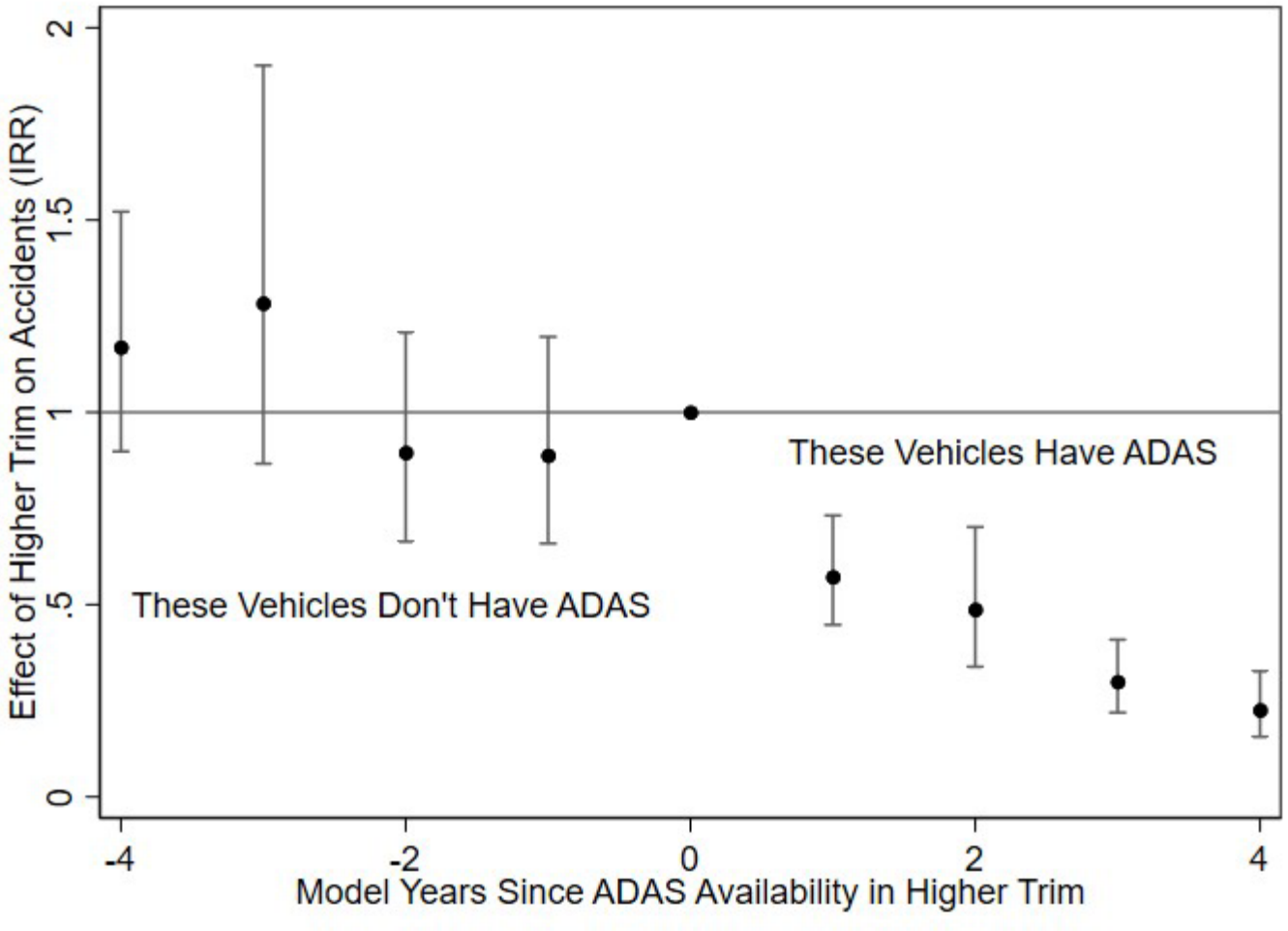
Notes: Incidence Risk Ratios are presented from Poisson maximum likelihood regressions with heteroskedasticity robust standard errors clustered by model year-make-model presented in parentheses. *** 99% significance, ** 95% significance.

Figure 1. Heterogeneous Effects of ADAS Safety Features on the Accident Rate (IRR)



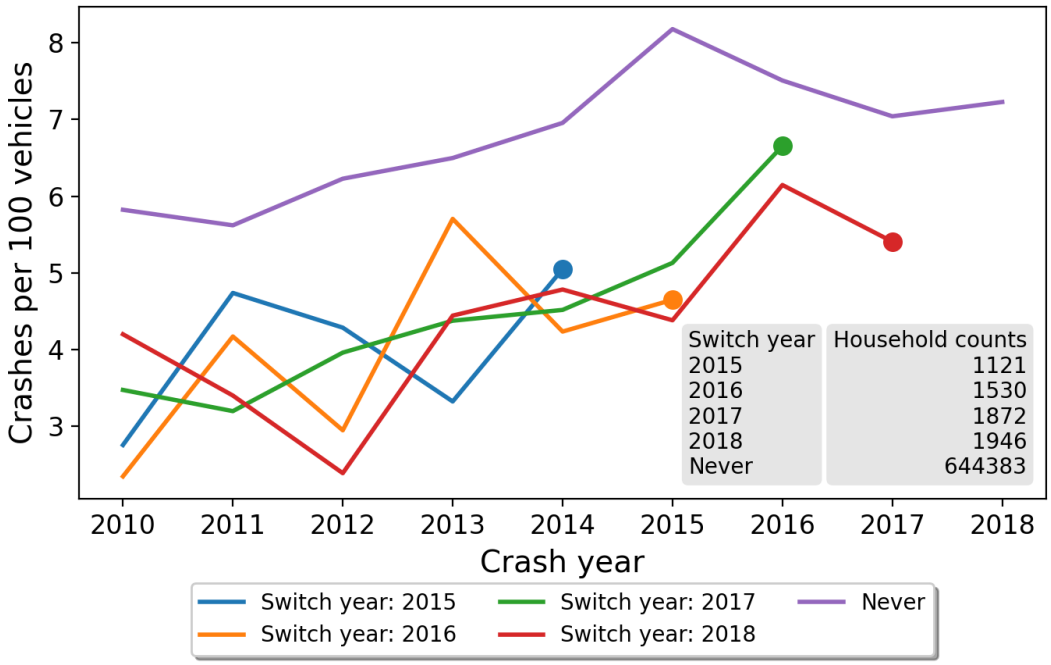
Notes: Incidence Risk Ratios are presented from Poisson maximum likelihood regressions with heteroskedasticity robust standard errors clustered by model year-make-model.

Figure 2. Event Study Style Plot of Regression Results



Note: Incidence Risk Ratios are presented from Poisson maximum likelihood regressions with heteroskedasticity robust standard errors clustered by model year-make-model.

Figure 3. Crash Rate by Year and Household ADAS Switch Year



Online Appendix

Description and Construction of the Data Set

As noted in the text, we constructed a data set to analyze the effects of ADAS on all automobile accidents that occurred in Texas from 2010 to 2018 by combining information from two main datasets: 1) police accident reports from the Texas Department of Public Safety, and 2) trim level vehicle attributes from leading vehicle data aggregators. The Texas police accident reports record all single and multi-vehicle auto accidents in the state of Texas involving motorists and pedestrians for the years 2010-2018, as well as the severity of the accidents, which range from vehicle damage only to a fatality. Importantly, the accident reports include the Vehicle Identification Number (VIN) of all vehicles that were involved in each accident.

We obtained the vehicle attributes by web scraping multiple leading vehicle data aggregators, including TrueCar, Inc., MotorTrend, and Kelly Blue Book. The attributes data are indexed at the detailed model year-make-model-trim level, which enables us to identify the specific safety features of a vehicle that vary at both the model year and the trim level.

The remaining task was to link the VINs from the accident reports with the vehicle attributes to identify whether ADAS safety technology was available on each vehicle in our sample. Our procedure was as follows. First, for a given VIN in the police accident reports, we used a commercially available VIN decoder to obtain its model year, make, model, and trim (henceforth nameplate).[27]

Second, although the vehicle attributes data contains detailed information on all the features available to a given nameplate, which includes the safety related features of interest here, ADAS safety features are marketed under different names by different automakers with no standardization. For example, Adaptive Cruise Control is called "Intelligent Cruise Control" by Nissan and "Radar Cruise Control with Stop and Go" by Mazda, even though both are the same underlying technology. We therefore used various string manipulation techniques coupled with manual inspection to correctly identify each ADAS safety feature for a given nameplate.

Finally, although the decoder provides a nameplate string for a given VIN in the police accident report, this string rarely matches the string in the vehicle attributes data, which prohibits a direct merge. For example, the VIN "5J8YD4H05LL024902" can be decoded as "2020, Acura, MDX, A-SPEC." Its counterpart in the attributes data is "2020 Acura MDX Technology and A-Spec Package," even though they are the same nameplate. We therefore used fuzzy string match techniques to link the two nameplates, which enabled us to combine the data on accidents and accident severity with the data that indicated whether ADAS was available for each vehicle in our sample.[28]

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[27] We should point out that not all VIN decoders can decode a VIN to the trim level; most can decode only to the model year-make-model level. For example, NHTSA provides a free VIN decoder that does not decode to the trim level. https://www.nhtsa.gov/vin-decoder

[28] The VIN decoder also provides attribute information, such as MSRP, body type, fuel type. We cross-checked attributes from both the decoder and our web scraped data and found that they generally agreed for the nameplates.

Summary of Non-ADAS and Non-Safety Related Trim Features

The non-ADAS and non-safety related trim features that were available for vehicles with high trim, but not for vehicles with low trim are as follows:

Non-ADAS Vehicle Safety Features
Rear and side view with simulated aerial camera
360 Degree Surround Camera
Panoramic View Monitor
Digital Backup Sensors
Active Blind Spot w/Front Park Sensor
Adaptive Light Control
Auto-Dimming Rearview Mirror
Bi-Xenon Cornering Headlights
Black Out LED Daytime Running Lights
Enhanced Active Park Assist w/Forward Sensing System
Inflatable Rear-Seatbelts
Night View Assist PLUS w/Pedestrian Detection
Side Curtain and Seat Mounted Side Impact Airbags
Trailer Tow Camera System
Heated Sideview Mirrors

Non-Safety Related Trim Features
Rear power outlet(s)
Cargo area power outlet(s)
Anti-Theft Alarm System w/Immobilizer
Intrusion Sensor
Heated Windshield Washer Reservoir (SPC)
Keyless Entry w/Hands-Free Tailgate Opening
Headlamp Washers
Premium Leather Collection
Heated Rear Seats

Appendix Figure 1. Empirical Distributions of Prices for Vehicles With and Without ADAS Safety Features