AI AT THE WHEEL:
THE EFFECTIVENESS OF ADVANCED DRIVER ASSISTANCE SYSTEMS

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Abstract. Automakers' recent introduction of advanced driver-assistance system technologies based on artificial intelligence raise longstanding questions of whether they improve safety and whether their adoption should be mandated 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 these safety technologies reduce all accidents by over 50% and fatal accidents by nearly two thirds. Notwithstanding those considerable benefits, we discourage mandating those safety technologies for all new vehicles.

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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 automatic windshield wipers, shatterproof glass, headlights, 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 be installed in all new vehicles, such as collapsible steering columns, seat belts, and dual front seat airbags, while states have passed mandatory seat belt use laws.[1]

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 be promote safety more efficiently and because drivers may adjust their behavior when a new safety technology is 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 the safety benefits of seat belts 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. Lave and Weber (1970), Peltzman (1975), and Wilde (1976) 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, which were mandated in 1998.

As shown in figure 1, beginning in the late 2000s, automakers have steadily installed an advanced driver-assistance system (ADAS) based on artificial intelligence in vehicles with higher

[1] Government highway expenditures also have been used to improve the safety of the road system.

levels of trim.[2] ADAS includes a suite of safety features that assist in both the forward dimension (e.g., automatic emergency braking and adaptive cruise control), and the lateral dimension (e.g., lane departure warning or blind spot collision prevention).[3] ADAS is standard for some vehicle makes and models, optional for other makes and models, and unavailable for the remaining makes and models. 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 and were used by most motorists, ADAS has thus far been voluntarily installed in vehicles by automakers and selected by motorists through their choice of vehicle.

The recent adoption of ADAS motivates our interest here in assessing whether it is effective 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.[4] It is therefore also of interest to shed light on whether NHTSA's proposed requirement is justified.

We conduct a causal assessment of the effectiveness of ADAS in reducing the probabilities of motorists being involved in all types of accidents, which improves upon previous work by exploiting a novel source of plausibly exogenous variation in the availability of ADAS that allows us to address several endogeneity issues that are inherent to analysis of the technological performance of vehicle safety features. We do so with the aid of a panel dataset of the accident

[2] A vehicle's trim includes powertrain options, aesthetic features, and comfort amenities as well as safety technology.
[3] With the exception of adaptive cruise control, ADAS features, in general, engage autonomously because they are often turned on by default. Features like lane departure warning and emergency braking cannot be turned off easily.
[4] 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. Additionally, vehicles traveling as fast as 37mph would need to come to a complete stop to avoid hitting pedestrians and the braking systems also would be required to detect pedestrians and cyclists at night.

histories of all registered vehicles in Texas from 2000 to 2018 and by constructing a novel panel dataset of the availability of ADAS-related safety features in all vehicles that were sold at all trim levels over this period. We combine those two data sources with a matching procedure that decodes the precise trim level of a vehicle from its Vehicle Identification Number (VIN). Importantly, this allows us to classify vehicles involved in accidents at the model year-make-model-trim level, which to the best of our knowledge, we are the first to do in an analysis of automobile safety. This innovation is central to our identification strategy: by combining the panel of vehicle accident histories with detailed information about the specific safety features of those vehicles from auto manufacturers, we can leverage the fact that ADAS became available at different times for different trim levels (notably within vehicles of the same make and model).[5]

We find that even after accounting for drivers' behavioral responses, ADAS is highly effective at improving automobile safety because it reduces accidents by over 50% and fatal accidents by roughly two thirds. Because ADAS can prevent a driver from getting into an accident, it is more effective at enhancing safety than other safety features, such as seat belts and air bags. ADAS also is notably more effective than seatbelts and airbags in reducing the probability of a motorist being involved in a fatal accident.[6]

Given the 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. We caution against such a policy without clear evidence of sizeable external benefits to other motorists relative to the private cost to consumers whose perceived benefits from ADAS are exceeded by the higher cost they would have to pay for ADAS-equipped vehicles, or evidence that the private costs have been reduced by a substantial decrease in the price of ADAS that is passed on to consumers by automakers, or evidence of improvements in autonomous automotive technology that dramatically increases the effectiveness and consumers' perceived benefits of ADAS.

Our caution is informed by our findings that motorists are informed about the benefits of ADAS because, on average, they appear to be willing to pay for their significant installation costs;

[5] 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.
[6] See https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811882.pdf and https://injuryfacts.nsc.org/motor-vehicle/occupant-protection/seat-belts

access to ADAS is equitable and does not appear to be affected by supply-side distortions; and the external benefits from mandating ADAS in all cars are unlikely to significantly increase their overall benefits, while such a mandate would create a sizable welfare cost to motorists who are forced to bear an installation cost of ADAS that exceeds their private valuation of those safety features' benefits.

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 in a given model year, 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 (for example, luxury editions) may have ADAS and others (for example, standard editions) may not. We therefore expand the definition of vehicle type as a combination of make, model and trim, where trim levels are indexed separately by j as defined in the data section.

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 available in later model years. At the same time, 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. Note the model year for vehicles manufactured up to June 2022 will be 2022, 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 (for example, 2016). Thus, our treatment, the availability of ADAS, denoted 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), 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-calendar year level and denote by A_{yijt} the total number of accidents of a given type 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 across trim levels, model years and calendar years to identify the causal effect of ADAS on accidents. Operationally, we use the calendar year as our main temporal dimension, and we identify the treatment effect using calendar year and make-model-model year fixed effects.[7]

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. This vehicle 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.[8]

<u>Specification</u>

We specify our empirical model of accidents A_{yijt} as:

$$A_{yijt} = \beta\, S_{yijt} + \lambda_{ij} + \lambda_{jt} + \lambda_{it} + \epsilon_{yijt} \quad (1),$$

where S_{yijt} is a dummy variable equal to one if ADAS was available on vehicles 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. Because our assessment

[7] 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. Using the example shown below in table 1, when the H trim level is treated in 2015, all H vehicles on the road are not treated, only those from model year 2015 and future model years are treated. Generally, treatment in a DID design would be consistent within the ijt dimension, while the treatment in our data structure is not consistent in that dimension.

[8] 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.

is based on vehicles, ADAS could be available on any vehicle as either standard equipment or purchased through an optional package.[9]

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 $cov\left(S_{yijt}, \epsilon_{yijt} | \lambda_{ij}, \lambda_{jt}, \lambda_{it}\right) = 0$. The conditions that could violate this interpretation are an unobserved influence on accidents that is correlated to ADAS adoption and varies across vehicles of the same make-model-trim, the same trim level over time, and the same makes and models over time. Those conditions rule out, for instance, any unobserved driver characteristic that is correlated with the decision to upgrade trim levels, and with any time trends in accident rates for specific vehicle make-models.

Drawing on the early experience with autonomous vehicles in controlled testing environments, the Insurance Institute for Highway Safety[10] and the Virginia Tech Transportation Institute (Blanco and others (2016)) found that autonomous vehicles were involved in fewer and less severe crashes than human-driven vehicles and that features such as lane departure and blind spot warnings reduced accident risk. Mosquet, Andersen, and Arora (2016) reach a similar conclusion. Those findings and the fact that our construction of the ADAS dummy variable is based on a suite of safety features installed in a vehicle suggest that β should have a negative sign.

Sources of Bias

There are three potential sources of bias in our specification. The main potential source of bias 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, which could compensate for a driver's

[9] 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, is it likely that most consumers who choose that vehicle opt for the optional ADAS features as well. The reason is that the entire trim package of a vehicle that offers optional ADAS tends to be more expensive than the entire trim package of the same or similar vehicle that does not offer this option. 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 such an option altogether.

[10] Insurance Institute for Highway Safety (IIHS) and Highway Loss Data Institute (HLDI), "Lane Departure Warning, Blind Spot Detection Help Drivers Avoid Trouble," IIHS/HLDI, August 13, 2017, http://www.iihs.org/iihs/news/desktopnews/stay-within-the-lines-lane-departure-warning-blind-spot-detection-help-drivers-avoid-trouble.

riskiness, instead of a safety feature, such as airbags, which does not compensate for a driver's riskiness but engages *after* a vehicle is involved in a collision.

We adopt an identification strategy specifically to mitigate this source of bias. The inclusion of make-model-trim fixed effects ensures that we effectively compare the accident outcomes of drivers with higher trim and lower trim vehicles before and after higher trim vehicles are equipped with ADAS. Thus, all individual features or behaviors that are correlated with driver safety and with the desire to purchase vehicles at higher levels of trim will not confound our estimates. Selection bias may arise due to differences in drivers' intrinsic safety that are correlated with their decision to purchase a specific trim level after ADAS is introduced within that make and model because the higher trim level vehicle was equipped with ADAS in that model year. As noted, however, a vehicle's trim includes notable non-safety features and amenities as well as safety technology; thus, we posit that any remaining selection bias should be small.

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 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 estimate of β^1. Although we assess the technological effectiveness of ADAS accounting for drivers' behavioral responses, we explore the nature of those responses based on estimates of the heterogeneous effects of ADAS by vehicle characteristics.

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, many of the vehicles (new and used) on the road during our sample period did not have ADAS available as an option at the time of manufacture.[11] Second, nearly 50% of the fatal accidents in our sample were single-vehicle 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, which describe the safety features that were available 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 such police reports filed between 2010-2018. The police reports contain the Vehicle Identification Number (VIN) of all vehicles that were involved in every accident along with information on the severity of the accident.

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 important to our analysis because different versions of the same vehicle make and model have different features.[12] We then obtained detailed information from vehicle data aggregators, such as TrueCar and MotorTrend, on the available autonomous safety features of every vehicle in our sample by scraping their websites, and employed string manipulation techniques to verify the accuracy of the availability of ADAS for every vehicle. Finally, we used fuzzy string match techniques to link the data on accidents and ADAS safety features. Details of this procedure are provided in the Data Appendix.

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

[12] 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.

In all, we constructed the annual accident and fatal accident prevalence of 5,850 distinct vehicles defined as a unique model year-make-model-trim combination over the nine year period from 2010-2018.

4. Results

We present the estimation results of the effect of the availability of ADAS on all accidents and fatal accidents in table 2.[13] Following previous safety research (e.g., Maheshri and Winston (2024)), we report maximum likelihood Poisson regression estimates because our dependent variable, accidents at the make-model-trim-calendar year level, takes on (small) nonnegative integer values. By exponentiating the parameters in equation (1), we obtain Incidence Risk Ratios (IRRs), which we present for the Poisson regression model to facilitate interpretation of our findings. An IRR greater than 1 corresponds to a positive relationship to vehicle accidents, and an IRR less than 1 corresponds to a negative relationship to vehicle accidents. For instance, an IRR of 1.10 indicates that a unit increase in the variable corresponds to a 10% increase in accidents, and an IRR of 0.9 indicates that a unit increase in the variable corresponds to a 10% decrease in 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.[14]

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, with the exception of trucks and expensive vehicles with an MSRP greater than $65,000.

[13] 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.

[14] For sensitivity purposes, we also specified the main temporal dimension in our analysis to be the model year as opposed to calendar year. Thus, we could use a difference-in-differences (DID) econometric design because our treatment variable is consistent within vehicle make, model, trim, and calendar year. We then estimated an event study of the effect of ADAS on accidents and we obtained similar findings on the effect of ADAS as in our preferred approach.

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 independently developed and integrated ADAS technology in their vehicles and have achieved different levels of safety performance.[15]

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.[16]

5. Discussion

Our analysis can be used to 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 decisions 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 worse off by undervaluing those features. (3) Access to 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 mandating it are met. Of course, it is understandable that policymakers want all motorists and possibly other people to benefit from the most effective

[15] 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.

[16] Two "reality checks" of the efficacy of ADAS, which would be useful to perform in the future, are the effect of ADAS on the nation's automobile fatalities and the insurance discounts provided for ADAS-equipped vehicles. The former check is premature because of the short time that ADAS-equipped vehicles have been part of the total US vehicle fleet and their modest share of the fleet. The latter check awaits an accurate determination by insurance companies of the tradeoff of 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.

automobile safety features to date[17], as supported by ours' and others' findings.[18] 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.[19] It is beyond the scope of this analysis to attempt to develop a methodology and to collect appropriate data to estimate the external of benefits of ADAA, but contextual evidence suggests that an estimate of those benefits would not significantly increase the large benefits we have already estimated for ADAS.

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 the 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.

It also is likely that consumers are well-informed about the effectiveness of an ADAS. To see this, note that the probability of a person dying in car crash during their lifetime is roughly 1.0%.[20] If a person owns roughly six cars during their lifetime[21], the probability of dying in one

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[17] 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.

[18] Reviews of studies of autonomous safety features by Wang et al. (2020) and by the Foundation for Traffic Safety (FTS) in its Research Brief provide evidence on the effectiveness of those features, although they do not control for behavioral offset effects as we do here.

[19] 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.

[20] https://www.curcio-law.com/blog/odds-of-dying-in-a-car-crash/.

[21] https://www.usedvwaudi.com/blog/2017/11/16/how-many-cars-will-you-go-through-in-one-lifetime.

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[22], 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.[23]

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, but this does not convincingly cast doubt on whether consumers are informed about the effectiveness of those safety features. Instead, they underscore the importance of recognizing that focusing on the average WTP masks motorists' heterogeneity. Indeed, our finding that ADAS has heterogeneous effects on accidents in accordance with different prices and manufacturers of vehicles suggests by implication that the different types of people who own those different vehicles are likely to vary 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 shown previously in figure 1, the availability of ADAS has notably increased over time. In addition, appendix figure 1 in the online appendix shows the distributions of manufacturers' suggested retail prices for all ADAS equipped and non-ADAS equipped vehicles in our sample in 2019. The figure shows that the supports of those distributions 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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[22] https://www.theglobalist.com/the-cost-of-a-human-life-statistically-speaking/.

[23] 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 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 safety, 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.

The speed with which ADAS has been introduced is notable and our findings strongly indicate that motorists have been benefiting from their effectiveness in improving safety. 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?	N	Y	N	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: Poisson maximum likelihood regressions with heteroskedasticity robust standard errors clustered by model year-make-model presented in parentheses. *** 99% significance, ** 95% significance.

Figure 1. Availability of ADAS Safety Features Over Time

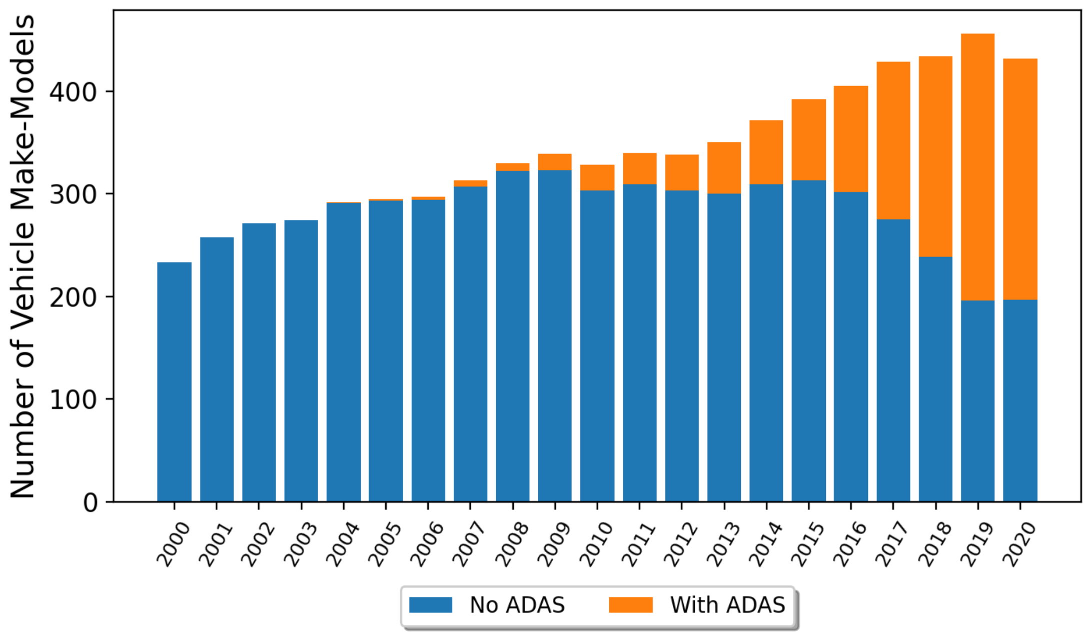


Figure 2. Heterogeneous Effects of ADAS Safety Features on the Accident Rate (IRR)

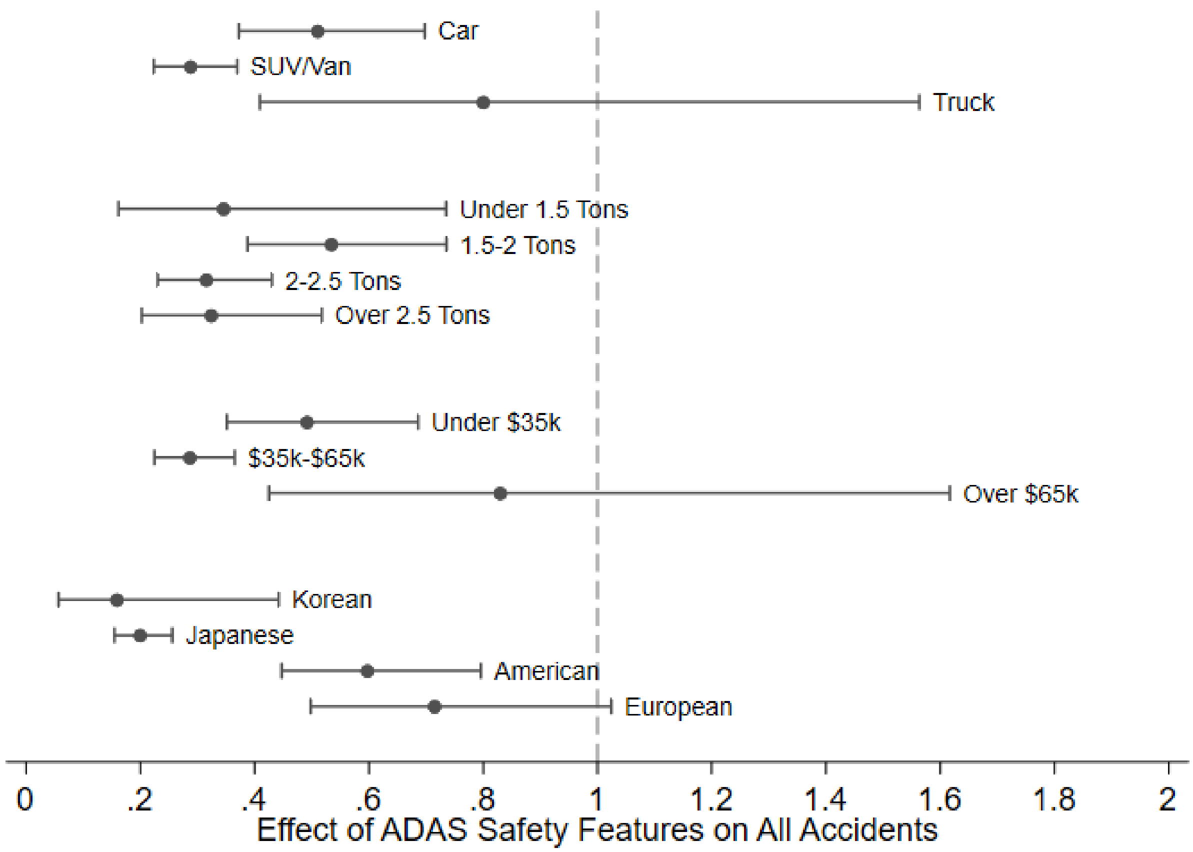
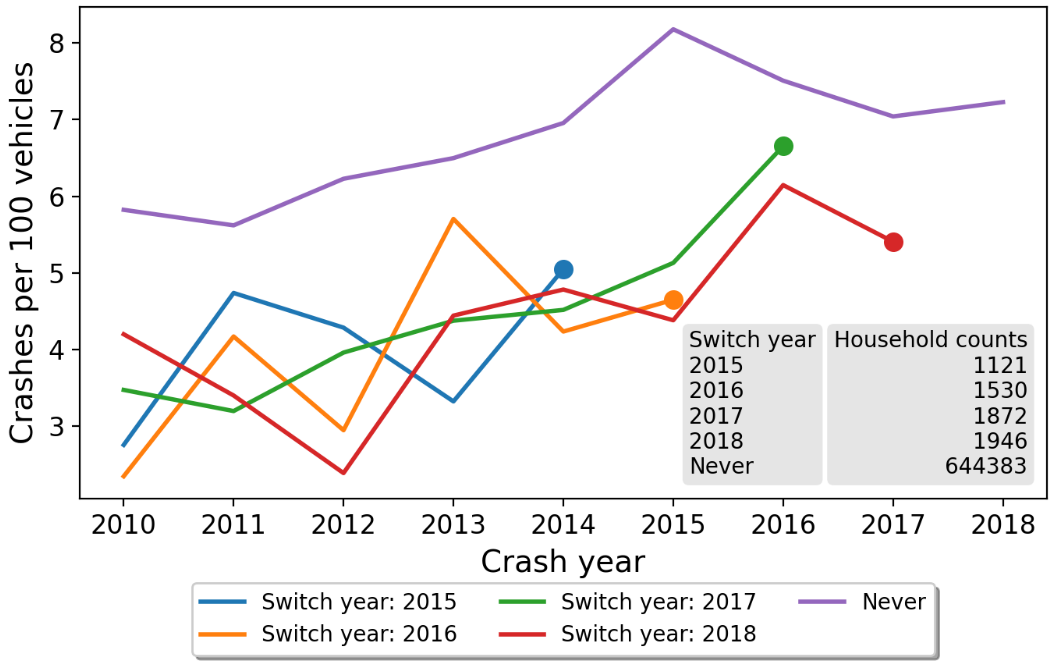


Figure 3. Crash Rate by Year and Household ADAS Switch Year



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).[24]

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.[25]

[24] 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

[25] 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.

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