NOTES

THE ROAD TO OPTIMAL SAFETY: CRASH-ADAPTIVE REGULATION OF AUTONOMOUS VEHICLES AT THE NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

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Autonomous vehicles are now driving people around in cities from San Francisco to Phoenix. But how to regulate the safety risks from these autonomous driving systems (ADS) remains uncertain. While state tort law has traditionally played a fundamental role in controlling car crash risks, this Note argues that the development of novel data tracking and simulation tools by the ADS industry has led to a regulatory paradigm shift: By leveraging these tools for regulatory analysis, the federal National Highway Traffic Safety Administration (NHTSA) could iteratively adapt and improve its regulatory standards after each crash. While many scholars have advanced proposals for how state products liability can adapt to ADS crashes, this Note is the first to propose such a model of "crash-adaptive regulation" for NHTSA and to show that this model will prove superior to tort liability in controlling ADS crash risks. In presenting this new regulatory model, this Note engages with two rich theoretical debates. First, it compares the efficacy of tort liability and agency regulation in controlling ADS crash risks. Second, it evaluates whether ADS safety standards should be set at the federal level or at the state level. It concludes that ADS' technical characteristics call for an agency regulatory scheme at the federal level and urges NHTSA to build the technological and operational expertise necessary to operate a crash-adaptive regulatory regime.

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Introduction

In June 2021, the automotive agency at last seemed to emerge from its slumber. After investigating the "violent crash" between a Tesla on autopilot and a tractor-trailer,[1] the National Highway Traffic Safety Administration (NHTSA) ordered manufacturers of automated driving systems (ADS) to report any crash involving autonomous driving technology.[2] Collecting data on these crashes would help NHTSA identify "emerg[ing]" ADS safety issues and tailor its regulatory requirements accordingly.[3]

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[1] Mychael Schnell, *NHTSA Investigators to Probe Tesla Crash with Tractor-Trailer*, The Hill (Mar. 16, 2021, 10:11 AM), https://thehill.com/regulation/transportation/543371-nhtsa-investigators-to-probe-tesla-crash-with-tractor-trailer [https://perma.cc/NWF9-SAND] (reporting that a NHTSA spokesperson announced that the agency created a Special Crash Investigation team to investigate this "violent crash").

[2] *NHTSA Orders Crash Reporting for Vehicles Equipped with Advanced Driver Assistance Systems and Automated Driving Systems*, Nat'l Highway Traffic Safety Admin. (June 19, 2021), https://www.nhtsa.gov/press-releases/nhtsa-orders-crash-reporting-vehicles-equipped-advanced-driver-assistance-systems [https://perma.cc/U8HN-WGDD].

[3] Tom Krisher, *US Agency Orders Automated Vehicle Makers to Report Crashes*, AP News (June 29, 2021), https://apnews.com/article/technology-business-cf8fd5c2101a9ddafffe2cb6c4155fbb [https://perma.cc/ZZV3-CE37] (reporting NHTSA Acting Administrator Steven Cliff's statement that "[b]y mandating crash reporting, the

NHTSA's response was overdue. While operating in a safety regulatory void, ADS-caused crashes had been piling up and already had taken the lives of ten individuals in just five years.[4] Most of these crashes had happened for unknown or apparently unjustified reasons. Even NHTSA's sister agency within the Department of Transportation, the National Transportation Safety Board (NTSB), had feuded with NHTSA over its lack of action. While NHTSA defines nationwide automotive safety standards, NTSB investigates the causes of automotive crashes. Earlier that year in February, NTSB had issued a public letter explicitly criticizing NHTSA's laissez-faire approach to ADS regulation.[5] The letter contrasted a dire ADS safety situation with NHTSA's optimism about ADS innovation.[6] And it challenged NHTSA's belief that it could defer the definition and enforcement of ADS safety standards to states or industry groups.[7] NTSB sounded the alarm and urged NHTSA to develop a proactive regulatory framework for ADS safety.[8] Otherwise, NHTSA risked turning into a "tombstone agency"—the nickname that aviation safety specialists gave the Federal Aviation Administration (FAA) after the FAA failed to avoid hundreds of deaths caused by flight autopilot systems.[9]

NHTSA's laissez-faire response also was insufficient. NHTSA's order focused on prospective risk investigation notwithstanding the

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agency will have access to critical data that will help quickly identify safety issues that could emerge in these automated systems").

[4] *Id.*

[5] Letter from Robert L. Sumwalt III, Chairman, Nat'l Transp. Safety Bd., to the U.S. Dep't of Transp. 1 (Feb. 1, 2021) [hereinafter NTSB Letter], https://www.regulations.gov/comment/NHTSA-2020-0106-0617 [https://perma.cc/3T8D-XKPN].

[6] *See id.* at 1–2, 4, 8–9 (suggesting that NHTSA has failed to provide adequate regulations to ensure ADS driver safety due to the agency's blind faith in companies' safety testing).

[7] *See id.* at 5 (urging NHTSA to "lead with detailed guidance and specific standards and requirements" after criticizing NHTSA's "willingness to let manufacturers and operational entities define safety" and arguing that the "traditional division of oversight" granting states the responsibility to monitor car drivers may fail to effectively regulate ADS).

[8] *See id.* at 1 ("[W]e believe that the Department of Transportation (DOT) and NHTSA must act first to develop a strong safety foundation that will support the framework envisioned for automated vehicles (AVs) of the future.").

[9] *See* Marc Canellas & Rachel Haga, *Unsafe at Any Level*, 63 COMMC'NS ACM 1, 31–34 (2020), https://cacm.acm.org/magazines/2020/3/243023-unsafe-at-any-level/fulltext [https://perma.cc/4C69-EPJ5] (noting that aviation historically has been plagued by designers ignoring defects until they have caused fatal accidents and warning that NHTSA's current approach to ADS could lead to similar tragedies); Rebecca K. Lutte & Brent D. Bowen, *The FAA: A Tombstone Agency? Putting the Nickname to the Test*, 18 AVIATION INST. FAC. PUBL'NS, Oct. 2000, at 12, 13 ("The [FAA] has been accused of possessing a tombstone mentality of acting only after a tragedy.").

advanced stage of ADS deployment. It did not impose any ADS safety requirements, only the reporting of crash data—data which the agency eventually used to merely publish high-level ADS crash statistics.[10] But ADS safety risks are neither "emerging" nor theoretical; they are faced by consumers every day. Tesla, although not providing a fully self-driving product yet, has aggressively pushed to consumers its "Autopilot" feature, which is responsible for eighty percent of autonomous driving crashes to date.[11] Waymo, Google's self-driving car unit, and Cruise, a close competitor, have launched fully autonomous ride-sharing services in Phoenix, San Francisco, and Austin.[12]

Perhaps most strikingly, NHTSA's data collection mandate seemed oblivious to ADS' groundbreaking data tracking capabilities. Whereas ADS vehicles capture millions of data points every second to track their environment and driving decisions,[13] NHTSA turned to the legacy technology of PDF documents and asked manufacturers to provide crash "narrative[s]" in textbox inputs.[14] If a picture is worth a thousand words, how many words would account for one terabyte (1,000 gigabytes) of ADS driving data—the amount captured by ADS sensors in less than an hour?[15] ADS manufacturers already use their

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[10] NHTSA, SUMMARY REPORT: STANDING GENERAL ORDER ON CRASH REPORTING FOR AUTOMATED DRIVING SYSTEMS (June 2022).

[11] *See* Joseph Choi, *NHTSA Orders Makers of Autonomous Vehicles to Report Crashes*, THE HILL (June 29, 2021, 3:04 PM), https://thehill.com/policy/transportation/automobiles/560767-nhtsa-orders-makers-of-autonomous-vehicles-to-report [https://perma.cc/GW9R-P8PJ] (reporting that twenty-five out of the thirty-one crashes then investigated by NHTSA had been caused by Tesla's Autopilot system).

[12] John Krafcik, *Waymo Is Opening Its Fully Driverless Service to the General Public in Phoenix*, WAYMO (Oct. 8, 2020), https://blog.waymo.com/2020/10/waymo-is-opening-its-fully-driverless.html [https://perma.cc/PDJ9-4AEB]; Andrew J. Hawkins, *Cruise Is Now Charging for Rides in Its Driverless Vehicles in San Francisco*, VERGE (June 23, 2022, 12:09 PM) https://www.theverge.com/2022/6/23/23180156/cruise-driverless-vehicle-charge-riders-san-francisco [https://perma.cc/S8EZ-YU7H]; *Rides*, GETCRUISE, https://getcruise.com/rides [https://perma.cc/Y6QE-NR24] (showing that Cruise now operates in Phoenix, San Francisco, and Austin).

[13] *See* Matt McFarland, *Your Car's Data May Soon Be More Valuable than the Car Itself*, CNN Business (Feb. 7, 2017, 09:05 AM), https://money.cnn.com/2017/02/07/technology/car-data-value/index.html [https://perma.cc/6FDS-VJNQ].

[14] NHTSA, STANDING GEN. ORD. 2021-01, GENERAL ORDER ON INCIDENT REPORTING FOR AUTOMATED DRIVING SYSTEMS (ADS) AND LEVEL 2 ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) viii, 35 (June 29, 2021) [hereinafter NHTSA CRASH REPORTING ORDER] (attaching in Appendix C a copy of the PDF form that manufacturers must fill to report crashes, which includes "crash description" drop-down options and a "narrative" textbox entry).

[15] *See* James M. Amend, *Storage Almost Full: Driverless Cars Create Data Crunch*, WARDSAUTO (Jan. 18, 2018) [hereinafter *Storage Almost Full*], https://www.wardsauto.com/technology/storage-almost-full-driverless-cars-create-data-crunch [https://perma.cc/5QKU-YJH2] ("A single autonomous test vehicle produces about 30 TB per day, which is 3,000 times the scope of Twitter's daily data.").

novel data technologies to define ADS safety requirements and optimize ADS safety performance. In the hands of regulators, the same data tools could optimize ADS safety standards by analyzing ADS crash data at scale. But NHTSA has not started building the internal capacity necessary to leverage such tools. Although the agency finally is showing some movement on ADS regulation, it seems miles away from what it could achieve if it adapted ADS data technologies for regulatory analysis.

NHTSA's regulatory response to the deployment of ADS on the road is of fundamental importance. ADS promise to deliver unprecedented road safety improvements.[16] Although ADS may instantly be statistically safer than humans once commercialized,[17] they will still drive us into accidents—indeed, they already have.[18] Lawmakers, agencies, and courts tread a very fine line in designing effective rules and incentives to reach ADS "optimal safety": Too stringent standards and too lax standards both present grave dangers, in lives not saved on the road. An under-deterrent scheme may cause ADS safety to plateau under its optimal level, leading to avoidable road deaths in the long term.[19] An over-deterrent scheme may prove even more costly. By delaying the widespread deployment of ADS and its accompanying reduction in accidents, it could postpone the major decrease in human-caused accidents that ADS promise, piling up unnecessary casualties as the delay persists.[20] While ADS already are driving us, the critical question of how government will regulate them to guarantee an optimal level of road safety remains unclear. Tort liability—often

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[16] ADS proponents inescapably highlight that human errors cause ninety-four percent of the nearly 40,000 yearly U.S. vehicular casualties, most frequently involving drunk, speeding, or distracted drivers. U.S. Dep't of Transp., *Risky Driving*, NAT'L HIGHWAY TRAFFIC & SAFETY ADMIN., https://www.nhtsa.gov/risky-driving [https://perma.cc/C8GA-U39X]. Once broadly commercialized, ADS should eliminate a substantial amount of these accidents by automating the driver out of driving.

[17] "[ADS'] superior safety will be broadly statistical," but "there will be individual incidents of diminished safety." Bryant Walker Smith, *Automated Driving and Product Liability*, 2017 MICH. ST. L. REV. 1, 18 (2017).

[18] An Uber-operated ADS killed Elaine Herzberg in March 2018. *Uber Settles with Family of Woman Killed by Self-Driving Car*, GUARDIAN (Mar. 19, 2018, 12:34 AM), https://theguardian.com/technology/2018/mar/29/uber-settles-with-family-of-woman-killed-by-self-driving-car [https://perma.cc/RE3S-6XSJ].

[19] *See* Kenneth S. Abraham & Robert L. Rabin, *Automated Vehicles and Manufacturer Responsibility for Accidents: A New Legal Regime for a New Era*, 105 VA. L. REV. 127, 145 (2019) (warning that "insufficiently exacting" liability standards for ADS crashes could lead to "considerably less-than-optimal liability").

[20] *See* Mark A. Geistfeld, *A Roadmap for Autonomous Vehicles: State Tort Liability, Automobile Insurance, and Federal Safety Regulation*, 105 CALIF. L. REV. 1611, 1679 (2017) (arguing that overly stringent safety standards would be "self-defeating" and create "disutility or safety costs" by delaying the deployment of life-saving ADS driving technology).

seen as the main deterrent force in reducing traditional car crashes[21]—could incentivize manufacturers to uphold appropriate ADS safety levels, but the handful of tort cases reviewing ADS-caused crashes have settled, were dismissed on technical grounds, or are currently pending.[22]

This Note tackles the threshold question of what institutional model of "road safety risk control" would best minimize the societal costs of ADS crashes and reach ADS "optimal safety."[23] It argues that NHTSA should take the wheel to become an "optimal regulator" setting *optimal* safety standards by harnessing the new ADS data technologies of (1) data tracking and (2) driving simulation, instead of keeping its contribution to *minimum* safety standards that tort liability augments to reach optimal safety.[24] For the first time, expert regulators have the technological tools to become more effective than tort law at controlling car crash risks.[25] NHTSA should abandon its wait-and-see approach and proactively leverage these tools to continuously update its safety standards based on the data analysis of new ADS

[21] *See, e.g.*, Frank A. Sloan, Bridget A. Reilly & Christoph M. Schenzler, *Tort Liability Versus Other Approaches for Deterring Careless Driving*, 14 INT. REV. L. ECON. 53, 53, 68 (noting that a key justification for imposing tort liability is that it deters injuries and finding empirical evidence that tort liability indeed deters people from driving carelessly); Stephen Teret, *Injury Control and Product Liability*, 2 J. PUB. HEALTH POL. 49, 51 (1981) ("During [the 1970s] an aspect of products liability law evolved which forced the automobile industry, under the economic threat of monetary judgments, to improve the safety of cars.").

[22] *See, e.g.*, Bernie Woodall, *Uber Avoids Legal Battle with Family of Autonomous Vehicle Victim*, REUTERS (Mar. 28, 2018, 10:35 PM), https://www.reuters.com/article/us-autos-selfdriving-uber-settlement/uber-avoids-legal-battle-with-family-of-autonomous-vehicle-victim-idUSKBN1H5092 [https://perma.cc/B8HH-YWYT] (reporting that the family of Elaine Herzberg, the first person to be killed by a self-driving vehicle, settled with Uber); Hudson v. Tesla, No. 80052957 (Fla. Cir. Ct. Oct. 30, 2018) (settled); Nilsson v. General Motors, No. 4:18-cv-00471-KAW (N.D. Cal. Jan. 22, 2018) (settled); Umeda v. Tesla, No. 20-cv-02926-SVK (N.D. Cal. Jan. 3, 2020) (dismissed on *forum non conveniens* grounds); Sz Hua Huang v. Tesla, No. 19CV346663 (Cal. Super. Ct. Apr. 26, 2019) (case pending); Banner v. Tesla, No. 50-2019-CA-0099662 (Fla. Cir. Ct. Aug. 1, 2019) (case pending).

[23] I call "optimal safety" the level of road safety achieved through the optimal use of societal levers available to control crash risks (including government-imposed regulation or liability and private sector interventions). *See* Steven Shavell, *A Model of the Optimal Use of Liability and Safety Regulation*, 15 RAND J. ECONS. 271, 276 (1984) (theorizing how the "optimal joint use of regulation and liability" can achieve optimal safety).

[24] Although NHTSA regulates automotive safety nationwide, the agency has limited its role to issuing minimum safety standards, on top of which state tort liability has controlled residual risks of crashes. *See infra* Section I.B.1.

[25] This Note only considers crash risks stemming from driving decisions made by ADS software. It does not engage with the regulation or liability issues raised by hardware failures, which present lesser challenges. *See* Geistfeld, *supra* note 20, at 1692 ("All crashes caused by defective hardware in the vehicle clearly fit within the existing liability regime.").

crashes, under a model that I call "crash-adaptive optimal regulation." This Note urges NHTSA to adopt this crash-adaptive model without further delay: As ADS technologies mature, NHTSA's window of opportunity to shape them for its regulatory purposes narrows.

This Note relies on two theoretical moves to make the case for an agency-led, federal crash-adaptive regulatory model. First, taking on the tort versus regulation theoretical debate,[26] this Note argues that agency regulation by NHTSA will prove more effective than tort liability by states to minimize residual ADS safety risks. Steven Shavell has theorized the comparative advantages of regulation and tort to reduce risks in different contexts.[27] He identified the "theoretical determinants" favoring either regulation or tort liability.[28] While tort liability clearly won on all counts in the context of human driving,[29] unique technical features of ADS alter two significant factors, namely (1) the difference in information about risky activities between private parties and regulators, and (2) the relative administrative costs of regulation and tort. Tort will struggle to force information out of ADS crashes, whereas regulators could leverage data tracking and driving simulation technologies to precisely reconstruct crashes.[30] And by integrating with data processes that manufacturers already operate

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[26] The legal academy has actively debated the conditions under which ex ante agency regulation or ex post tort liability better regulate risky activities. *See, e.g.*, Shavell, *Liability for Harm Versus Regulation of Safety*, 13 J. L. STUD. 357 (1984) (building a theoretical model to compare the relative benefits of agency regulation and tort liability); Catherine M. Sharkey, *Products Liability Preemption: An Institutional Approach*, 76 GEO. WASH. L. REV. 449 (2008) (discussing the tension between agency regulation and "tort as regulation" and introducing a decisionmaking model for federal judges to determine when federal regulation should preempt state tort law).

[27] *See* Shavell, *supra* note 26, at 359–64. Often, both regulation and tort are used in tandem because tort can discover safety insights ex post that would be hard or costly for an agency to uncover ex ante. Agency regulation sets minimum standards, and tort liability then "take[s] up some of the slack associated with" a minimum standard to fill up to an optimal standard. Shavell, *supra* note 23, at 272.

[28] Shavell, *supra* note 26, at 358. Shavell identifies four "theoretical determinants," or factors: (1) whether the agency or private parties have better knowledge about the risky activities; (2) whether regulation or tort provides lower administrative costs; (3) whether tort defendants would have the financial ability to compensate for the harm they caused; and (4) whether it is likely that harmed victims will sue under tort law. *Id.* at 359–64.

[29] *See id.* at 366–68 (explaining that for "typical tort[s]," of which a car crash would be an example, liability proves superior to regulation because (1) private parties possess better information as they engage in the activity, (2) liability is less costly as costs only arise when accidents happen, (3) liability insurance often covers for damages caused by the accident, and (4) victims are likely to sue as they are often able to identify their harm and the responsible party). In this context, tort liability justifiably has acted as the preferred mechanism to reduce residual risks of accidents, after regulation has set minimum standards via automotive manufacturing regulation (mostly at the federal level) and traffic laws (at the state and local levels). *See supra* note 27 and accompanying text.

[30] *See infra* Sections I.B.2, II.A.

today, regulators can control the administrative costs of running an adaptive regulation model.[31]

Second, this Note addresses whether safety standards should be set at the federal or state level.[32] A direct implication of NHTSA adopting this Note's proposed crash-adaptive model is that a federal regulator would set ADS optimal safety, leaving a much smaller regulatory role—if any—to state tort law. Three conventional arguments from the debate on whether to nationalize product safety strongly support a national ADS regulatory model. First, ADS safety requires federal expertise.[33] Second, leaving ADS safety to the states creates significant risks of spillover effects.[34] Third, and most compellingly, ADS safety standards benefit from not only uniformity but also centralized optimization, which counsels against decentralized state experimentation. This Note focuses on the regulatory role (in setting incentives to minimize crash risks) for tort and does not address the compensatory role (in compensating victims after crashes) that state

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[31] *See infra* Section II.C.

[32] This has been another rich theoretical debate within legal academia. *See* Sharkey, *supra* note 26, at 451–52 ("Products liability is a notably fraught area, where arguments for national uniform standards compete vigorously with arguments in favor of more localized experimentation."); Richard L. Revesz, *Federalism and Interstate Environmental Externalities*, 144 U. PA. L. REV. 2341, 2342, 2414–15 (1996) (examining how to "lay the foundation for a more rational allocation of decisionmaking authority in the environmental arena between the federal government and the states"); Roberta Romano, *Is Regulatory Competition a Problem or Irrelevant for Corporate Governance?*, 21 OXFORD REV. ECON. POL'Y 212, 226 (2005) (arguing that the federal government should play a key role in preventing negative externalities stemming from decentralized state-level corporate law regimes); *see also* Gary T. Schwartz, *Considering the Proper Federal Role in American Tort Law*, 38 ARIZ. L. REV. 917, 924–40 (1996) (casting doubt on the idea that decentralized state legal regimes produce state law "experiment[s]" that enable incremental regulatory improvements). *But see* Sharkey, *supra* note 26, at 484 ("But the ascendancy of the pro-federalization thesis—as a descriptive, but especially, as a normative matter—is by no means assured. Equally strong abstract factors tend to cut in the opposite direction, favoring state or more local regulation."); Larry E. Ribstein & Bruce H. Kobayashi, *An Economic Analysis of Uniform State Laws*, 25 J. LEGAL STUD. 131, 141 (1996) (noting that regulating safety at the state level accounts for regional differences in policy preferences); Harvey S. Perlman, *Products Liability Reform in Congress: An Issue of Federalism*, 48 OHIO ST. L.J. 503, 507–09 (1987) (arguing for the benefits of "[s]tate experimentation," which "permits the simultaneous implement of different solutions" and the "comparative measurement of [the effectiveness of] a variety of plausible reforms").

[33] "Federal expertise" refers to the expertise that federal administrative, judicial, and legislative institutions can build, as opposed to their state-level counterparts.

[34] "Spillover effects" refers to the impact that seemingly unrelated events in one jurisdiction can have on the economies of other jurisdictions. *Spillover Effect*, CORP. FIN. INST. (Dec. 22, 2022), https://corporatefinanceinstitute.com/resources/economics/spillover-effect [https://perma.cc/G7Q7-7LYX] (noting that spillover effects are often "externalities" that extend into areas beyond the authority of the government where the externalities are produced). In the context of this Note, the impact that ADS regulation in one state has on ADS safety levels in other states would constitute spillover effects.

tort law may preserve nor opine on whether NHTSA's regulations should fully preempt state tort law.[35]

With this theoretical grounding, this Note argues that NHTSA is the only institution capable of adequately regulating ADS toward optimal safety by using new ADS technologies for regulation. But NHTSA's window of opportunity may close once wider ADS commercial deployment prohibitively increases the costs of retrofitting regulatory use cases into already mature and popular ADS data technology products.[36] Accordingly, it is imperative for NHTSA to act as early as possible and build the necessary internal capacity to implement a crash-adaptive regulatory model able to guarantee maximum ADS road safety for all Americans.

Legal scholars have debated ADS regulation and liability at length, but none has yet identified the data technologies developed by the ADS industry as powerful tools for NHTSA to control ADS safety risks. Scholars largely have ignored the threshold question of who should regulate residual risks of ADS crashes, following path dependencies and positing tort law as a natural and effective answer.[37] In doing so, they have ascribed a modest role to NHTSA and advanced "tort as regulation" as the principal mechanism to achieve ADS optimal safety.[38] Even Shavell did not seem to reconsider whether his "theoretical determinants" would favor regulation in the ADS context before he set to analyze what form of tort liability would most effectively incentivize manufacturers' and consumers' safety precautions.[39]

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[35] Legal scholars have advanced a variety of ADS crash compensation regimes, based on tort liability, insurance, or a national victim compensation fund. *See* Smith, *supra* note 17, at 52–56 (arguing that products liability can adapt to ADS crashes and preserve its post-crash compensatory role); Steven Shavell, *On the Redesign of Accident Liability for the World of Autonomous Vehicles*, 49 J. L. STUD. 243, 246, 279–80 (2020) (advocating for a strict liability rule paying liability awards to the state rather than crash victims and relying on first-party insurance to compensate victims); F. Patrick Hubbard, *"Sophisticated Robots": Balancing Liability, Regulation, and Innovation*, 66 FLA. L. REV. 1803, 1866–67 (2014) (evaluating a proposal that ADS manufacturers form a fund compensating ADS victims). The "crash-adaptive optimal regulation" model presented in Part II makes federal preemption of post-crash state tort liability more likely, as under this model NHTSA's regulations have fully displaced "tort as regulation." But preserving a compensatory role for torts still may counsel against federal preemption.

[36] *See infra* Section II.C.

[37] *See, e.g.*, Hubbard, *supra* note 35, at 1865–66 (arguing that products liability design defect doctrine would work as is); Sophia H. Duffy & Jamie Patrick Hopkins, *Sit, Stay, Drive: The Future of Autonomous Car Liability*, 16 SMU SCI. & TECH. L. REV. 453, 471–73 (2013) (arguing that strict liability would effectively regulate ADS).

[38] Sharkey, *supra* note 26, at 459, 466 (defining "tort as regulation" as one of the "two faces of tort law in the Supreme Court," alongside "tort as compensation").

[39] Shavell, *supra* note 26.

A few commentators have envisioned more limited responsibilities for tort law but have done so by removing any role for government in reducing residual risks. Mark Geistfeld, for example, has argued that federal safety standards should preempt state tort liability as long as ADS are twice safer than the average human driver.[40] In this scenario, NHTSA still defines minimum safety standards ex ante, but government forfeits controlling residual risks beyond these minimum thresholds to prevent delays in deploying life-saving ADS vehicles.[41] ADS industry lobbyists have pushed for the preemption of state tort law and for self-regulatory regimes relying on industry safety standards.[42]

This Note is the first to argue that a model of "adaptive regulation"—going beyond strictly ex ante regulation—will prove superior to both ex post tort liability and self-regulation models in reducing residual risks of accidents and to identify NHTSA as the only institution capable of implementing such a model. Some legal scholarship has called for enlarging NHTSA's role in regulating ADS (including additional congressional authorization), but these proposals have focused on ex ante regulation and have not envisioned NHTSA expanding its interventions both premarket and postmarket under adaptive regulation.[43] Legal scholars have discussed the benefits of adaptive regulation, notably in the context of dynamically-evolving

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[40] Geistfeld, *supra* note 20, at 1653.

[41] *See id.* (noting that there is widespread concern that the rate of ADS development is hampered by uncertainty about manufacturer accident liability and arguing for federal regulation that would preempt tort liability as long as aggregate testing data shows that the ADS is twice safer than the average human driver).

[42] *See* Jeff Plungis & Keith Naughton, *Driverless Car Supporters Urge National Laws to Override State, Local*, INS. J. (Mar. 16, 2016), https://www.insurancejournal.com/news/national/2016/03/16/402012.htm [https://perma.cc/78KJ-EZJG] (describing efforts by Google, General Motors, and other ADS companies to have federal law displace the "greatest obstacle" that state and local laws pose for ADS innovation (quoting Senator John Thune)); *see also* Alex Gangitano, *Industry Spends Big to Sell Safety of Driverless Cars*, THE HILL (Sept. 26, 2019, 6:00 AM), https://thehill.com/policy/transportation/463124-industry-spends-big-to-sell-safety-of-driverless-cars [https://perma.cc/B8YN-CTVA].

[43] Amin R. Yacoub, *Liability and Regulatory Oversight of Semi-Autonomous and Autonomous Vehicles*, 29 B.U. J. SCI. TECH. L. 1 (2023). Premarket interventions impose requirements on manufacturers before they introduce their product on the market. Postmarket interventions impose—often more continuous—requirements on manufacturers once their product is available on the market. Typically, safety regulators may require "premarket approval" (manufacturers must meet certain requirements to sell their product) before engaging in "postmarket monitoring" (the regulator monitors potential safety issues and imposes fines or recalls in case of safety violations). *See, e.g.*, U.S. FOOD & DRUG ADMIN., U.S. DEP'T OF HEALTH & HUMAN SERVS., BALANCING PREMARKET AND POSTMARKET DATA COLLECTION FOR DEVICES SUBJECT TO PREMARKET APPROVAL: GUIDANCE FOR INDUSTRY AND FOOD AND DRUG ADMINISTRATION STAFF 4, 6 (2015), https://www.fda.gov/media/88381/download [https://perma.cc/R8B9-DQW9].

technologies such as ADS, but they have not applied this model to ADS regulation nor reconsidered it in light of novel ADS data technologies.[44]

This Note proceeds in three parts. Part I lays bare the dangers stemming from the divergence between the ADS industry's technological revolution and NHTSA's regulatory torpor. ADS software soon will be driving the world. This move to software-based driving is fundamentally transforming both car "driving" and car "manufacturing." As a result, the status quo regulatory response that NHTSA plans for ADS—relying on torts and self-regulation—will fail to achieve optimal safety. Part II charts a safer path forward, putting NHTSA firmly at the wheel. New ADS data technologies can become powerful information-forcing tools and offer NHTSA an unprecedented opportunity to become an "optimal regulator" by issuing adaptive regulations based on the analysis of crash data premarket and postmarket. This Part introduces the corresponding "crash-adaptive optimal regulation" model and details its components. Part III grapples with the immediate implication of NHTSA implementing the crash-adaptive regulatory model: For the first time since the invention of the automobile, the responsibility to ensure optimal road safety would move from states to the federal government. This Part demonstrates that we can safely hand over the keys to federal regulators. Three arguments from the debate on nationalizing product safety standards—related to expertise, spillover effects, and uniformity—have special strength for ADS. This Note concludes with a call to action for NHTSA to start as soon as possible in building the necessary technological and operational expertise to run an effective crash-adaptive regulatory scheme.

I
Regulatory Standstill Amid the Automotive Revolution

Long gone is the time when the U.S. government was pioneering ADS development. After spearheading research and funding for early

[44] *See* Rachel E. Sachs, *Regulating Intermediate Technologies*, 37 Yale J. Reg. 219, 219, 269 (2020) (discussing adaptive regulation of "intermediate technologies" that improve through time and identifying autonomous vehicles as a prime example); *see also* Robin K. Craig & J.B. Ruhl, *Designing Administrative Law for Adaptive Management*, 67 Vand. L. Rev. 1, 1–8 (2014) (arguing that "adaptive management" of regulation through a "multistep, iterative process" can be effective in regulating dynamically evolving risks in many regulatory domains including public safety); Charles K. Whitehead, *The Goldilocks Approach: Financial Risk and Staged Regulation*, 97 Cornell L. Rev. 1267 (2012) (applying adaptive regulation concepts to financial regulation).

autonomous vehicle prototypes in the 1960s,[45] the Defense Advanced Research Projects Agency (DARPA) sparked the momentum leading to recent ADS technological breakthroughs with its autonomous vehicle Grand Challenges in the early 2000s.[46] Fast forward twenty years, the federal government plays a significantly downsized role in realizing ADS' safety promise. Rather than taking up DARPA's baton, NHTSA has focused on removing roadblocks to ADS innovation to let the automotive technologists charge ahead on their own.

And charged ahead they have. This Part explains how the ADS industry is revolutionizing daily automotive activities. To do so, the industry has developed powerful data tracking and driving simulation technologies that also could prove transformative to how regulators control road safety risks. This Part then highlights that NHTSA—the industry's main federal regulator—has shown no plans to harness these tools yet and instead plans on applying its status quo regulatory response to ADS. Last, this Part argues that NHTSA settling on this default regulatory response would present grave risks for short-term and long-term road safety.

A. A Revolution in Motion: Self-Driving Cars, Still-Learning Drivers

Software keeps eating the world,[47] and it soon will be driving the world. Technology and car companies have made significant progress toward replacing human drivers with machine drivers, or ADS. In the process, the automotive industry has changed the way it designs, develops, and tests car products by adopting "agile" methodologies from the software industry. The cars drive themselves and they keep learning to drive with every trip. Regulators must adapt to this new world of "self-driving cars" with "still-learning drivers" (i.e., machine drivers that never fully complete their learning phase).

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[45] *See generally Shakey the Robot*, DARPA, https://www.darpa.mil/about-us/timeline/shakey-the-robot [https://perma.cc/CC45-LC9R] (describing the development of a robot that could move on its own in the 1960s); ALEX ROLAND & PHILIP SHIPMAN, STRATEGIC COMPUTING: DARPA AND THE QUEST FOR MACHINE INTELLIGENCE, 1983–1993 (2002).

[46] *The Grand Challenge*, DARPA, https://www.darpa.mil/about-us/timeline/-grand-challenge-for-autonomous-vehicles [https://perma.cc/P9KC-PZ8T]; Alex Davies, *Inside the Races that Jump-Started the Self-Driving Car*, WIRED (Nov. 10, 2017, 7:00 AM), https://www.wired.com/story/darpa-grand-urban-challenge-self-driving-car [https://perma.cc/RH9Y-GNPB] ("The Darpa Grand Challenges did more than drive the invention of autonomous vehicles—they fostered a community that now leads the industry.").

[47] Marc Andreesen, *Why Software Is Eating the World*, WALL ST. J. (Aug. 20, 2011), https://www.wsj.com/articles/SB10001424053111903480904576512250915629460 [https://perma.cc/977P-QE2F] (explaining that "software is eating the world" by driving "a dramatic and broad technological and economic shift in which software companies are poised to take over large swathes of the economy").

Autonomous vehicle technology is well underway to have software replace humans as drivers.[48] Indeed, fully automated cars without a steering wheel already are driving people around. In multiple cities including Phoenix, Arizona, anyone with a smartphone can hail a Waymo One or Cruise robo-taxi and sit back in awe while the ADS automagically drives itself to their destination.[49] The ongoing deployment of ADS is fundamentally changing the nature of driving.

ADS are ushering a driving revolution and a manufacturing revolution, as they are transforming both car drivers—the driving *actors*—and car manufacturers—the makers of driving *products*. First, cars are not driven by our familiar humans anymore, but by complex artificial intelligence software agents, whose behavior is decided by opaque probabilistic pattern recognition.[50] Machine drivers present three major differences with human drivers that impact how government should regulate ADS: (1) they have perfect memory of their driving actions;[51] (2) ADS manufacturers program their driving behavior to be consistent and reproducible;[52] and (3) a single, central-

[48] Despite the major ADS technological progress detailed in this Note, the ADS industry is still far from fully automating driving in all road situations. *See* Wayne Ma, *Inside Apple's Eight Year Struggle to Build a Self-Driving Car*, THE INFO. (July 11, 2022, 6:00 AM), https://www.theinformation.com/articles/inside-apples-eight-year-struggle-to-build-a-self-driving-car [https://perma.cc/9FZD-48ZH] (noting that ADS companies have invested a total of $30 billion into developing self-driving cars but are "far from ready to operate on a big scale" and do not "know how long it will take to get there").

[49] Krafcik, *supra* note 12; *Redefine How You Move Around Phoenix*, WAYMO, https://waymo.com/phx [https://perma.cc/PTH9-RXRK] (noting that Waymo offers "fully autonomous rides"); *Rides*, *supra* note 12. Journalist Malcolm Gladwell enthusiastically described his ADS experience. *See* Malcolm Gladwell, *I Love You Waymo*, REVISIONIST HIST. PODCAST (June 24, 2021), https://www.pushkin.fm/episode/i-love-you-waymo [https://perma.cc/2UWA-ZESZ]. The two competitors have expanded their commercial offerings to San Francisco, California, and Austin, Texas. *Redefine How You Move Around San Francisco*, WAYMO, https://waymo.com/sf [https://perma.cc/M4UN-QPT5] (stating that they "are safely operating a fully autonomous, publicly available ride-hailing service in . . . San Francisco"); *Rides*, *supra* note 12 (showing availability in San Francisco and Austin).

[50] *See* Sorin Grigorescu, Bogdan Trasnea, Tiberiu Cocias & Gigel Macesanu, *A Survey of Deep Learning Techniques for Autonomous Driving*, J. FIELD ROBOTICS (2019), https://arxiv.org/abs/1910.07738 [https://perma.cc/5BTR-E273].

[51] *See Data Storage and AI Are Driving the Evolution of Autonomous Cars*, VENTUREBEAT (May 4, 2020, 5:39 AM) [hereinafter *Data Storage and AI*], https://venturebeat.com/2020/05/04/data-storage-and-ai-are-driving-the-evolution-of-autonomous-cars [https://perma.cc/4C7Q-7HRG] (explaining that the ability to record granular driving data in computer data storage was key to enabling ADS development).

[52] *See* Grigorescu et al., *supra* note 50, at 12 (noting that "predict[ing] . . . the behavior of the vehicle" is important to optimize passengers' comfort and safety); Xuanyu Wang, Xudong Qi, Ping Wang & Jingwen Yang, *Decision Making Framework for Autonomous Vehicles Driving Behavior in Complex Scenarios via Hierarchical State Machine*, 1 AUTONOMOUS INTELLIGENT SYS. 1, 11 (2021) (proposing an ADS driving decisionmaking model aimed at consistently achieving the "best driving strategy" when faced with a complex driving situation).

ized driver operates an entire—maybe nationwide—fleet of vehicles.[53] As Section I.B.2 and Part II will show, these first two characteristics render an agency regulation model augmented by ADS data technology more effective in responding to new crash information than tort law, for the first time in history. Section III.C will return to the third characteristic to show how ADS' uniform and centralized nature calls for safety standards set at the national level—not the state level.

Second, car products are not developed and commercialized like traditional cars anymore, but like software. In its quest to redefine driving, the automotive industry has undergone a manufacturing revolution. It used to be that a manufacturer would complete a car before releasing it on public roads. No car drives the streets of San Francisco with its roof or trunk half-built. Conversely, self-driving cars have started operating, and will continue to operate, as incomplete, or still-learning. ADS manufacturers have adopted the agile methodologies of software development to deploy their ADS driving models on public roads as soon as "minimally viable" safety-wise, and continuously update ADS features and performance postmarket.[54]

Agile is a motto in software development. It represents an adaptive and iterative approach to project management that focuses on quickly bringing products to market and thereafter iteratively delivering improvements postmarket.[55] Car manufacturers traditionally adopted a very different approach, known as waterfall.[56] Under waterfall, manufacturers complete and validate specialized tasks from one phase (e.g., testing the resistance of specific wheel materials) before moving to the next phase (e.g., testing the crash resistance of the

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[53] Geistfeld, *supra* note 20, at 1621–22 ("In effect, an entire fleet [of ADS] will be guided by a single driver . . . .").

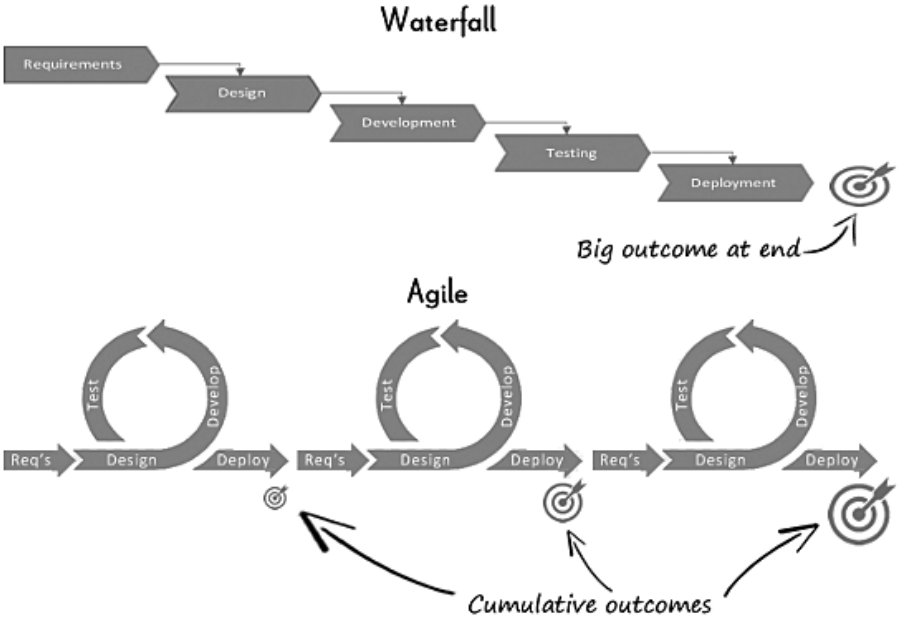
[54] *See* Hamesh Chawla, *What Self-Driving Cars Can Teach Us About Software Testing*, Atlassian (May 17, 2017), https://www.atlassian.com/blog/software-teams/what-self-driving-cars-can-teach-us-about-software-testing [https://perma.cc/BS2Y-5BL5] (explaining why ADS manufacturers substantially benefit from using agile methodologies); Kyle Field, *Tesla Has Applied Agile Software Development to Automotive Manufacturing*, Clean Technica (Sept. 1, 2018), https://cleantechnica.com/2018/09/01/tesla-has-applied-agile-software-development-to-automotive-manufacturing [https://perma.cc/7YJJ-XUE9] (describing the "agile development" process at Tesla and noting that it has produced vehicles that are in a "permanent beta state"); *see also* Deloitte, Autonomous Driving: Moonshot Project with Quantum Leap from Hardware to Software & AI Focus 36 (2019) (applying the "minimum viable product" concept to ADS development).

[55] *See What Is the Agile Methodology?*, Atlassian, https://www.atlassian.com/agile [https://perma.cc/95RK-HMEG] (defining agile software development).

[56] Deloitte, *supra* note 54, at 34 (noting that car "[c]ompanies are increasingly replacing classical waterfall structures with agile approaches"); Christoph Gauger, Kai Heller, Karen Lellouche Tordjman, Andrew Loh & Benjamin Rehberg, *An Agile Game Plan for Automakers*, Boston Consulting Grp. (June 10, 2019), https://www.bcg.com/publications/2019/agile-game-plan-automakers [https://perma.cc/PS2S-JXFA].

assembled wheel), in a linear and sequential fashion. A delivered product remains static—it has completed all sequential phases of development and validation. With agile, however, a delivered product continues to receive updates in perpetuity—it is never fully completed. Even after commercialization, ADS will keep learning how to drive with every new situation they encounter, because they lack humans' "general intelligence" to adapt to new settings.[57] They are self-driving cars with still-learning drivers.

IMAGE 1. WATERFALL VS. AGILE PROCESSES



These driving and manufacturing revolutions promise not only to greatly reduce the frequency of car accidents,[58] but also to transform the ways in which government can minimize the residual risks of accident, a process known as road safety "risk control."[59] Car crashes present a ubiquitous risk in U.S. society,[60] and state and federal regulators since the dawn of the automobile have closely scrutinized

[57] *See* NICK BOSTROM, SUPERINTELLIGENCE 22 (2014) ("Machines are currently far inferior to humans in general intelligence.").

[58] *See supra* note 16 and accompanying text.

[59] *See generally* Shavell, *supra* note 23, at 271–78 (presenting an economic model to evaluate tort liability and regulation as "means of controlling accident risks").

[60] Automobile crashes constitute the leading cause of death for Americans aged 15 to 24, and the second leading cause of death for Americans aged 25 to 34. Jerry L. Mashaw & David L. Harfst, *From Command and Control to Collaboration and Deference: The Transformation of Auto Safety Regulation*, 34 YALE J. REG. 167, 261 (2017).

the drivers ("actors") and manufacturers (of driving "products") now facing radical transformations.[61] The ADS revolution is not only transforming these driving and manufacturing regulated activities but also developing technologies that could prove invaluable for government to control road safety risks.

Two technologies that have enabled the fast progress in ADS performance promise new oversight capabilities for regulators able to harness them. First, data tracking has been the fuel of ADS development. The ADS industry is the epitome of a big data industry.[62] Autonomous cars' driving decisions are controlled by their driver AI model, which relies on deep learning pattern recognition techniques.[63] Deep learning feeds on vast amount of data to train AI models to continuously drive more accurately and more safely, which is being made possible by tracking from sensors capturing granular information on the car's surrounding environment, every second and every yard driven.[64] Although they can achieve impressive levels of driving performance, deep learning models are highly complex, such that even their designers often cannot explain their inner functioning.[65] But continuous data tracking enables government to mandate manufacturers to store "explainable" driving decisions from the moments preceding a crash, which can be used to precisely reconstruct crash circumstances when investigating safety incidents.[66]

Second, if data tracking has been the fuel of ADS progress, driving simulation seems bound to become its turbocharger. Machine

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[61] *See generally* JERRY MASHAW & DAVID HARFST, THE STRUGGLE FOR AUTO SAFETY (1990) (chronicling the history of automotive regulation in the United States).

[62] *See generally Data Storage and AI*, *supra* note 51 (describing the amount of data required to functionalize ADS).

[63] *See generally* Grigorescu et al., *supra* note 50, at 8–13.

[64] John Quain, *These High-Tech Sensors May Be the Key to Autonomous Cars*, N.Y. TIMES (Sept. 26, 2019), https://www.nytimes.com/2019/09/26/business/autonomous-cars-sensors.html [https://perma.cc/AV4M-SKV5] (explaining the types of sensors that autonomous cars rely on).

[65] *See* Cynthia Rudin & Joanna Radin, *Why Are We Using Black Box Models in AI When We Don't Need To? A Lesson From an Explainable AI Competition*, HARV. DATA SCI. REV. (Nov. 22, 2019), https://hdsr.mitpress.mit.edu/pub/f9kuryi8/release/6 [https://perma.cc/8TP4-FGW9] ("[E]ven those who design [machine learning algorithms] cannot understand how variables are being combined to make predictions."); *see also* Jessica Newman, *Explainability Won't Save AI*, BROOKINGS (May 19, 2021), https://www.brookings.edu/techstream/explainability-wont-save-ai [https://perma.cc/N9UB-FCKH] (describing the "black box problem" in AI and how the goal of explainability is insufficient given different stakeholders' needs).

[66] By making driving decisions "explainable," I mean that regulators or judges should have the ability to understand the chain of driving decisions made by the ADS system and identify which decisions or failures were responsible for the crash. Only by guaranteeing this level of explainability could regulators or judges define appropriate ADS safety standards. *See infra* note 94–98 and accompanying text.

learning engineers have developed powerful simulation techniques that expose ADS-piloted "virtual vehicles" to a vast array of driving conditions and enable much faster testing of driving performance and safety compared to on-road testing. A year of on-road driving can be simulated in a couple of hours.[67] This opportunity for time savings has become critical as ADS manufacturers are grappling with lingering safety issues: Any updates to their ADS model to account for new safety issues may reset the mileage clock for testing, leading to significant delays if performed on physical roads.[68] Simulation is a reliable tool to analyze road safety because ADS driving behavior is consistent and reproducible.[69] ADS manufacturers are now fiercely competing to build[70] or buy[71] the best-performing simulation tools to give their engineering team an edge in resolving the most challenging ADS safety scenarios.

ADS companies have used driving simulation in ways resembling safety regulation analysis. They have simulated crash counterfactuals to determine what ADS model changes may have prevented a crash—similar to a regulator analyzing what safety standards would prevent a specific type of accident.[72] ADS manufacturers also have used simula-

[67] Luca Castignani, *Road Testing or Simulation?*, MSC SOFTWARE 85 (2019), https://web.archive.org/web/20220325095430/https://www.mscsoftware.com/sites/default/files/road-testing-or-simulation-the-billion-mile-question-for-autonomous-driving-development.pdf [https://perma.cc/8YB7-JSHK] (reporting that while it took ten years for Waymo to accumulate 16 million kilometers on public roads, Waymo simulates 13 million kilometers per day using a fleet of twenty thousand virtual vehicles).

[68] *See* NIDHI KALRA & SUSAN M. PADDOCK, RAND, DRIVING TO SAFETY: HOW MANY MILES OF DRIVING WOULD IT TAKE TO DEMONSTRATE AUTONOMOUS VEHICLE RELIABILITY? 1–3, 10 (2016), https://www.rand.org/content/dam/rand/pubs/research_reports/RR1400/RR1478/RAND_RR1478.pdf [https://perma.cc/MUS6-ACSQ].

[69] *See supra* note 52 and accompanying text. The ADS manufacturer Waabi even claims to be able to "ditch[] real cars" and rely solely on simulation testing. Will D. Heaven, *This Super-Realistic Virtual World Is a Driving School for AI*, MIT TECH. REV. (Feb. 18, 2022), https://www.technologyreview.com/2022/02/18/1045784/simulation-virtual-world-driverless-car-autonomous-vehicle-school-ai-cruise-waabi [https://perma.cc/37C5-G2H5].

[70] Major ADS manufacturers have developed their own simulation tools. *See, e.g.*, *Simulation City: Introducing Waymo's Most Advanced Simulation System Yet for Autonomous Driving*, WAYPOINT: THE OFFICIAL WAYMO BLOG (July 6, 2021), https://blog.waymo.com/2021/06/SimulationCity.html [https://perma.cc/79US-4TA4] (announcing and describing a proprietary simulation system). Open-source solutions also are being developed. *See, e.g.*, CARLA, https://carla.org [https://perma.cc/EN7S-ZUBU] (open-source simulator for autonomous driving research); Pei Li, Arpan Kusari & David J. LeBlanc, *A Novel Traffic Simulation Framework for Testing Autonomous Vehicles Using SUMO and CARLA*, U. OF MICH. TRANSPORT. RSCH. INST. (Oct. 11, 2021), https://arxiv.org/ftp/arxiv/papers/2110/2110.07111.pdf [https://perma.cc/7WEW-3JGV] (open-source framework to simulate complex and realistic driving environment for ADS testing).

[71] An industry has emerged to offer simulation capabilities to ADS developers. *See, e.g.*, APPLIED INTUITION, https://www.appliedintuition.com [https://perma.cc/TLF9-JBLT].

[72] *See infra* note 129 and accompanying text.

tions to assess whether replacing the car's human driver with an ADS would have prevented a crash[73]—akin to a liability analysis evaluating whether a reasonable driver would have crashed in the same scenario. As Part II will show, NHTSA could readily adapt such techniques to design and update its ADS safety standards based on crash data. Instead of investing in innovative regulatory methods leveraging new ADS technologies, however, NHTSA has defaulted to the status quo regulatory model it came to adopt to oversee road safety for traditional cars.

B. The Enduring and Misguided Status Quo in ADS Regulation

On this revolutionary journey, NHTSA has taken a backseat both on the technological and the regulatory lanes. The agency has lagged in building technological ADS expertise and has not adequately considered the use of data tracking and driving simulation as regulatory tools.[74] And it has shied away from issuing definitive guidance on how it intends to regulate ADS. Far from becoming agile and adaptive, NHTSA has adopted a wait-and-see approach, remaining stuck at stage one of a clunky waterfall process.

1. NHTSA's Status Quo

NHTSA is the United States' most important regulator for road safety. Located under the U.S. Department of Transportation,[75] the agency states that its mission is to "[s]ave lives, prevent injuries and reduce economic costs due to road traffic crashes, through education, research, safety standards and enforcement activity."[76] Since 2016, NHTSA has issued four ADS policy guidance documents exuding

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[73] *See infra* notes 130–31 and accompanying text.

[74] The Department of Transportation has not updated its "Artificial Intelligence Activities" webpage since 2019. *See U.S. DOT Artificial Intelligence Activities*, U.S. DEP'T OF TRANSP., https://www.transportation.gov/AI [https://perma.cc/8VQE-VQ92] (last updated Sept. 23, 2019). The agency has been slow to engage with data tracking, the first foundational ADS technology described in Section I.A. NHTSA's policy guidance documents also seem to ignore the ongoing shift to simulation testing. Its latest Advanced Notice of Proposed Rulemaking only considers physical on-road testing to investigate ADS safety—ignoring the option to use simulation testing. *See* Advanced Notice for Proposed Rulemaking, Framework for Automated Driving System Safety, 85 Fed. Reg. 78058 (Nov. 19, 2020) (to be codified at 49 C.F.R. pt. 571), at 55 & n.96 [hereinafter NHTSA ANPRM] (explaining that NHTSA cannot evaluate ADS safety standards yet because it "independently and anonymously purchases vehicles for testing and cannot do so if those vehicles are not being sold to the public").

[75] *Organization Chart*, U.S. DEP'T OF TRANSP., https://www.transportation.gov/org-chart [https://perma.cc/UG83-SHPC] (listing the "U.S. Department of Transportation" as NHTSA's "parent agency").

[76] *NHTSA's Core Values*, NHTSA, https://www.nhtsa.gov/about-nhtsa/nhtsas-core-values [https://perma.cc/L259-FVUU].

enthusiasm for ADS technology and hope for its capacity to reduce road accidents.[77] However, NHTSA has not provided clarity regarding what safety standards should apply to ADS manufacturers to protect the public from ADS-caused crashes.[78]

The little guidance the agency has provided reflects that NHTSA intends to adopt its status quo regulatory approach to ADS. Most importantly, NHTSA has made clear that it intends to preserve states' oversight of ex post crash liability.[79] On the ex ante regulatory side, NHTSA is considering multiple self-regulatory options that would rely on the ADS industry to properly self-police to reach optimal ADS safety levels.[80] In any occasion, NHTSA plans on applying its "established FMVSS [Federal Motor Vehicle Safety Standards] Framework to ADS Safety Principles,"[81] thereby setting minimum standards premarket and occasionally ordering recalls postmarket, on top of which state tort law liability or industry self-regulation would

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[77] *See* NHTSA, FEDERAL AUTOMATED VEHICLES POLICY 5–6 (Sept. 2016) [hereinafter NHTSA GUIDANCE 1.0], https://www.transportation.gov/sites/dot.gov/files/docs/AV%20policy%20guidance%20PDF.pdf [https://perma.cc/6PHG-EPAT] (heralding ADS as "the greatest personal transportation revolution since the popularization of the personal automobile"); NHTSA, AUTOMATED DRIVING SYSTEMS 2.0: A VISION FOR SAFETY ii-iii (2017) [hereinafter NHTSA GUIDANCE 2.0], https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf [https://perma.cc/8MTM-4AA7] (touting ADS' promise to save many lives by preventing the many car crashes due to faulty human behavior); U.S. DEP'T OF TRANSP., AUTOMATED DRIVING SYSTEMS 3.0: PREPARING FOR THE FUTURE OF TRANSPORTATION ii-iii (Oct. 2018) [hereinafter DOT GUIDANCE 3.0], https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf [https://perma.cc/5DGQ-3MEV] (highlighting that transportation automation has the potential to not only increase road safety but also increase productivity and facilitate freight movement); NAT'L SCI. & TECH. COUNCIL, AUTOMATED DRIVING SYSTEMS 4.0: ENSURING AMERICAN LEADERSHIP IN AUTOMATED VEHICLE TECHNOLOGIES 1–5 (2020) [hereinafter NHTSA GUIDANCE 4.0], https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/360956/ensuringamericanleadershipav4.pdf [https://perma.cc/CG4K-HC23] (presenting ADS as an opportunity to strengthen American leadership on technology and innovation).

[78] *See* NHTSA GUIDANCE 1.0, *supra* note 77, at 11–15 (only suggesting voluntary safety data reporting from ADS manufacturers and postponing the articulation of a mandatory safety regime); NHTSA GUIDANCE 2.0, *supra* note 77, at 16 (merely providing a loosely defined framework of "voluntary safety self-assessment" for ADS manufacturers); DOT GUIDANCE 3.0, *supra* note 77, at iv-xi, 35–41 (providing "guiding principles" and elements of a "strategy" to regulate ADS but once again failing to provide any positive vision for what safety regulation of ADS will look like); NHTSA GUIDANCE 4.0, *supra* note 77, at 8–9 (dedicating only one page out of a fifty-page report to safety issues and presenting no concrete path toward defining ADS safety standards).

[79] *See* NHTSA GUIDANCE 1.0, *supra* note 77, at 38 (stating that "[r]egulating motor vehicle insurance and liability" would remain "[s]tates' responsibilities").

[80] NHTSA ANPRM, *supra* note 74, at 34–39 (describing a system of "voluntary mechanisms" under which ADS companies would retain flexibility regarding how to define and ensure safety).

[81] *Id.* at 47.

fill up to "optimal safety."[82] This position of deferring to states or to industry reflects NHTSA's modus operandi in controlling road safety risks.

To fulfill its statutory mission of avoiding "unreasonable risks of accidents,"[83] NHTSA indeed has crystallized on a low-touch regulatory framework deferring significant road safety responsibilities to state tort law and, to a lesser extent, car manufacturers. Usually, NHTSA relies on state tort law to "take up some of the slack" resulting from setting under-deterring nationwide minimum safety standards.[84] State tort law historically has regulated car "actor" drivers and car "product" manufacturers through post-crash liability.[85] By defining post-crash liability, state tort law plays a fundamental role in setting optimal road safety—or, at least, is seen as playing such a role.[86] On rare occasions, NHTSA passes the slack to the private sector by preempting state tort law to provide more flexibility for industry innovation.[87] In all cases, NHTSA provides leeway for manufacturers to self-certify their compliance with its ex ante minimum standards, a form of self-regulation.[88]

A modest role for NHTSA in setting incentives for optimal safety is contingent—not necessary—and departs from Congress's original

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[82] Under its statute, NHTSA has authority to order recalls for vehicles presenting safety defects. *See* 49 U.S.C. § 30119–20 (describing criteria for recalls and "[r]emedies for defects and noncompliance").

[83] 49 U.S.C. § 30102(a)(9).

[84] Shavell, *supra* note 23, at 277; *see also* MASHAW & HARFST, *supra* note 61, at 43–44, 87–92 (arguing that in the 60s and 70s, courts revolutionized product liability law in response to rising car crash casualties, while NHTSA suffered court defeats that weakened its ability to impose safety standards via rulemaking).

[85] *See, e.g.*, Babcock v. Jackson, 12 N.Y.2d 473, 477 (1963) (automobile negligence action by automobile guest against driver's executrix); Volkswagen of America, Inc. v. Young, 321 A.2d 737 (Md. 1973) (suit against car manufacturer for defective car design leading to driver's death).

[86] *See* Teret, *supra* note 21, at 51 (stating that the threat of severe liability for product defects led manufacturers to improve car safety). *But see* MASHAW & HARFST, *supra* note 61, at 43–45, 155 (arguing that although tort law often is considered to be a major car crash deterrent and embodies the "remedial form that our legal culture has always preferred," it has had a modest impact on the broader issue of automobile safety).

[87] *See* Geier v. Am. Honda Motor Co., 529 U.S. 861 (2000) (unsuccessful negligence suit by a woman injured in a car with a lack of passive restraints, despite the model not being required by NHTSA to have passive restraints).

[88] UNDERSTANDING NHTSA'S REGULATORY TOOLS, NHTSA, https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/understanding_nhtsas_current_regulatory_tools-tag.pdf [https://perma.cc/R2PB-B5DL] (explaining that NHTSA's organic statute "creates a self-certification system of compliance"); *see also* ADMIN. CONF. OF THE U.S., RECOMMENDATION 94-1: THE USE OF AUDITED SELF-REGULATION AS A REGULATORY TECHNIQUE (June 16, 1994) [hereinafter RECOMMENDATION 94-1] (presenting self-certification of standard compliance as one form of self-regulation that agencies should consider to reduce costs).

vision for NHTSA's role, which was frustrated by a series of judicial defeats for the agency and negative safety outcomes caused by some of its regulations.[89] These previous setbacks have made NHTSA culturally reluctant to assert broad regulatory authority, especially with regard to early-stage technologies like ADS.[90] In its latest Advanced Notice of Proposed Rulemaking (ANPRM), NHTSA justified its—at least initial—laissez-faire approach by stating that the agency "has learned from previous experiences that establishing FMVSS prior to technology readiness can lead to adverse safety consequences."[91]

A close analysis of ADS technology reveals compelling reasons why the tort law and self-regulation solutions traditionally embraced by NHTSA likely will fail to reach ADS optimal safety—compelling a more ambitious role for NHTSA. Both status quo approaches present grave perils. State tort law would fail to adapt to the transformation, following the ADS "driving" revolution, of the driver that it has regulated for more than a century.[92] Self-regulation would impose more costs than it would save given aggressive and self-serving commercialization practices by manufacturers following the ADS "manufacturing" revolution.

2. Tort Liability: Information-Forcing Tools Fall Short

As long as humans were at the wheel, relying on state tort law to regulate car safety made theoretical sense under Shavell's framework

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[89] MASHAW & HARFST, *supra* note 61, at 95–102 (describing the series of judicial defeats from the 1970s that caused NHTSA to be "[h]aunted by the specter of judicial invalidation"). *See generally* Paccar, Inc. v. Nat'l Highway Traffic Safety Admin., 573 F.2d 632, 643 (9th Cir. 1978) (explaining that a NHTSA standard imposing short stopping distances for trucks increased risks of truck accidents because the brake "antilock" technology on which the standard relied was not mature enough).

[90] *See* MASHAW & HARFST, *supra* note 61, at 19–20, 91–94, 102–03 (explaining that two decisions, Chrysler Corp. v. Dept. of Transp., 472 F.2d 659 (6th Cir. 1972), and *Paccar*, 573 F.2d 632, made it very challenging for NHTSA to regulate novel automotive technologies, after which the agency followed the U.S. legal culture of preferring remedial interventions (by "recalling 'defective automobiles'") to "adopting regulatory standards").

[91] NHTSA ANPRM, *supra* note 74, at 44–45 (recounting the increased safety risks caused by the NHTSA truck stopping distance standard evaluated in *Paccar*).

[92] Mark Geistfeld has pointed out that reliance on state tort law, which many scholars advocate for and NHTSA has endorsed, strikes an uneasy balance given NHTSA's simultaneous assertion that it "strongly encourages States to allow [the Department of Transportation] alone to regulate the performance of [ADS] technology and vehicles." NHTSA GUIDANCE 1.0, *supra* note 77, at 37; Geistfeld, *supra* note 20, at 1677 (2017) ("[H]ow can the states retain this liability regime while also ceding sole regulatory authority to NHTSA? To attain uniformity across the country, state tort law must somehow be adequately coordinated with the federal regulatory regime."). This Note explores this tension further and shows that ADS calls for abandoning the status quo.

for comparing regulation to tort liability.[93] In this context, relying on tort law provided better information-forcing tools and lower administrative costs. Scholars largely have not questioned the continued importance of ex post tort liability following the transition from human to machine driving. Rather, they mostly have analyzed how products liability doctrine could and should adapt in the context of ADS.[94] Some have also ascribed a "compensatory" role to torts in providing damages to ADS crash victims, which this Note does not address.[95] No court opinion, however, has yet clarified how tort doctrines would adapt to self-driving cars.[96]

In the ADS context, state tort law is unlikely to reach optimal safety because tort courts probably would fail to (1) enact and (2) apply effective ADS liability standards. The tort courtroom enjoys the best access to crash information when humans are at the wheel but will lack effective information-forcing tools once machines take over the driver's seat, which will profoundly alter the nature of the "actor" that tort law traditionally has regulated.

First, tort judges would struggle to define liability standards as they would lack the data access and technical expertise necessary to probe into the AI "black boxes" and ensure that ADS driving decisions are "explainable."[97] AI explainability requires appropriate data tracking and model documentation by manufacturers *before* the crash.[98] If no ex ante regulator has set these requirements, the judges hearing cases of first impression almost certainly would lack the tech-

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[93] *See supra* notes 28–29 and accompanying text (describing the four "determinants" identified by Shavell to compare tort and agency regulation as: (1) whether the agency or private parties have better knowledge about the risky activities; (2) whether regulation or tort provides lower administrative costs; (3) whether tort defendants would have the financial ability to compensate for the harm they caused; and (4) whether it is likely that harmed victims will sue under tort law).

[94] *See supra* notes 37–39 and accompanying text.

[95] *See supra* note 35 and accompanying text.

[96] *See supra* note 21 and accompanying text.

[97] *See supra* note 66 (defining "explainability" in the context of ADS driving decisions). Judges only could decide on issues of product defect or causation in ADS crash cases if the ADS driving decisions are sufficiently explainable. *Cf.* Ashley Deeks, *The Judicial Demand for Explainable Artificial Intelligence*, 119 COLUM. L. REV. 1829 (2019) (arguing that judges should demand access to artificial intelligence algorithms at issue in legal cases, which will then shape what explainable AI means).

[98] The machine learning community has focused on building tools for model documentation. *See* Margaret Mitchell, Simone Wu, Andrew Zaldivar, Parker Barnes, Lucy Vasserman, Ben Hutchinson, Elena Spitzer, Inioluwa D. Raji & Timnit Gebru, *Model Cards for Model Reporting*, *in* PROCS. OF THE CONF. ON FAIRNESS, ACCOUNTABILITY, & TRANSPARENCY 220–29 (2019) (providing a framework for AI model reporting to increase transparency and explainability).

nical training to set requirements through judicial precedents.[99] Their ex post inquiry further would be constrained by the extent to which ADS manufacturers limited the amount of potentially incriminating data that they store and by the judges' ability to identify the actionable data that is missing.[100] No court has yet grappled with these issues, and we should doubt that any court could do so effectively.[101]

Second, and most importantly, even with access to pre-crash sensor data and explainable driving decisions, tort juries would struggle to apply traditional tort liability standards to ADS driving conduct. So long as humans have been in the driver's seat, courts have applied the negligence doctrine to the human driver's behavior and the products liability doctrine to manufacturers of defective car components.[102] Many legal commentators have concluded that eliminating human drivers would shift crash responsibility to manufacturers under products liability and have shown optimism in the ability of reasonableness-based design defect doctrines to adapt to ADS.[103] But

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[99] *Cf.* Han-Wei Liu, Ching-Fu Lin & Yu-Jie Chen, *Beyond* State v. Loomis*: Artificial Intelligence, Government Algorithmization, and Accountability*, 27 INT'L J. L. & INF. TECH. 122 (2019) (criticizing the *State v. Loomis* Wisconsin Supreme Court decision as showing this court's failure to understand the workings of AI risk assessment tools and their negative impact on criminal defendants).

[100] There are precedents for car manufacturers avoiding liability because they failed to produce the data necessary to understand crash circumstances. *See, e.g.*, McAlonan v. Tracy, No. L-487-05, 2011 WL 6125 (N.J. Super. Ct. App. Div. 2010) (holding Toyota not liable for defective airbag design when it complied with federal standards even though it did not test for the specific conditions of the accident). ADS manufacturers have lobbied federal regulators to limit the amount of data they must report after ADS-caused crashes. *See* Russ Mitchell, *Autonomous Car Developers Lobby to Defang Safety Data Regulations*, L.A. TIMES (Dec. 31, 2021, 5:00 AM), https://www.latimes.com/business/story/2021-12-31/industry-lobbies-to-defang-safety-data-regulations-for-autonomous-vehicles [https://perma.cc/75HY-JQN2]. But absent data tracking and reporting mandates, manufacturers may exclude incriminating information. *See Storage Almost Full*, *supra* note 15 (reporting that Hyundai only stores what it deems to be "essential" data from its ADS operations, which may exclude data relevant to determine legal liability for ADS failures).

[101] As explained in this Section, courts would lack the technical understanding necessary to prescribe what data ADS should collect to evaluate potential tort liability from an ADS crash, and tort juries would struggle to apply tort doctrines of product defect and causation to ADS' AI-based driving decisions. Part II shows that data tracking and driving simulation would prove much superior information tools—by leveraging ADS' perfect memory and the reproducible nature of their driving decisions—and end the need for tort trials.

[102] *See, e.g.*, Babcock v. Jackson, 191 N.E.2d 279 (N.Y. 1963) (applying negligence doctrine to driver in car accident); Volkswagen of America, Inc. v. Young, 312 A.2d 737 (Md. 1974) (applying negligent design doctrine to manufacturer after car accident).

[103] *See* Geistfeld, *supra* note 20, at 1619 ("To date, scholars have reached 'the shared conclusion' that elimination of a human driver will shift responsibility onto manufacturers as a matter of products liability law, with most tort litigation involving claims for design or warning defects." (quoting NAT'L ACADS. OF SCIS., ENG'G, & MED., A LOOK AT THE LEGAL ENVIRONMENT FOR DRIVERLESS VEHICLES 35 (2016), https://nap.nationalacade

others compellingly have pointed to crucial differences between evaluating reasonableness or causation for human crashes and ADS crashes.[104] Applying any of the three most common products liability doctrines would present major challenges. A consumer expectation test (which imposes liability if the product fails to meet the reasonable expectations of consumers[105]) would be inappropriate: Humans would struggle to grasp the extent to which ADS should have super-human capabilities.[106] Under "risk-utility" (which evaluates whether the product design's utility outweighs its inherent risks[107]), ADS manufacturers would argue that crash risks not captured by their already protracted model training and testing process are few and far between and not worth imposing the prohibitive financial costs of further ADS testing—which may deter the manufacturing of ADS entirely. Showing "alternative design" (which evaluates whether there exists a reasonable alternative design that would make the product reasonably safe[108]) would also prove challenging. AI models are not designed as car components are; data scientists have less control over how the

mies.org/catalog/23453/a-look-at-the-legal-environment-for-driverless-vehicles [https://perma.cc/H8PW-5QBP])); *see also supra* text accompanying note 35.

104 Andrew Selbst, a law professor with advanced degrees in electrical engineering who has focused on the ability of tort law to adapt to AI, notably stated that standard products liability doctrine "may not work" for ADS liability given the "incompatibility of [AI models'] statistical logic with individual case outcomes." Andrew D. Selbst, *Negligence and AI's Human Users*, 100 B.U. L. Rev. 1315, 1375 (2020); *see also* Abraham & Rabin, *supra* note 19, at 143 ("[G]iven the greatly heightened complexity and sophistication of [ADS computer systems], judicial and jury assessment of the acceptable limits of engineering capability for alleged design defects . . . will come to be needlessly contentious and costly."). Jury evaluation would be further complicated by the trade secrets surrounding ADS systems. *See* Selbst, *supra*, at 1365 ("As a result of the secrecy, we know little of what individual companies have learned about the errors and vulnerabilities in their products. Under these circumstances, it is impossible for the public to come to any conclusions about what kinds of failures are reasonable or not.").

105 *See* Restatement (Second) of Torts, § 402A cmt. i (Am. L. Inst. 1965) (stating that for a product to be unreasonably dangerous, "[t]he article sold must be dangerous to an extent beyond that which would be contemplated by the ordinary consumer who purchases it, with the ordinary knowledge common to the community as to its characteristics").

106 *See* David Danks & Alex John London, *Algorithmic Bias in Autonomous Systems*, *in* Proceedings of the Twenty-Sixth International Joint Conference on Artificial Intelligence 4691, 4694 (Carles Sierra ed., 2017) (identifying issues of human-machine "interpretation bias").

107 *See* Barker v. Lull Engineering Co., 537 P.2d 443, 446 (Cal. 1978) (establishing the risk-utility standard of defective design as an alternative to the "unreasonably dangerous" standard).

108 *See* Restatement (Third) of Torts: Products Liability § 2(b) (Am. L. Inst. 1998) (stating that a product "is defective in design when the foreseeable risks of harm posed by the product could have been reduced or avoided by the adoption of a reasonable alternative design . . . and the omission of the alternative design renders the product not reasonably safe").

product functions and instead code their models to probabilistically maximize aggregate performance.[109] In all cases, the probabilistic nature of ADS models would prevent juries from reliably evaluating tort's reasonableness and causation elements.[110]

Relying on expert witnesses or adopting an easier-to-administer strict liability standard would not resolve these ADS-specific issues. Unlike in other domains, AI models' inner workings often evade technical experts—and sometimes even the models' own designers.[111] A plaintiff's expert, without the ability to mandate data tracking for explainability ex ante or access to advanced simulation tools to reconstruct crash circumstances ex post, would prove equally powerless in assessing ADS liability. Adopting strict liability would not solve all these administrability issues, as juries still would face the same challenges in evaluating causation.[112] Additionally, strict liability may over deter ADS manufacturers and inflict costly delays—in lives not saved—to the broader deployment of commercial ADS.[113]

Given the challenges described above in accessing the necessary ADS crash data, applying traditional car crash liability doctrines to machine-driven cars, and evaluating product liability causation for probabilistic products, both state and federal courts would be ill-equipped to build the necessary technical expertise for effective ADS tort trials. But state courts may be at an even greater disadvantage given the lower financial and technological resources of state judiciaries.

3. Self-Regulation: Standards Plateau Below Optimal Safety

When regulating human-driven cars, NHTSA's reliance on self-regulation also was theoretically justified. In this context, the benefits of self-regulation—such as decreased administrative costs and better safety outcomes[114]—outweighed its costs[115]—including risks of cartel behavior, gradual loss of resources and expertise at the agency, lack of

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[109] *See* Geistfeld, *supra* note 20, at 1645–47.

[110] *See* Smith, *supra* note 17, at 47 (explaining that because AI drivers act as probabilistic agents, plaintiffs often would fail to causally connect model design or training changes to the actual harm).

[111] *See supra* note 65 and accompanying text.

[112] *See supra* note 110 and accompanying text.

[113] *See* Geistfeld, *supra* note 20, at 1639 (warning against application of a strict liability rule, the uncertainty of which could impede the widespread deployment of crash-reducing ADS technology); *cf.* Abraham & Rabin, *supra* note 19, at 132 (advocating for imposing strict ADS liability, but only once ADS represents twenty-five percent of all road vehicles to avoid deterring early adoption).

[114] *See* RECOMMENDATION 94-1, *supra* note 88, at 1. The benefits of self-regulation may be greater when the regulated industry's technical and operational expertise greatly facilitates compliance testing or even the formulation of regulatory rules. *See id.* at 2.

accountability, and under-enforcement.[116] A few scholars have advocated for providing more flexibility for safety innovation from the private sector by relying on self-regulation via industry standards or preempting tort law with NHTSA's FMVSS safety regulations.[117] Still, the recent accidents caused by car automation, as well as the response by manufacturers, do not inspire confidence in the industry's ability to adequately self-regulate.[118]

Indeed, a laissez-faire approach entrusting ADS manufacturers to independently reach an appropriate level of safety beyond NHTSA's FMVSS minimums is misguided as well. Under agile manufacturing, the regulated product overseen by automotive regulation has become dynamic instead of static. This counsels against providing manufacturers more flexibility to self-regulate via industry standards. Self-regulatory options, which raised little concern for traditional cars, present both short-term and long-term risks for ADS.

Self-regulation or delayed regulation would lead to short-term safety risks upon ADS commercialization. Without premarket constraints, manufacturers may aggressively push to market car products with remaining safety defects, essentially using consumers as road safety "guinea pigs."[119] Tesla's Autopilot feature has caused scores of deaths and has been criticized for being rolled out as a "beta" ver-

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[115] For example, letting manufacturers self-certify their compliance with FMVSS enabled administrative efficiencies—and potentially safety innovation—while the specter of tort liability preserved manufacturers' accountability. *See* NHTSA, Notice Regarding the Applicability of NHTSA FMVSS Test Procedures to Certifying Manufacturers, 85 Fed. Reg. 83143, 83147 (Dec. 21, 2020) (highlighiting that NHTSA's self-certification approach serves "safety-innovation goals" by giving more flexibility to manufacturers); *see also* ADMIN. CONF. OF THE U.S., RECOMMENDATION 2012-7: AGENCY USE OF THIRD-PARTY PROGRAMS TO ASSESS REGULATORY COMPLIANCE 1, 6 (2012) (recommending that agencies evaluate self-certification programs—which require "regulated entities to self-assess and report their compliance"—for their potential to "achieve efficiencies through reducing [the agency's] direct compliance assessment costs and resource needs"); Jennifer M. Pacella, *If the Shoe of the SEC Doesn't Fit: Self-Regulatory Organizations and Absolute Immunity*, 58 WAYNE L. REV. 201, 201 (2012) (identifying liability as promoting accountability and protection from liability as contributing to a lack of accountability). In addition, NHTSA's decision to preempt state laws regarding passive restraint systems (which limits the regulatory burden on manufacturers) has fostered safety innovation by manufacturers. *See* Geier v. Am. Honda Motor Co., 529 U.S. 861, 875 (2000).

[116] *See, e.g.*, Benjamin P. Edwards, *The Dark Side of Self-Regulation*, 85 U. CIN. L. REV. 573, 605 (2017) (warning against the risks of cartel behavior); Pacella, *supra* note 115 (warning against potential lack of accountability and lack of enforcement).

[117] *See supra* notes 38–40 and accompanying text.

[118] *See* NTSB Letter, *supra* note 5, at 2 (highlighting recent accidents involving ADS); *see also infra* note 121 and accompanying text (discussing how Tesla has responded to ADS crashes by blaming human drivers or passengers).

[119] Joann Muller, *We're All Guinea Pigs for Tesla's Latest Self-Driving Tech*, AXIOS (Oct. 23, 2020), https://www.axios.com/2020/10/23/tesla-self-driving-beta-software [https://perma.cc/W6MF-D3L9].

sion.[120] Tesla and other leading ADS manufacturers have responded to the accidents by blaming the humans in the car.[121] Relying on manufacturers to self-police on ADS safety may transform NHTSA into a "tombstone agency," the moniker infamously earned by the FAA after it failed to prevent avoidable deaths from flight automation—a parallel transportation technology.[122] Standard-setting bodies within the automotive industry, such as Underwriters Laboratories, have mounted efforts to build consensus industry standards to harmonize ADS safety approaches.[123] Their first released safety frameworks offer wide flexibility for ADS manufacturers to define the standards they intend to uphold and to self-evaluate, which would fail to generate adequate incentives for optimal safety.[124]

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[120] Greg Bensinger, Opinion, *Why Tesla's 'Beta Testing' Puts the Public at Risk*, N.Y. TIMES (July 30, 2021), https://www.nytimes.com/2021/07/30/opinion/self-driving-cars-tesla-elon-musk.html [https://perma.cc/HYB9-FACA].

[121] Neal E. Boudette, *Tesla Says Autopilot Makes Its Cars Safer. Crash Victims Say It Kills.*, N.Y. TIMES (Sept. 1, 2021), https://www.nytimes.com/2021/07/05/business/tesla-autopilot-lawsuits-safety.html [https://perma.cc/4SX8-ZVH3] ("The company has often faulted drivers of its cars, blaming them in some cases for failing to keep their hands on the steering wheel and eyes on the road while using Autopilot."); Jack Stilgoe, *Tesla Crash Report Blames Human Error – This Is a Missed Opportunity*, THE GUARDIAN (Jan. 21, 2017, 6:10 AM), https://www.theguardian.com/science/political-science/2017/jan/21/tesla-crash-report-blames-human-error-this-is-a-missed-opportunity [https://perma.cc/FRN7-EZQF] (noting that some consumer groups denounced an ADS crash report by NHTSA that "accepted Tesla's line and blamed the human, rather than the 'Autopilot' technology and Tesla's aggressive marketing"); *see also* Sam Levin, *Uber Blames Humans for Self-Driving Car Traffic Offenses as California Orders Halt*, THE GUARDIAN (Dec. 15, 2016, 12:25 PM), https://www.theguardian.com/technology/2016/dec/14/uber-self-driving-cars-run-red-lights-san-francisco [https://perma.cc/U84U-BQE2]; Answer to Plaintiffs' Original Petition, Affirmative Defenses and Jury Demand at paras. 7–8, Fields v. Tesla, No. 2021-162207 (Tex. Dist. Ct. 80th Oct. 22, 2021) (disclaiming responsibility for plaintiffs' alleged injuries and identifying responsible third parties). In late 2022, California passed a law banning Tesla from advertising its Autopilot feature as "Full Self-Driving." *See* Ricardo Cano, *New California Law Bans Tesla from Advertising as Fully Self-Driving*, GOV. TECH. (Dec. 23, 2022), https://www.govtech.com/policy/new-california-law-bans-tesla-from-advertising-as-fully-self-driving [https://perma.cc/NNF4-BP8Q] (explaining that the California legislature passed this law to prevent what it deemed to be "deceptive and misleading" marketing by Tesla).

[122] *See supra* note 8 and accompanying text. The FAA's deferral of authority to plane manufacturers to self-certify safety also led to two Boeing 737 Max tragic accidents in 2019, killing 346 people. Sinéad Baker, *FAA Boss Says It Let Boeing Partly Self-Regulate the Software Thought to Be Behind Both Fatal 737 Max Crashes*, INSIDER (Mar. 28, 2019, 8:46 AM), https://www.businessinsider.com/faa-let-boeing-self-regulate-software-believed-737-max-crashes-2019-3 [https://perma.cc/3DBY-5HVJ].

[123] *See* Press Release, Underwriters Laboratories, Underwriters Laboratories Publishes UL 4600 Autonomous Vehicle Standard (Apr. 1, 2020), https://ulse.org/news/underwriters-laboratories-publishes-ul-4600-autonomous-vehicle-standard [https://perma.cc/CBN7-L5AN].

[124] *See* Underwriters Laboratories, Proposed First Edition of the Standard for Safety for the Evaluation of Autonomous Products, UL 4600, at 41–51 (Dec. 13, 2019), https://users.ece.cmu.edu/~koopman/ul4600/191213_UL4600_VotingVersion.pdf [https://perma.cc/

Even if future industry standards prove more prescriptive, self-regulation probably would not reach long-term optimal safety. The industry may settle on a plateau of "good enough" safety instead of pushing forward to optimal safety, leaning on a narrative that "good enough" ADS safety already offers unprecedented safety benefits. The ADS lobby has built its public relations campaign on the idea that ADS, even if imperfect, still would save many lives as long as they are sufficiently safer than humans.[125] But "sufficiently" safe is unlikely to mean optimally safe, especially if defined by self-interested industry actors.[126] To fulfill its statutory mandate, NHTSA should not settle for this plateau but instead should ensure that ADS vehicles are still learning toward an optimal level of safety.[127] The agency has the regulatory authority to mandate granular data reporting for all ADS crashes,[128] which standard-setting industry bodies could not replicate. ADS technological advances can equip NHTSA to embrace a model of adaptive regulation that matches the industry's agile and adaptive commercialization processes by continuously improving safety standards. By doing so, NHTSA would become an unprecedentedly effective optimal regulator for road safety.

II
Crash-Adaptive Optimal Regulation of ADS Safety: A New Model for NHTSA

Realizing the full promise of ADS safety will require NHTSA to depart from its regulatory status quo and assume a much more significant role in controlling residual risks of ADS crash to reach optimal safety. As a first theoretical move, this Note shows that the ADS revolution turns on its head the conventional wisdom stating that tort

6HPH-YJXH] (requiring ADS manufacturers to provide "arguments" and "evidence" for why their ADS is safe enough but leaving them leeway to justify the appropriateness of their safety precautions and the option to self-certify compliance).

125 *See* Nellie Bowles, *Uber, Google and Others Form Self-Driving Car Lobby to Shape US Policy*, The Guardian (Apr. 27, 2016, 1:07 PM), https://www.theguardian.com/technology/2016/apr/26/uber-google-lyft-ford-volvo-self-driving-car-lobby [https://perma.cc/KV2W-JLZH]; Plungis & Naughton, *supra* note 42 (describing a U.S. Senate hearing emphasizing that ADS—unlike humans—never get distracted and therefore would prevent collisions).

126 To be sure, even a plateau of "sufficiently" safe ADS driving could save many lives if it replaced human driving. Securing ADS' immediate promise, however, should not come at the expense of realizing their long-term potential. This Note identifies a regulatory path to reach this full potential that both ADS proponents and skeptics have missed.

127 *See supra* notes 54, 57 and accompanying text (describing the agile model of manufacturing and the fact that ADS keep learning even after being put on the market).

128 NHTSA started using this authority through its June 2019 Order, albeit unsatisfactorily by asking for much less data than it could have given ADS' powerful data capabilities. *See* NHTSA Crash Reporting Order, *supra* note 14.

law is a better tool than agency regulation to regulate car safety. This Part sheds light on the unprecedented opportunity that new data tracking and simulation technologies offer NHTSA to become an optimal regulator. By establishing a model of crash-adaptive optimal regulation, NHTSA could analyze premarket and postmarket crash data to continuously optimize its ADS safety standards based on new safety information.

A. Using ADS Data Technology for Regulatory Purposes

The data tracking and simulation technologies that ADS manufacturers have used commercially could become a regulatory game changer for NHTSA. While manufacturers have used data tracking and simulation to continuously monitor, evaluate, and improve their ADS products, NHTSA could use the same technology to continuously monitor ADS safety risks, evaluate potential safety standards, and improve its regulatory regime toward optimal ADS safety. When evaluating ADS accidents during on-road testing, engineers determine whether the ADS behavior leading to the crash could have been avoided by imposing more stringent but still reasonable safety constraints (in which case they would update their model).[129] NHTSA would conduct similar analyses when designing safety standards or investigating ADS crashes. Skirting even closer to road safety regulatory analysis, Waymo has recently used simulation counterfactuals to make marketing claims regarding how safe its ADS are.[130] The company's engineers reconstructed dozens of fatal crashes that occurred in Arizona in the past decades, replaced the human driver with their ADS in the simulation, and claimed that their ADS would not have crashed in the same safety situations.[131] Adapting similar methods to safety regulation, regulators could simulate crash counterfactuals to determine what safety requirements may have prevented a crash.[132]

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[129] For example, after its self-driving car almost hit a jogger, Apple updated its ADS to better identify pedestrians. *See* Ma, *supra* note 48. Apple said that the car mistakenly identified the jogger as a stationary object, then a stationary person, until finally identifying it as a moving person. *Id.* Apple determined that the car almost certainly would have hit the jogger if the backup driver had not intervened and implemented a fix to avoid similar accidents in the future. *Id.*

[130] Andrew J. Hawkins, *Waymo Simulated Real-World Crashes to Prove Its Self-Driving Cars Can Prevent Deaths*, THE VERGE (Mar. 8, 2021, 3:00 PM), https://www.theverge.com/2021/3/8/22315361/waymo-autonomous-vehicle-simulation-car-crash-deaths [https://perma.cc/T7Y7-4W4K].

[131] *Id.*

[132] The literature on AI in the administrative state has recognized that agencies should build AI internal capacity not only to effectively regulate AI products, but also to leverage AI in how they design and operationalize regulation. *See, e.g.*, DAVID FREEMAN ENGSTROM, DANIEL E. HO, CATHERINE M. SHARKEY & MARIANO-FLORENTINO

NHTSA has acknowledged the promise of simulation technology for evaluating safety risks in specific driving situations but has not considered using simulations to inform its standard-setting activities.[133]

NHTSA should follow the ADS industry's lead in using data tracking and simulation as post-crash information-forcing tools. Because of the heightened focus on simulation by the ADS industry, we can expect driving simulation technology to keep improving to the point where it will prove invaluable to ADS regulators.[134] The agency's current plans for post-crash information forcing—collecting crash narratives in PDF documents to inform ex ante standards[135] and deferring to tort proceedings to refine standards ex post[136]—tries to fit a model developed for human driving oversight to the fundamentally different challenge of machine driving oversight. Unlike a tort court, ADS engineers do not ask human witnesses to recount crash circumstances, which we saw would fall short with ADS crashes.[137] They ask the most reliable witness, the self-driving car itself, which has perfect memory.[138] Unlike traditional car manufacturers, ADS manufacturers control the agent that will drive their product users and can preprogram this agent to consistently and reproducibly follow specific safety requirements.[139] Because manufacturers control the driving agent both premarket and postmarket, NHTSA could impose data tracking mandates and use information derived from post-crash regulatory analysis to dynamically update its safety standards—manufacturers then could dynamically update their models to comply.

CUÉLLAR, GOVERNMENT BY ALGORITHM: ARTIFICIAL INTELLIGENCE IN FEDERAL ADMINISTRATIVE AGENCIES 71–74 (2020); Deirdre K. Mulligan & Kenneth A. Bamberger, *Procurement as Policy: Administrative Process for Machine Learning*, 34 BERKELEY TECH. L.J. 773, 822–24 (2019). In a parallel to how NHTSA could leverage driving simulation, the Food and Drug Administration (FDA) has built research programs and public-private partnerships to explore the use of "in silico [simulated] clinical trials," which could boost the speed and representativeness of drug testing. Tina Morrison, *How Simulation Can Transform Regulatory Pathways*, FDA (Aug. 9, 2018), https://www.fda.gov/science-research/about-science-research-fda/how-simulation-can-transform-regulatory-pathways [https://perma.cc/C8PC-XBA9].

133 *See* NHTSA ANPRM, *supra* note 74, at 25–26 (explaining how ADS simulation tools such as Instantaneous Safety Metric (ISM) and Model Predictive Instantaneous Safety Metric (MPrISM) could identify dangerous car trajectories in real-time and estimate "safety risk[s] associated with the given snapshot of the driving state," but failing to consider leveraging such tools to design and update crash-adaptive safety standards).

134 *See supra* notes 69–71 and accompanying text.

135 *See supra* note 14 and accompanying text.

136 *See supra* note 79 and accompanying text.

137 *See supra* Section I.B.2.

138 *See supra* Section I.A.

139 *See supra* note 52 and accompanying text.

B. A Framework for Crash-Adaptive Optimal Regulation

Harnessing data tracking and simulation technologies would enable NHTSA to become an optimal regulator, under a model that I call "crash-adaptive optimal regulation." NHTSA would collect and analyze crash data both premarket and postmarket, plugging into the industry's data tracking functionalities and adopting its simulation techniques to maximize road safety across manufacturers. First, NHTSA would mandate ADS manufacturers to collect the data necessary to reconstruct crashes after the fact through ADS simulations.[140] Following an ADS crash, NHTSA would (1) collect crash reconstruction data from the ADS data tracking capabilities;[141] (2) reconstruct the crash events through its own driving simulator to evaluate whether the ADS decision maintained a reasonable level of risk throughout the crash event;[142] and (3) decide whether to update its ADS safety standards to prevent future occurrences of similar accidents based on the safety insights garnered from this evaluation. Using simulations to analyze the crash circumstances, NHTSA could, at low cost,[143] generate counterfactuals to determine the list of actions the ADS could have taken to avoid the crash (e.g., brake one second earlier, or detect a pedestrian three seconds faster). Based on this list of redemptory ADS actions, NHTSA then could determine the best safety standard to issue to avoid this type of crash while minimizing the societal costs of regulation.[144] By adopting such data tracking and simulation regulatory tools, NHTSA would access the most accurate

[140] NHTSA could compel ADS manufacturers to submit the ADS tracking data necessary for crash reconstruction. *See* Stephen P. Wood, Jesse Chang, Thomas Healy & John Wood, *The Potential Regulatory Challenges of Increasingly Autonomous Motor Vehicles*, 52 SANTA CLARA L. REV. 1423, 1438–47 (2012) (detailing NHTSA's authority to regulate ADS).

[141] The FDA has similarly required drug manufacturers to submit "adverse event reports" following health incidents caused by their drugs. Catherine M. Sharkey & Kevin M.K. Fodouop, *AI and the Regulatory Paradigm Shift at the FDA*, 72 DUKE L.J. ONLINE 86, 102 & n.74 (2022).

[142] NHTSA need not fully develop simulation technologies in-house. It could partner with a private vendor, as long as it keeps a firm grip on the technology's requirements and its inner workings. *See* ENGSTROM ET AL., *supra* note 132, at 89–90; *cf.* Mulligan & Bamberger, *supra* note 132, at 831–40 (arguing that it is primordial for agencies to build technical expertise and maintain visibility over and understanding of any AI model they use for policymaking). Multiple simulation-as-a-service companies have emerged and would be great candidates to consider for such a public-private partnership. *See supra* notes 69–70.

[143] *See infra* notes 163–64 and accompanying text.

[144] To determine the most efficient standard, NHTSA would calculate the benefits and the costs generated by potential standards. Here as well, simulation techniques could prove helpful. ADS manufacturers rely on similar simulation techniques when testing their ADS driving performance via simulations. *See supra* notes 68–69 and accompanying text. Generating crash counterfactuals focuses on simulating the specific circumstances of an

and comprehensive safety information-forcing tools ever available to optimally control a ubiquitous safety risk.

After moving to a crash-adaptive model, NHTSA's premarket and postmarket regulatory analysis would converge. After an on-road crash, NHTSA's premarket and postmarket oversight would perform essentially the same crash safety analyses, although they may lead to different remediation requirements for manufacturers. Premarket crash remediation could involve a request to extend the premarket testing period or a mandate to update the ADS software to address specific unreasonable safety risks before commercializing the ADS.[145] Postmarket crash remediation could involve a software update through "over-the-air" recall[146] to address specific unreasonable safety risks or a physical vehicle recall if such risks cannot be mitigated.[147] At each stage, this crash-adaptive model would act as a federal regulatory optimization process pushing NHTSA's rules closer to their societally optimal level. This convergence between premarket and postmarket oversight activity stems from the dynamic interplay between the regulated activities of ADS driving and manufacturing. A

individual crash, whereas calculating the benefits and costs from a proposed standard would simulate safety outcomes across all U.S. drivers, passengers, and pedestrians.

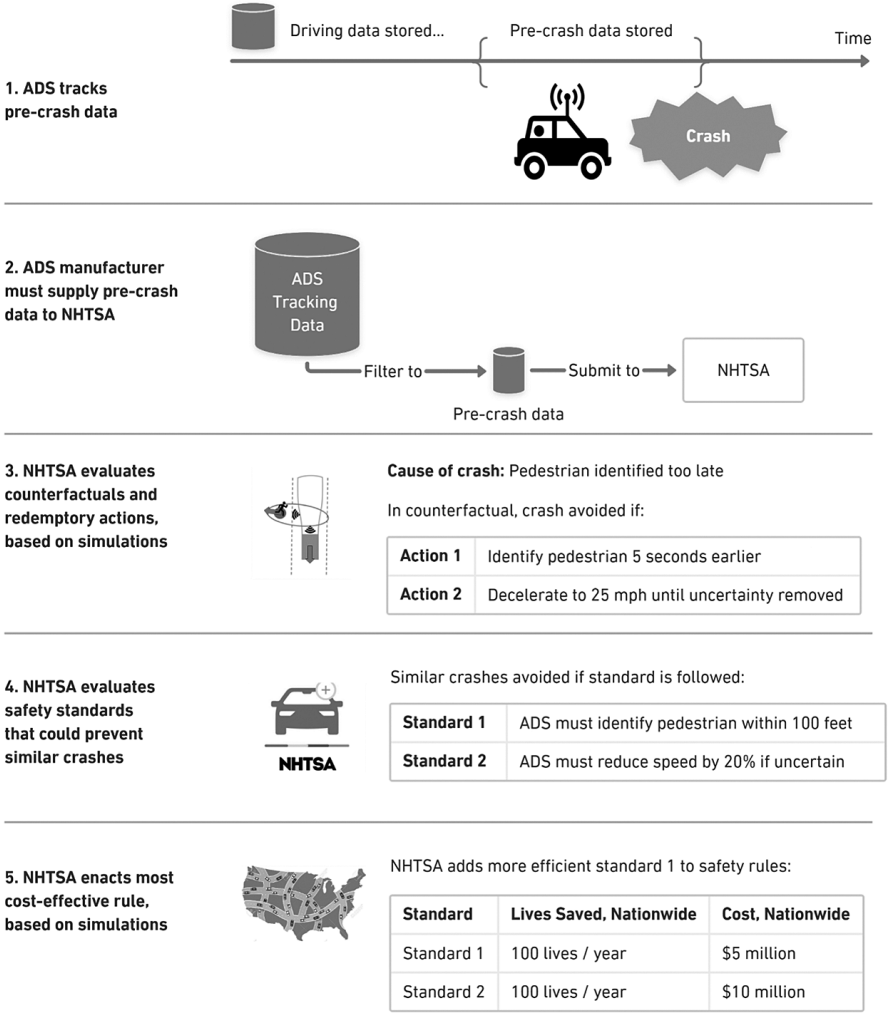
[145] NHTSA does not operate a premarket approval regime but instead lets manufacturers self-certify that they comply with all NHTSA safety regulations. Notice Regarding the Applicability of NHTSA FMVSS Test Procedures to Certifying Manufacturers, 85 Fed. Reg. 83143, 83145 (Dec. 21, 2020) ("Under the system of self-certification established by the Safety Act, NHTSA does not pre-approve vehicles, through testing or other means, before they can be sold or otherwise introduced into interstate commerce. Instead, . . . vehicles must be certified as compliant by the manufacturer."). Still, NHTSA already has the statutory authority necessary to impose the premarket remediation steps envisioned by the crash-adaptive model: Under its current regime, it could issue opinion letters stating that the manufacturer does not comply with its standards and threaten a future recall if the manufacturer self-certifies and commercializes its ADS without making the necessary updates. *See supra* note 81. Some scholars have argued that Congress should grant NHTSA additional authority to block ADS commercialization until NHTSA grants the vehicle premarket approval. *See, e.g.*, Yacoub & Briggs, *supra* note 43, at 1 ("[T]his article proposes conferring a regulatory authority upon [NHTSA] to review emerging technologies such as [ADS] vehicles before they are released to the public."). While this could facilitate NHTSA's oversight of short-term risks at ADS commercialization, *see supra* Section I.B.3, it would not be necessary to implement the crash-adaptive regulatory model this Note proposes.

[146] An "over-the-air" recall addresses safety risks by updating the car's software instead of physically recalling vehicles. Carolyn Fortuna, *Is "Recall" Really the Right Word in the Era of Auto Over-the-Air Updates?*, CLEANTECHNICA (July 24, 2022), https://cleantechnica.com/2022/07/24/is-recall-really-the-right-word-in-the-era-of-auto-over-the-air-updates [https://perma.cc/R5WX-NLSS].

[147] NHTSA already has the necessary statutory authority to order such software updates via recall. *See supra* note 81. Indeed, Tesla has responded to multiple NHTSA recall orders via over-the-air recall. Steven Loveday, *NHTSA Issues Another Recall Related to Tesla's Boombox Feature*, INSIDEEVS (Apr. 15, 2022, 9:36 AM), https://insideevs.com/news/580195/tesla-safety-recall-boombox-feature-summon [https://perma.cc/B6UA-8Q5Y].

still-learning ADS keeps being manufactured while it drives.[148] Merely focusing on premarket manufacturing testing would blind regulators not only to the future evolution of the driving system but to new safety risk scenarios not uncovered in premarket testing, which can never be comprehensive.[149]

IMAGE 2. STEPS OF PROPOSED CRASH-ADAPTIVE RULE UPDATES BY NHTSA



148 *See supra* notes 53–56 and accompanying text.

149 *See* KALRA & PADDOCK, *supra* note 68, at 10 (concluding that comprehensive testing before commercialization is impossible). Although some ADS regulatory commentators have put their faith in premarket testing, *see, e.g.*, Geistfeld, *supra* note 20; Yacoub & Briggs, *supra* note 43, this Note argues that an adaptive regulatory model incorporating new crash information will prove superior.

The idea of expanding ex ante regulation into a continuous regime of adaptive regulation to respond to AI products is not new[150] and is especially appropriate in the ADS context. Rachel Sachs has argued that an adaptive regulatory model may be particularly useful for what she categorizes as "intermediate technologies," i.e., technologies that follow agile iterative cycles of development and continue to be improved over time even after products are made available to consumers, of which ADS are a prime example.[151] Putting theory to practice, the Food and Drug Administration (FDA) is experimenting with various models of adaptive regulatory management in its oversight of AI medical devices—which, like ADS, also involve AI agents making life-death decisions.[152] It has recognized the need to adjust its approval process to the dynamic nature of AI models and is adopting an AI-tailored "total product lifecycle-based regulatory oversight."[153] The technical features and subject matter of ADS make them an even better candidate for data-driven adaptive regulation than the AI medical devices overseen by the FDA. ADS collect more granular data than medical devices, and the impact of their driving decisions on surrounding cars is easier to model than the impact of medical devices' operations on patients' health and physiology.[154]

C. Justifications for Agency Regulation over Tort and Self-Regulation

NHTSA's shift to a crash-adaptive model is justified on theoretical—not only pragmatic—grounds. Under the theoretical frameworks discussed in Part I, agency regulation becomes the most effective lever to control road safety risks, superior to both tort liability and self-regulation. We saw that given the technical features of ADS driving and the dynamic nature of ADS manufacturing, relying on torts and self-regulation would impose great societal costs.[155] The availability of crash-adaptive regulation further alters the equations

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150 *See supra* note 43 and accompanying text.

151 *See* Sachs, *supra* note 44, at 220–22, 268–71.

152 *See* U.S. Food & Drug Admin., Artificial Intelligence/Machine Learning (AI/ML)-Based Software as a Medical Device (SaMD) Action Plan 1 (Jan. 2021), https://www.fda.gov/media/145022/download [https://perma.cc/Z6PV-F2U5].

153 *Id.* at 1.

154 The FDA has used AI to analyze medical "adverse events" from drugs and AI medical device operations. *See* Sharkey & Fodouop, *supra* note 141, at 95–97. Similarly, NHTSA's crash-adaptive regulatory model would take regulatory action based on car crash adverse events.

155 *See supra* Sections I.B.2, I.B.3.

comparing agency regulation to torts and to self-regulation.[156] Under Shavell's framework, agency crash-adaptive regulation would operate on lower administrative costs than tort courts (Shavell's second factor) leveraging automated data gathering and analysis[157] and—most importantly—would have better access to post-crash information than tort courts (Shavell's first factor), which would lack effective information-forcing tools.[158] Having "perfect memory," the self-driving car will prove a much more reliable witness than the involved humans, but it will speak the language of data and simulation. Equipping the fifty tort systems with data and simulation technology would prove daunting and—if feasible at all—extremely costly. But without such technology, the tort judges and juries, besides struggling with resolving the controversy at hand,[159] may do a "poor job" at setting a societally optimal liability standard without ADS technical expertise.[160]

TABLE 1. NHTSA'S STATUS QUO MODEL VS. CRASH-ADAPTIVE OPTIMAL REGULATION MODEL[161]

	Risk Control Method	Institution	Ex Ante	Ex Post
Status Quo Regime	Ex Ante Regulation	NHTSA	Safety standards setting minimum safety	
	Ex Post Tort Liability	Tort		Crash liability complementing regulation to optimal safety
	Self-Regulation	Industry	Reliance on industry to reach optimal safety	Reliance on industry to correct toward optimal safety
Proposed Regime	Crash-Adaptive Optimal Regulation	NHTSA	Safety standards aiming at optimal safety	Updated safety standards getting closer to optimal safety

Crash-adaptive optimal regulation also would prove more cost-efficient than self-regulation: It would avoid the high societal costs (in lost safety and increased accidents) of self-regulation described above[162] while keeping administrative costs under control for both the

156 *See supra* notes 25–26 and accompanying text (identifying the four factors of Shavell's framework comparing the desirability of tort liability and agency regulation in different contexts).

157 *Id.*

158 *See supra* Section I.B.2.

159 *Id.*

160 Richard B. Stewart, *Regulatory Compliance Preclusion of Tort Liability: Limiting the Dual-Track System*, 88 GEO. L.J. 2167, 2173 (2000) (arguing that "the tort system generally does quite a poor job" in making societal risk-benefit tradeoffs).

161 This table excludes NHTSA's ex post recall activity, as it enforces safety standards but does not define them.

162 *See supra* Section I.B.3.

government and corporations. ADS companies already track the vast majority, if not all, of the necessary data for crash-adaptive regulatory analysis[163] and would only need to submit such information after crashes—a supposedly rare event if ADS manufacturers keep up to their promises. Compared to self-regulation, under which each manufacturer analyzes its own crashes independently, crash-adaptive regulation also would have the significant benefit of propagating safety benefits learned from one crash to all car manufacturers. Analyzing crashes generates new insights into what rare driving situations may be challenging for ADS to safely manage, which even extensive premarket testing may not discover. A regulator has the ability and incentives to propagate the corresponding safety requirements to every manufacturer under its jurisdiction, making all local ADS safer—not only the ADS from the manufacturer that experienced the rare crash situation.[164] For example, after analyzing a crash where a Waymo ADS failed to detect a pedestrian wearing grey clothes matching the road's color, the regulator would realize the risk of ADS failing to distinguish objects of similar color and could issue a new mandate for all ADS to, for example, "detect pedestrians wearing clothes whose color matches their environment from a 100-feet distance."[165]

Transforming its automotive regulatory model to become crash-adaptive would present major challenges for NHTSA, but these challenges are not insurmountable. This transformation will require Congress to grant NHTSA increased funding and a partial exemption from the Administrative Procedure Act's strictures to enable a model of "adaptive regulation"—departing from the mold of traditional notice-and-comment rulemaking.[166] But the odds of legislative action

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[163] *See* Quain, *supra* note 64 (surveying the safety data tracked by major ADS manufacturers); *supra* note 129 and accompanying text (showing that ADS companies already perform crash reconstruction with the data they collect from ADS driving).

[164] Part III will emphasize the advantage of having a federal regulator propagating such safety requirements at the national level, instead of state regulators whose safety learnings only benefit residents of their state.

[165] Actual standards would be more complex and correlate identification distance with vehicle speed.

[166] Looking back at the crash-adaptive steps involved in defining ADS safety standards laid out in Section II.B, NHTSA would have clear statutory authority to (1) collect "crash reconstruction" data and (2) reconstruct the crash events through driving simulation. *See supra* notes 140–42 and accompanying text. But importantly, allowing a third step where NHTSA would update its safety standards dynamically based on crash simulation insights rather than through the traditional (and much slower) notice-and-comment rulemaking process would require statutory updates. The necessary updates would include exempting NHTSA's new ADS regulatory process from the federal Administrative Procedure Act and defining new procedural requirements tailored to crash-adaptive regulation. Legal scholars of adaptive regulation have advanced proposals—including draft legislation—

benefit from the bipartisan concerns for road safety and the recent rise in road deaths—which some legislators have started to rally behind to promote ADS legislation.[167] NHTSA's transformation also will demand building technological capacity in a domain where government has struggled to compete for talent with private industry.[168] But other agency successes in building internal AI capacity offer hope for NHTSA's prospects.[169] As another challenge, commentators or the public may oppose NHTSA's heightened scrutiny, or what some may call surveillance, of driving data. But NHTSA can easily address these concerns by minimizing its scrutiny to pre-crash data[170] and by highlighting the minimal privacy invasion from a crash-adaptive road safety regime. ADS record sensor information on their surroundings,

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adjusting the APA's strictures to enable adaptive regulatory models. *See* Craig & Ruhl, *supra* note 44, at 63 (proposing the "Model Adaptive Management Procedure Act," a draft model legislation creating a track for specific types of agency decisionmaking to adopt adaptive regulatory frameworks). In case manufacturers do not comply with the crash-adaptive standards, NHTSA's current statutory authority already would enable it to impose the premarket or postmarket remediation requirements described in Section II.B. *See supra* notes 145, 147.

167 *See* David Shepardson, *U.S. House Lawmakers Look to Jump-Start Self-Driving Legislative Push*, REUTERS (Aug. 8, 2022, 7:02 AM), https://www.reuters.com/business/autos-transportation/us-house-lawmakers-look-jump-start-self-driving-legislative-push-2022-08-08 [https://perma.cc/5BVZ-4MNJ] (reporting on bipartisan legislative efforts in the House and the Senate to promote new ADS regulatory frameworks and noting that lawmakers highlighted the recent rise in traffic deaths); Dan Zukowski, *With Autonomous Vehicle Caucus, Congress Members Aim to Advance Technology for Self-Driving Car*s, SMART CITIES DIVE (Sept. 8, 2022), https://www.smartcitiesdive.com/news/autonomous-vehicle-technology-congressional-caucus-formed/631394 [https://perma.cc/MLP2-3V5A] (reporting that House representatives formed a bipartisan Congressional Autonomous Vehicle Caucus in August 2022); *NHTSA Early Estimates Show Record Increase in Fatalities Nationwide*, NAT'L HIGHWAY TRAFFIC SAFETY ADMIN. (Aug. 17, 2022), https://www.nhtsa.gov/press-releases/early-estimates-first-quarter-2022 [https://perma.cc/C6YT-3GLN] (reporting that NHTSA estimated that road deaths rose seven percent between 2021 and 2022, reaching their highest levels since 2002).

168 *See* NAT'L SEC. COMM'N ON A.I., FINAL REPORT 121 (2021), https://www.nscai.gov/wp-content/uploads/2021/03/Full-Report-Digital-1.pdf [https://perma.cc/69KL-3B8B] (identifying the government's disadvantage in competing for "technical talent" as the "greatest impediment" to its success in implementing its AI strategy).

169 *See* Sharkey & Fodouop, *supra* note 141, at 105–09 (describing the FDA's early successes in hiring technical talent and innovating in AI); Nitisha Baronia, David Freeman Engstrom, Daniel E. Ho, Shawn Musgrave & Catherine M. Sharkey, *Building Internal Capacity*, *in* GOVERNMENT BY ALGORITHM: ARTIFICIAL INTELLIGENCE IN FEDERAL ADMINISTRATIVE AGENCIES 71, 73 & nn.29–30 (David Freeman Engstrom, Daniel E. Ho, Catherine M. Sharkey & Mariano-Florentino Cuéllar eds., 2020) (describing successes in building AI technical capacity from the Social Security Agency, the Internal Revenue Service, and the Securities and Exchange Commission).

170 For example, NHTSA could require ADS companies to submit crash reconstruction data for the minute preceding the crash (or whatever timeframe it deems necessary). This also would help alleviate concerns surrounding the cost of storing vast amount of driving data. *See infra* notes 209–10 and accompanying text (noting the significant storage requirements for driving data).

which mostly involve public roads or shared private areas (such as parking garages) and does not contain any personal identifiable information (PII).[171] With these initial challenges met, NHTSA would face the challenging task of designing and operationalizing an adaptive regulatory process to dynamically update safety standards based on crash reconstruction and simulation.[172] But in doing so, NHTSA could draw guidance from the experience of environmental regulators—which have successfully implemented similar adaptive regulatory systems in some contexts—and the rich legal literature on adaptive regulation.[173]

This Note does not purport to resolve these open questions. But it underlines that, as the principal federal expert automotive agency, NHTSA has a decisive institutional edge in implementing the crash-adaptive regulatory standards that will prove necessary to reach optimal ADS safety.

The window of opportunity for NHTSA to successfully build a crash-adaptive regulatory model is narrowing. Left to its own devices, the ADS industry may converge toward ADS model architecture that does not allow the driving decision explainability required to optimize safety standards based on post-crash data tracking and simulation.[174] Or its lobbying arms may successfully argue that its driving simulation and safety evaluation methods have matured to the point that it would prove too costly to retrofit them to meet belated regulatory requirements.[175] Accordingly, this Note sends a pressing message: NHTSA should hurry to start on the challenges identified above. NHTSA implementing crash-adaptive regulation represents our only viable

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171 Some tracked information could give limited insights as to the passengers' identity, such as exact location or time of day, but these data could be excluded or blurred to prevent identification.

172 Solving the administrative law and process issue of how to adapt NHTSA's rulemaking procedures to enable the issuance of crash-adaptive safety rules is outside the scope of this Note.

173 *See* Sachs, *supra* note 44, at 250 ("Environmental law has made use of adaptive management and regulatory strategies to help enable environmental regulations to iterate in the face of new information or changing conditions."); Justin R. Pidot, *Governance and Uncertainty*, 37 CARDOZO L. REV. 113, 156 (2015) ("[A]daptive regulation is ubiquitous in natural resources law. The Department of Interior, which houses the U.S. Fish and Wildlife Service, Bureau of Land Management, and National Park Service has an adaptive management working group, and each component has incorporated adaptive management into site-specific management decisions.").

174 Current ADS developers are adopting as their ADS model architecture either a "sequential perception-planning-action pipeline," which allows a good level of explainability, or an "end2end learning system," which acts as a black box. *See* Grigorescu et al., *supra* note 50, at 3–4 (explaining that a sequential perception-planning-action pipeline can be designed using non-deep learning methods, but an end2end system cannot).

175 *Cf. supra* note 100 and accompanying text (describing existing efforts by the ADS industry to lobby against strict regulation).

route to ADS optimal safety. Alternative automotive regulatory institutions at the state level would prove incapable of effectively controlling ADS safety risks.

III
National Optimization over State Experimentation

If NHTSA were to embrace crash-adaptive optimal regulation, responsibility for optimal road safety would move from the state level to the federal level. Part II showed that shifting from tort liability to adaptive regulation as the principal lever of optimal safety is theoretically justified. As a second theoretical move, this Part shows that the transition from state to federal optimal safety standards is justified under another debate comparing federal centralized regulation of product safety to state level experiments. Arguments for uniform product safety and liability standards at the national level are not new. In a lively debate, arguments for federal liability standards have clashed with defenses of the fifty state products liability regimes.[176] Three of these arguments carry special weight when applied to ADS and justify a federal system of ADS crash risk control: the need for federal expertise, the risks of state spillover effects, and the benefits from regulatory centralization.

A. The Need for Federal Expertise

First, controlling ADS safety risks will require deep technical expertise. A first argument in favor of nationalizing product safety standards points to the technical nature of many products and the need for expertise to regulate risks of product malfunction, which is easier to build at the federal level.[177] Regulators will need technological expertise not only to understand ADS technology and appropriately set product requirements, such as data tracking mandates, but also to themselves leverage ADS data tracking and simulation tools.[178] The reluctance of even NHTSA, an expert federal agency, to

176 *See* Sharkey, *supra* note 26, at 451–52 ("Products liability is a notably fraught area, where arguments for national uniform standards compete vigorously with arguments in favor of more localized experimentation.").

177 *See* Revesz, *supra* note 32, at 2375 & n.123 (arguing that it would be costly for states to replicate the expertise of the federal government in setting environmental liability standards); Keith N. Hylton, *Preemption and Products Liability: A Positive Theory*, 16 Sup. Ct. Econ. Rev. 205, 213 (2008) ("[T]he expertise of the agency is a factor that suggests that errors are less likely under the agency regime wherever expertise on product risk characteristics and utility is valuable in setting the optimal (or common law) standard." (emphasis omitted)).

178 *See supra* Section II.A.

provide regulatory guidance attests to the technological complexity of ADS. But NHTSA would be better placed than both state legislators (who may define tort standards by legislation) and state courts (which define most tort standards through judicial opinion) in building the necessary expertise. Section I.B.2 showed that courts, and in particular state courts, would struggle to build the necessary expertise to design ADS liability standards.

On the regulatory side, Congress and NHTSA would be at a decisive advantage over state legislatures and agencies in building the necessary expertise to define and operate a crash-adaptive regulatory model.[179] They can harness more resources, especially compared to small states—which, if optimal safety is driven at the state level, would have to build their own ADS regulatory capabilities.[180] It also would make sense to pool the relevant expertise at the national level, especially given the scarcity of talent with the necessary technical understanding of AI and ADS technology, rather than replicating expertise for all fifty states.[181] AI models' inner workings often evade even their own designers, unless manufacturers explicitly constrained the model to provide "explainability."[182] Without the necessary expertise, state legislatures and agencies would fail to probe into the AI "black boxes," as already has happened in various other areas of application for AI.[183] In this case, manufacturers are unlikely to guarantee explainability on their own because improving explainabilty would increase their development costs and risks of crash liability.[184]

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179 *See* Ivan Pereira, *Will State-by-State Regulation of Self-Driving Vehicles Work — and Keep People Safe?*, ABC NEWS (Jan. 31, 2022, 6:30 AM), https://abcnews.go.com/US/state-state-regulation-driving-vehicles-work-people-safe/story?id=82463123 [https://perma.cc/TQ3B-3MAN] (noting that Professor Philip Koopman, an expert in ADS safety, "would argue states generally don't have the technical expertise to regulate [ADS]" and to "get the data from the companies and look at software").

180 *See* Revesz, *supra* note 32, at 2375 & n.123 (noting that the "type of expertise" developed by the federal government to evaluate the interstate impact of pollutant emission "would be costly for states to replicate").

181 *See id.* (highlighting the federal government's advantage over states in building technical expertise on pollution); *see also supra* note 168 and accompanying text (highlighting the difficulties for governments in finding and retaining experts).

182 *See supra* notes 97–98 and accompanying text.

183 *See* RASHIDA RICHARDSON, JASON M. SCHULTZ & VINCENT M. SOUTHERLAND, AI NOW, LITIGATING ALGORITHMS 2019 US REPORT: NEW CHALLENGES TO GOVERNMENT USE OF ALGORITHMIC DECISION SYSTEMS 5–13 (2019) (showing that many defendant states sued for their use of AI tools had very little understanding of the tools' inner functioning). Conversely, a majority of AI tools used by federal agencies were built in-house. *See* ENGSTROM ET AL., *supra* note 132, at 7 ("While many agencies rely on private contractors to build out AI capacity, a majority of profiled use cases (53%) are the product of in-house efforts by agency technologists.").

184 *Cf. supra* note 100 and accompanying text (showing how the ADS industry already is lobbying against tracking data that could support liability).

The convergence of premarket and postmarket regulatory activities reflected by the crash-adaptive model provides further reasons to rely on federal expertise.[185] Because the regulatory activities required for premarket testing and postmarket crash analysis will converge, grouping both functions with the same regulator would save scarce resources (both monetary and in terms of technical talents) and strengthen institutional expertise. NHTSA sets nationwide safety standards that state legislatures and agencies cannot depart from.[186] While NHTSA could efficiently centralize premarket and postmarket crash data analysis under one roof, as suggested in Part II, state legislatures and agencies could not.

B. The Risks of State Spillover Effects

Avoiding spillover effects represents the second major argument in favor of nationalizing product safety risk control.[187] State spillover effects in ADS road safety would have costly consequences, in terms of lives not saved on the road. Individual states overseeing liability would devise an array of over-regulatory and under-regulatory regimes, driven by each state's own economic or political interests.

The early stages of ADS regulation already have displayed wide variations across states that could pave the way for a "race to the bottom."[188] For now, states mainly have engaged in regulation of ADS testing. While some states have constrained the testing of ADS, notably to protect their incumbent auto industry champions,[189] others

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185 *See supra* Section II.B.

186 49 U.S.C. § 30103(b) (stating in its preemption clause that a state may establish "a [safety] standard applicable to the same aspect of performance of a motor vehicle . . . only if the standard is identical to the [federal motor vehicle safety] standard").

187 *See* Revesz, *supra* note 32, at 2375 (showing that "[f]ederal regulation of interstate externalities is necessary" to avoid pollution spillover effects because high transaction costs would prevent states from reaching an optimal solution through bargaining); Richard B. Stewart, *Pyramids of Sacrifice? Problems of Federalism in Mandating State Implementation of National Environmental Policy*, 86 YALE L.J. 1196, 1215 (1977) (showing that spillover effects in environmental regulation are "not easily remedied under a decentralized regime" of state liability).

188 *See* Kaveh Waddell & Kia Kokalitcheva, *States Are Sewing a Patchwork of AV Regulations*, AXIOS (Oct. 27, 2018), https://www.axios.com/2018/09/28/states-are-sewing-a-patchquilt-to-regulate-av [https://perma.cc/6FDQ-NEFN] (noting the role of a state's regulatory scheme in automakers' decisions); *see* Lucian Arye Bebchuk, *Federalism and the Corporation: The Desirable Limits on State Competition in Corporate Law*, 105 HARV. L. REV. 1435, 1444–45, 1458–94 (theorizing a "race for the bottom" in state corporate regulation).

189 *See* Johana Bhuiyan, *A Series of U.S. State Laws Could Prevent Uber or Google from Operating Self-Driving Cars*, VOX (Feb. 25, 2017, 5:11 PM), https://www.vox.com/2017/2/25/14738966/self-driving-laws-states-gm-car-makers [https://perma.cc/RC9X-2468] (noting that Michigan—home to the U.S. auto industry—and other states have made it hard for ADS software companies to test their ADS).

have taken a permissive approach authorizing manufacturers to test with very few restrictions.[190] Differences in approaches have been driven by states' economic or political interests. For example, Arizona decided to remove restrictions to attract ADS companies to its state and benefit its job market and local economy.[191] The state then saw the first fatal ADS accidents, when Elaine Herzberg was killed by an ADS near Tempe, Arizona.[192] While it is hard to tell whether tougher testing regulations would have avoided the accident, Herzberg's death illustrates the potential risks of laissez-faire approaches to ADS safety and liability requirements that some states may adopt.

When it will come to post-crash ADS liability, states also may adopt a wide variation of maladapted regimes. Like with testing, states may adjust their ADS liability policy to favor their own economic or political interests. States like California or Arizona, willing to attract or retain the ADS industry and bolster their industry champions, may impose too-lenient liability. On the other end of the spectrum, states with little connection or political animosity toward the ADS industry may impose excessive liability to please their political constituencies or improve their residents' accident compensation.[193] Even without favoring their interests, states may implement significantly over- or under-deterrent liability regimes for lack of institutional capability in building the necessary ADS expertise, as highlighted above.[194]

Both over- and under-deterrent liability regimes spurred by spillover effects would prove highly costly. States with underdeterrent

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190 *See, e.g.*, Douglas A. Ducey of Ariz., Executive Order 2018-04 (Mar. 1, 2018), https://apps.azdot.gov/files/sitefinity-files/Executive-Order-2018-04.pdf [https://perma.cc/NR86-E9NG]; Mark Harris, *Exclusive: Arizona Governor and Uber Kept Self-Driving Program Secret, Emails Reveal*, GUARDIAN (Mar. 28, 2018, 2:36 PM), https://www.theguardian.com/technology/2018/mar/28/uber-arizona-secret-self-driving-program-governor-doug-ducey [https://perma.cc/T4YH-J5BL] (mentioning laissez-faire approach adopted by the Arizona governor).

191 *See* Press Release, Douglas A. Ducey, Governor of Arizona, Governor Ducey Tells Uber 'CA May Not Want You, But AZ Does' (Dec. 22, 2016) ("Arizona welcomes Uber self-driving cars with open arms and wide open roads. While California puts the brakes on innovation and change with more bureaucracy and more regulation, Arizona is paving the way for new technology and new businesses.").

192 *Supra* note 18.

193 For example, states with large populations of truck drivers at risk of losing their jobs to driving automation may oppose ADS technology for political reasons and exact overdeterrent liability. *See* Evan Halper, *The Driverless Revolution May Exact a Political Price*, L.A. TIMES (Nov. 21, 2017, 9:15 AM), https://www.latimes.com/politics/la-na-pol-self-driving-politics-20171121-story.html [https://perma.cc/N5H6-JEQ8] (noting the potential consequences of automation for truck drivers).

194 *See supra* Section III.A.

schemes may allow unnecessary crashes.[195] States with overdeterrent schemes could significantly delay the introduction of ADS and their road safety improvements.[196] This delay would affect the state in question, but it even could affect even the entire nation if the prospects of additional liability in a populous or economically influential state deters innovation and business investment in ADS.[197] State strict liability regimes, for which multiple legal scholars have advocated, likely present such overdeterrence dangers.[198]

C. National Centralization and Optimization

The need for uniformity constitutes the third classic argument for nationalizing product safety.[199] Product manufacturers often operate nationwide and provide uniform products across state lines, such that imposing fifty different standards arguably makes little sense.[200] In rebuttal, defenders of state liability praise the merits of the fifty laboratories of democracy.[201] Some even see states as an initial catalyst for

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195 *See supra* note 19 and accompanying text.

196 *See supra* note 20 and accompanying text.

197 Some states may influence the national market with their ADS liability policy, just as California drove the entire car industry to follow its CO2 emission standards. *See* Rachel Becker, *Five Automakers Finalize Deal with California to Clean Up Car Emissions*, CALMATTERS (Aug. 17, 2020), https://calmatters.org/environment/2020/08/california-clean-car-emissions [https://perma.cc/7J89-6S2R]. However, the risks of overdeterrence are more significant for ADS (risks of delaying or killing a life-saving technology) than for greenhouse gas emission reduction (marginal risks to economic productivity and output), especially as more and more competitors are dropping out of the ADS race. *See* Andrew J. Hawkins, *The Autonomous Vehicle World Is Shrinking—It's Overdue*, VERGE (May 7, 2021, 9:00 AM), https://www.theverge.com/22423489/autonomous-vehicle-consolidation-acquisition-lyft-uber [https://perma.cc/NP2K-7MU2] (noting the recent consolidation of the autonomous vehicle industry).

198 Strict liability may become the preferred liability framework once ADS have been widely adopted. But until then, it may deter innovation and commercialization, harming road safety prospects. *See supra* note 113 and accompanying text (noting the deterrent effects of strict liability).

199 *See* Gary T. Schwartz, *Considering the Proper Federal Role in American Tort Law*, 38 ARIZ. L. REV. 917, 929 (1996) (showing that, for general products liability, "inter-state variations in common law doctrine are both more frequent and more significant than they are in other sectors" of tort common law torts). *But see* Stephen D. Sugarman, *Should Congress Engage in Tort Reform?*, 1 MICH. L. & POL'Y REV. 121, 127 (1996) ("[S]tate tort laws today are broadly the same in product injury cases.").

200 *See* Schwartz, *supra* note 199, at 924 ("[T]he imperatives of mass production require the manufacturer to sell the same product throughout the nation. But in doing so, the manufacturer encounters products liability rules emanating from fifty different state jurisdictions. Just on the face of things, this looks bizarre.").

201 *See, e.g.*, Alexandra B. Klass, *Tort Experiments in the Laboratories of Democracy*, 50 WM. & MARY L. REV. 1501 (2009) (surveying different tort law "experiments" from across the nation); Perlman, *supra* note 32, at 507 ("State experimentation permits the simultaneous implementation of different solutions.").

effective regulation of uncertain technologies.[202] But in the ADS context, the benefits of uniformity will outweigh the benefits of state-level experimentation. NHTSA, despite paving the way for fifty state liability standards, still has acknowledged the need for uniform ADS regulatory requirements.[203] Beyond national uniformity, ADS call for national centralization and optimization—not for state experimentation. Just like ADS companies centralize learnings from driving data to optimize the safety performance of a singular driving system, NHTSA should centralize regulatory learnings from safety incidents to optimize a safety regulatory scheme benefitting all U.S. car passengers and pedestrians.

Software technology, and AI systems in particular, favor system uniformity and rely on data centralization.[204] ADS manufacturers therefore build a single ADS "driver" operating across the nation and learning from safety incidents that any vehicle in the fleet encounters anywhere in the nation.[205] In contrast, early ADS testing has been regulated by a patchwork of disparate state standards,[206] and ADS safety requirements probably will display similar levels of variability unless the federal government acts to nationalize it.[207]

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202 *See* Thomas W. Merrill & David M. Schizer, *The Shale Oil and Gas Revolution, Hydraulic Fracturing, and Water Contamination: A Regulatory Strategy*, 98 MINN. L. REV. 145, 151–52 (2013) (applying the "state catalysts" theory to the regulation of hydraulic fracking).

203 *See* NHTSA Guidance 1.0, *supra* note 77, at 7 ("[A] manufacturer should be able to focus on developing a single [ADS] fleet rather than 50 different versions to meet individual state requirements.").

204 Uniformity simplifies design and development and reduces maintenance costs. *See Design Process*, BRAINKART, https://www.brainkart.com/article/Design-process_9075 [https://perma.cc/VG7R-VX2S] (including as a principle: "The [software] design should exhibit uniformity and integration"). Beyond uniformity, AI favors the centralization of data within a single learning system. Such a centralized system can observe more data and therefore reach more optimal driving learning outcomes. The need to centralize data in a single model to achieve best performance has long been recognized in other industries leveraging AI. *See* Neo Yi Peng, *How Renaissance Beat the Markets with Machine Learning*, TOWARDS DATA SCI. (Jan. 2, 2020), https://towardsdatascience.com/how-renaissance-beat-the-markets-with-machine-learning-606b17577797 [https://perma.cc/728F-5FAQ] (explaining how Renaissance Technology—the most successful hedge fund in history—created a single AI model covering all asset classes instead of separate models for each asset class).

205 *See supra* note 53 and accompanying text. The ADS company Wayve has taken an even more aggressive approach to uniformity, claiming that its single model can adapt to new cities without having been tested in its streets before. *See AV2.0*, WAYVE, https://wayve.ai/technology/av2-0 [https://perma.cc/WFE9-K4DF].

206 *See* Pereira, *supra* note 179 (quoting the director of MIT's Advanced Vehicle Technology Consortium as stating that "[i]t is a failure of national policy . . . that states are creating this patchwork system").

207 *See supra* Section III.B.

There are clear downsides to a state-based approach imposing fifty different liability standards on ADS manufacturers. It would increase the engineering complexity of achieving ADS safety, further complicating an already daunting technological challenge. Different states may not only differ in the standards they apply to determine liability after a crash. They also may require the tracking of different data elements and disparate model documentation requirements,[208] which would further increase ADS development challenges and substantially multiply data storage costs. ADS in testing already generate staggering amounts of data, estimated at around thirty terabytes of data per vehicle per day.[209] Although regulators should mandate specific data tracking requirements to inform regulatory analysis, as manufacturers may avoid retaining driving data that could incriminate them,[210] regulators should avoid duplicating storage costs where possible. Imposing fifty different data tracking requirements at the state level would have the exact opposite effect and may cannibalize ADS manufacturers' safety compliance or safety research budgets.

On top of additional product costs, ADS manufacturers also would face highly variable litigation outcomes—an inevitable feature of a fifty-standard products liability regime that courts' discomfort with AI technology may exacerbate.[211] Such litigation risks may adversely affect ADS development not only due to its potential monetary impact on manufacturers but also due to its potential impact on public trust in ADS. U.S. consumers have remained skeptical of autonomous vehicles,[212] and a slew of early adverse judicial decisions could delay mass adoption of ADS and their safety benefits. On the other hand, being able to comply with one federal standard—even a frequently updated one under crash-adaptive optimal regulation—

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[208] Section I.B.2 argued that tracking such data likely would be necessary to accurately determine crash liability. State legislatures, agencies, or courts would suffer from an expertise deficit which would make them unlikely to converge toward the same liability standards. *See supra* Section III.A.

[209] *Storage Almost Full*, *supra* note 15.

[210] *See supra* notes 100, 184 and accompanying text (noting manufacturers' resistance to tracking potentially incriminating data). Meanwhile, NHTSA has not issued data tracking requirements yet. *See* NTSB Letter, supra note 5, at 1 (calling for "the standardization of [ADS] data collection").

[211] *See* Schwartz, *supra* note 199, at 929–30 (noting that "[w]ithin products liability, then, the inter-state variations in common law doctrine are both more frequent and more significant than they are in other sectors of the common law of torts," such that manufacturers "[f]ac[e] quite extensive yet quite uncertain liability").

[212] *See, e.g.*, Andrew J. Hawkins, *Americans Still Don't Trust Self-Driving Cars*, VERGE (May 19, 2020, 12:01 AM), https://www.theverge.com/2020/5/19/21262576/self-driving-cars-poll-av-perception-trust-skepticism-pave [https://perma.cc/9STM-AGTT] (reporting on a survey that found that significant portions of the public doubt the safety of autonomous vehicles).

would improve predictability and reduce the risks of adverse legal outcomes for manufacturers.

The downsides of the fifty-standard approach are clear, but the usual benefits ascribed to it do not hold for ADS safety. The traditional narrative in favor of state-level products liability standards posits that states act as regulatory laboratories.[213] This empirical claim has been generally challenged in the context of products liability. Gary Schwartz has argued that state law "experiments" are not valid experiments because manufacturers do not adapt their operations based on different liability positions.[214] ADS manufacturers indeed will deploy the same ADS driver nationwide.[215] Given the technical challenges raised by ADS liability, the state laboratories may further crumble because each state would fail to explore the entire universe of potential liability standard options. Even the best liability standard reached by one of the fifty states may be a local optimum, constrained by their lack of expertise in mandating the right data tracking requirements[216] or devising the right crash reconstruction protocol. Regulating at the state level is also sometimes perceived as decreasing the risks of regulatory capture, but a more technologically competent NHTSA may in fact prove less prone to capture than state regulators given its superior ability to evaluate the risks of industry-proposed solutions and identify alternative routes more aligned with the public interest.

Instead of state parallel experimentation, ADS safety would benefit from federally centralized optimization. A federal regulator like NHTSA could not only ensure the nationwide uniformity of safety requirements (limiting financial and reputation costs for manufacturers) but also could emulate the data and learning centralization leveraged by commercial ADS models to optimize safety requirements iteratively and ensure that the entire U.S. population benefits from a continuously improving optimal level of safety. Part II argued that regulators should centralize safety insights across their jurisdiction, instead of letting manufacturers simply update their model on

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213 *See, e.g.*, Perlman, *supra* note 32, at 507–08 (promoting state competition as comparatively advantageous to yield optimal policy outcomes).

214 Schwartz, *supra* note 199, at 931 (observing that "as a practical matter manufacturers lack the ability to modify their products (or even adjust their prices) in order to take into account the liability position a particular state might adopt," making "[t]hese state-law experiments . . . dramatically lacking in the feedback that valid experiments generally need").

215 *See supra* note 53 and accompanying text (discussing the centralized fleet).

216 *See supra* note 100 and accompanying text (explaining that car manufacturers have in the past managed to win litigation by failing to deliver the necessary car data).

their own.[217] A federal regulator would prove much more effective in this regard, compared to state institutions. First, it would be able to monitor all crashes across the nation and feed significantly more data into its regulatory optimization process, leading to more societally beneficial safety requirements than what states could design. Seeing more safety incidents, a federal regulator would have more opportunities to improve its regulations based on new information and would more closely match the ADS industry's agile update cycle. Second, it would be able to uphold these superior safety standards for the entire U.S population.

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This Part has shown that although product safety is usually regulated at the state level in the United States, strong theoretical justifications call for regulating ADS safety at the federal level. First, the federal government stands a greater chance of achieving the technical expertise necessary. Second, a federal regime would avoid interstate spillover effects leading to unnecessary delays in introducing life-saving ADS vehicles, or unnecessary deaths once ADS achieve broader commercialization. Third, a nationally centralized regulator would reduce engineering costs and litigation uncertainty for manufacturers and be able to analyze more crash data to optimize ADS safety standards under a crash-adaptive model. The crash-adaptive optimal regulatory model introduced in Part II thus provides the best institutional design to regulate ADS safety not only by giving primary regulatory responsibilities to an agency, rather than tort law, but also by defining safety standards at the federal level, not state level.

Conclusion

This Note concludes with a call to action for NHTSA. Since the invention of the automobile, state tort law has exercised significant influence on controlling road safety risks, which has eclipsed NHTSA's role. But ADS are ushering a technological and regulatory revolution, which demands a centralized nationwide adaptive regulatory regime overseen by an expert federal agency. NHTSA should take the wheel to implement a novel "crash-adaptive optimal regulation" model and drive us toward optimal road safety. While the agency has stayed in the backseat and remained blind to the growing promise of data tracking and simulation techniques in revolutionizing automotive safety regulation, it is the best positioned government

[217] *See supra* note 164 and accompanying text.

institution to build ADS expertise, centralize ADS safety analysis, and propagate ADS safety insights to ensure maximum road safety for all Americans.

Even if Congress and NHTSA agree with the conclusion of this Note, NHTSA will face technical and institutional challenges in regulating the ADS industry. On the technical side, the agency may find difficulties in building sufficient internal capacity, competing with private industry for talent. On the institutional side, even shifting to an adaptive and iterative crash-adaptive model may not make NHTSA nimble enough to keep up with the ADS industry's fast-paced "agile" software update cycle. If NHTSA can overcome these two challenges, it will face the daunting task of building a rulemaking process factoring simulation results from reconstructing crashes into optimal updates to ADS safety standards.

These questions are outside the scope of this Note. What this Note has shown is that these challenges are inescapable if we hope to realize ADS' safety promise and that NHTSA, as the main federal automotive regulator, has a decisive institutional edge in solving them effectively. NHTSA's crash-adaptive regulation of autonomous vehicles is the safe road forward.