Financial Services Observer

September 2024

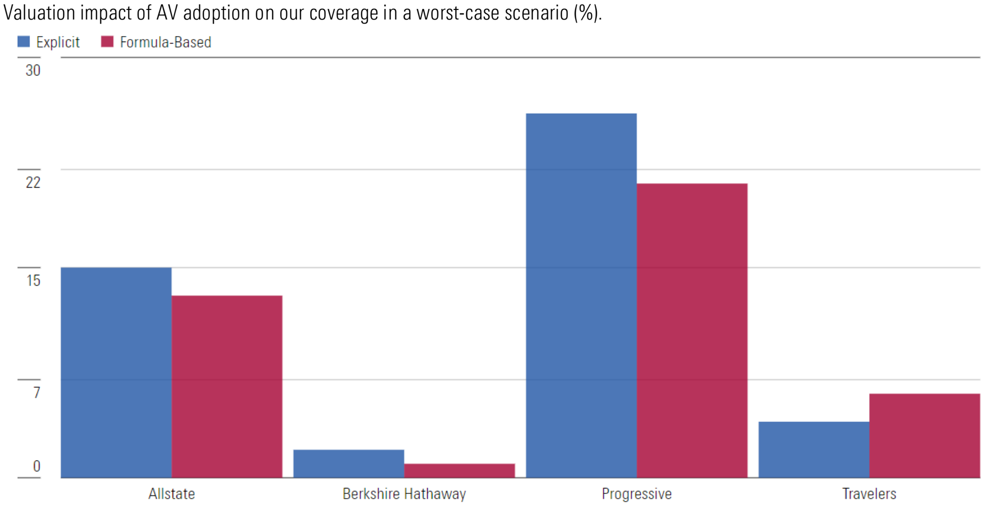
Insuring Autonomy: Analyzing the Implications of Self-Driving Cars for the Auto Insurance Industry

Contents

Executive Summary

Autonomous vehicles could have profound positive and negative impacts on the auto insurance industry. Self-driving cars could massively reduce accidents by eliminating human errors and, in the long run, could shift the liability from drivers to manufacturers, making personal auto insurance obsolete. We believe that fully autonomous vehicles are closer than most people think from a technology perspective, but the period from technological development to mass adoption is significantly higher than the market anticipates. In our most aggressive adoption scenario, we think most cars on the road could be automated to a level where insurance is largely unnecessary within 20 years. We don't think investors should discount auto insurance stocks based on this risk today. But with the group trading at a hefty premium to historical book multiples, from a long-term perspective, we question whether current valuations are justified for businesses that might become obsolete.

Exhibit 1 Insurers That Rely Heavily on Auto Insurance and Have a Moat Are Most at Risk From AV Adoption
Valuation impact of AV adoption on our coverage in a worst-case scenario (%).



Source: Morningstar. The worst-case scenario for auto insurers is the best-case (very aggressive) AV adoption scenario.

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Key Takeaways

Understanding Autonomous Capability:
What Is It, Where Are We Now, and Why Does It Matter for Auto Insurers?

- Despite significant investments, the journey toward fully autonomous vehicles has been fraught with disappointments for both investors and technology enthusiasts.
- More recently, however, rapid technological advancements in computer vision, artificial intelligence, machine learning, sensors, radar, lidar, and enhanced processing power have resulted in dramatically improved autonomous driving capabilities in real-world environments.
- While excitement for self-driving cars tends to ebb and flow in media and the general public, investors have consistently directed capital to this emerging sector. Median venture capital valuations for autonomous driving startups have grown by 6 times compared with 2019 levels.
- The current market size for autonomous systems remains limited, but the market for the technology Is expected to grow rapidly in upcoming years as the technology evolves. PitchBook estimates the global market size for autonomous driving to be around $300 billion by 2030.
- Levels of autonomy range from 0 (momentary assistance) to 5 (fully autonomous with no driver involvement). The most advanced of the current offerings range from Level 2 to 4, in our view. Level 2 is most prevalent, while Level 4 is only available via robotaxi services like Waymo.
- The capabilities of a human driver are limited, but the capabilities of self-driving technology have no strict limit and are evolving at an extremely rapid pace.
- The number of car crashes and fatalities per miles driven fell continuously from 1980 to 2010, with the accident and fatality rate over that period declining almost 70%. But that progress has stalled; in fact, the accident and fatality rate has increased modestly since then. About 90% of crashes are caused primarily by human error, and human driving habits and behavior are notoriously difficult to change.
- The latest versions of autonomous driving systems are already safer than humans. A study done by Waymo and Swiss Re concluded that Waymo's driverless vehicles incurred no bodily injury claims compared with 1.11 claims per million miles for human driving benchmarks. In terms of property damage, Waymo's driverless vehicle incurred 0.78 claims per million miles, compared with 3.26 for human driving benchmarks.
- The entire point of autonomous cars is that the driver is no longer in control. Therefore, it is hard to see how the owner of a driverless car could be found legally liable for damage. In our view, car insurance would most likely morph into product liability insurance and would ultimately be borne by the auto manufacturers when Level 4 or 5 autonomy is achieved.
- In our view, as long as there is material driver involvement, personal auto insurance will remain necessary. Further, we believe the regulatory environment around auto insurance is likely to lag the technology changes.
- As such, we think multiple hurdles will need to be overcome for drivers to no longer be required to maintain some level of insurance. First, highly autonomous—and affordable—vehicles will need to be available on a wide scale. Second, current regulations around personal insurance will need to be changed on a state-by-state basis. Finally, fully autonomous vehicles (Level 4 or 5) will need to meaningfully replace nonautomated and even partially automated cars on the road.

Timeline for Self-Driving Technology Development and Adoption Is Far From Certain: Mapping Out Scenarios

- We think the most important factors that will affect AV penetration rates are the timeline of technological development (defined as the year when a 0.25% Level 4 AV adoption rate is achieved), pace of AV technology adoption, and scrappage rate of the existing car fleet. We have developed three scenarios for each of these factors: very aggressive, aggressive, and moderate.
- For the first factor, we calculate that based on the very aggressive scenario for technological development (for instance, Tesla robotaxi tech improves substantially and goes mainstream), a 0.25% adoption rate is reached in early 2026.
- We looked at adoption rates of previous technologies as a guide for how long it will take Level 4 or 5 AV technology to reach an 80% adoption rate from 10%. In our very aggressive scenario, we predict it would be 7 years, in our aggressive scenario 14 years, and in our moderate scenario 18 years.
- For scrappage rates, we took historical data as a baseline, but our very aggressive and aggressive scenarios assume scrappage rates increase materially over time, as autonomous vehicles will be so much better than traditional cars that consumers would be willing to let go of their old cars much faster.
- We take our projections for each of these three categories and turn them into our penetration rate projections. Under our very aggressive, aggressive, and moderate scenarios, 60% of the cars on the road will be Level 4 autonomous or higher by 2044, 2053, and 2060, respectively.

Quantifying the Impact: Valuation Implications for Our Auto Insurance Coverage

- Our very aggressive AV adoption scenario equates to a worst-case valuation scenario for our auto insurance coverage. We used our models in two ways to quantify the impact of AV adoption on our insurance coverage in the very aggressive scenario.
- In the first method (explicit), we prepared a 10-year stage one period that assumes no meaningful impact from autonomous cars. We assume cars stay in the Level 3 range for most of this period, and a lag in regulatory response means auto insurance remains required even if it is not really necessary.
- We use the end point of this stage one to begin stage two, which is another 10-year period. In this stage, we assume that the adoption of autonomous technology leads to premium declines at the same rate as the adoption of AVs. We also assume underwriting results weaken due to cost deleveraging, pushing returns toward the cost of equity. At the end of stage two (the point at which our adoption scenario assumes the percentage of cars on the road that are Level 4 or higher approaches 60%), with the end of the industry in sight, we assume insurers abandon the line due to declining volume and returns.
- In the second method (formula-based), we again project an explicit 10-year stage one. But we then use the implied decline in overall premiums from our first method and input this as the net income growth rate for stage two.
- We see a few main takeaways from this exercise. First, results are not dramatic and are within our margin of safety. Second, and somewhat obvious, a higher proportion of auto insurance increases obsolescence valuation risk. Finally, moaty companies are more at risk, given that their franchises are the most valuable.

- We don't think investors should be discounting these stocks today, but we do think there should be a ceiling on the book multiples for auto insurers, given that these franchises might not exist in 20 years. This is especially relevant today, as a strong near-term outlook has our coverage trading at hefty premiums to historical multiples. While our worst-case scenario represents only 26% downside from our fair value estimate for Progressive, it would be over 50% downside from the current stock price.
- There is potentially a positive scenario for auto insurers. If full autonomy proves difficult to achieve but partially autonomous cars meaningfully improve safety, auto insurance could remain necessary for decades to come, and auto insurers could potentially draft off lower accident rates for years. Historical results suggest auto insurers produced stronger returns when accident rates were falling before 2010.

Who Is Leading the Race? US and China in Heated Competition as Europe Falls Behind

- Autonomous driving technology is a foundational technology. We think it is essential to analyze which region or country is leading in the development of autonomous driving technology, as this has a substantial impact on the speed of technology adoption.
- Europe has some very interesting companies in the autonomous vehicle space and is still a leader in some niche areas, but we do not think its AV tech ecosystem is capable of taking the pole position in this race.
- To assess the relative state of China and the US when it comes to autonomous cars, we have developed a framework that considers six factors (in declining order of importance): software stack, competitiveness and dynamism, government and policy support, hardware stack, maturity of ecosystem, and consumer acceptance.
- There are key areas like AV software development where the US clearly seems to be ahead, but China seems to have a material advantage in areas like competition, hardware, cost-competitiveness, testing, and consumer acceptance. There are other areas like policy support, regulatory frameworks, and the overall maturity of the AV ecosystem where it is not clear which country has a lead.
- Overall, though, our sense is that China has a slight advantage in this race when we consider all factors.

US Auto Insurance Coverage

Name/Ticker	Economic Moat	Currency	Fair Value Estimate	Current Price	Price/ FVE	Uncertainty Rating	Morningstar Rating	Market Cap (Bil.)
Allstate ALL	None	USD	138	190.26	1.38	Medium	★	50.2
Berkshire Hathaway BRK.B	Wide	USD	427	456.68	1.07	Low	★★	982.8
Progressive PGR	Narrow	USD	151	256.91	1.70	Medium	★	150.3
Travelers TRV	Narrow	USD	214	241.54	1.13	Medium	★★	54.8

Data as of close Sept. 17, 2024.

Understanding Autonomous Capability: What Is It, Where Are We Now, and Why Does It Matter for Auto Insurers?

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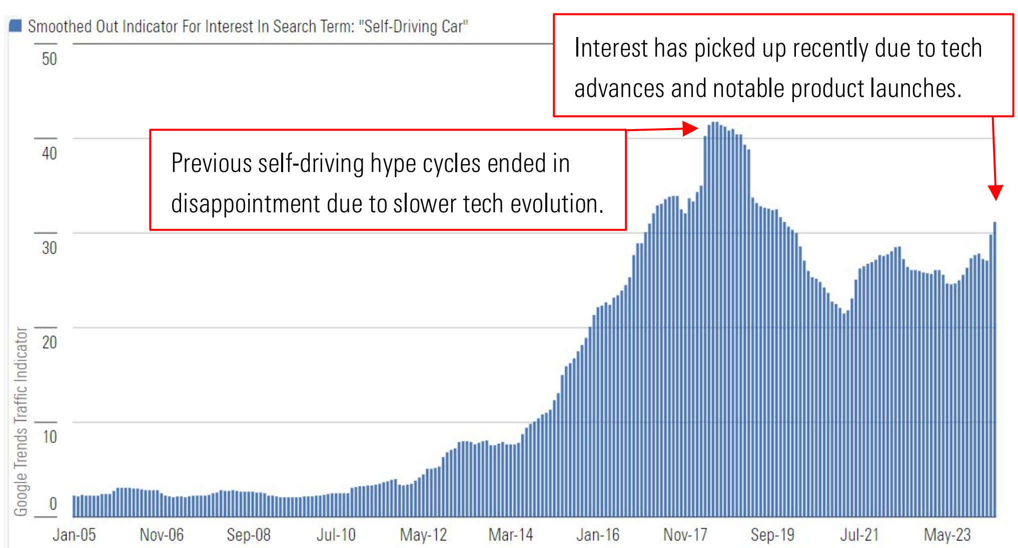
Self-driving cars have long been a science fiction dream, promising a new era of safer, more efficient, and accessible mobility for all. However, despite significant investments, the journey toward fully autonomous vehicles has been fraught with disappointments for both investors and technology enthusiasts. In our view, the main reason for the relatively slow progress has been technological hurdles in the development of self-driving capabilities coupled with overestimation of technological readiness.

Developing capabilities to safely navigate unpredictable scenarios on public roads has been a challenge for companies in this sector. However, the industry has been getting better at handling edge cases for self-driving cars, such as navigating through darkness, heavy rain or snow, unexpected road blockages, and so on. Rapid technological advancements in computer vision, artificial intelligence, machine learning, sensors, radar, lidar, and enhanced processing power have resulted in dramatically improved autonomous driving capabilities in real-world environments, and we believe we are now much closer to a fully self-driving car than we have ever been.

Exhibit 2 Self-Driving Cars Generated Excitement Earlier, but Speed of Technology Evolution Has Been Disappointing

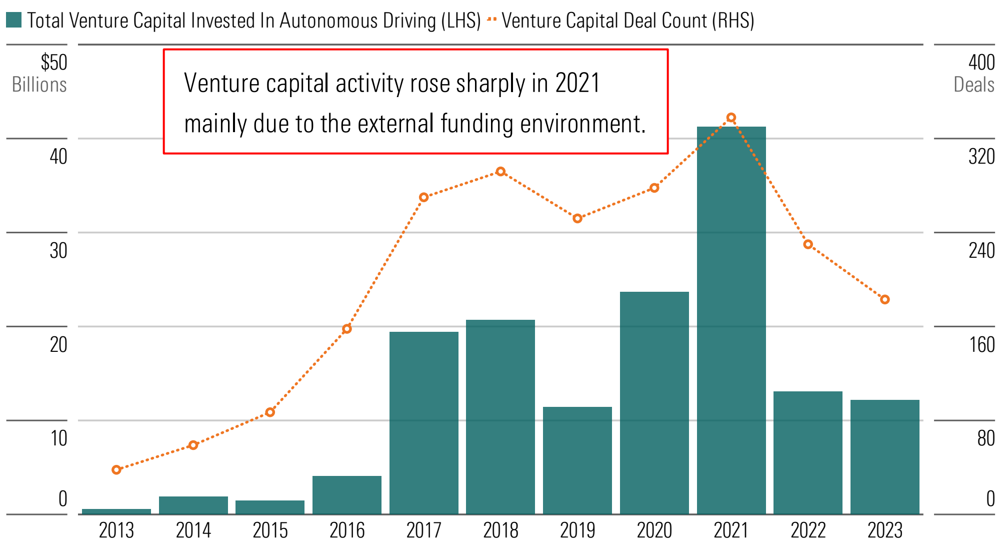


Source: Google Trends, Morningstar. Data as of May 30, 2024.

While Media Attention Has Varied, Money Never Stopped Flowing Into Autonomous Driving
Given that autonomous driving is such a nascent sector, the performance of a few publicly listed companies in the sector is not a good representation of what is happening in this field. We think the activity in the private equity and venture capital markets is a much better representation of developments in the sector.

While the excitement about self-driving cars tends to ebb and flow with the media and the general public, venture capital has consistently been invested in this emerging sector. The sharp spike in capital invested in the sector in 2021 and the subsequent fall seen in Exhibit 3 is largely a reflection of the external funding environment rather than developments in the sector.

Exhibit 3 VC Activity in Autonomous Driving Started Picking Up in 2017 and Has Remained Relatively Strong

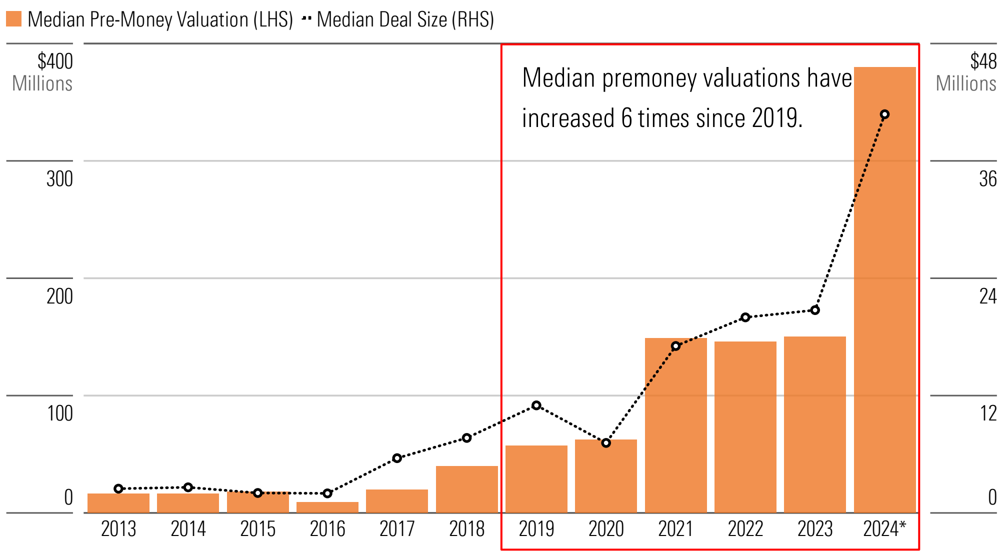


Source: PitchBook, Morningstar.

Looking beyond the headline capital flows, we can see clear signs of the autonomous driving ecosystem maturing. While the total number of deals in the space has declined, median deal size has grown by about 4 times and median premoney valuations have grown by about 6 times in the past five years.

We think the relatively buoyant venture capital valuations for autonomous driving startups reflect the fact that the technology behind self-driving capabilities has improved dramatically, and product monetization is now in sight. The maturing of the sector has also led to the consolidation of startup companies. In our opinion, we are still in the very early stages of the journey toward fully autonomous driving, but we are broadly seeing the right environment for the sector to develop.

Exhibit 4 VC Valuations in AV Sector Have Remained Buoyant as Technological Capabilities Have Evolved Rapidly



Source: PitchBook, Morningstar. Calculations for 2024 are based on data as of the end of May; therefore, the deal sample size is relatively small compared with previous years.

Self-Driving Cars Can Be Categorized Based on Levels of Driving Automation

As per the widely quoted classification from the Society of Automotive Engineers, self-driving technology can be classified into various levels based on the amount of automation and the involvement of humans. The levels range from 0, where there is no meaningful automation, to 5, where the vehicle is completely automated and can operate under all environments without any input from humans.

Level 0 systems (momentary driver assistance) contain features that are limited to providing warnings and momentary assistance. Level 1 systems (driver-assistance systems) include features like adaptive cruise control or lane-keeping assistance, which are limited in their scope to provide steering, brake, or acceleration support to the human driver. Level 2 systems are often referred to as additional/partial automation systems and tend to combine various driver-assistance features in one integrated platform. Examples of such systems include highway pilot or city navigation on autopilot features, which provide steering, brake, and acceleration support to the driver. Human drivers are expected to remain fully engaged and attentive while using systems at or below Level 2.

Level 3 systems (conditional automation) are responsible for all aspects of driving a vehicle under certain strictly specified conditions such as highway driving. These systems may have difficulties navigating certain environments such as darkness, heavy rain or snow, unexpected road blockages, heavy traffic, and so on. These systems can require human drivers to take control during specific circumstances.

Level 4 or higher automation systems do not require any human intervention at most times. These systems can operate completely on their own in complex environments like city or highway driving. Vehicles operating without any human drivers behind the wheel are examples of this level. However, Level 4 systems currently often operate within geofenced parameters under specified conditions. Level 5 systems (full automation) are vehicles of the future: They do not need any sort of human input and can operate anywhere in any condition. These vehicles will not need controls for people like brakes, a steering wheel, or an acceleration pedal.

There are many interpretations of the various levels of autonomy by different analysts and organizations, and the definitions have constantly been updated at the margin. In our opinion, these levels should be thought of as a spectrum rather than distinct buckets of classification, since different systems in the same category can have substantially different capabilities. We have attempted to simplify the classification of automation systems in Exhibit 5.

Exhibit 5 Self-Driving Cars Can Be Classified by the Levels of Driving Automation

Classification of Self-Driving Systems Based on Levels of Automation

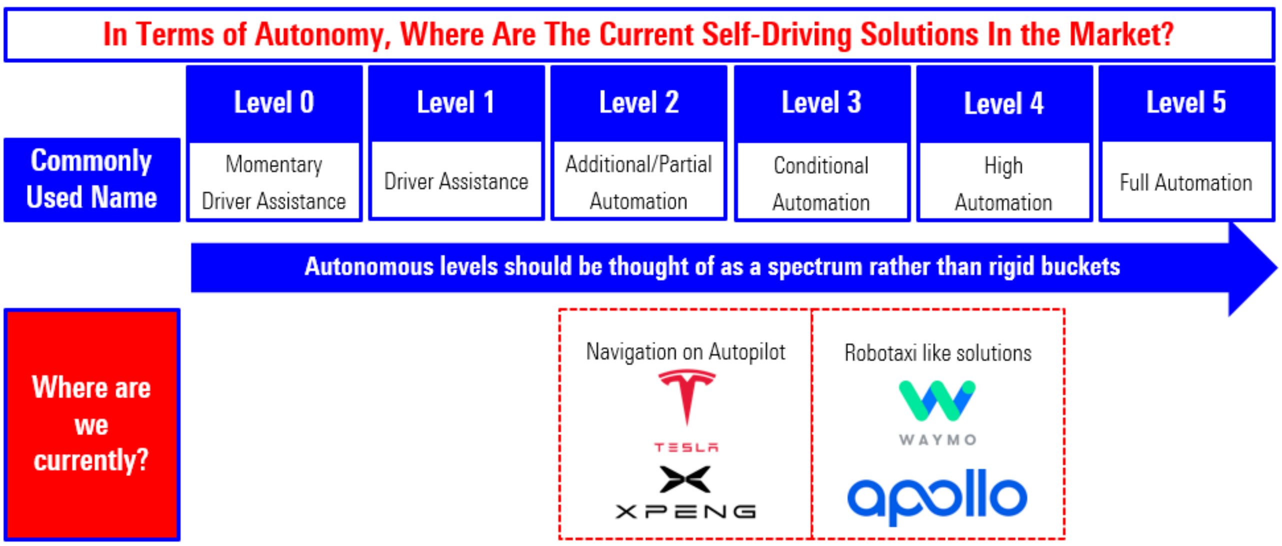
	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Commonly Used Name	Momentary Driver Assistance	Driver Assistance	Additional/Partial Automation	Conditional Automation	High Automation	Full Automation
Amount of Human Driver Involvement	These are driver support features.			These are automated driving features.		
	Humans are primarily responsible for supervising the system, monitoring the environment, and driving the vehicle.			The system is primarily responsible for driving. Humans are not expected to drive even if they are sitting in the driver's seat.		
				Humans take over based on conditions	Operates under MOST conditions	Operates under ALL conditions
Examples	Emergency braking, collision, or lane departure warning	Adaptive cruise control, lane-keeping assistance	Highway pilot, navigation on autopilot	Auto-parking, traffic jam chauffeur, advanced NOA	Local robotaxis operating under known/mapped environments	Robotaxis that can drive anywhere under all conditions

Source: Morningstar, SAE International, National Highway Traffic Safety Administration.

Market-Leading Autonomous Driving Solutions Range From Level 2 to Level 4

The next question is where we are in the autonomy spectrum from a technological perspective. A simplistic way to think about this is to segment the systems that are currently in the market into two categories.

Exhibit 6 Self-Driving Solutions Currently in the Market Range From Level 2 to Level 4 Autonomous Capabilities



Source: Morningstar, SAE International, National Highway Traffic Safety Administration. Logos do not suggest where the companies are in the self-driving spectrum; they are just examples of the solutions.

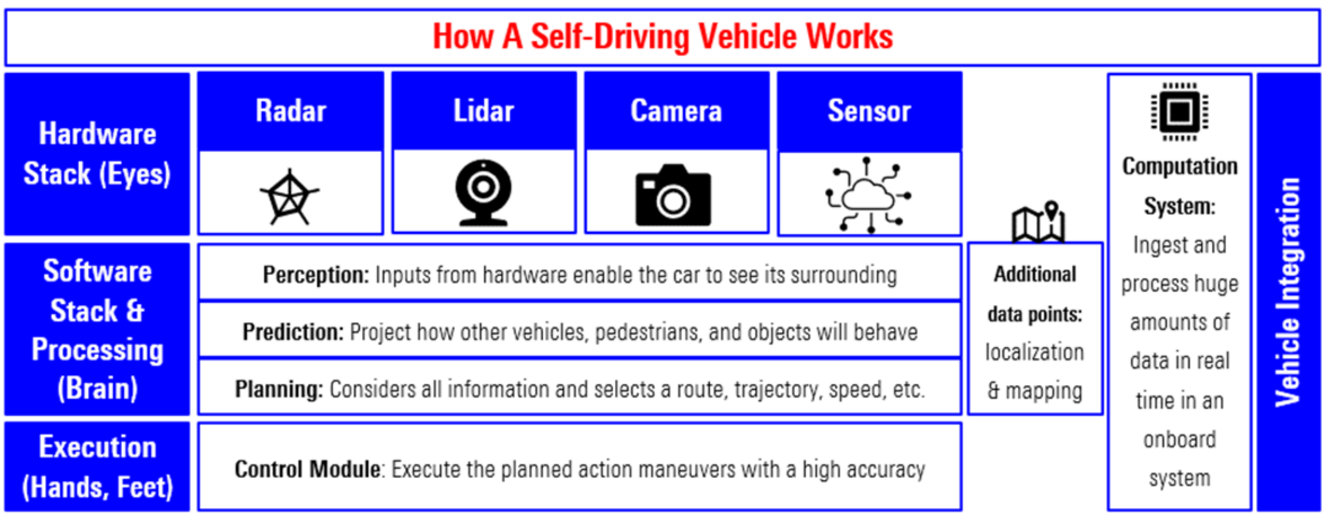
The first category includes driver assistance or navigation on autopilot systems like Tesla's FSD Supervised or XPeng's XNGP. These NOA systems have many names, but essentially they can be integrated into current mass-market vehicles relatively easily and require a human behind the wheel to supervise the vehicle at all times. These systems can autonomously brake, accelerate, stop, steer, overtake, and change lanes in a complex urban or highway environment. The key point is that they require continuous inputs from a human driver. However, the NOA systems in the market are rapidly improving their autonomous capability, and we think the leading systems can already be classified as having some Level 3 autonomous characteristics.

The second category includes solutions from companies like Waymo, Cruise, Apollo, and Pony.ai, which offer robotaxis that are capable of driving without a human behind the wheel. The current market solutions in this category are often geofenced: The rides are limited to certain geographical locations where the software is trained extensively on location-specific parameters. While robotaxi solutions are improving at a dramatic pace, they still have lower performance in certain environments like heavy rainfall, darkness, and chaotic traffic scenarios. We think that the leading robotaxi solutions in the market have achieved mid- to high Level 4 autonomous capabilities, albeit with important geographic limitations that would preclude wide-scale adoption at this point.

Understanding How Self-Driving Cars Work

The technology behind autonomous driving capabilities is very complicated. Our goal in this section is to simplify the complexities of an AV. Different companies use slightly different approaches to autonomous driving; therefore, we aim to highlight the widely used technological approaches by various companies rather than focusing on a specific company's technology stack.

Exhibit 7 Simplified Tech Architecture: Hardware, Software, Processing, and Control Module Work in Harmony to Make Real-Time Decisions



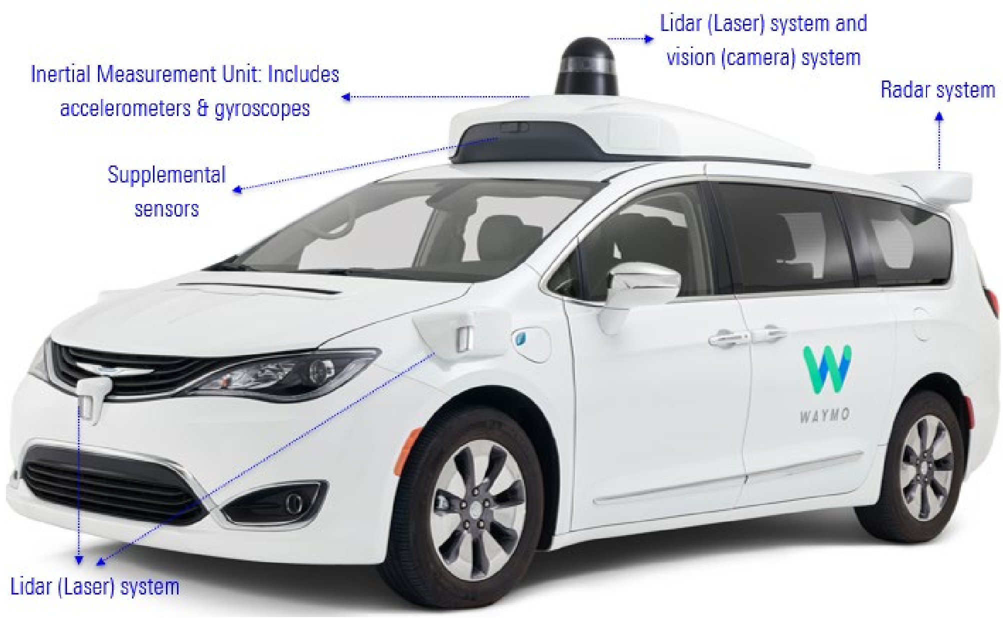
Source: Morningstar.

Exhibit 7 attempts to visually show the technology architecture behind self-driving cars. Different companies have different approaches to achieving autonomy as well as drastically different technology stacks, so this is a simplified explanation of the workings of a self-driving vehicle.

The Hardware Stack Replaces Human Driver's Eyes

Self-driving cars can be understood by drawing analogies with various human body parts to illustrate how autonomous cars perceive, analyze, process, and respond to real-life driving challenges. The hardware stack of the vehicle includes different types of sensors, radar, lidar, and cameras to create a vision of the external environment around the vehicle and can be thought of as replicating the function of a human driver's eyes and ears. Exhibit 8 shows the various additional hardware components in a Level 4 self-driving vehicle that are not present in a traditional car.

Exhibit 8 Self-Driving Vehicles Have Additional Hardware Components Not Found in Traditional Cars



Source: Morningstar, Waymo, company filings.

The purpose of these hardware components is to collect various forms of information from the surroundings and send it to the brain of the car for further processing, similar to how human senses work. Companies prefer taking inputs of various types and combining them for the purpose of enhanced perception, since each type of hardware component has its own strengths and weaknesses. Exhibit 9 shares some of the strengths and weaknesses of the various hardware components commonly used for autonomous driving.

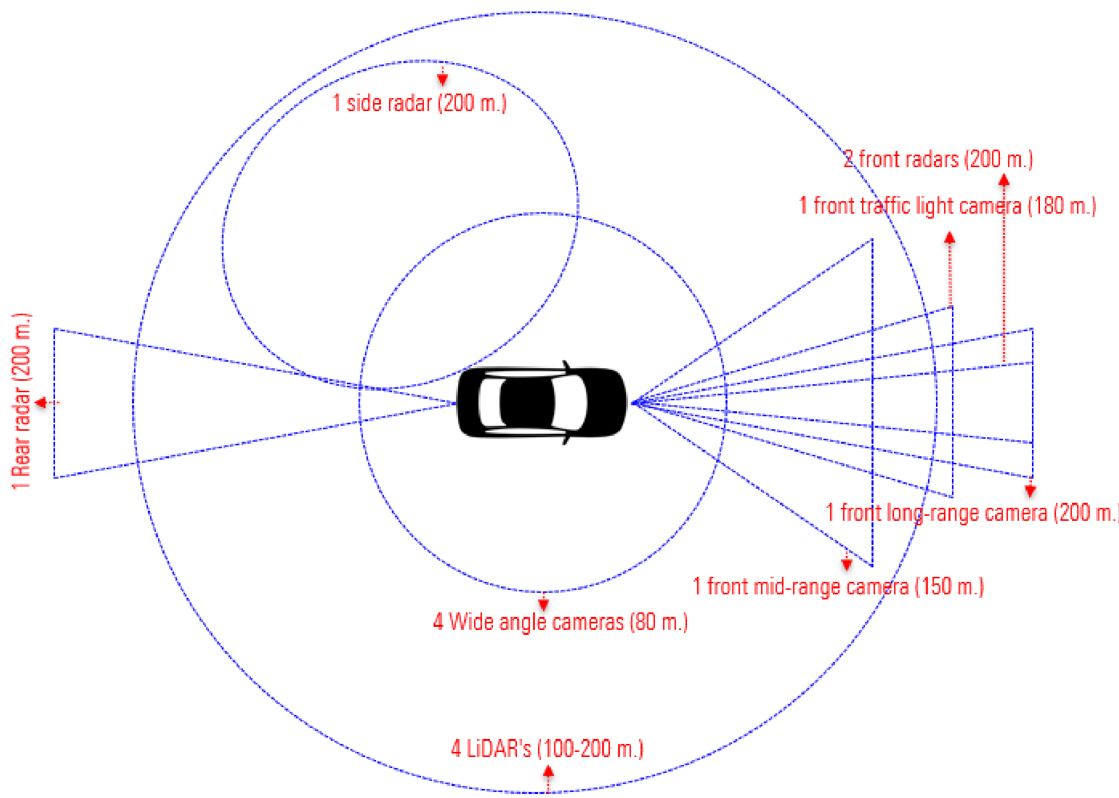
Exhibit 9 Hardware Components Have Strengths and Weaknesses, So Companies Prefer Using Multiple Inputs

Hardware Component	Strength	Weakness
Cameras	Affordable, good at color and visual recognition	Performance suffers in darkness, weather sensitivity, can struggle with distances
LIDAR (Light Detection and Ranging)	Good at 3D mapping, longer range, work in all types of lighting conditions	Affordability is an issue, weather sensitivity
Radar	Can work well in adverse weathers, speed detection, can see through obstacles	Shorter range, high cost, lower resolution leading to lower recognizability
Sensors	Affordable, generally durable in most conditions	Shorter range, lower resolution

Source: Morningstar, Waymo, Pony.ai, WeRide, Aurora Innovation.

The reason for having different types of hardware components is to get as many data points as possible to enhance a vehicle's perception capabilities and safety. Exhibit 10 offers an example of how Pony.ai autonomous vehicles combine inputs from various hardware components to form a 360-degree vision. It can potentially be argued that the current technology enables self-driving cars to see beyond the capabilities of the human eye in terms of range and the ability to monitor all sides of a vehicle simultaneously.

Exhibit 10 Combination of Various Hardware Components Allows Autonomous Vehicles to Have 360-Degree Vision and Perceive Surroundings Continuously



Source: Morningstar, Pony.ai.

Software Replaces the Driver's Brain

The software stack and onboard computational system in an autonomous car are analogous to a human driver's brain. These systems process a vast amount of data that comes from the hardware stack and additional data sources like high-definition mapping to make real-time decisions and navigate the vehicle in traffic. The software stack contains highly complex algorithms to interpret data, make decisions, and send commands to the control module of the vehicle. Given that the industry is in its infancy, there are no standardized terms and standards for self-driving software. Exhibit 11 explains the various functions that the software performs in a self-driving car.

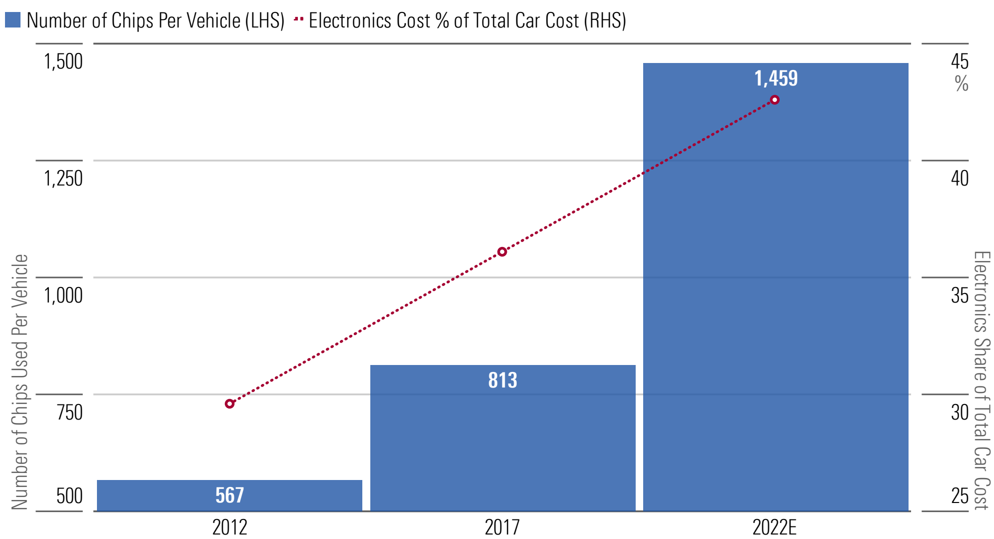
Exhibit 11 How the Software Stack of a Self-Driving Vehicle Works

Function	Commonly Used Name	Description
Where is the vehicle?	HD mapping and navigation	Uses detailed information from special maps
What is around the vehicle?	Perception	Helps the vehicle see its surroundinsg and identify different objects
What is likely to happen?	Prediction/Simulation	Predicts the motion, speed and direction of objects around it
What should the vehicle do?	Planning	Directs precise movement, speed and route maneuvers to the control module

Source: Morningstar, Waymo, Pony.ai, WeRide, Cruise.

The other feature of self-driving cars is the use of microelectronics and computing power for processing data and making decisions. The trend toward more processing power and electronics will likely be turbocharged in the advent of autonomous driving.

Exhibit 12 Computing Power Increasing Rapidly in Vehicles; This Trend Will Be Turbocharged in the Self-Driving Era



Source: Morningstar, Car and Driver, Deloitte analysis. Data as of Nov. 30, 2021. The number of chips per vehicle for 2022 is an estimate. Electronics share of total car cost for the given years is calculated by extrapolating the data in the Car and Driver article.

Deloitte estimates that the number of chips in new energy vehicles more than doubled from 567 per vehicle in 2012 to 1,459 in 2022. Its analysis also finds that the need for information processing and data storage is positively correlated with the level and maturity of autonomy with vehicles. According to *Car and Driver*, a separate study by Deloitte found that electronics are now responsible for 40% of a new car's total cost, up from 18% in 2000. We believe that these trends will be turbocharged in an era of autonomous cars, as computing power will be at the very core of these vehicles.

There are many other components in the software stack for a self-driving vehicle. For instance, both internal and external communications networks are essential for Level 5 fully self-driving features. The internal network in a self-driving vehicle plays a role similar to the human body's nervous system as it connects, coordinates, and relays information in various components of the vehicle. A fully functional external communications network that allows a vehicle to communicate with itself and with other objects in its environment, like traffic signals, has not yet been fully realized in any region of the world. However, there has been extensive research on these solutions using 5G technology, and progress has been made in recent years.

High-definition maps are another important element in the self-driving ecosystem, analogous to a human driver's memory. HD maps provide highly detailed and precise information on the driving space. These maps include information on road lanes, pedestrian walkways, traffic lights, possible objects near the road, and real-time road and traffic updates. The data provided by HD maps is analyzed in conjunction with the vehicle hardware stack data to create a better perception of the vehicle's surroundings and plan for upcoming maneuvers. HD maps can provide insights to autonomous cars on the route ahead and real-time precise information on construction work, road closures, and so on. The information from HD maps becomes particularly important in conditions like adverse weather, when data from vehicle sensors is less reliable.

Control Module Replaces Driver's Hands and Feet

Finally, the control module of the car governs acceleration, steering, braking, and so on and is analogous to a human driver's hands and feet. The control module of a self-driving car receives instructions from the vehicle's software and is responsible for executing those instructions.

The capabilities of a human driver are limited, but the capabilities of self-driving technology have no strict limit and are evolving extremely rapidly. For instance, humans have two eyes with a visual field of about 180 degrees, but autonomous cars can have many eyes with a visual field of 360 degrees, can see beyond obstacles, and have a range beyond that of a human eye. Driving habits and behavior of humans are very difficult to change, but that is not the case with autonomous cars, which can change driving characteristics based on a change in their software. Self-driving cars are highly disruptive because although it takes time for robots to catch up with human capabilities, once they do catch up, humans do not have a good record of competing with robots.

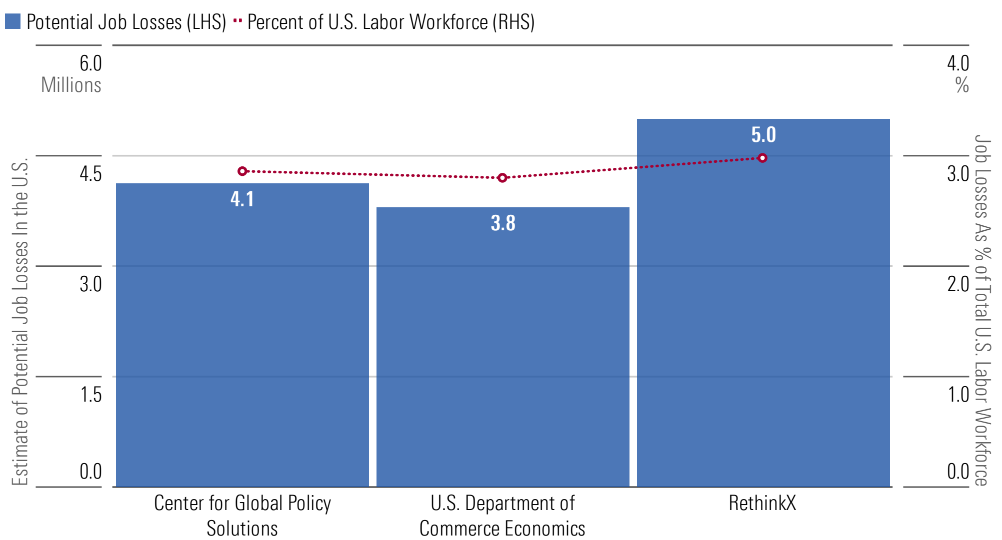
Self-Driving Cars Are a Massive Market Opportunity That Could Disrupt Multiple Industries

One of the reasons that self-driving cars receive so much attention is that the technology is clearly a massive market opportunity and has the power to seriously disrupt various industries. There have been various studies published on the impact of autonomous vehicles on job losses with slightly varying estimates. A way to think about job disruptions from autonomous vehicles is to think about the direct impact on jobs that mostly involve driving motor vehicles, such as truck drivers, bus drivers, taxi drivers, and so on, as well as the indirect impact on jobs that somewhat involve driving, such as firefighters, electricians, construction workers, and so on.

Most of the studies peg the number of direct job losses associated with autonomous driving to be around 4 million-5 million in the US, with a relatively smaller impact on a much larger number of jobs that partially involve driving. A study published by the US Department of Commerce's Economics and Statistics Administration estimates that as of 2015, the US had approximately 3.8 million workers, or 2.8% of the total US workforce, that could be classified as motor vehicles operators and another 11.6 million workers, or 8.5% of the total US workforce, that could be classified as on-the-job drivers, for whom driving is a material part of the job.

A study published by the Center for Global Policy Solutions, using US Census Bureau data for 2010-14, estimates that approximately 4.1 million workers, or 2.9% of the total US workforce, are employed directly in the driving profession. While we think that people displaced by the evolution of this technology will find other jobs over time, self-driving technology does have massive implications for workers and policymakers.

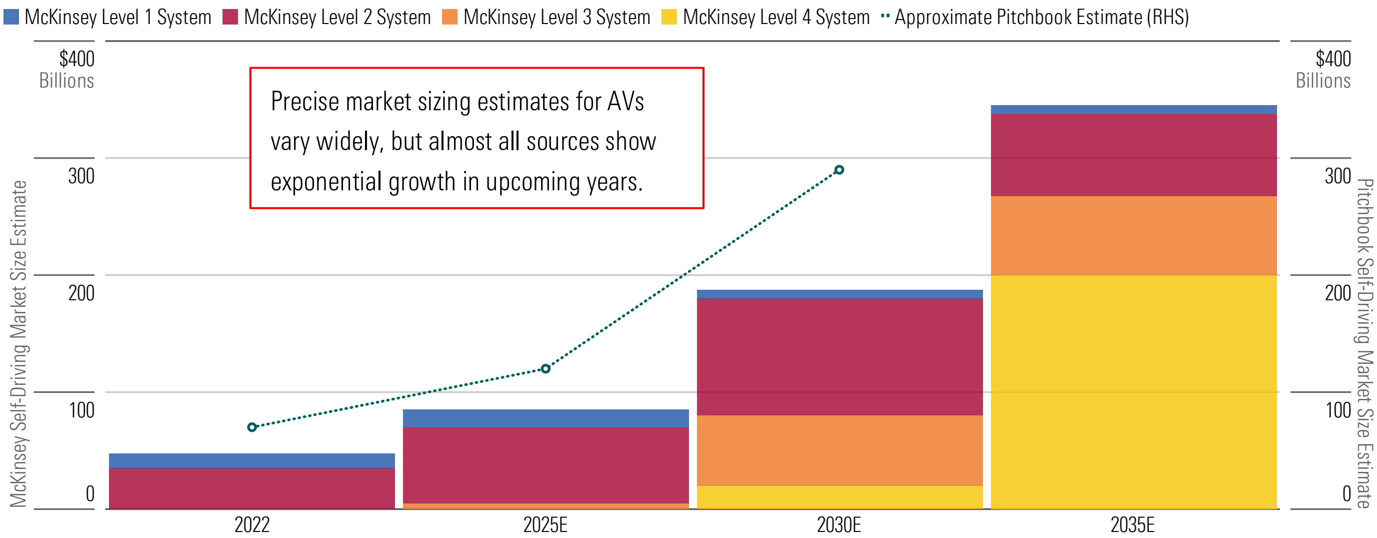
Exhibit 13 Self-Driving Cars Could Result in a Massive Number of Job Losses



Source: Morningstar, Center for Global Policy Solutions, US Department of Commerce, RethinkX. Data as of Dec. 31, 2017.

Given that the technology is still in its early stages, medium- to long-term estimates of the market size of the autonomous driving opportunity vary significantly. McKinsey estimates that the global market for passenger car advanced driver-assistance systems and autonomous driving systems could reach $300 billion-$400 billion by 2035. PitchBook is slightly more aggressive, pegging the global market size for autonomous driving at around $300 billion by 2030.

Exhibit 14 Market for Autonomous Systems Is Limited Now but Expected to Grow Rapidly in Upcoming Years as Technology Evolves



Source: PitchBook Mobility Tech Overview, McKinsey Center for Future Mobility, Morningstar. Data as of Dec. 31, 2023. Levels 1, 2, 3, and 4 in McKinsey estimates refer to levels of autonomy.

S&P Global Mobility expects 37% of global light-vehicle sales to have "Level 2+" autonomy by 2035. We recognize that projecting precise market sizes is a highly uncertain exercise, given the current stage of technology development for autonomous driving. But we argue that self-driving technology is a massive revenue opportunity, and investors for the most part have recognized this, as evidenced by the high valuations of various upstarts in this business that have yet to earn any revenue.

Autonomous cars have the potential to significantly disrupt many industries. The first-order impacts to industries like traditional car manufacturers, suppliers of components for traditional vehicles, trucking, logistics, auto insurers, and ride-hailing services are clearly visible. There are second-order disruption potentials as well in industries including public transport, parking facilities, processing capabilities, connectivity, healthcare systems, and fuel consumption.

Exhibit 15 AVs Can Dramatically Disrupt Many Industries; First-Order Disruptions Are Well Known, but Second-Order Disruptions Will Also Be Huge

Industries That Can Potentially Be Disrupted By Autonomous Driving

First Order Disruptions (Direct Impact)	**Vehicle Manufacturers**	**Component Manufacturers**	**Trucking & Logistics**	**Auto Insurance**	**Ride-Sharing/Taxi's**
	Different focus and technologies are required compared to a traditional car.	Entire supply chain for OEMs can be disrupted. Will have new winners & losers.	Human drivers are by far the biggest cost component in trucking & last-mile delivery.	Self-Driving cars become drastically safe and change the auto insurance landscape.	Drivers are by far the biggest cost component. Autonomous fleets make economic sense.
Second Order Disruptions (Indirect Impact)	**Public Infrastructure**	**Parking**	**Connectivity & Processing**	**Healthcare Systems**	**Fuel Consumption**
	Autonomy needs a different public infrastructure. Public transit will also be impacted.	Demand for parking spaces declines with a reduced need for personal car ownership.	Autonomous cars need strong connectivity and process huge amounts of data continuously.	Better emergency services. Lower road accidents reduce burden on healthcare systems.	Autonomous vehicles can be optimized to be more fuel-efficient.

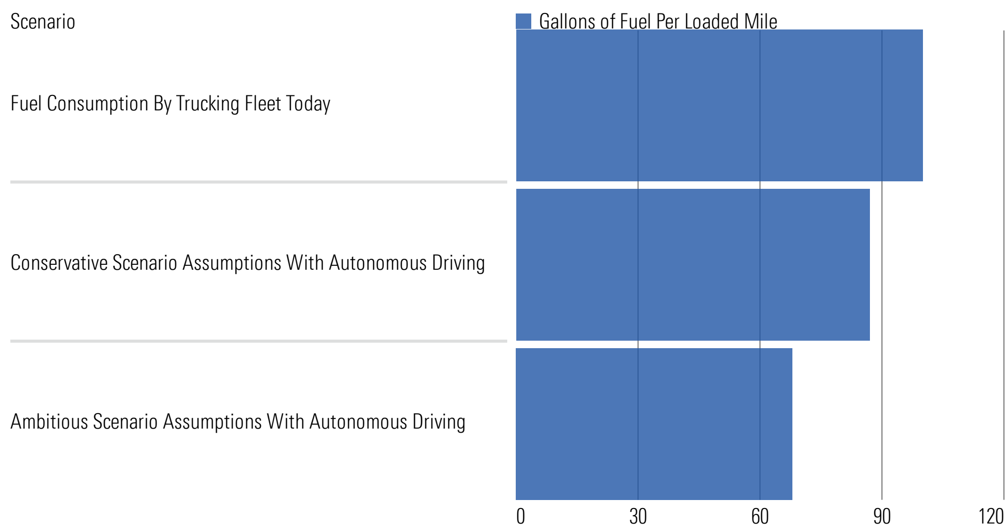
Source: Morningstar.

Fully autonomous driving solutions can also have a substantial impact on industries not mentioned in Exhibit 15. As an example, autonomous vehicles can free up around 50 minutes a day for a typical driver in the US. We think this could have a positive impact on social media platforms.

In this report, we limit our analysis to the impact of autonomous vehicles on the auto insurance industry. However, to put our larger point in context, let's look at the second-order consequences of autonomous driving technology on the oil industry. At first thought, it doesn't seem that fuel consumption and thereby the oil industry will be affected by the emergence of autonomous vehicles. However, recent studies have shown that autonomous vehicles can be optimized to be more fuel-efficient, resulting in materially lower fuel consumption.

Aurora Innovation, a self-driving company focused on trucks, recently published a report showing that fuel consumption for trucks can potentially be reduced by 13%-32% on average through autonomous driving solutions, by optimizing for factors like peak speeds, idling, sensor drag, deadhead reduction, and reduced congestion.

Exhibit 16 Autonomous Vehicles Can Have Second-Order Consequences Like Lower Fuel Consumption



Source: Aurora Innovation, Morningstar. Fuel-saving data from Aurora's white paper, "The Sustainability Opportunity of Autonomous Trucking."

It could be argued that Aurora published this report to better market its products. While some of the assumptions in the Aurora study are probably a bit on the aggressive side, there is enough scientific literature to substantiate claims of better fuel efficiency through optimized driving. We include the fuel efficiency statistics because autonomous vehicles can almost be thought of as a foundational technology, the impact of which will go far beyond sectors that we think of directly being affected, given the second- and third-order consequences of the disruption.

Exhibit 17 Various Independent Research Studies Have Substantiated Claims of Fuel Savings From Self-Driving Cars

Souces of Savings	Estimated Percentage of Fuel Savings In An Era of Self-Driving Cars
Congestion	0%-4%
Eco-Driving	Upto 20%
Platooning	3%-25%
De-emphasizing Performance	5%-23%
Improved Crash Avoidance	5%-23%
Vehicle Right Sizing & Ride-Sharing	21%-45%

Source: Morningstar, Center for Sustainable Systems at University of Michigan. Wadud, Z., et al. 2016. "Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles." Brown, A., et al. 2014. "An analysis of possible energy impacts of automated vehicles."

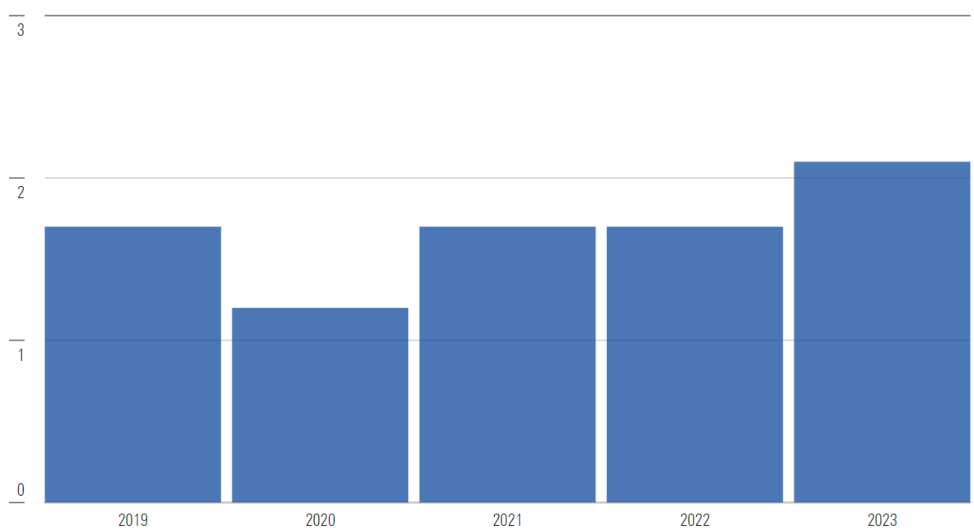
Autonomous Vehicles Potentially Shift Liability for Auto Accidents

While autonomous vehicles could reduce the number of accidents, which would clearly be a positive for auto insurers, they also have the potential to upend the industry in the long term. In our view, it's best to start the discussion about the impact of driverless cars at the end point. In a world where all cars were fully autonomous, would auto insurance still be necessary? If so, what would it look like?

The entire point of autonomous cars is that the driver is no longer in control. Therefore, it is hard to see how the owner of a fully autonomous car could be found legally liable for damage. In our view, car insurance would most likely morph into product liability insurance and would ultimately be borne by the auto manufacturers or the company that provided autonomous capability in the vehicle. In this scenario, auto insurance would become a somewhat niche commercial insurance line, and its nature would change so dramatically that it is difficult to see how existing carriers would continue to service it.

But even in a world where all cars are fully autonomous, there could still be a small amount of room for personal auto insurance, although the risks covered would change significantly. Over time, we would expect auto insurance to shift into something more similar to homeowners insurance, where the majority of the coverage provided is aimed at offering protection to car owners in the event that a vehicle is stolen or damaged by things other than traffic collisions, like hail or flooding. Catastrophe losses typically are not a meaningful item for auto insurance, though. For instance, catastrophe losses represented only about 2% of premiums for Allstate over the past five years. If auto insurance coverage were limited to this area alone, the industry would shrink to a negligible size.

Exhibit 18 Catastrophe Losses Are Not a Material Source of Claims for Auto Insurers
Catastrophe losses as a percentage of net earned premiums for Allstate's personal auto business.



Source: Company filings, Morningstar.

While fully autonomous vehicles might be the hoped-for end point, progress toward this goal is likely to come in stages, with varying levels of driver involvement along the way. We believe discussion of driverless cars tends to blur the distinction among levels of automation, which can lead to an overly aggressive view of the timeline over which the auto insurance market might be affected. In our view, as long as there is any significant driver involvement, personal auto insurance will remain necessary.

Liability auto insurance coverage is likely to remain compulsory in the states where it already is required, even for highly automated cars. The main reason most states require liability insurance coverage is to ensure that drivers can cover the cost of damage to property and/or people in the event of an accident. While driverless cars are expected to eventually reduce accidents dramatically, the risk of collision posed by autonomous vehicles in manual mode will remain for some time. It will be far easier for state insurance commissioners to continue to require some form of liability insurance for all vehicles as opposed to eliminating coverage for highly automated vehicles (although the premiums for fully autonomous vehicles could be much lower and will be reduced further as more driverless cars hit the road and the technology builds up a record of safely preventing collisions). Further, we believe the regulatory environment around auto insurance is likely to lag the technology changes.

As such, we think multiple hurdles will need to be overcome before drivers are no longer required to maintain insurance. First, highly autonomous vehicles will need to be available on a wide scale. Second, regulations around insurance will need to be changed on a state-by-state basis. Finally, autonomous vehicles will need to meaningfully replace nonautomated and even partially automated cars on the road.

Exhibit 19 Classification of Automation Systems Necessary to Determine Accident Liability; Current Regulatory and Legal Frameworks Are Fuzzy at Best

Who Is Liable For Accidents Involving Cars With Autonomous Driving Technology?

	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Commonly Used Name	Momentary Driver Assistance	Driver Assistance	Additional/Partial Automation	Conditional Automation	High Automation	Full Automation
Human Involvement	These are driver "support" features. Support word is important.			These are automated driving features. Human involvement is often limited.		
Who Is mainly Responsible?	Humans are primarily responsible to supervise the system, monitor the environment and drive the vehicle			The system is primarily responsible for driving. Depends on conditions as well		The system is fully responsible
Who is liable during accidents?	Self-driving companies have gone out of their way to ensure that human drivers are held liable for accidents since these are only "support" features.			Legal frameworks fuzzy. Conditions are important. Humans remain "primarily" liable.	More automation => Liability shifts towards system manufacturers. Primarily, the system/vehicle manufacturer is liable.	
Impact on Insurance	Minimal direct impact on auto insurance industry. Regulators will require insurance. Safer cars can have a mixed impact.			Minor impact on auto insurers.	Auto insurance gets disrupted. Becomes product liability insurance.	

Source: Morningstar, SAE International, National Highway Traffic Safety Administration.

Exhibit 19 shows a framework for how to think about who is liable for accidents involving cars with autonomous driving technology. Given that regulatory details are scant and legal precedents are limited, the details in this exhibit should be thought of as opinions rather than facts. In our opinion, human drivers would primarily be held completely liable for vehicles containing Level 2 systems or below. In case of fully autonomous vehicles (Level 5), the system/vehicle manufacturers would be held completely liable and auto insurance would morph into some sort of product liability insurance.

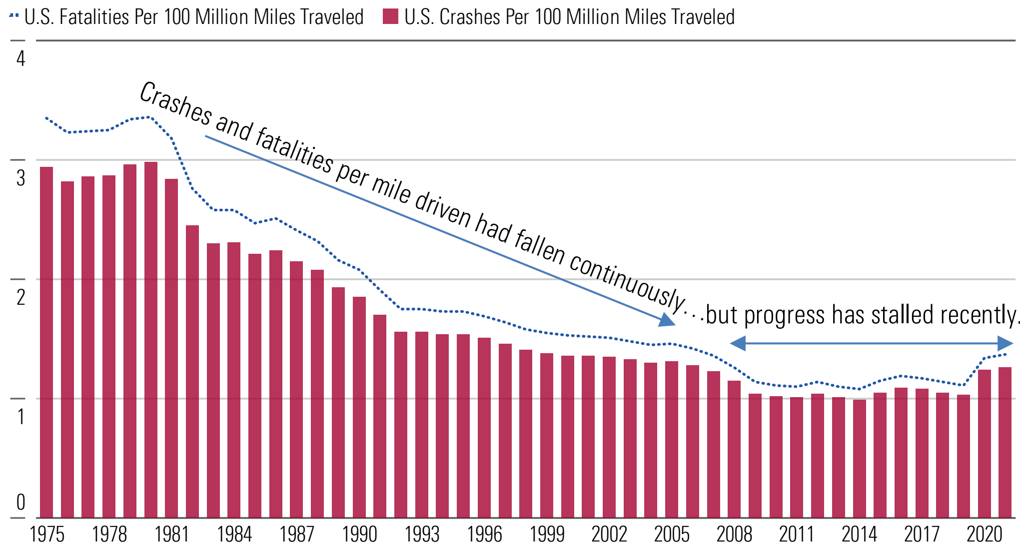
It gets tricky for Level 3 and Level 4 systems. In case of accidents involving cars with Level 3 and 4 autonomy, liability can be either with humans or the system or a combination, depending on factors like external conditions, geographic location, and legal structures. What makes the question of who bears the liability interesting is the fact that levels of autonomy are more like a spectrum rather than buckets. A high-level principle is that systems with higher autonomy should lead to liability shifting away from humans and toward system manufacturers.

After considering the latest industry developments, regulatory commentary, and legal opinions, our sense is that the primary liability remains with the human driver in Level 3 systems, given the importance of external conditionality in this level of autonomy. System manufacturers will certainly try to keep the definitions of external conditions under which their systems can operate fully autonomously relatively constrained from a legal perspective, to avoid being held liable for accidents. More importantly, we believe that regulatory developments will significantly lag technological developments in the industry, and regulators will lean toward keeping the liability with human drivers until a high level of autonomy is achieved. For this reason, we believe that the auto insurance industry will see only minor direct impact from Level 3 autonomy. We think this dynamic changes substantially as we move from Level 3 to Level 4, though. We believe the traditional auto insurance industry starts getting disrupted as we reach Level 4 autonomy, and system manufacturers would be held primarily liable for accidents.

Autonomous Vehicles Could Reduce the Number of Accidents

While AVs could make auto insurance obsolete in the long run, the near-term impact should primarily be positive, as they could lower the number of auto accidents. To understand how autonomous cars might affect safety and auto insurance, it's helpful to understand historical trends in the industry. The number of car crashes and fatalities per miles driven had fallen continuously until about 2010 as automakers layered on more and more safety features. However, progress has stalled in recent years.

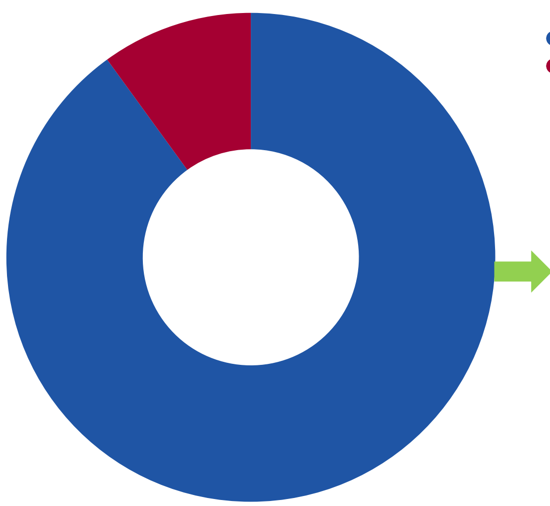
Exhibit 20 Crashes Per Miles Driven Fell Continuously Until About 2010, but Progress Has Stalled



Source: National Highway Traffic Safety Administration, Morningstar. Data as of May 30, 2024.

There are various arguments for the recent flattening of the safety trend in recent years, such as relative saturation of safety features in automobiles, higher driver distraction, rigid driving behaviors, increased traffic congestion, decaying public infrastructure, weaker enforcement of traffic laws, and socioeconomic factors. We believe that flattening can best be explained by driving behaviors that are difficult to change, more distracted driving, and most importantly, relatively smaller incremental improvements in automotive safety features.

Exhibit 21 Human Errors Are Estimated to Cause About 90% of Vehicle Crashes in the US



Reason Behind A Road Crash	%
Estimate of Crashes Caused by Human Errors	90.00
Others	10.00

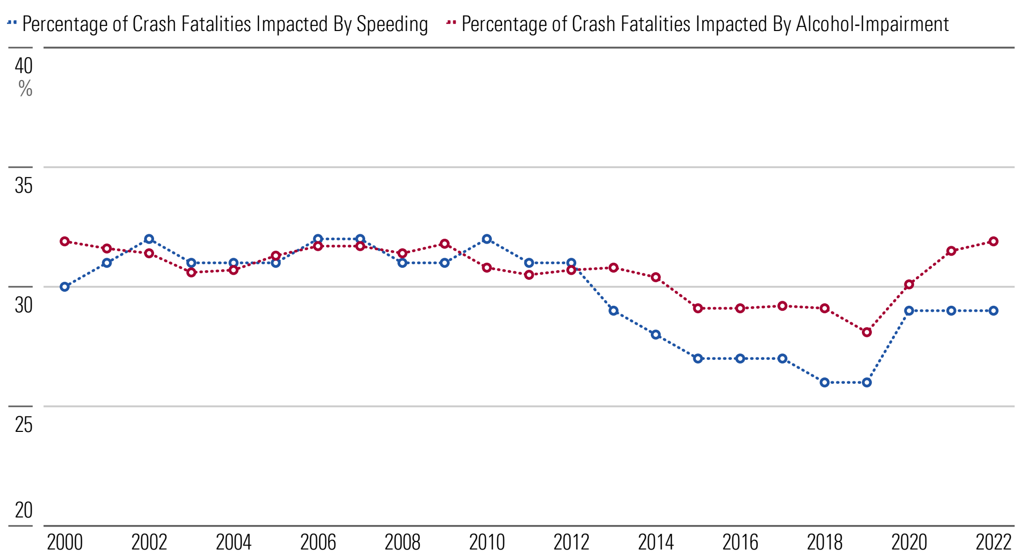
Given that human errors are primarily responsible for most vehicle crashes, reducing human involvement in driving has massive inherent potential to improve safety.

Source: Autonomous Vehicle Industry Association, Morningstar.

Per the Autonomous Vehicle Industry Association, approximately 43,000 fatalities were recorded on US roads due to crashes in 2022, and about 90% of the motor vehicle crashes were primarily caused by human error. Human driving habits and behavior are notoriously difficult to change, and the fact that a disproportionate number of accidents are caused by human errors means that at least theoretically, autonomous driving capabilities can dramatically affect vehicle safety.

Another example of how difficult it is to change human driving habits and behavior is the impact of speeding on crashes and fatalities. Even after continuous efforts to rein in speeding-related accidents, the total number of speeding-related fatalities and the percentage of fatalities related to speeding have remained in a relatively tight band over the past two decades. The story isn't much different for alcohol-impaired driving, which continues to be responsible for around 30% of all vehicle crash fatalities in the past two decades.

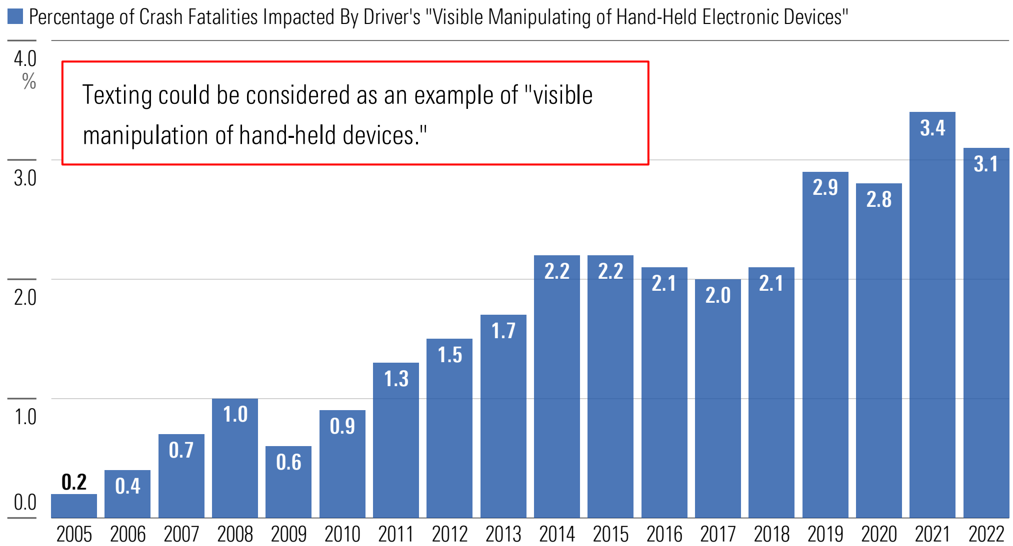
Exhibit 22 Don't Bank on Changing Human Driving Behavior to Improve Road Safety



Source: National Safety Council, Morningstar. Alcohol-impaired driving fatalities involve crashes with at least one driver with a blood alcohol concentration of 0.08 grams per deciliter or higher.

Some evidence suggests that things have gotten worse for other leading causes of vehicle crashes such as distracted driving, as seen in Exhibit 23.

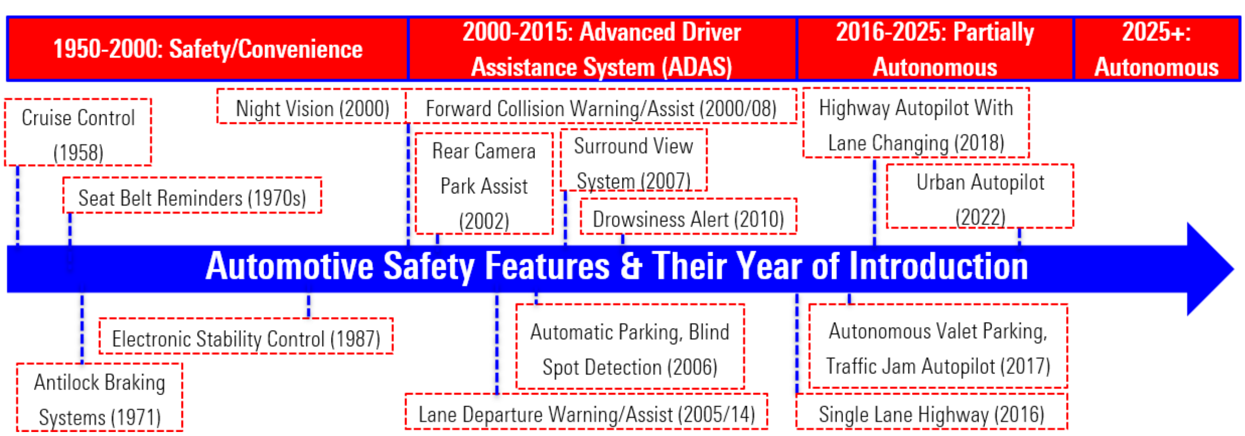
Exhibit 23 Distracted Driving Due to Hand-Held Device Use Has Gone Up Sharply



Source: National Safety Council, NHTSA Fatality Analysis Reporting System, Morningstar.

The main point is that human errors are responsible for most of the crashes, and improving human driving behavior is difficult. Given how hard it is to change driving behavior, we attribute most of the improvement in driving safety from 1980 to 2010 to better safety features in cars. We also believe that vehicle safety has stalled in the past decade primarily because of the saturation of safety features.

Exhibit 24 Timeline for Evolution of Automotive Safety Features Per the Year of Introduction Into Mass-Market Vehicles



Source: Morningstar, Boston Consulting Group.

Automotive manufacturers would rightly argue that they have continued to innovate and add safety features to their vehicles in the past decade or so, as seen in Exhibit 24. However, an argument can be made that incremental safety improvements from features like single-lane highway assist, autonomous valet parking, parking blind spot detection, and traffic jam autopilot is minimal. These features provide convenience but do little to prevent crashes on roads. It can also be argued that the safety features introduced in some of the latest and high-end models have not yet made it into a critical mass of vehicles to materially affect crash rates. Still, we think improving safety going forward will require a dramatic change, and autonomous features look like the only realistic avenue to provide that change.

Some of the market-leading solutions for highway autopilot and urban autopilot have Level 2+ autonomous characteristics and have the potential to massively improve safety. The introduction of navigation on autopilot capabilities can drastically reduce vehicles crashes and fatalities as they reduce human errors, which are responsible for most of the crashes. In our opinion, autonomous driving features can be the biggest catalyst for improving vehicle safety. To determine the impact of autonomous systems on vehicle safety, the next question is how the driving records of the latest autonomous systems compare with human driving records.

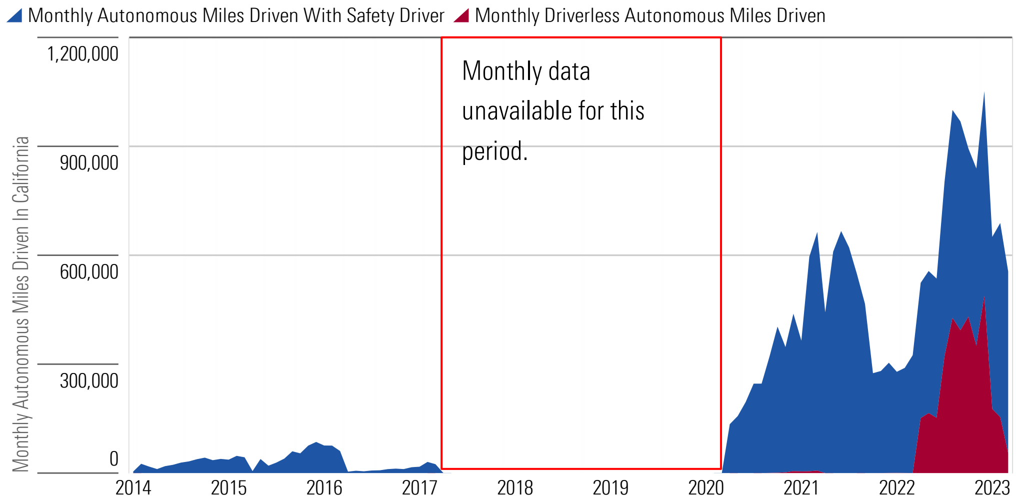
Latest Versions of AV Systems Are Already Safer Than Humans and Will Only Get Better

We think it is most relevant to compare the safety records of Level 3 and Level 4 systems in the market with human drivers rather than comparing the safety record of navigation on autopilot systems, since Level 3 and Level 4 systems are the more technologically advanced and most of the NOA systems include continuous inputs from human drivers. Further, as we think about enhanced safety from autonomous driving, the technology has huge potential for disruption, but the impact on the auto industry has been minimal to date, given that Level 2 or higher autonomous technology has not evolved enough to potentially change industry dynamics.

As shown in Exhibit 19, we believe that the liability principally remains with the human driver up to at least Level 3 autonomy. The leading products in the autonomous driving market have achieved Level 3+ autonomy, but the absolute number of these vehicles is negligible on US roads. For the industry to be materially affected, we believe a critical mass of vehicles on roads needs to achieve a certain level of autonomy. We will discuss the possible timeline for disruption in more detail later in this report, but for now, we will focus on the capabilities of the current technology.

California is widely considered to be a hub for autonomous driving startups in the US. Exhibit 25 shows that autonomous miles driven (Level 3 or 4) by various companies in California have increased exponentially over the past decade. It took more than two years for companies to cumulatively register their first million autonomous miles in real-life conditions in California. However, a million autonomous miles now seems achievable within a month in California, per some of the latest reports. We believe that autonomous miles driven will continue to increase exponentially in the coming years as mass-market commercialization of robotaxis seems closer than it's ever been.

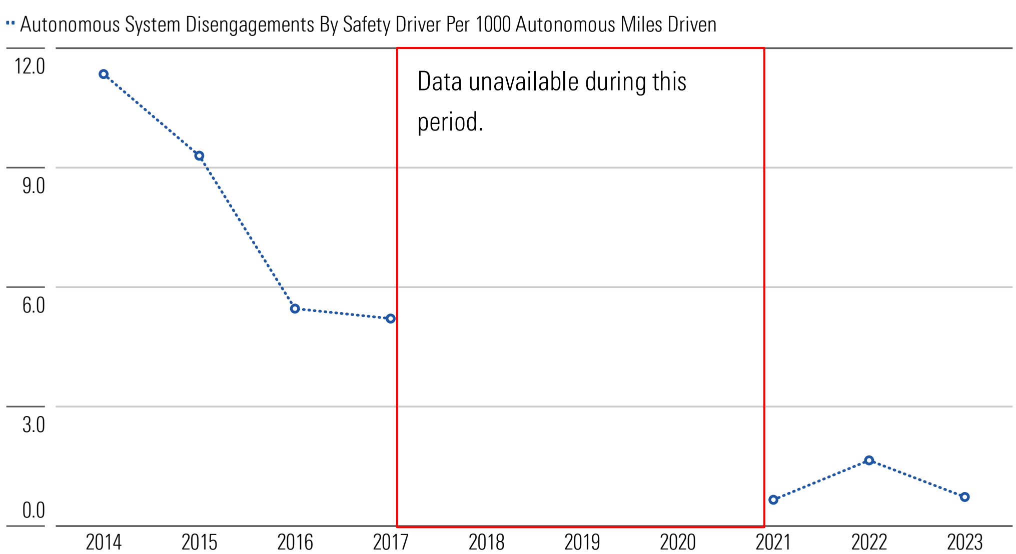
Exhibit 25 Autonomous Miles Driven Have Increased Exponentially in California Over the Past Decade



Source: California Department of Transportation, Brookings Institute, Morningstar. Data as of Nov. 30, 2023.

One way to measure the capability of autonomous vehicles to operate in real-life conditions is to measure disengagements per autonomous mile driven by the system itself or by safety drivers, who were required to be seated behind the wheel during the early phases of the development of autonomous technology. Lower disengagements per autonomous mile means that the system is good enough to navigate real-life traffic conditions without needing interventions.

Exhibit 26 Autonomous System Disengagements by Safety Drivers Have Fallen Drastically Over the Past Decade

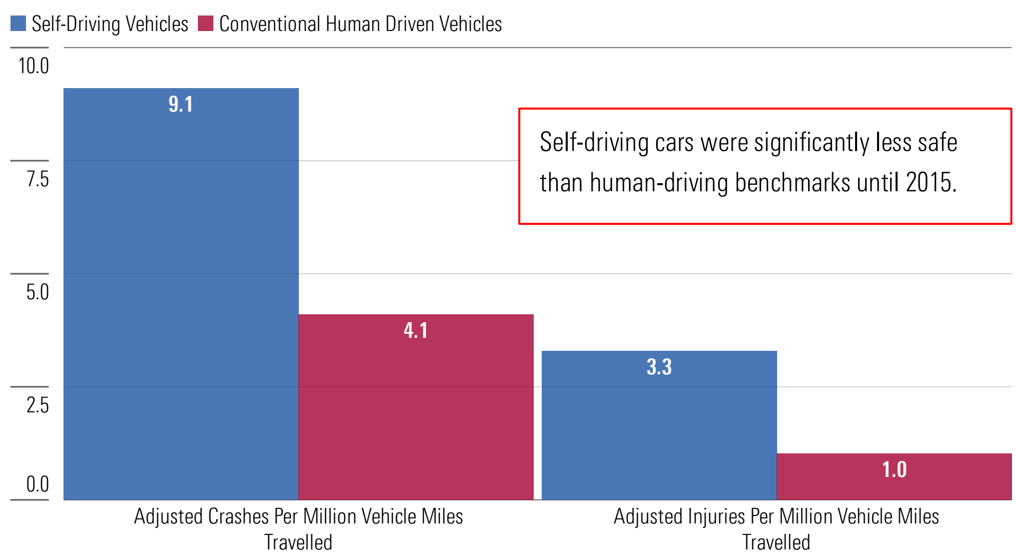


Source: California Department of Transportation, Brookings Institute, Morningstar. Data as of Nov. 30, 2023. Annual disengagement rates are calculated by taking the average of monthly disengagement rates in 2014-17 per Brookings Institute data. Annual disengagement rates in 2021-23 are calculated by dividing total disengagements within a year with total autonomous miles driven as per the California DMV disengagement report.

Exhibit 26 shows that disengagements per autonomous miles driven have been falling rapidly over the past decade. Note that this exhibit includes numbers from all the companies operating in California within a particular period. Generally speaking, newer upstarts testing their autonomous systems tend to have substantially higher disengagements than market-leading systems. This tends to make the disengagement data in Exhibit 26 more volatile from year to year. Disengagement figures for market-leading systems are considerably better than the overall numbers suggested in the below exhibit.

Some of the widely quoted figures in media and legal journals suggest that autonomous vehicles are less safe than conventional human-driven vehicles. An example is a study published in October 2015 by Schoettle and Sivak analyzing real-world crashes involving self-driving vehicles. The paper concludes that after making several adjustments, self-driving cars had more than twice the crash rates and more than triple the injury rates per million vehicle miles traveled compared with conventional human-driven cars. But this study was done using data from autonomous systems introduced on roads in 2015, which were quite nascent at that time. The technology for autonomous driving has improved drastically since then.

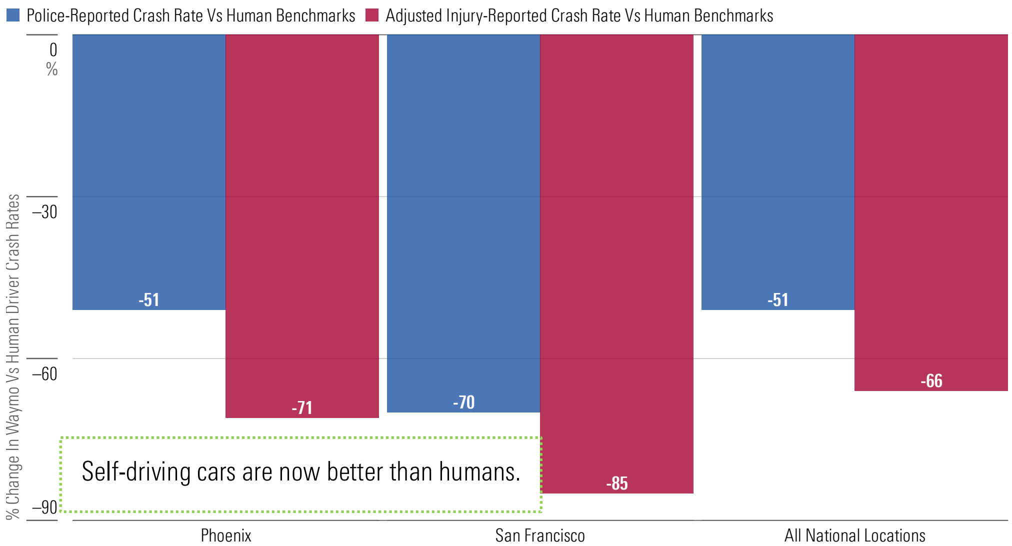
Exhibit 27 AVs Had Higher Crash and Injury Rates When They Were First Allowed on Roads for Testing



Source: Morningstar, Schoettle, B., et al. 2015. "A preliminary analysis of real-world crashes involving self-driving vehicles." Data as of Oct. 30, 2015.

For the reasons discussed above, we think it is best to use the driving data record of leading autonomous solution providers rather than data for all companies to compare safety with human drivers. Our purpose is not to identify the leading autonomous driving platforms, but for the sake of our analysis, we believe Waymo is perhaps one of the leaders in this field.

Exhibit 28 Latest Data From Waymo's Driverless Level 4 AVs Shows Significantly Lower Crash Rates



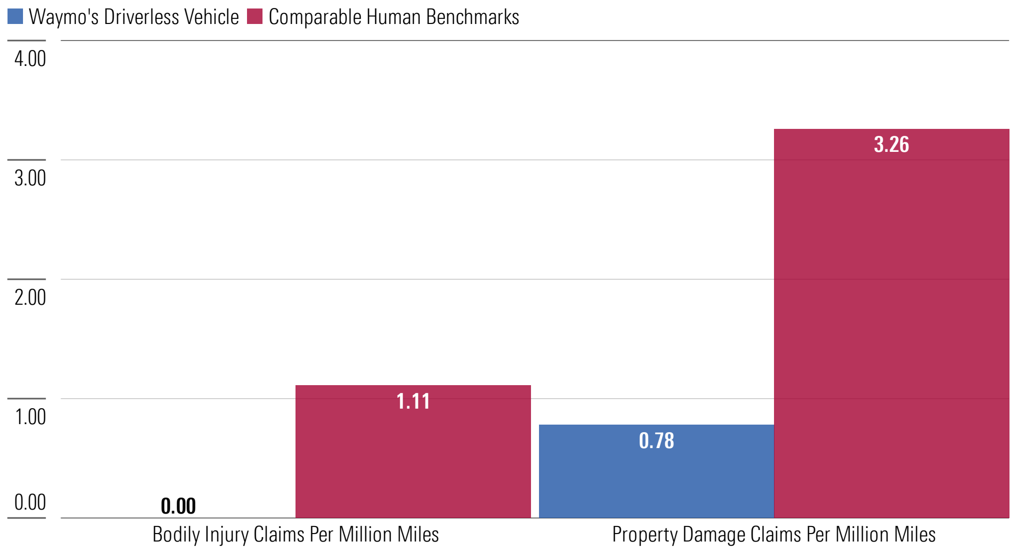
Source: Morningstar, Waymo, Kusano et al. 2023. "Comparison of Waymo rider-only crash data to human benchmarks at 7.1 million miles." Data as of Dec. 20, 2023. Negative bars indicate the percentage by which Waymo's driverless cars had lower crash rates compared with human benchmarks.

Exhibit 28 shows the extent to which Waymo's driverless cars outperformed on safety parameters compared with human-driving benchmarks. The data was compiled based on 7.1 million miles of automated real-world driving, which we think is a big enough sample size. We believe that self-driving cars have to be materially better than human drivers from a safety perspective in order to be widely accepted. If this study is anything to go by, we have solid evidence that driverless autonomous cars are already safer than human drivers. More importantly, The safety parameters for self-driving vehicles will only improve from here.

Waymo and Swiss Re (one of the world's biggest reinsurance companies) jointly published a research paper assessing the risk associated with autonomous vehicles. The study used liability claims data from Swiss Re to compare the real-life claims produced by Waymo's driverless autonomous vehicle with ZIP-code-adjusted human driving liability claims. The study was based on 3.8 million autonomous miles driven by Waymo's Level 4 solution, which we think is a large enough sample size.

The study concluded that Waymo's driverless vehicle incurred no bodily injury claims, compared with 1.11 claims per million miles for human-driving benchmarks. In terms of property damage, Waymo's driverless vehicle incurred 0.78 claims per million miles, compared with 3.26 for human driving benchmarks. This study directly shows the implications of autonomous driving for the insurance industry. We will discuss the financial implications of autonomous driving solutions for our coverage in much more detail later in the report. The conclusion from this section is that leading AV systems are already significantly better than human drivers, and with time, their safety will only increase.

Exhibit 29 Waymo's Driverless Autonomous Driving Vehicle Had Fewer Bodily Injury and Property Damage Claims



Source: Morningstar, Waymo, Swiss Re. Data as of Oct. 12, 2023.

Timeline for Autonomous Driving Technology Development and Adoption Is Far From Certain: Mapping Out Scenarios

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In the previous section, we discussed the details of autonomous driving technology and its potential impact on the auto insurance industry. In this section, we use this analysis to inform our projections on the timeline for autonomous driving technology development and adoption in the US. Given the uncertainties inherent in technological development and the pace of adoption, we think it is better to think about this in terms of scenarios.

To avoid confusion, we want to clarify the difference between the terms "adoption rate" and "penetration rate" in our discussion. We define adoption rate as the percentage of new vehicles sold that have a certain level of AV capability. For instance, if 1.5 million cars out of 15 million cars sold have Level 4 capability, then the adoption rate would be 10%. We define penetration rate as the percentage of vehicles on US roads that have a certain level of AV capability. For instance, if 12 million cars out of a total of 300 million cars on US roads have Level 4 capability, then the penetration rate would be 4%. For auto insurers, what really matters is penetration rate rather than adoption rate per these definitions, but the adoption rate drives the penetration rate.

Setting Baseline Assumptions to Further Explore Various Scenarios

We have made certain assumptions to help us analyze and clearly visualize the implications of autonomous driving. These assumptions may not perfectly reflect reality, but we think they will have minimal impact on our final calculations while significantly assisting in our analysis.

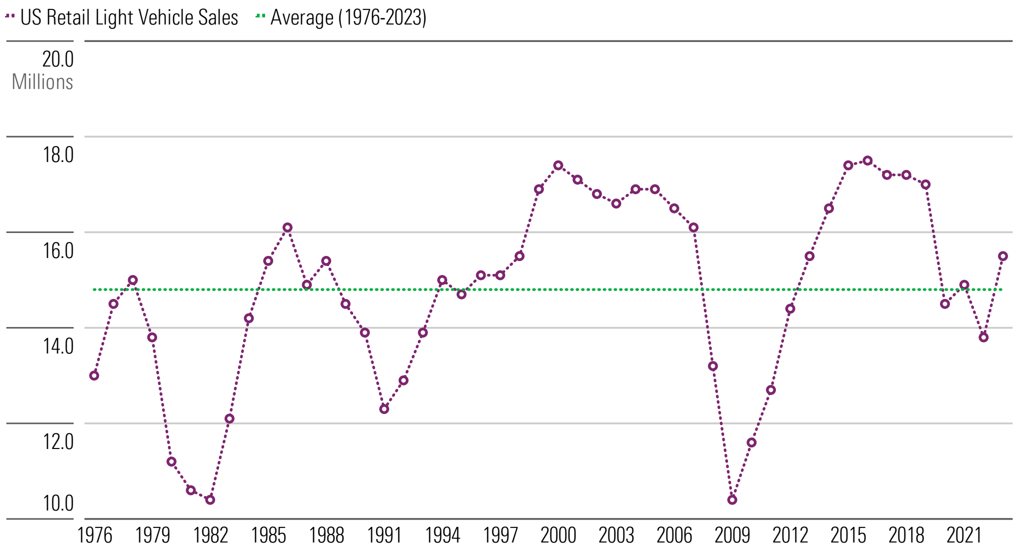
The first major assumption is that the auto insurance business won't be affected significantly until Level 4 or higher autonomy is achieved at scale. This is because even in Level 3 autonomy, humans will have to take control in many conditions and can be held responsible in the case of an accident. Additionally, there is a lot of incentive for system manufacturers to keep classifying their autonomous systems as Level 2 from a legal and regulatory point of view, even when they are Level 3 in actual capability, to avoid any product liability claims. From an auto insurance perspective, what really matters is the penetration rate of Level 4 or Level 5 vehicles on roads.

The second assumption is that the auto insurance business will start to be materially affected only after the penetration rate of self-driving vehicles has reached a certain critical mass. For us, this number is around 10%. As we incorporate our AV penetration rate scenarios into our cash flow models for auto insurers, this is the timeline beyond which AVs begin to materially affect auto insurance business. As the penetration rate increases, we think that insurance companies will try to protect their original business, but that business will continue to slump at an increasing rate. As we approach a 60% penetration rate, we assume that the traditional insurance business will largely stop creating any value and the capital on insurance balance sheets will be returned to shareholders.

In real life, the presence of Level 2 and Level 3 autonomy will certainly affect the safety of vehicles. However, for the purpose of calculations in this segment, we assume that Level 2 and Level 3 systems have a minimal impact on the auto insurance business.

Finally, in our analysis, we will ignore the cyclical nature of automobile sales and assume that retail sales in the US will grow noncyclically from our midcycle estimate of 15 million vehicles annually in the future. This assumption should have minimal impact on our final conclusions.

Exhibit 30 Vehicle Sales Are Cyclical and Have Averaged Around 15 Million Units a Year in the Past Five Decades



Source: Morningstar, US Bureau of Economic Analysis, Federal Reserve Bank of St. Louis. Data as of Oct. 31, 2023.

Penetration rates for autonomous vehicles (Level 4 and Level 5) is perhaps the single most important factor for us to quantify the valuation impact on our auto insurance coverage. In this discussion, we will estimate the year in which the penetration rate reaches 10% and 60% in various scenarios.

Identifying the Most Important Factors Affecting AV Penetration Rates

Our calculations for the penetration rate (percentage of Level 4 and Level 5 AVs on the road) depend on a few key inputs. While our calculation involves various factors, we believe that three are by far the most important. The first is the timeline for technology development, which indicates the precise year for Level 4 autonomous technology to be mature and affordable enough to be introduced in mass-market vehicles. We define this as the year by which Level 4 technology reaches at least 0.25% of all new vehicles sold in the US. We believe that AV technology will have developed enough to be included in mass-market vehicles when the adoption rate reaches this level. The second is the rate at which adoption of self-driving cars increases. Third is the scrappage rate for the existing car fleet.

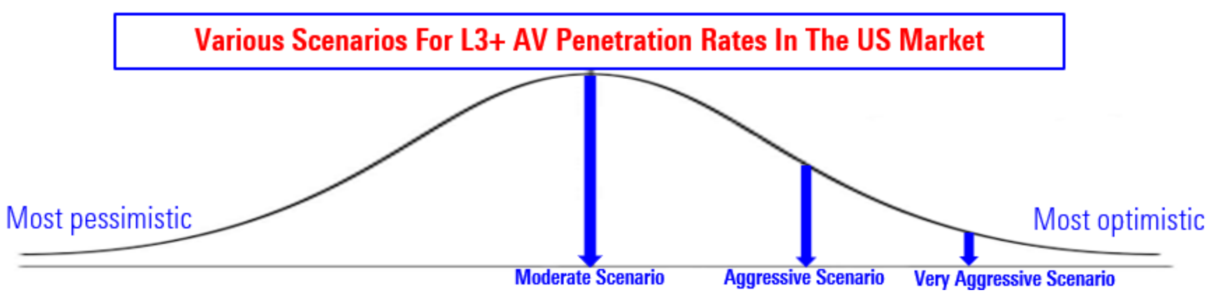
Exhibit 31 Penetration Rate of Level 4 or Level 5 Vehicles Will Primarily Depend on Tech Development, Pace of Adoption, and Salvage Rate of Existing Fleet

Major Factors Impacting the Penetration Rate of Autonomous Vehicles		
Timeline of Technology Development	**Pace of Technology Adoption**	**Scrappage Rate of Existing Car Fleet**
While robotaxis are already being employed on roads, we think the turning point comes when level 4 autonomous technology becomes mature enough to be introduced in mass-market vehicles. **This will mark the year in which this happens.**	After the introduction of level 4 autonomy in mass-market vehicles, this refers to the speed at which it gets adopted by various OEMs in the car models. **It can be thought of as the percentage of car sales in a particular year that are autonomous**.	Introducing autonomous technology that adds significant value can materially change **the speed at which consumers ditch their old vehicles and buy new ones.** This will impact the scrappage rate of the existing car fleet.

Source: Morningstar. .

In our analysis, we focus on three scenarios for the AV penetration rate in the US: very aggressive, aggressive, and moderate scenarios.

Exhibit 32 Three Scenarios for Tech Development, Pace of Adoption, and Salvage Rate of Existing Car Fleet for Calculating AV Penetration Rate in US



Source: Morningstar.

In the very aggressive scenario, we take the most optimistic assumptions for the three factors based on our opinion of the technology and our previous conclusions. The very aggressive scenario for AV penetration rates corresponds with the worst-case scenario for auto insurance companies. We focus the most on this scenario in this report because it helps us determine the possible valuation impact on our auto insurance coverage. In the aggressive scenario, our projections are slightly higher than what we believe is the most likely case. In the moderate scenario, our projections correspond with what we believe is the most likely outcome. For the sake of simplicity, we have not focused on scenarios on the other end of the curve that correspond with slower-than-expected evolution and adoption of AV technology.

When we are discussing any factors in this section, we are essentially talking about Level 4 and Level 5 autonomous vehicles. We are not concerned about Level 3 or below. Also, all the discussion in this section corresponds to the US and the unique dynamics in this market. Precise projections for other markets like China could be materially different.

Timeline for Technology Development Depends on Ability to Launch Core Technological Capabilities in Mass-Market Products

The first question when we think about a breakthrough technology is the core development of the technology under ideal laboratory conditions. In case of autonomous vehicles, the core technology has already been developed under laboratory conditions and is now being readied for mass deployment in real-life conditions.

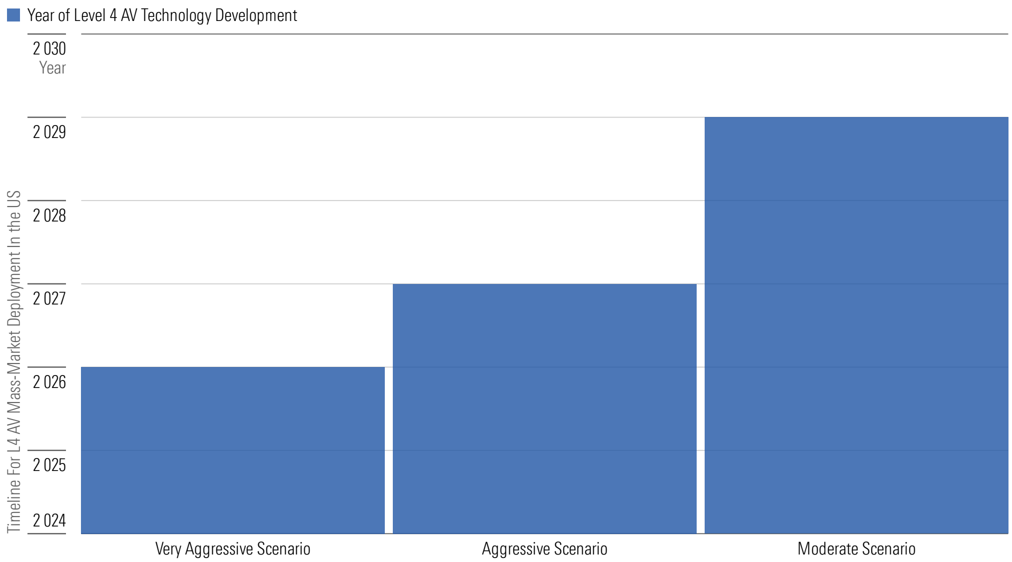
The way we define the timeline for technology development for this report is the point at which Level 4 autonomous technology becomes mature enough to be deployed in mass-market vehicles. For instance, when will original equipment manufacturers launch vehicles equipped with Level 4 autonomy that ordinary consumers can buy or use in robotaxi services? To precisely measure the year in which this happens, we define the breakpoint for technological development to be the year in which 0.25% of vehicles sold in a particular country have Level 4 or higher autonomous capability. This number is around 40,000 vehicles in the US market.

We estimate that the breakpoint for 0.25% of vehicles sold having Level 4 AV capability in the US is early 2026 in the very aggressive scenario, mid-2027 in the aggressive scenario, and 2029 in the moderate scenario. These assumptions are based on the latest developments in AV technology, recent product launches, and our analysis of the regulatory environment and market conditions. The 2026 estimate in the very aggressive scenario is based on a company like Tesla rolling out a robotaxi product and companies like Waymo introducing new robotaxis on US roads. We estimate that total new Level 4 AVs introduced on the roads exceeds the 0.25% breakpoint on an annualized basis in 2026 in the very aggressive scenario.

Executives of various AV companies have publicly made comments that imply that the breakpoint could be even earlier, but we remain skeptical. The most talked-about possibility related to this is Tesla launching its FSD software in a couple of years with capabilities that can be classified as Level 3 or higher. While this is possible, we don't think it is highly probable, given our assessment of the current capabilities of leading navigation on autopilot systems.

In our very aggressive scenario, we include a probabilistic assessment of NOA systems reaching Level 4 capability by 2026. In our aggressive scenario, we reduce the probabilistic assumptions in the very aggressive scenario to arrive at the 2027 number. Our moderate (most likely) scenario assumes that leading NOA systems will be stuck at Level 3 for a few more years and the breakpoint of 0.25% adoption happens predominantly thanks to public robotaxis from Waymo, Cruise, and other providers.

Exhibit 33 Timeline for Mass-Market Deployment of Level 4 AV Technology in the US Market in Various Scenarios



Source: Morningstar.

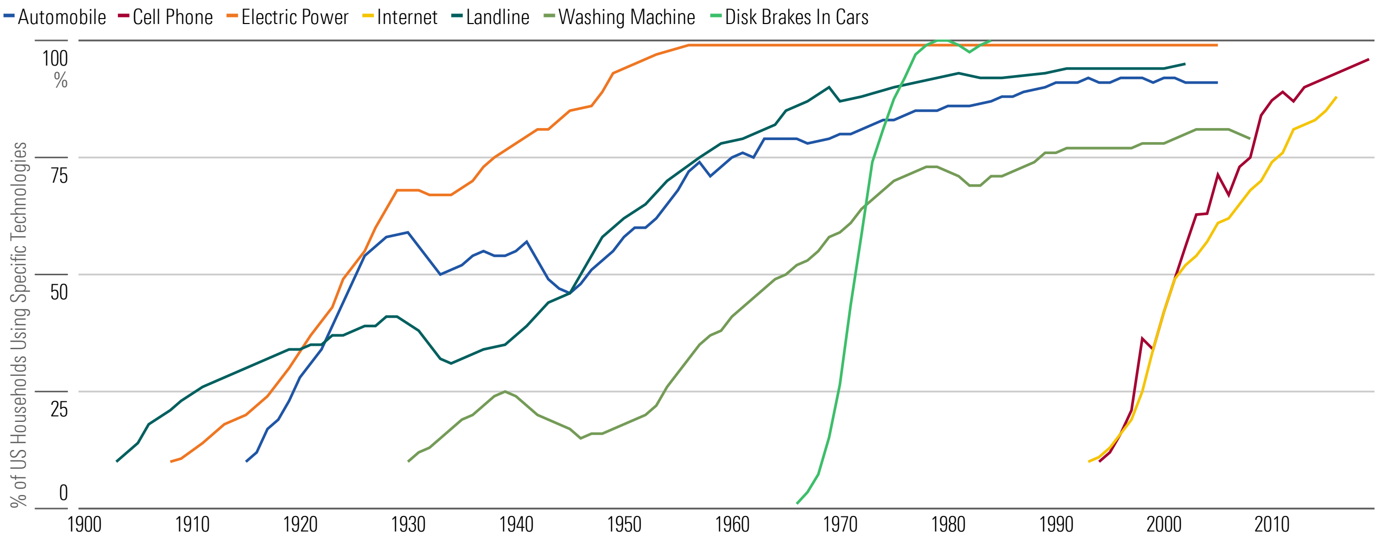
While this may seem a bit too optimistic, industry articles like "Baidu Launches New $28,000 Robotaxi In Wuhan" (Forbes) and "GAC Aion & Didi Autonomous Driving JV to Mass-Produce Robotaxi" (Car News China) show the increasing affordability and the plans for mass-producing Level 4 vehicles. We have been closely following updates, executive interviews, and company announcements from leading solutions providers in the AV industry and are increasingly confident in our assertion that self-driving vehicles are very close to being launched in mass-market solutions.

Pace of Technology Adoption: Comparing AV Adoption With Smaller-Ticket Items Like Mobile Phones Is Imprudent, but There Is Still a Case to Be Made for Rapid Adoption

The second most important factor in determining the penetration rate of autonomous vehicles is the pace of AV technology adoption. We are essentially trying to predict the speed at which AV technology will be present in the majority of new vehicles after it starts being introduced in mass-market vehicles for regular consumer use.

The pace of adoption of a technology depends on a number of factors, including technological, economic, social, regulatory, and market conditions. Empirical evidence in various research publications suggests that everything else equal, the pace of technological adoption has increased materially in recent decades. As an example, the amount of time it took for internet penetration to reach most US households was substantially shorter than the penetration speed of landlines. Exhibit 34 shows the share of US households using a specific technology in a specific year. The slope of the various lines gives us a sense of the speed of penetration for various technologies in the US.

Exhibit 34 Penetration Speed for Various Technologies Has Improved Notably in Recent Decades Compared With Early Part of 20th Century



Source: Morningstar; Dediu, Comin, and Hobijn, Our World in Data, 2004.

A way to measure the pace of penetration is the number of years for the technology to reach 80% of households from 10%. Exhibit 35 shows that the speed at which the penetration rate for various technologies increases can vary quite a bit depending on various factors. It took 72 years for washing machines to reach to 80% of US households from 10%, compared with only 15 years for color TV.

Exhibit 35 Speed of Penetration Rate for Various Technologies Can Vary Significantly

Technology	Years Taken For Adoption To Reach 80% From 10%
Washing Machine	72
Landline	59
Automobile	55
Air Conditioning	46
Electric Power	34
Refrigerator	20
Internet	19
Cell Phone	15
Color TV	15
Disk Brakes In Cars	6

Source: Morningstar; Dediu, Comin, and Hobijn, Our World in Data, 2004.

Given that the pace of technological diffusion is not consistent, it is essential to analyze the factors affecting the pace of technology diffusion and how it fits in our framework for autonomous vehicles.

In Exhibit 36, we contextualize the factors that will affect AV adoption rates in the US market. We believe that maturity, interoperability, cost, economics, and regulatory issues are the most important factors determining the pace of AV technology diffusion in the US market. We have rated each of these factors on a five-point favorability scale that indicates if the conditions for faster technology diffusion are conducive or not. A highly favorable rating for a specific factor indicates that the specifics related to the factor will enable a faster pace of AV technology diffusion, while a highly unfavorable rating indicates the opposite.

We have rated the economics of AV adoption as being highly favorable to faster adoption of AV technology, given the substantial cost benefit that a solution like robotaxis would have over a human-driven taxi, especially when deployed at scale. We have also rated the maturity of AV technology as favorable, given our belief that AV technology is advancing at a rapid pace and is increasingly ready for real-life deployment as the capability improves. AV technology can easily be integrated into new energy vehicles with relatively fewer hardware requirements and continuous over-the-air software updates, but it is very difficult to integrate these capabilities into existing traditional car fleets, and it requires extensive infrastructure updates at all levels for Level 4 or Level 5 autonomy. In our opinion, regulatory concerns are one of the biggest roadblocks for mass adoption of AV technology; regulators could err on the side of conservatism in approving and monitoring higher levels of autonomy on public roads.

Exhibit 36 Analyzing the Impact of Various Factors on the Speed of AV Technology Diffusion in US

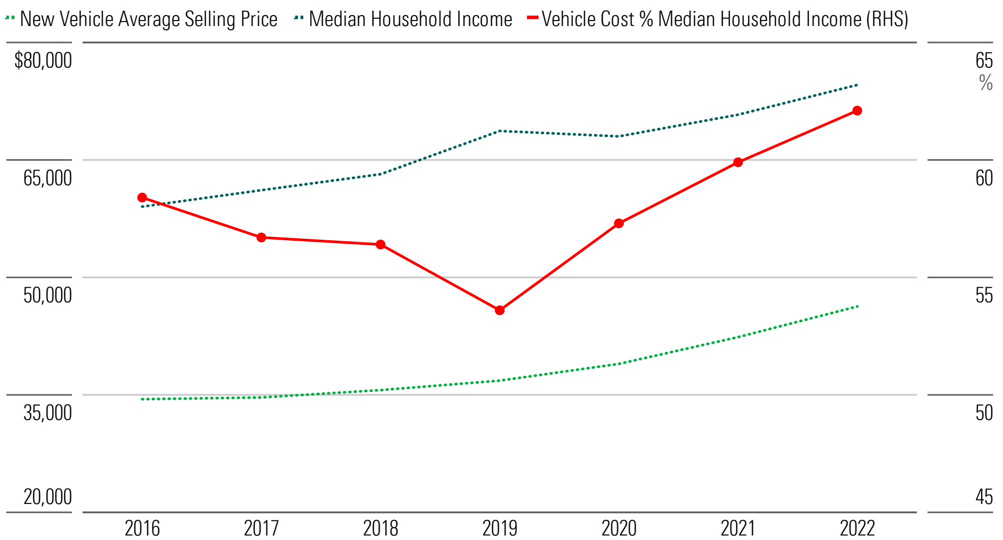
Factor	Consideration	Importance for AVs	Favorability for AVs	Comments
Maturity of Technology	Is it ready for widespread adoption? Where is it in the maturity curve?	High	Favorable	Rapid tech advancements
Interoperability & Compatibility	How easily does the technology fit into existing ecosystem?	High	Unfavorable	Difficult to convert existing fleet into AVs
Ease of Adoption	How easy is it to adopt the technology in terms of usability?	Medium	Neutral	Easy to integrate into new vehicles, but needs infrastructure upgrades
Cost of Adoption	Is it a small or a big purchase?	High	Unfavorable	Median car price is about 60% of US household income
Economics of Adoption	What's the ROI of adoption?	High	Highly Favorable	Robotaxis could be very cost-effective
Economic and Market Environment	Is the economic climate conducive?	Low	Neutral	Long-term US economic outlook remains strong
Social and Cultural Acceptance	How open are people to adopt the technology?	Low	Unfavorable	Social acceptance of AVs remains low
Regulatory & Legal Factors	Is the regulatory and legal environment supportive?	High	Highly Unfavorable	Regulation is a major concern
Competitive Dynamics	Will competition leads to innovation and lower prices?	Medium	Neutral	Competition in the US market is lower than in China

Source: Morningstar.

Given the extensive infrastructure requirements, cost of adoption, and regulatory hurdles, we believe that the pace of diffusion for AV technology will be on the slower side compared with some recent technologies like cellphones. Also, it will be very difficult to covert the existing car fleet into fully autonomous vehicles, given the extensive changes that would have to be made. We strongly believe that most of the growth in autonomous vehicles on the road will come from new vehicles being integrated with AV technologies. Certain car models from Tesla already have hardware integrated to enable autonomous driving capability, but that is an exception rather than a norm. The proportion of cars with built-in hardware to enable autonomy on US roads is quite small. New-age electric vehicles are more conducive to the integration of autonomous driving features than traditional internal combustion vehicles. Given this dynamic, the speed of EV adoption will also be an important factor for enabling autonomy in the US.

The staunchest supporters of AV technology often highlight that the economics of self-driving cars will be so much better compared with human drivers that this will overpower all other inhibitors to the technology. We agree that the economics of AV technology is probably the biggest catalyst for the adoption of the technology, but cost will be a major factor in this case. Buying a cellphone or subscribing to an internet connection were relatively small monetary decisions for a typical US household compared with buying a new vehicle that costs on average about 60% of the typical US household income. The cost of an autonomous vehicle would almost certainly be much higher than that.

Exhibit 37 Technological Diffusion of AVs Will Be Affected by High Cost of New Vehicles

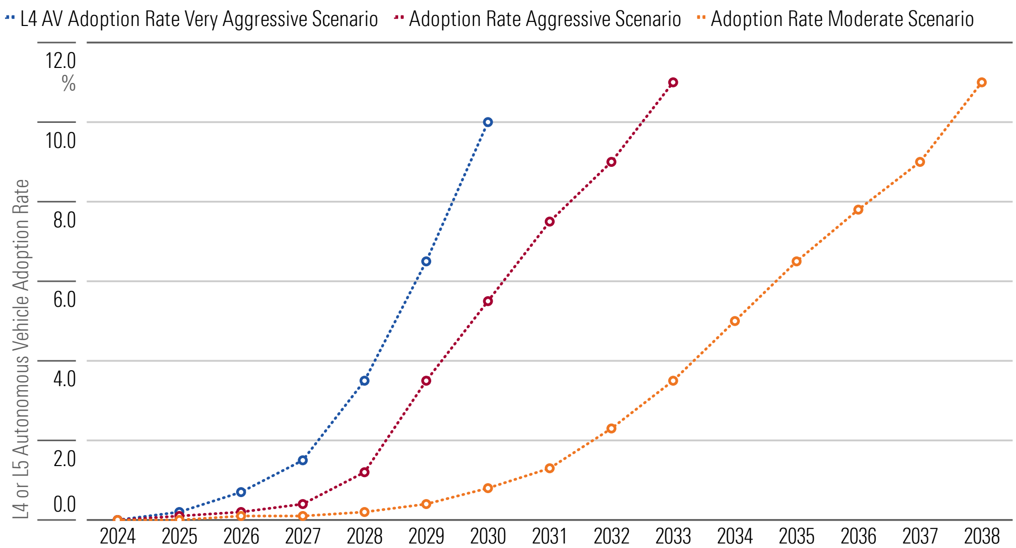


Source: Morningstar, Federal Reserve Bank of St. Louis, Statista. Data as of Dec. 31, 2022.

Given that vehicle costs are a big decision for households, the penetration rate of AV technology will be a function of the natural replacement rate of vehicles. The replacement rate of the existing fleet can be accelerated by the introduction of AV technology, but it won't be anything close to the replacement cycle of a smaller item like a cellphone. Because of this, we believe that comparing the pace of AV adoption with that of smaller-ticket items like cellphones or smaller vehicle improvements like disc brakes is imprudent.

We have used the conclusions from the above discussion and historical technology diffusion data to inform the adoption rate scenarios below. We project that the adoption rate for Level 4 AVs can reach 10% by 2030, 2033, and 2038, respectively, in the very aggressive, aggressive, and moderate scenarios.

Exhibit 38 Adoption Rate for Level 4 AVs Can Reach 10% as Early as 2030 in Very Aggressive Scenario

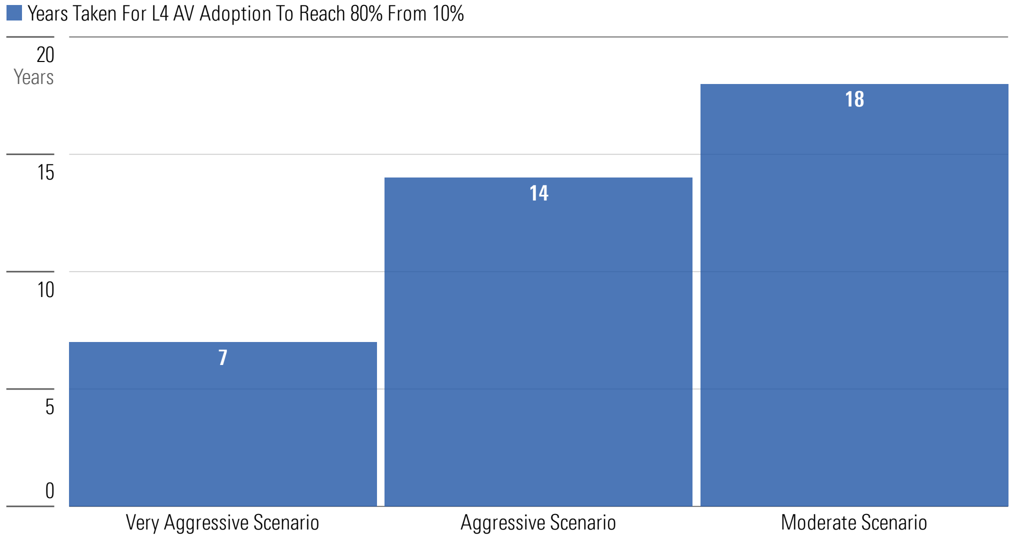


Source: Morningstar estimates.

We project that it would take just seven years for adoption rate to increase from 10% to 80% in the very aggressive scenario, based on the assumption that Level 4 autonomy can be achieved with minimal hardware upgrades and the leaders in the technology would be willing to license their AV technology to other OEMs, leading to rapid adoption.

In the aggressive and moderate scenarios, we project that it will take 14 and 18 years, respectively, for the adoption rate to increase from 10% to 80%. In these scenarios, we assess that infrastructure updates, regulatory roadblocks, the cost of AV solutions, and the speed at which the technology matures will weigh on the speed of adoption rate increases by varying degrees. The amount of hardware enhancements required to achieve Level 4 autonomy, the various business models, and the market dynamics among incumbents will also have a material impact on the pace of adoption.

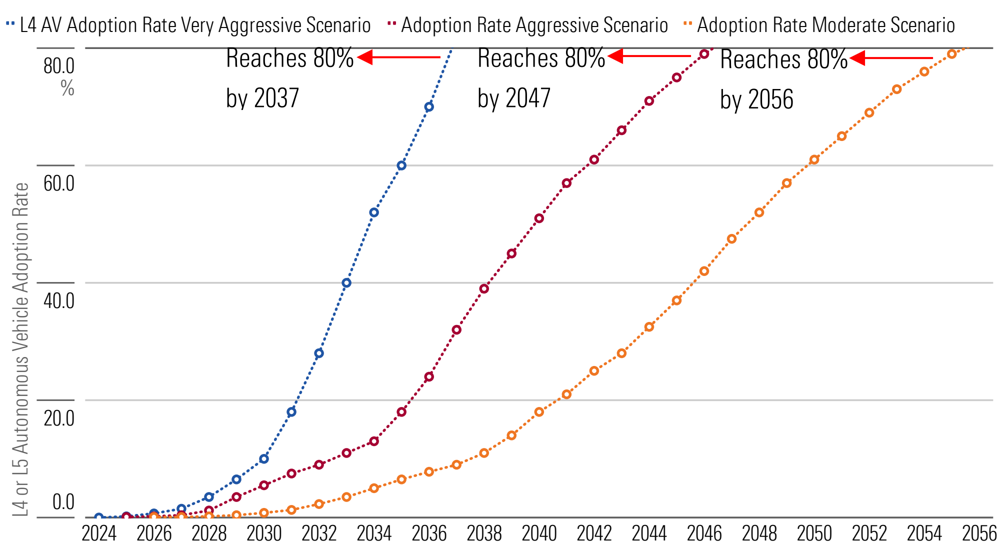
Exhibit 39 Adoption Rate for Level 4 Goes to 80% From 10% in Just Seven Years in Very Aggressive Scenario



Source: Morningstar.

We project that an 80% adoption rate for Level 4 AVs happens by 2037, 2047, and 2056 in the very aggressive, aggressive, and moderate scenarios, respectively. We believe that the speed of adoption will increase materially after a 10%-15% adoption rate is achieved. This is because the bulk of the initial investment in developing AV technology is in advancing the software stack for autonomous driving, and software is highly scalable. Hardware will also play an important role, but the cost of the hardware stack will come down exponentially over time as adoption increases, as seen with lidar costs.

Exhibit 40 We Project 80% Adoption Rate for Level 4 AVs By 2037 in Very Aggressive Scenario

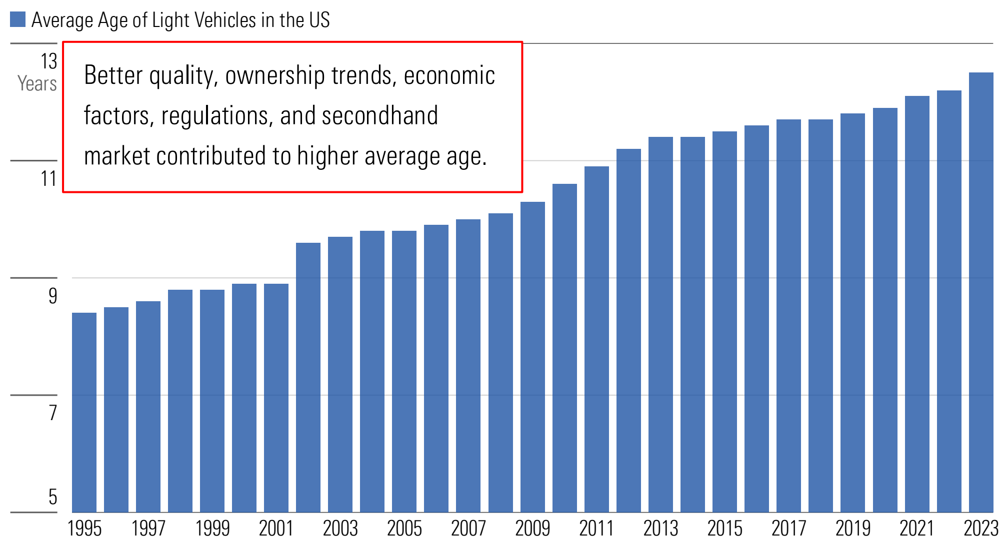


Source: Morningstar estimates.

Scrappage Rate of Existing Fleet: Rates Can Increase Materially When New Vehicles With Autonomous Technology Become Significantly Better for Consumers

The final piece of the puzzle is determining the rate at which the old vehicle fleet gets replaced by new vehicles. There are two ways to think about this: The first is the average age of vehicles on the road, and the second is the rate at which vehicles on US roads are scrapped. The average age of vehicles on US roads has inched up in the past three decades due to improved quality, ownership trends, lower affordability, regulations, and most importantly, the development of a secondhand car market.

Exhibit 41 Average Age of Americans' Light Vehicles Has Inched Up in the Past Three Decades

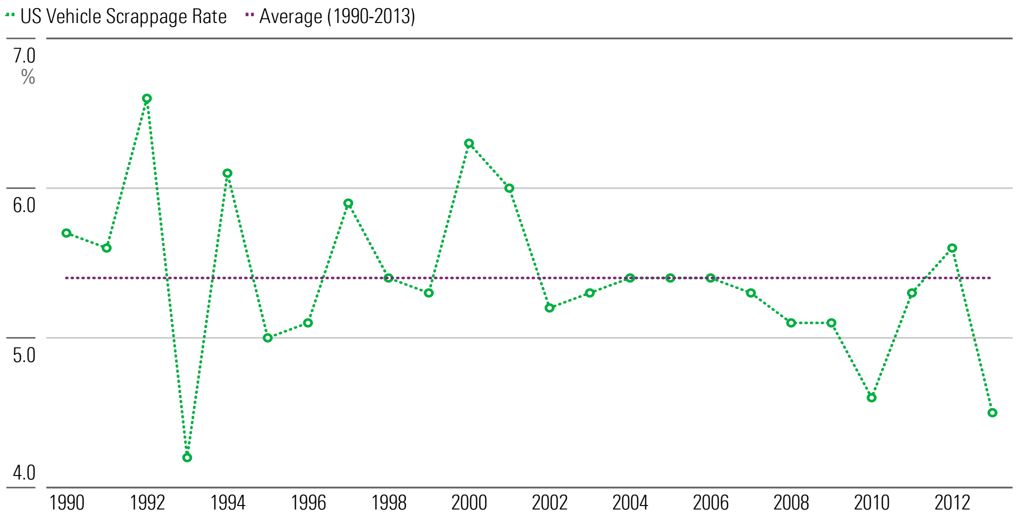


Source: Morningstar, Bureau of Transportation Statistics.

In our model, we have adjusted for the fact that we will probably require relatively fewer vehicles in a fully autonomous future, as the same car can serve more people. We use the scrappage rate as the key driver to incorporate the rate at which the car fleet renews. The scrappage rate is the most important factor determining the average age of the vehicle fleet in the US. The average age will go up when the scrappage rate goes down, and vice versa.

Exhibit 42 shows that the vehicle scrappage rate can vary from year to year depending on economic and other factors, but it has generally remained between 5% and 6%. The long-term vehicle scrappage rate has been around 5.4% per historical data. We weren't able to find the latest scrappage data, but given that the average age of vehicles has risen recently, our sense is that the scrappage rate in recent years has been near the lower end of the historical range.

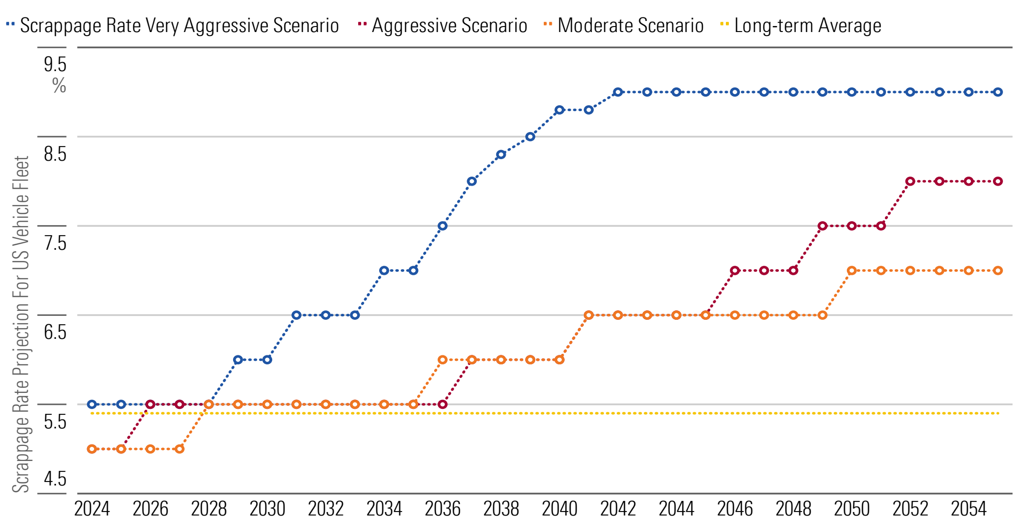
Exhibit 42 US Vehicle Scrappage Rates Can Vary From Year to Year Haven't Changed Much



Source: Morningstar, Bureau of Transportation Statistics.

We use more-optimistic assumptions on the scrappage rate than the historical averages in all three scenarios, because we believe that vehicles with autonomous capability will induce consumers to replace their old cars faster than they otherwise would. The upside for scrappage rates is limited by the fact that cars are a relatively large purchase, and even if we have a radical change in technology with a much-improved use case, the number of people willing to make the change will be limited by affordability. The supply side of the vehicle manufacturing equation also limits drastically higher scrappage rates.

Exhibit 43 Vehicle Scrappage Rate Assumptions in Various Scenarios



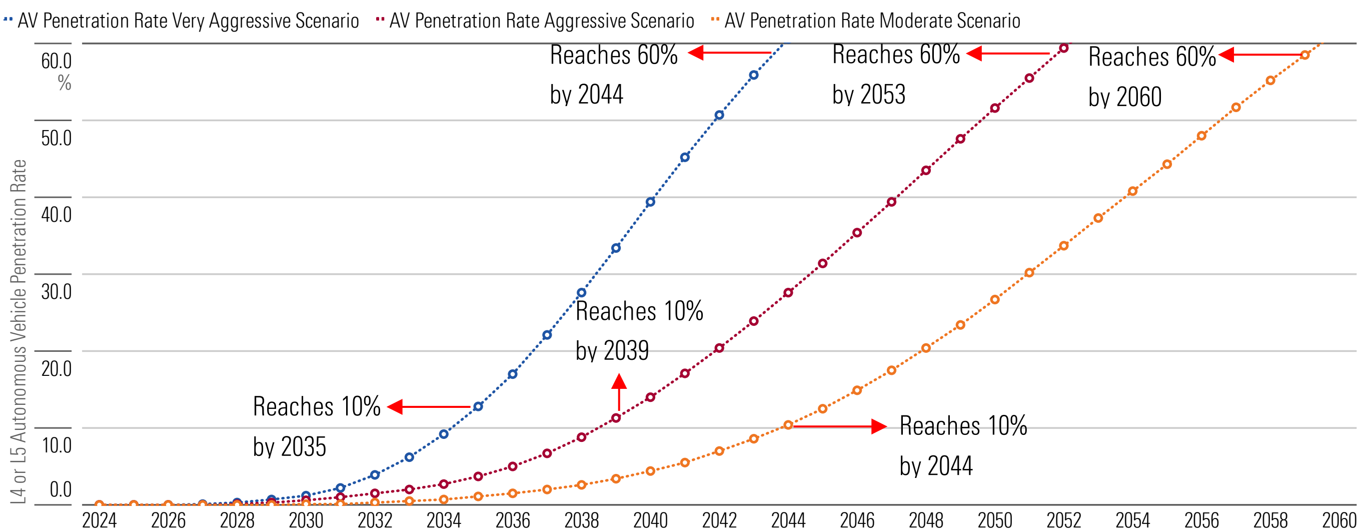
Source: Morningstar, Bureau of Transportation Statistics.

Projecting Autonomous Vehicle Penetration Rates in US Using Above Estimates

We have used estimates for technology advancements, pace of AV adoption, and vehicle scrappage rates to calculate the penetration rate of autonomous vehicles on US roads using our proprietary model. The impact of AVs on auto insurers will be limited until a critical mass is reached; therefore, the penetration rate for AVs is an important number for measuring the impact on the auto insurance industry.

We assume that 10% penetration is where AVs begin to materially affect the auto insurance business. The business enters a secular decline at an increasing pace as the penetration rate increases from 10% to 60%; it stops creating any value and the capital on insurance balance sheets will start to be returned to shareholders when the penetration rate moves toward 60%.

Exhibit 44 Penetration Rate for Level 4 Autonomous Vehicles Reaches 10% by 2035 and 60% by 2044 in Very Aggressive Scenario



Source: Morningstar.

We project that Level 4 autonomous vehicle penetration will reach 10% by 2035 and 60% by 2044 in the very aggressive scenario. The very aggressive scenario is the worst-case scenario for auto insurers. Even in the very worst-case scenario, auto insurers have 10 years of normal business followed by 10 years of accelerated secular decline. In the aggressive scenario, we project that AV penetration rate reaches 10% by 2039 and 60% by 2053. In the moderate scenario, we project that AV penetration rate reaches 10% by 2044 and 60% by 2060. In the next section, we will use the conclusions from this discussion to estimate the valuation impact on our auto insurance coverage.

Quantifying the Impact: Valuation Implications for Our Auto Insurance Coverage

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We Can Tweak Our DCF Models to Estimate the Impact on Our Auto Insurance Coverage

With our worst-case (most aggressive) adoption scenario outlined, we can apply it to our valuation models. At Morningstar, we use our proprietary discounted cash flow models to value companies. These models include a 5- or 10-year explicit projection period, which we call stage one. This is followed by stage two, in which we assume an average growth rate and a return on equity over a set period.[1] In stage three, or perpetuity, we assume returns hold at the cost of equity indefinitely and no value is created or destroyed. The full length (stage one plus stage two) to reach stage three is typically 10 years in the case of a no-moat company and 15 years in the case of a narrow-moat company.

In our worst-case scenario, it takes 20 years for the percentage of cars on the road with Level 4 or 5 autonomy to approach 60%. We think at this point, publicly held auto insurers will cease auto insurance operations. With the market cut by more than half, we think it would be difficult to earn an acceptable return, even given the relative lack of fixed costs for insurers. More importantly, obsolescence would be a clear inevitability at this point, and we don't think publicly traded insurers would see value in riding the industry all the way down. Mutual insurance companies make up 6 of the top 10 personal auto insurers in the US, and since they are not profit-motivated, they might hang on until the end. We think the market would impose more discipline on publicly traded insurers, and it would be difficult to justify continuing to allocate capital to a doomed industry.

Since the adoption of autonomous cars takes longer than 10 years even in our worst-case scenario, we need to use our discounted cash flow models in a unique way to fully capture the long-term valuation impact. We use two methods. In the first method, the explicit approach, we model an initial 10-year stage one. We then use the final year of stage one to begin another explicit 10-year projection, which we call stage two. We therefore explicitly project the entire 20-year period to the point where insurers exit the personal auto space. We then proceed directly to the stage three perpetuity or liquidation value, depending on whether we think the franchise will continue to operate in other lines.

As a backstop, we also use another method, the formula-based approach. We again start with an explicit 10-year stage one. However, we then revert to our typical formula-based stage two, using the stage two projected decline in premiums as the basis for our assumed stage two growth rate. We

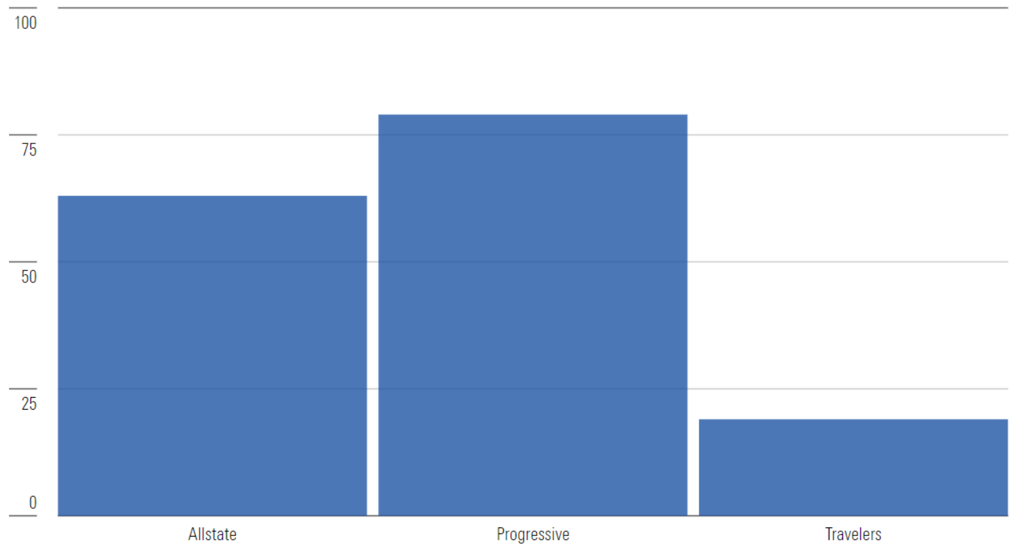
1 Our discounted cash flow model for insurance companies is a free cash flow to equity model, unlike our general discounted cash flow model, which is a free cash flow to the firm model. In our insurance model, cost of equity replaces weighted average cost of capital and return on equity replaces return on invested capital.

proceed again to stage three perpetuity or liquidation value, depending on whether we think the franchise will continue to operate in other lines.

Some Auto Insurers Would Just Drop Auto and Move On; Others Would Go Out of Business

To determine our approach to the stage three value, we need to decide whether an insurer would simply cease auto insurance operations and carry on with other lines or go out of business entirely. No insurer we cover is a pure auto insurance player, although some come much closer than others. As can be seen in Exhibit 45, the percentage of personal auto insurance premiums differs across our coverage.

Exhibit 45 Exposure to Personal Auto Differs Across Our Coverage
Personal auto premiums as a percentage to total premiums



Source: Company filings, Morningstar.

Within personal lines insurance, auto and homeowners constitute the two main lines. Most insurers that offer one also offer the other, as bundling insurance policies is viewed as a way to create stickier customers. Given returns in the space, the efficacy of this approach could be debated. But within our coverage, we see different approaches. For Travelers and Allstate, both auto and homeowners are self-sufficient and each line is expected to generate an acceptable return. As a result, we think the homeowners business for these two would remain in operation even if they exited personal auto. For Travelers, the ongoing nature of the franchise is a bit more obvious, given that about 60% of its premiums come from commercial insurance, and the personal lines operations are roughly evenly split between auto and homeowners. For Allstate, auto constitutes the bulk of its premiums, but it is also a significant player in homeowners, and this market would continue to exist. We think it is reasonable to think Allstate would continue on even if it exited auto.

Progressive is the most concentrated in personal auto. Its homeowners line was acquired in 2015 and constitutes 4% of total premiums. The homeowners business has never been profitable on a stand-alone basis, with the combined ratio for this line averaging 107% over the past five years. We think the company uses homeowners as something of a loss leader to drive growth in its profitable personal auto business. As such, we can't see it maintaining its homeowners business if it exited personal auto.

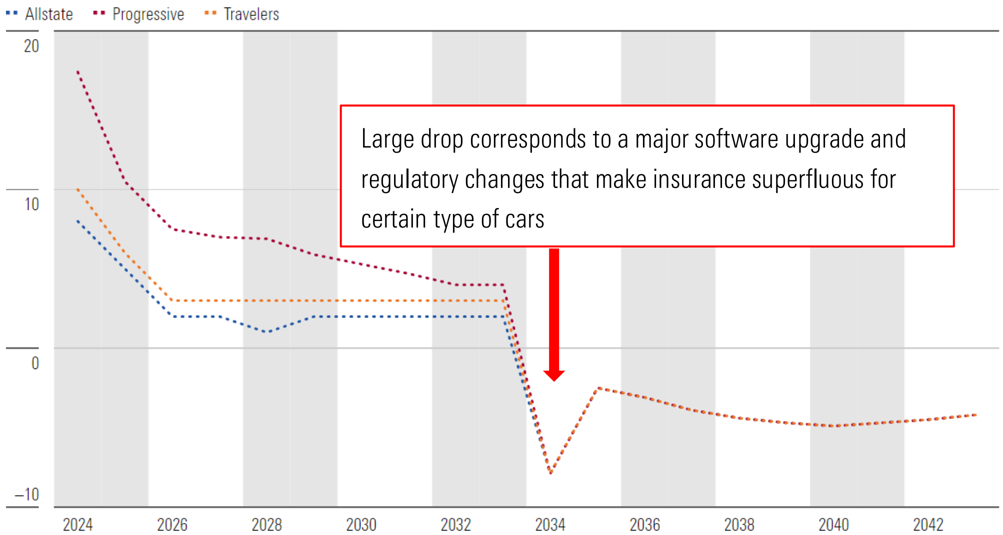
Progressive also has a commercial auto business that represents 17% of premiums and is very profitable. However, we think the nature of commercial auto coverage would also change in the face of autonomous vehicles, becoming more similar to traditional commercial liability lines and sold to auto manufacturers as opposed to companies that maintain auto fleets. We think this business would then shift to more traditional commercial insurers. As such, we think it is best to assume that this line becomes obsolete along with personal auto, especially as we are building a worst-case scenario. Since we don't see either of these lines persisting, we think it is appropriate to assume that Progressive would completely cease operations if it exited auto insurance.

We Assume a Steady Fade to Obsolescence as Autonomous Cars Start to Dominate the Road
In our explicit stage one projections, we assume no meaningful impact from autonomous cars. We think cars will need to reach at least Level 4 autonomy, and possibly Level 5, to make auto insurance unnecessary. Additionally, it will take time for regulatory requirements around auto insurance to change; we think these regulatory changes will likely lag the reality on the ground a bit. As such, we think assuming a status quo situation over the next 10 years is reasonable. Given the strong pricing increases the industry has seen recently, our projections assume relatively strong growth in the near term.

However, in our stage two assumptions, we assume that the auto insurance industry starts to decline in line with the percentage of autonomous cars on the road. In the first year of our stage two assumptions, we assume a relatively large drop, as existing Level 3 or below cars have their software upgraded and regulatory changes make insurance superfluous for cars with a certain level of autonomy. After that, we assume a relatively steady decline as autonomous cars steadily replace traditional vehicles. During this period, we assume an underlying 1% growth rate due to household formation as an offset to the secular decline. However, we also assume completely flat pricing, as we think pricing increases would be difficult to achieve in a declining industry, and improved safety would likely make pricing increases unnecessary.

Traditionally, Progressive has seen much stronger growth than Allstate or Travelers, given its large presence in the direct channel, which has steadily taken share from the agent channel over time. We assume this growth differential persists in our stage one projections. However, we think this difference will disappear once the industry enters a state of decline, and we assume a uniform stage two growth rate for all three companies.

Exhibit 46 Growth Converges as the Industry Enters a Period of Decline
Year-over-year personal auto net earned premium growth (%).



Source: Morningstar.

In terms of underwriting performance, we assume two partially offsetting trends. First, we assume that better safety for autonomous cars reduces loss ratios by 50 basis points annually through our stage two projections. Second, we assume that lower volume leads to cost deleveraging, and the expense ratio increases 100 basis points annually through the stage two projection period. The net impact is underwriting margins declining by 50 basis points annually. We think that in the period of decline, underwriting results and returns are likely to fall to a level that will eliminate any excess returns and may even push returns to a level that is value-destructive. This would then be a spur for these companies to abandon the personal auto line by the end of stage two, when most cars on the road are autonomous at a level that does not require insurance.

With all that laid out, we can discuss the impact on the individual auto insurers in our coverage. While we have not mentioned Geico yet, we will use the results from our analysis of Progressive to estimate an impact on Geico and Berkshire Hathaway. Once we have outlined the impact on individual companies, we will offer some overall takeaways from this analysis.

Despite a Heavy Presence in Auto, the Impact on Allstate Is Not Dramatic

In Exhibit 47, we show the potential impact of the worst-case scenario relative to our fair value estimate for Allstate. Although Allstate derives the majority of its premiums from auto insurance, the impact on our fair value estimate is not dramatic and is well within our margin of safety. Using our explicit and formula-based approaches, we estimate 15% and 13% declines in value, respectively. We believe the majority of the difference is due to explicitly forecasting annual stage two ROE in the explicit approach and estimating overall ROE in the formula-based approach. But the difference between the two approaches is not major. We would attribute the relatively modest valuation impact largely to the fact that we don't believe that Allstate has a moat and that any future excess returns will be modest. As a result, only a relatively modest amount of value destruction occurs. In our stage two projections, ROE holds at about 10%, and the company exits prior to any major value destruction.

Exhibit 47 Allstate Sees a Meaningful but Modest Valuation Impact
$ millions

	Explicit		Formula-Based	
Item	Undiscounted	Discounted	Undiscounted	Discounted
Stage 1	15,400	15,400		15,400
Stage 2	26,850	11,342		11,801
Liquidation Value	9,914	4,188		2,974
Total		30,930		30,176
Time Value Adjustment		5%		5%
Adjusted Total		32,336		31,548
Shares Outstanding		263		263
Per Share Value		118		120
Current FVE		138		138
Discount to Current FVE		15%		13%

Source: Morningstar.

Progressive Sees a Relatively Large Impact, but It Stays Within Our Margin of Safety

Progressive sees a much more sizable valuation impact, with 26% and 21% declines in value using our explicit and formula-based approaches, respectively. Relative to other insurers, Progressive produces very strong returns. In this case, its narrow moat is a negative, as much more value is lost through obsolescence. Stage two starts with Progressive still generating a strong ROE of 19%, modestly less than its historical average. But over the course of stage two, returns steadily fall to a level roughly in line with its COE, and the company then shuts down operations. While Progressive sees by far the largest cut to its valuation, the amount is still within our margin of safety.

Exhibit 48 Progressive Sees a Deeper Cut to Its Valuation
$ millions

	Explicit		Formula-Based	
Item	Undiscounted	Discounted	Undiscounted	Discounted
Stage 1	34,291	34,291		34,291
Stage 2	53,362	22,541		28,133
Liquidation Value	29,756	5,309	23,198	4,139
Total		62,142		66,564
Time Value Adjustment		5%		5%
Adjusted Total		65,227		69,868
Shares Outstanding		588		588
Per Share Value		111		119
Current FVE		151		151
Discount to Current FVE		26%		21%

Source: Morningstar.

Travelers Sees Only a Modest Impact

Unsurprisingly, Travelers sees only a small impact, with 4% and 6% declines in value using our explicit and formula-based approaches, respectively. With personal auto only representing about 20% of overall premiums, Travelers' exposure is limited. Additionally, while we believe Travelers does have a narrow moat that stems from its commercial operations, we don't think its auto business enjoys a moat. With returns on this side limited and premiums relatively low as a part of the overall mix, the potential obsolescence of this line doesn't appear to be a major issue for Travelers.

Exhibit 49 Travelers Sees Only a Modest Valuation Impact
$ millions

	Explicit		Formula-Based	
Item	Undiscounted	Discounted	Undiscounted	Discounted
Stage 1	20,630	20,630		20,630
Stage 2	30,959	13,078		12,809
Liquidation Value	27,425	11,585		10,882
Total		45,292		44,321
Time Value Adjustment		5%		5%
Adjusted Total		47,512		46,494
Shares Outstanding		232		232
Per Share Value		205		200
Current FVE		214		214
Discount to Current FVE		4%		6%

Source: Morningstar.

The Impact on Geico and Berkshire Hathaway Is Negligible

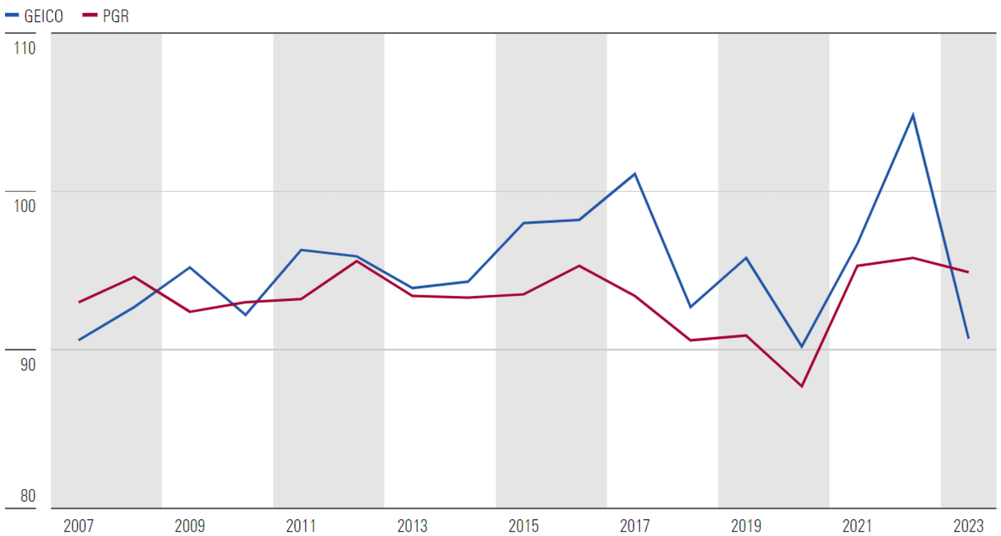
Geico is just one part of Berkshire Hathaway, and we don't get the same level of disclosure. As a result, we don't believe running a full analysis on Geico is warranted or feasible. But we can estimate the impact on Geico by utilizing our analysis on Progressive. Our analysis assumes that Geico and Progressive are comparable franchises in terms of valuation. At this moment, that is potentially generous to Geico, as the two companies' results have diverged since the advent of telematics.

Progressive pioneered the use of telematics with its Snapshot program, which started in 2010. The main benefit of telematics is that it provides an insurer with more-accurate assessments of the risks of individual policyholders, allowing it to better segment and price its risks by offering discounts to the safest drivers and charging riskier drivers a more appropriate premium.

While Progressive was the first major insurer to develop a telematics program, other insurers quickly followed suit, which muted any additional underwriting advantage Progressive might have seen. The one exception has been Geico, which ignored telematics for years. Geico now has its DriveEasy program but remains a laggard in this area. As a result, we think Geico has been facing an adverse selection issue. While other insurers operate with what appears to be an information advantage, we think Geico has been dealing with a portfolio of relatively higher-risk drivers than many of its peers.

Historically, Geico and Progressive produced combined ratios on par with each other, but their results have diverged since the advent of telematics. Geico's relative performance did improve in 2023, and while that was partially due to a dramatic decline in advertising spending that likely cannot be maintained long-term, loss ratios are improving. While we think Geico still has a moat, its poorer performance since telematics became an issue has raised questions. That said, more-recent results show signs that consistent underwriting profitability has become top priority for the firm, even if it means pulling back on growth and market share gains. In the long run, we think Geico can get back on track and that Progressive remains a reasonable valuation proxy for Geico's value.

Exhibit 50 Geico's Performance Relative to Progressive's Has Weakened Since the Advent of Telematics
Combined ratio (%).



Source: Company filings, Morningstar.

Berkshire Hathaway keeps a large amount of excess capital within its insurance operations. To avoid any distortions from this, we think it is best to avoid using any book and balance sheet figures and instead focus on premium levels, which are unaffected by investment choices. In Exhibit 51, we assume that Geico's franchise multiple to premiums is the same as Progressive's and that the resulting valuation discount is also the same. We then compare the loss of value with the overall value of Berkshire Hathaway using our fair value estimate. As can be seen, there are 2% and 1% declines in value using our explicit and formula-based approaches, respectively. This analysis is inexact, but given the low level of impact, we think it is safe to conclude that any obsolescence risk for Geico is negligible compared with the overall value of Berkshire Hathaway. This is not surprising, given the breadth of Berkshire Hathaway's businesses and the size of its investment portfolio.

Exhibit 51 The Impact on Geico and Berkshire Hathaway Is Negligible
$ millions.

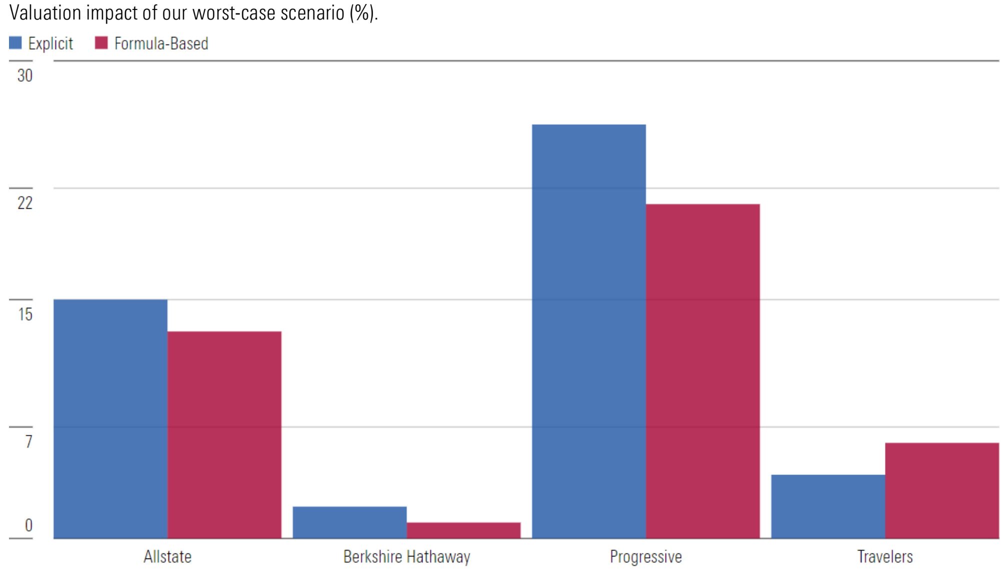
	Explicit	Formula-Based
Progressive		
Market Cap @ Fair Value Estimate	88,713	88,713
2023 Net Earned Premiums	58,644	58,644
Price/Premiums Multiple @ Fair Value Estimate	1.51	1.51
Geico		
2023 Net Earned Premiums	39,264	39,264
Implied Value Using Progressive Premiums Multiple	59,396	59,396
Discount Under Worst-Case Scenario	26%	21%
Valuation Impact on Geico	15,724	12,617
Berkshire Hathaway Market Cap @ Fair Value Estimate	927,283	927,283
Valuation Impact on Berkshire Hathaway	2%	1%

Source: Company filings, Morningstar.

Looking at Valuation Impacts Across Our Coverage, We Can Draw Some Conclusions

In Exhibit 52, we show the valuation impact of our worst-case analysis across our coverage. We have a few takeaways from this exercise. First, and somewhat obvious, is that having a higher proportion of premiums coming from auto insurance raises the risk of obsolescence. Well-diversified insurers such as Travelers arguably face only minimal risk if auto insurance becomes obsolete. Second, moats are a negative in this context, as the higher the value of the franchise, the more value is at risk.

Exhibit 52 Insurers That Are Reliant on Auto Insurance and Have a Moat Are Most at Risk
Valuation impact of our worst-case scenario (%).



Source: Morningstar.

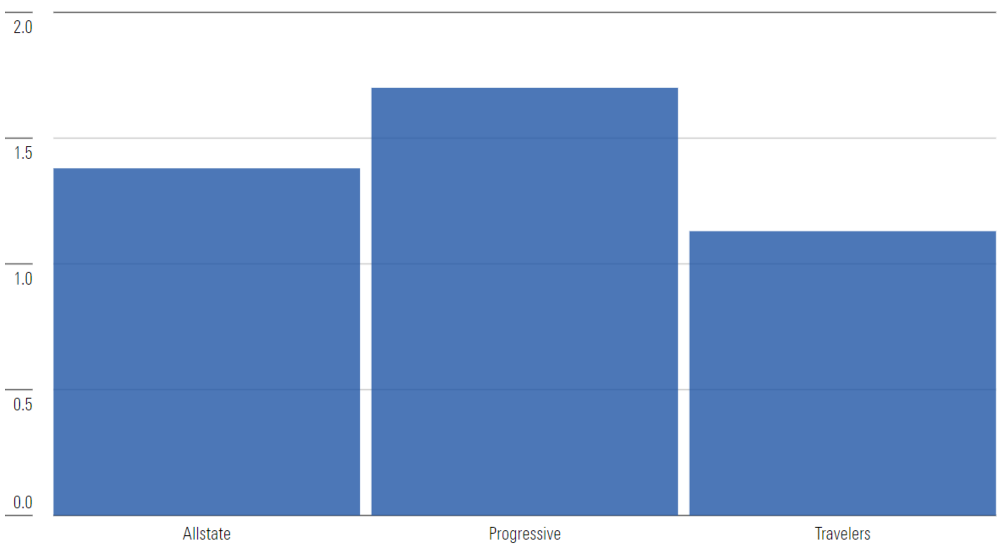
Both Allstate and Progressive derive most of their premiums from auto insurance, but the valuation impact on Progressive is greater. Given Progressive's relatively high returns, this makes sense. Finally, the impact on all of our coverage is relatively modest and within our margins of safety. Limited returns in the space and the long timeline to obsolescence even in an aggressive scenario limit the valuation impact today.

Don't Discount Auto Insurers Today, but Be Careful on Valuation

We think a further conclusion is that investors shouldn't discount these stocks today based on the risk presented by autonomous cars, as even in the most extreme case, the valuation impact is still within our margin of safety. However, we do think investors should consider whether there is a ceiling on the multiple they should pay for a business that may become obsolete. We think this is especially true today, as insurance stocks have run up thanks to industry tailwinds.

Higher interest rates have boosted investment income and had a material positive impact on overall returns for our domestic property and casualty insurance coverage. Interest rates and investment income are only part of the story for insurers, but the outlook for underwriting is strong as well, in our view. Following a few years of solid price increases, commercial insurers have seen underwriting margins stabilize at attractive levels. Personal auto insurers have endured some difficulties recently, but strong pricing increases have improved combined ratios. With both sides of the profit picture already strong or improving, we expect the P&C insurers we cover to generate unusually attractive results in the near term. However, we believe the market has overreacted to these tailwinds, and we see our domestic P&C insurance coverage as generally overvalued.[2]

Exhibit 53 Our Auto Insurance Coverage Looks Overvalued
Price/fair value estimate.



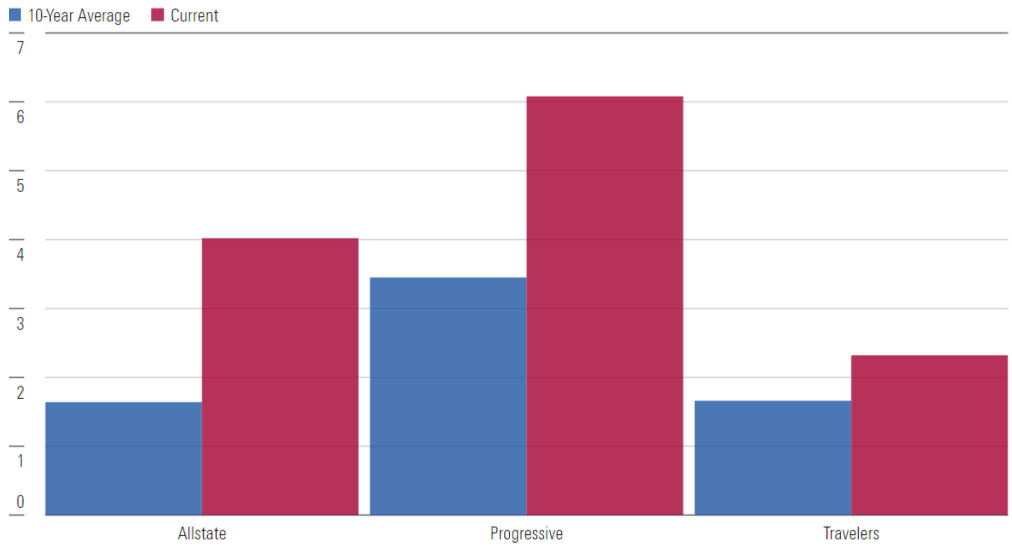
Source: Morningstar. Data as of Aug. 17, 2024.

As shown in Exhibit 54, most of our auto insurance coverage trades at a significant premium to historical adjusted book multiple averages. Our fair value estimates hinge on the idea that returns for our coverage will ultimately return to a level roughly in line with historical averages. Given the highly competitive and

2 For more details, please see our presentation Despite the Interest-Rate Tailwind, P&C Insurers Are Overvalued.

mean-reverting nature of the industry, we think this is highly likely. If the industry does mean-revert over the next few years, investors will pay an overly rich price today for most of our coverage.

Exhibit 54 Book Multiples Are Inflated Relative to Historical Averages
Price/adjusted book multiple.



Source: Company filings, Morningstar. Data as of Aug. 17, 2024. Book values have been adjusted to exclude intangible assets and accumulated other comprehensive income.

But these higher multiples today also mean that long-term investors are taking on a greater level of valuation risk if our worst-case scenario were to occur. While our worst-case scenario for Progressive results in a discount of only 21%-26% relative to our fair value estimate, the discount would be 54%-57% relative to the current stock price. We appreciate the quality of Progressive's franchise and the tailwinds it is enjoying at the moment, but we think long-term investors are taking a considerable gamble at the current market price.

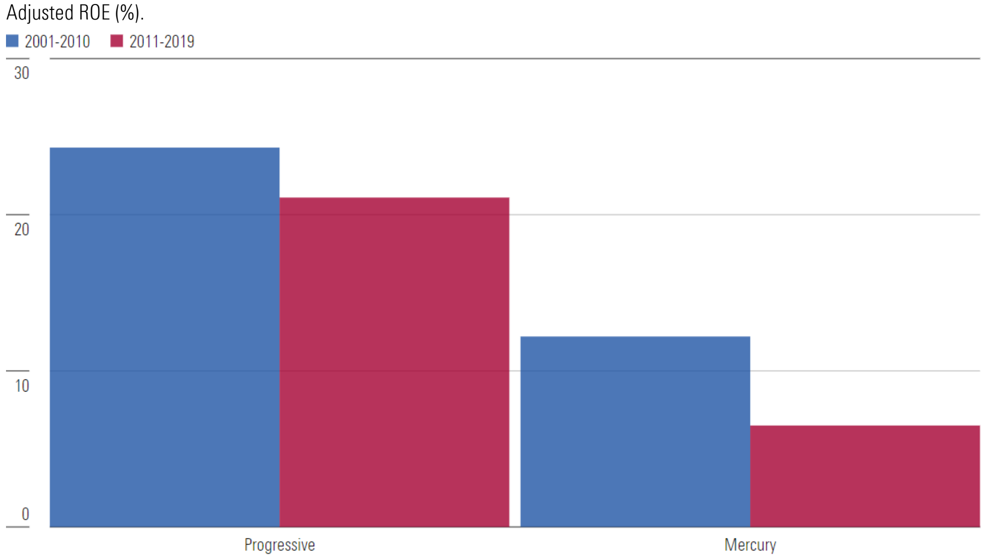
There Is a Potential Upside Scenario as Well

We have focused on the potential downsides of autonomous cars, but there is a plausible scenario where autonomous cars represent a long-term positive for auto insurers. We have laid out some scenarios on the adoption of autonomous cars, as we believe there is considerable uncertainty on the arrival at scale of autonomous cars at Level 4 or higher. The valuation impact of potential obsolescence is fairly limited even in a relatively rapid scenario. If instead the path to obsolescence is extended, the current valuation impact would grow even more muted. On the other hand, we have discussed the potential for autonomous cars to meaningfully lower accident rates, even at lower levels of autonomy. If the wide-scale introduction of Level 3 or lower cars to the road occurs fairly quickly but the introduction of more fully autonomous cars (Level 4 or above) proves more difficult than expected, we could see a very long period where auto insurers enjoy a tailwind from lower accident rates. It is plausible to believe that the benefits from this period could materially outweigh potential obsolescence down the road.

It could be argued that even if autonomous cars lower accident rates, pricing will quickly adjust for this trend and negate any positive impact on auto insurer returns. We think pricing would certainly adjust over time, given the competitive nature of the industry, but that pricing is likely to lag a bit, which would likely set up an ongoing tailwind for insurers.

Previously, we discussed long-term trends in accident rates and how accident rates fell consistently and meaningfully from about 1980 to 2010 before plateauing and actually increasing a bit after 2010. In Exhibit 55, we show adjusted ROEs for Progressive and Mercury General, the two publicly traded domestic companies that derive the vast majority of their revenue from auto insurance. We limited the analysis to these two names as we think including more-diversified insurers would just muddy the picture. As can be seen, both companies generated higher average returns in the decade ended in 2010 than they did in the nine years that ended in 2019. We cut off the second period at 2019, as we believe the pandemic in 2020 (and the dramatic reduction in miles driven during lockdown) and its aftermath was a unique and likely nonrepeatable event that would skew our results.

Exhibit 55 Auto Insurers Earned Stronger Returns When Accident Rates Were Falling
Adjusted ROE (%).



Source: Company filings, Morningstar. We have adjusted ROE to exclude realized gains and losses from net income and intangible assets and accumulated other comprehensive income from book value.

We recognize the limits of this analysis, given the small sample size and the fact that multiple factors influenced returns during these periods. Still, we believe the results support the idea that if autonomous cars meaningfully lower accident rates, auto insurers would see a material and ongoing benefit from this trend. We said previously that we don't believe investors should discount auto insurers today for potential obsolescence; this upside scenario further supports that idea, in our opinion.

Appendix: Who Is Leading the Race?
US and China in Heated Competition as Europe Falls Behind

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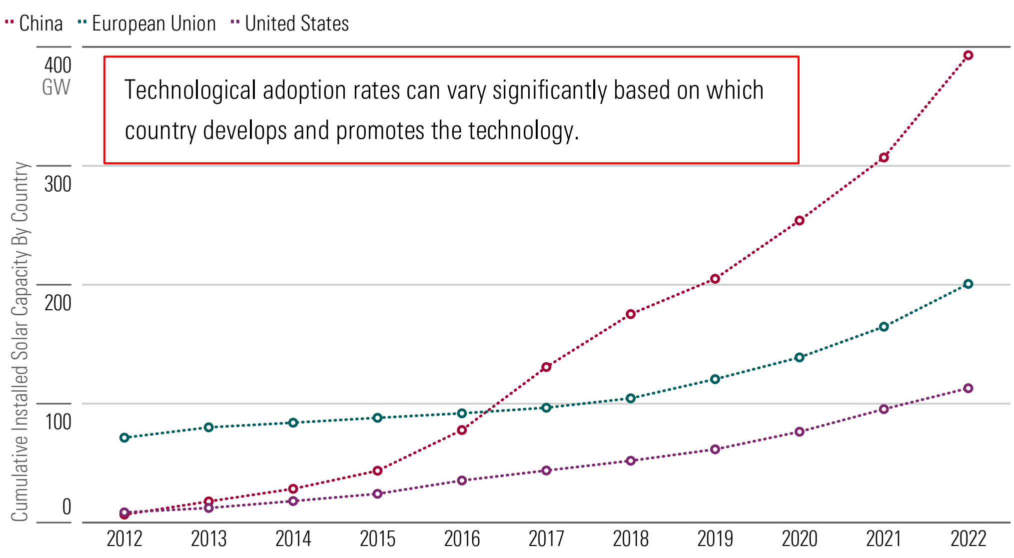
Leadership in the Technology Race Has a Major Impact on The Speed of Technology Adoption
Autonomous driving technology is a foundational technology, and it will have sizable implications. We think it is essential to analyze which region or country is leading in the development of autonomous driving technology, as this has a substantial impact on the speed of technology adoption, at least in the near to medium term.

The reason for the varying speed of adoption is that countries leading in a particular technology tend to attract more investment, often get government policy and regulatory support, foster development of infrastructure and innovation ecosystem, and generate economies of scale. This lowers the cost of the technology, resulting in more consumer acceptance and faster adoption. There are various examples of this phenomenon, from steam engines and power looms to solar panels and electric vehicles. The countries that pioneered these technologies were often the fastest to adopt them. Technologies tend to flow through to other countries as well, but the time lag could be considerable. Given that we want to understand how long it will take for autonomous cars to affect the domestic auto insurance industry, it's important to understand where the US stands relative to other countries and regions.

Exhibit 56 Chinese Adoption of Solar Energy Increased Exponentially as It Gained Competitiveness



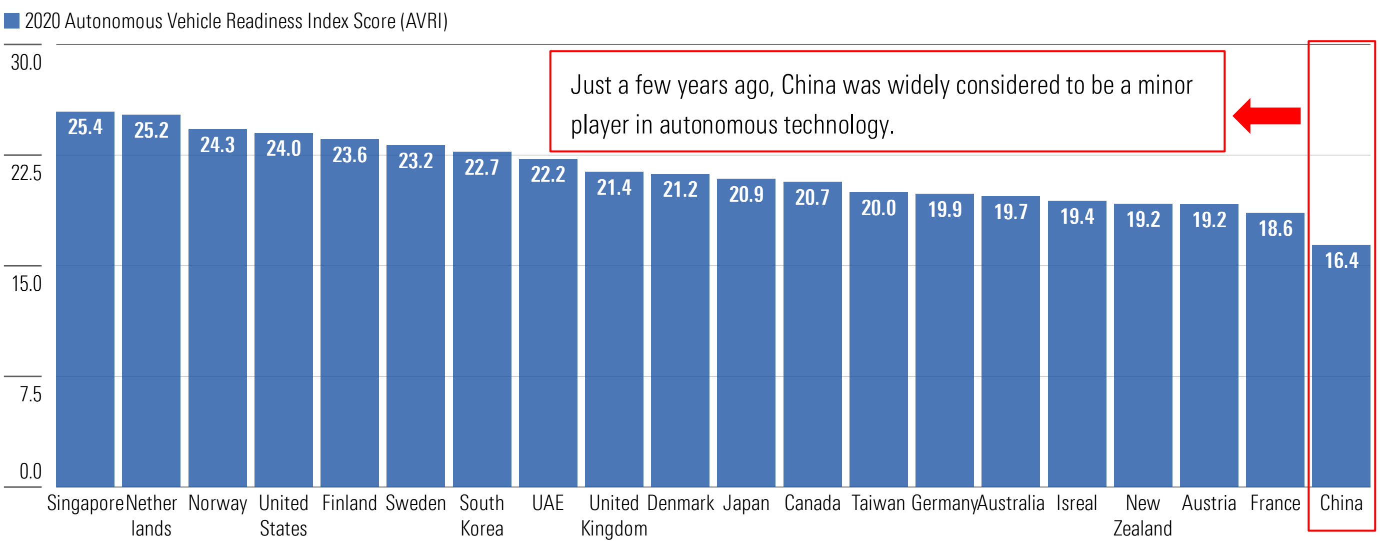
Source: Morningstar, International Renewable Energy Agency.

Europe Is Out of the Pole Position:
A Three-Way Competition Has Now Essentially Become a Two-Country Race

In our discussion for technology leadership, we are focused mainly on Europe, China, and the US, since these three are the biggest and most important players in the autonomous driving industry. While countries like Singapore, Israel, Japan, and South Korea also have some notable strengths in specific areas, none of them have anything close to the entire ecosystem that is required for self-driving technology to be developed and adopted at scale.

If we look at research papers and reports published just a few years ago, the US and Europe were widely considered to be the leaders in the field of autonomous driving, with China a distant follower. For instance, in the 2020 Autonomous Vehicles Readiness Index published by KPMG, China was ranked 20th, far behind the United States and European countries. We think the KPMG ranking was a good representation of the market consensus at that time.

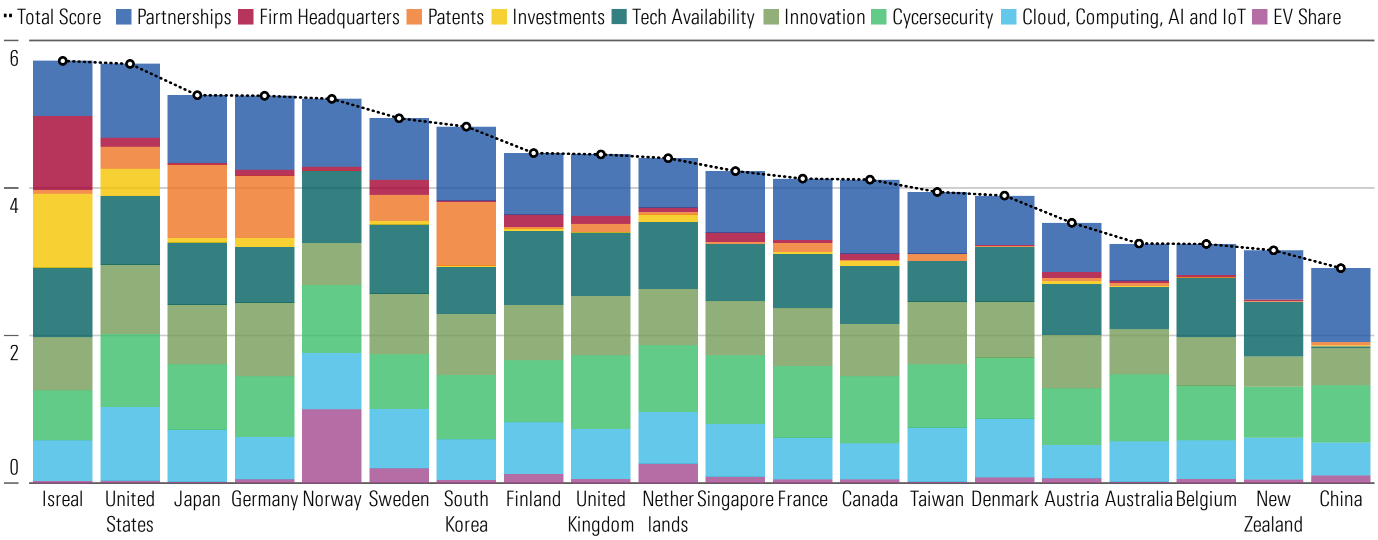
Exhibit 57 The US and Various European Countries Were Rated Significantly Ahead of China in Terms of AV Readiness Just a Few Years Ago



Source: Morningstar, KPMG International. Data as of Dec. 31, 2020.

It could be argued that the AVRI report is focused on preparedness for the conditions necessary for the adoption of autonomous vehicles in various countries, and it gives excessive weight to factors like regulations, government initiatives, legislative frameworks, infrastructure, and consumer acceptance. But even if we were to analyze the rankings based on just the technology scores, the results did not seem to change much, as seen in Exhibit 58. The US and leading European countries like Germany were ranked far ahead of China in areas like patents, availability of latest technologies, investments, and innovation.

Exhibit 58 China Was Lagging Far Behind the US and Europe on Most Parameters in Technology and Innovation for Autonomous Vehicles as of 2020



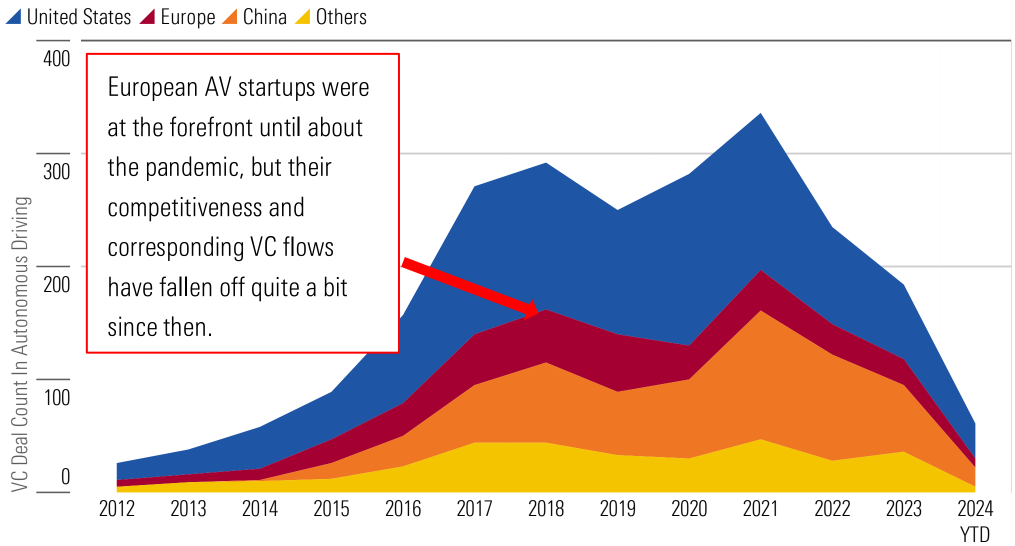
Source: Morningstar, KPMG International. Data as of Dec. 31, 2020.

Our aim with this discussion is not to challenge the conclusion of a particular report or the consensus view of a few years ago, but to highlight that autonomous driving technology is evolving rapidly—and so are the winners and losers in this race. Given the pace of technology evolution, we think it is essential for investors in the space to track the latest developments.

After analyzing the latest product launches, competitive environment, dynamism in innovation ecosystem, and the pace of execution in various regions, we think Europe is largely out of the race. It certainly has some very interesting companies in this space and still is a leader in some niche areas, but we do not think its AV technology ecosystem is capable of taking the pole position. This is in sharp contrast with the consensus view just a few years ago, when autonomous driving was perhaps seen as an example of Europe's tech prowess. We think fragmented markets, overregulation, a risk-averse funding environment, general loss of competitiveness in software algorithms, and possibly a strategic shift of the automotive industry due to market-related challenges are all to blame for Europe's falling behind.

We can see the relative decline of European autonomous driving prospects in venture capital flows from PitchBook. Exhibit 59 shows the number of venture capital deals in the autonomous driving sector by region. European startups maintained a decent share until about 2019, but the deal count fell significantly after that. The deal counts for the US and China have been roughly similar in the autonomous driving sector in recent years. This is despite the fact that valuations and the general funding environment in China have been soft in the past couple of years.

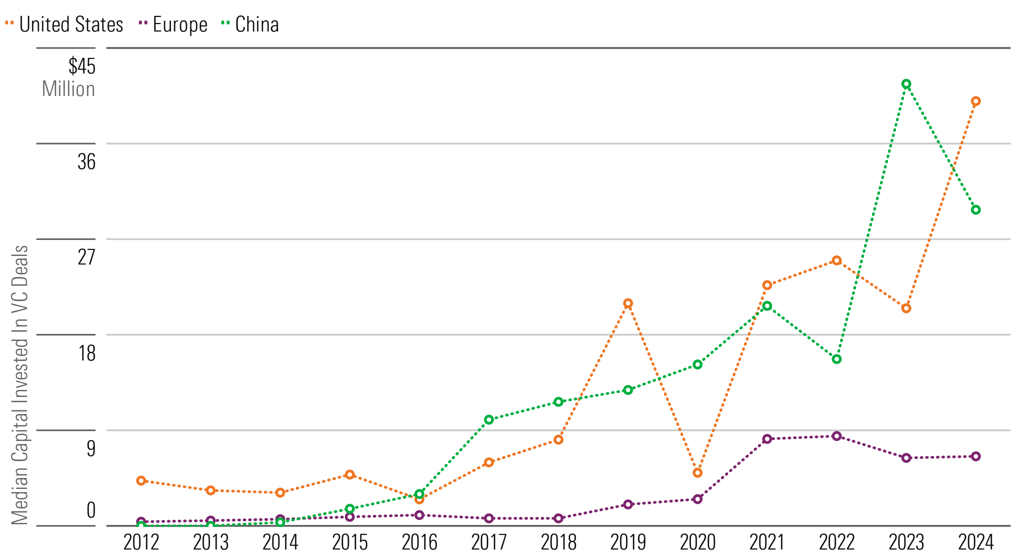
Exhibit 59 European Deal Flow Fell Off Notably After the Pandemic, With US and China Gaining Deal Share



Source: Morningstar, PitchBook. Data as of June 14, 2024.

The difference between Europe and the other two competitors is even more stark if we look at median capital invested in VC deals in the autonomous driving sector. Median capital invested has been around 4 times lower for Europe compared with the US and China in the past few years.

Exhibit 60 Median Capital Invested in Europe VC Deals Is Multiples Lower Than US and China



Source: Morningstar, PitchBook.

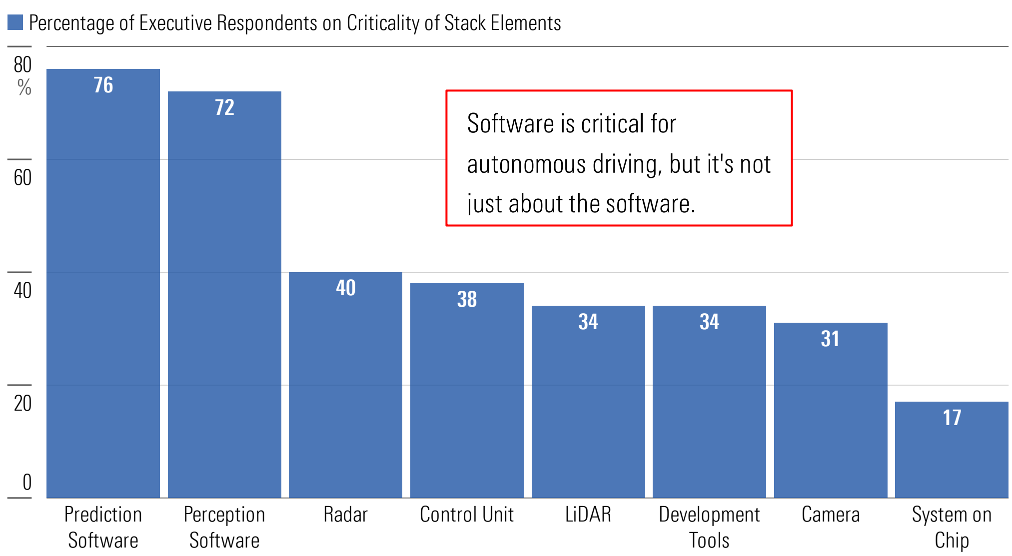
US vs. China Autonomous Driving Showdown: Entire Ecosystem Matters

In this section, we dive deeper into the intense competition between the US and China to establish supremacy in autonomous driving technology. However, this technology is still nascent, and any sort of prediction is highly uncertain. Our aim is not to declare a winner but assess where things stand and provide a framework to think about future progression in this field.

There is often a tendency to assess the progress of various countries in autonomous driving based on singular factors such a funding, revenue, regulatory development, hardware and software development, and so on. These sorts of comparisons can potentially work in weeding out countries/regions from the leadership race, but we think they can be misleading when comparing the US and China. We believe that the leadership race in autonomous driving technology has largely been reduced to these two superpowers. Other countries have strengths in niche areas, but they do not have the entire ecosystem needed for the mass adoption of autonomous driving technology.

While individual factors like regulatory support, funding, consumer attitudes, adoption by the automotive industry, technological advancement, ease of deployment, and infrastructure all matter, it is eventually about how well these factors are integrated.

Exhibit 61 Software Considered to Be Critical Element in Achieving Autonomy by Most Executive Survey Responders



Source: Morningstar, McKinsey. Data as of Jan. 5, 2024.

Still, certain areas are more important than others in the development of this technology. A recent survey of industry executives in the autonomous driving industry shows that most consider software to be the most critical element in the development of this technology. While software is undoubtedly important, other components related to the hardware stack are also important.

We have seen industry commentary that China will not be able to achieve supremacy in AV technology because of Washington's strict sanctions around semiconductor technology. Semiconductor sanctions will have a huge impact on the development of technologies like generative artificial intelligence models. However, they are relatively a much smaller concern for the adoption and development of autonomous driving technology. This can be seen in Exhibit 61, where "system on chip" was considered to be critical by only 17% of survey responders. The reason is that processing power required for achieving autonomy is not a major bottleneck. Further, recent Chinese advances in semiconductor design and manufacturing have lowered concerns about Washington's semiconductor sanctions in autonomous driving technology.

Exhibit 62 Framework to Assess and Compare Autonomous Driving Capabilities of the US And China

Our Simplified Framework To Assess Autonomous Driving Capabilities Within A Country

Software Stack	Competition & Dynamism	Government & Policy Support	Hardware Stack	Maturity of Ecosystem	Consumer Acceptance
Software is the key. This pillar includes but is not limited to algorithms, data collection, AI, computer vision, processing power, etc.	Competition & dynamism drive innovation, tech advancement, cost efficiency, investments, improvements, and mass adoption.	Includes legal and regulatory frameworks, government policies, and funding. Policy support can hugely accelerate progress.	Often neglected, we believe that developing the hardware stack is essential. This includes lidars, sensors, cameras, radars, vehicle integration, etc.	Includes smart infrastructure, communication systems, industry partnerships, funding, human capital, testing, market size, ease of deployment	Adoption is impacted by trust, transparency, regulatory support, public opinion, managing disruption, and viable business models.

Pillars are arranged in descending order of importance (Most to least important)

Source: Morningstar.

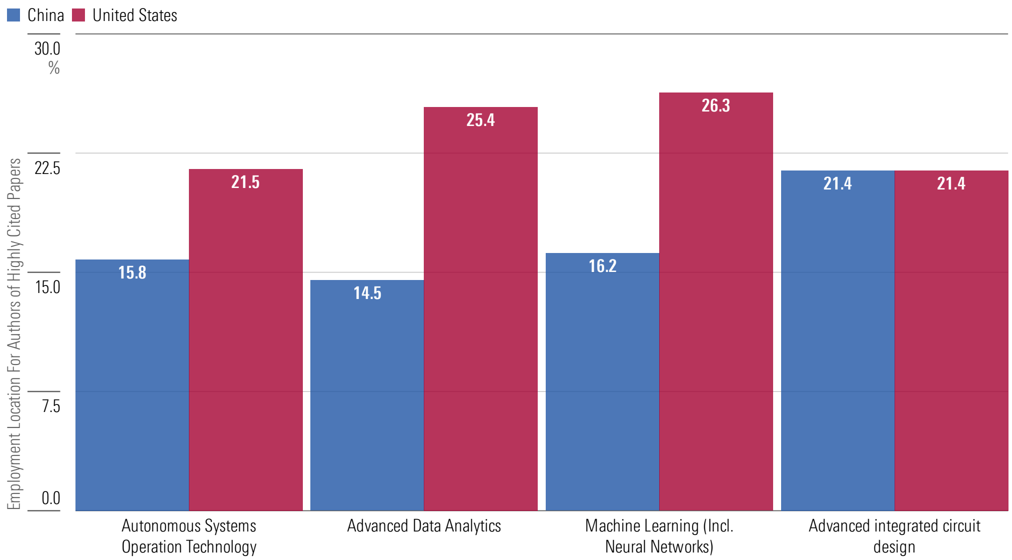
We have developed a framework to assess the progress of autonomous driving technology, and we will assess the progress of the autonomous driving technology industry in both the US and China using this framework. We think it is very difficult to precisely quantify the progress of each country based on the six pillars in the above framework given the nascency of the industry. Our objective with analysis in this section is to get things directionally correct rather than putting precise numbers to each pillar.

Autonomous Driving Software: US Has a Lead in Software, but Not by as Much as in Other Areas Like Generative AI

While the US and China both have mature software industries, the US has a lead in this field, given its large market size, innovation ecosystem, highly profitable and influential Big Tech firms, global reach, access to world's best talent, robust funding environment, and strong regulatory support.

It is extremely difficult to quantify a country's strength in software, especially in an emerging field, given its intangible nature. We are mainly concerned about software development and research progress in technologies that directly relate to autonomous driving. Exhibit 63 compares the percentage of authors of highly cited papers in fields related to autonomous driving software that work in the US and China. A much larger percentage of leading researchers in these fields are employed in the US than in China.

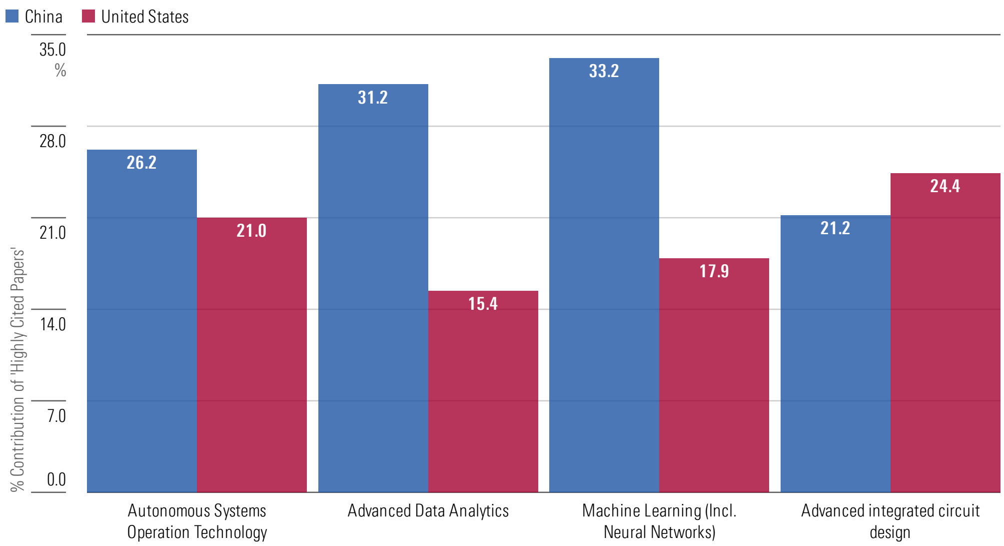
Exhibit 63 US Benefits From More Mature Software Ecosystem That Attracts Top Talent From Around the Globe



Source: Morningstar, Australian Strategic Policy Institute. Data as of June 17, 2024. The bars show the employment location for the authors of the top 10% of highly cited papers in various fields as published by the critical technology tracker of the Australian Strategic Policy Institute.

However, if we check the location of publication of highly cited papers in the same fields, a very different story emerges. As seen in Exhibit 64, China seems to be publishing significantly more high-quality research in these areas than the US. The difference in the two exhibits demonstrates that a significant number of top researchers in these fields are emigrating from China to the US after publishing their initial research in China. In our opinion, the ability of the US to attract top research talent from around the globe is one of its biggest strengths in this competition. Exhibit 64 compares the two countries in terms of quality of research rather than quantity of research. The speed at which China has caught up with the US in core research in these fields is remarkable.

Exhibit 64 China Is Catching Up Rapidly in Core AV Technologies, as Seen by Its Contribution of Top-Quality Papers



Source: Morningstar, Australian Strategic Policy Institute. Data as of June 17, 2024. The bars show the weighted fraction of papers in the top 10% of highly cited papers in various fields as published by the critical technology tracker of the Australian Strategic Policy Institute.

The fact that a larger percentage of leading research talent works in the US despite China having a lead in research publications speaks volumes about the ability of the US to attract world-class talent. We think this is a major advantage. The US has a more mature and better-funded technology and software ecosystem that enables it to better convert core research into commercial software products.

Overall, we think the US is ahead of China in terms of the development of the software stack for self-driving cars. Also, various Chinese self-driving startups have opened offices in Silicon Valley to test and develop their technology which is not true the other way around. This indicates that Chinese companies recognize the importance of being present in the Silicon Valley ecosystem and tapping its talent.

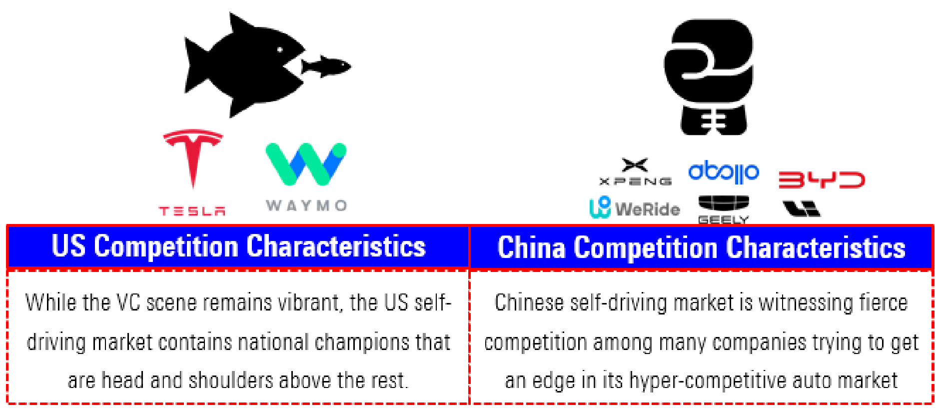
Developing the software stack for self-driving cars is the most important and perhaps the most challenging aspect in developing autonomous vehicle technology. It is absolutely at the center of the progress in this technology and is extremely critical. In our opinion, the US' lead in autonomous driving software development is its biggest advantage over China. However, the US' lead here is nowhere near as big as its lead in other areas like generative artificial intelligence.

Online comparisons of the latest versions of US and Chinese NOA and Level 4 autonomous driving systems have mixed reviews. Some testers rate US systems to be better, while others rate Chinese systems as better. This shows that the current capability of US and Chinese AV software stacks is neck to neck, and any lead that US companies possess is relatively narrow.

Industry Dynamism and Competition in Autonomous Driving:
US Depends on a Few National Champions While China Has Incredibly Fierce Competition

Competition is at the heart of capitalism. It forces companies to be their best, because if they aren't, they will cease to exist. Competition is probably the most important driver of incremental improvements that lead to advancements in technology and innovation. Competitive environments encourage businesses to stay ahead of their rivals, leading to more dynamism in the market. Historically, there has been a strong correlation between competitive intensity and the pace of innovation. We rank competitive intensity as the second most important pillar in analyzing the tech race between the US and China in autonomous driving.

Exhibit 65 China's Hypercompetitive Market Is Creating Strong Incentive for Companies to Innovate



Source: Morningstar.

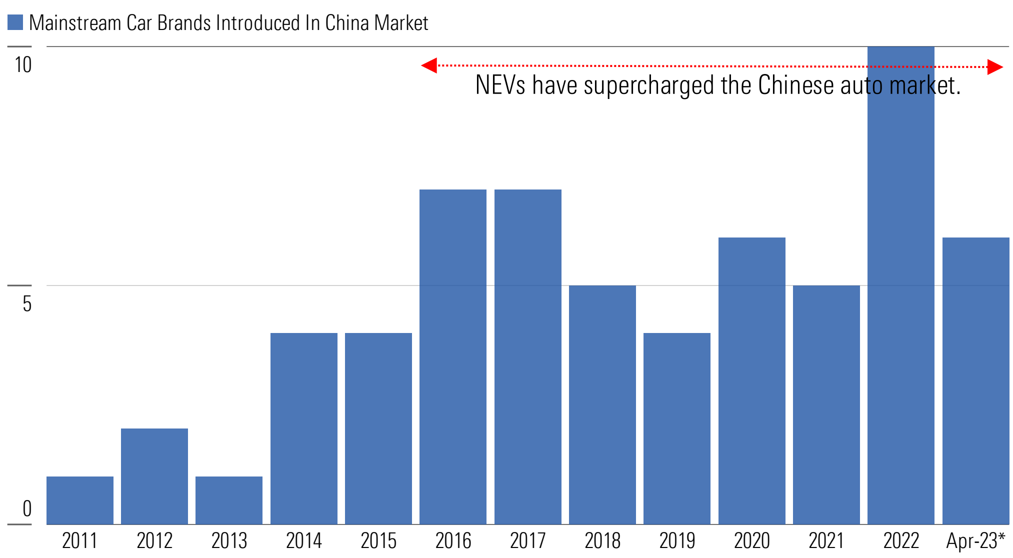
In our assessment, there is a significant difference in competitive intensity in the US and Chinese self-driving markets. While the funding scene remains robust, the US autonomous driving market is dominated by national champions that are well above the rest. There are various companies and startups in the US, but there is a considerable technology gap between the leader and the second-, third-, or fourth-ranked player in a segment. Take the example of the navigation on autopilot market: In this market, Tesla is widely considered to be the market leader, with legacy OEMs trailing far behind in terms of technology development.

The competitive environment in China is very different, as various companies are engaged in extremely fierce competition to get an edge in the hypercompetitive automobile market. *MIT Technology Review* recently documented the extent of the competition among various companies in the Level 2 NOA market. It noted that in early 2023, Haomo.ai announced plans to launch its NOA product in 100 Chinese cities by the end of 2024. In April 2023, Huawei announced plans to reach 45 cities by the end of the year. Three days later, Li Auto announced plans to expand its NOA service to 100 cities by the end of 2023. This was followed by announcements from a host of other EV competitors to expand their NOA offerings to even more cities at earlier dates. This is an excellent example of the brutal competition in the Chinese market.

In the Chinese market, autonomous capabilities are considered an important element for mass-market electric vehicles. Companies try to outcompete each other by providing better technological features, including NOA capability. This is in sharp contrast with the US automobile market, which has become more protectionist in recent years. Generally speaking, autonomous capabilities for mass-market cars have not yet become the competitive focal point in the US that they are for Chinese EV manufacturers.

We believe the biggest advantage that China has over the US is its dynamic and hypercompetitive automobile market, especially for electric vehicles where autonomous capabilities are becoming a core selling point. Exhibit 66 shows the number of mainstream car brands that have entered the Chinese market in the past few years. The data should only be interpreted directionally, as it is from an article in which the number of car brands is calculated manually. This would certainly result in missing some smaller upstarts or lesser-known brands. Our larger point is that no other car market has anywhere close to the competition that the Chinese market has. The vibrancy of the Chinese car market has been turbocharged by the evolution of battery technology in the past few years. By some estimates, China currently has over 150 active car brands. Very few of these brands will survive in the long term, but the ones that do will likely be strong competitors.

Exhibit 66 China's Auto Market Has Significantly More Churn and Competition Than Other Major Auto Markets



Source: Morningstar, Just Auto, Motor1.com. Data as of April 30, 2023. The data for the last bar is for the first four months of 2023. The data for this exhibit is from an article in which new car brands are manually estimated. Due to this, smaller and lesser-known car brands are probably not included. NEVs = new energy vehicles, which include battery and plug-in hybrid cars.

Competition is not limited to the final assembly of cars; it's present in the entire supply chain, from hardware components and software providers to supporting system providers. The competitive intensity is not the same in all industries, but it could be called quite fierce in most self-driving-related industries.

Take the example of high-definition maps in Exhibit 67. HD maps provide much more information than regular maps and are very helpful for autonomous driving systems. The exhibit shows that car manufacturers have partnered with various HD map providers in the China market. This type of competition among various HD map providers has fostered innovation, wider coverage, and cost-effectiveness in the Chinese HD map market.

Exhibit 67 OEMs Partner With Different HD Map Providers in the China Market, Fostering Strong Competition

Automaker/Car Brand	HD Map Partner
Mercedes Benz & Audi	Here
BMW	NavInfo, Here
Great Wall, Changan, BAIC, Chery, GAC Tesla	Baidu
Geely, Cadillac	AutoNavi (Amap)
Nissan, Toyota and Honda	Dynamic Map Platform
Hyundai	Netradyne, Baidu
SAIC	KOTEI Big Data
Xpeng and FAW	AutoNavi (Amap), eMapgo

Source: Morningstar, ResearchInChina. Data as of Dec. 31, 2020.

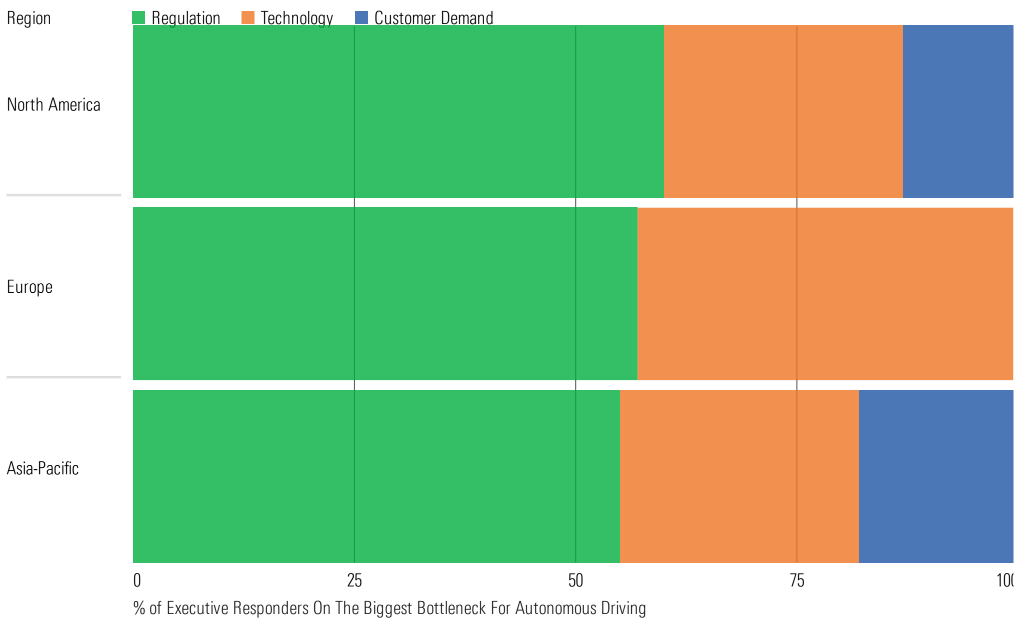
Also, unlike the US market, the competitive positioning of various players in the self-driving ecosystem is often not that clear, which we see as good for competition. When various companies are clustered around each other in terms of technological capabilities, it leads to faster advances because there is much more of a competitive threat to incumbents.

While China benefits from more competition in this industry, it could be argued that there are historical examples of the national champion approach working better than the fragmented competition approach. We think the national champion approach can work well in more mature industries where scale matters a lot, but the fragmented competition approach is perhaps better for industries where innovation and technological advancements are the key considerations.

Policy Support for Autonomous Driving: Both Governments Have Shown Support, but China Has Leaped Ahead in Testing

While policy and regulatory support plays a role in almost all industries, we think it is especially important in autonomous driving. A stable and supportive policy environment can be a major catalyst for testing, development, and the eventual deployment of autonomous driving technology. Exhibit 68 shows that regulation is considered to be the biggest bottleneck in the advancement of autonomous technology, per a McKinsey executive survey—bigger than even technology.

Exhibit 68 Executive Survey on Autonomous Driving Show That Regulation Is Considered the Biggest Bottleneck

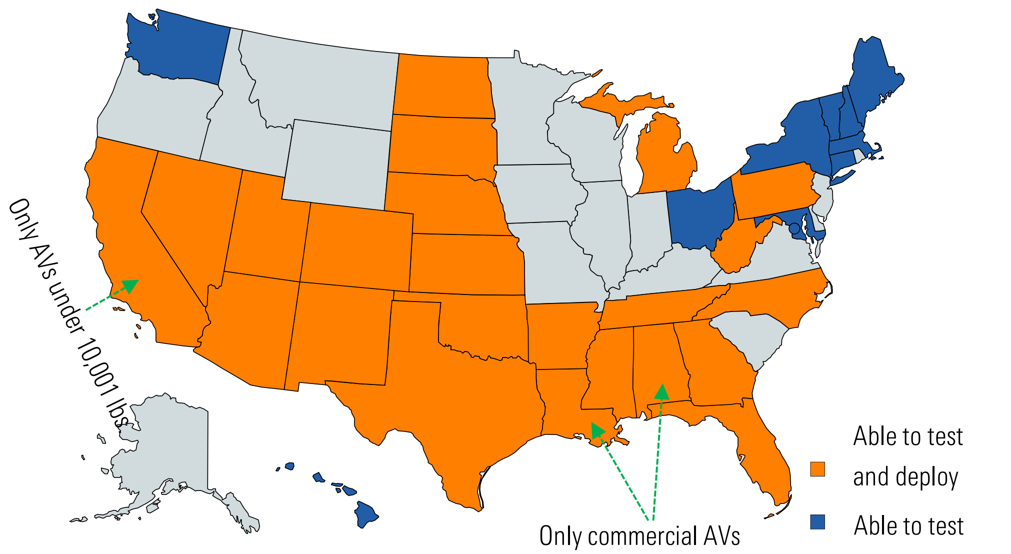


Source: Morningstar, McKinsey. Data as of Jan. 5, 2024.

Standards, regulations, and legal frameworks in the autonomous driving industry are still in the early stages of development, but they are evolving rapidly as the technology advances. Exhibit 69 shows that autonomous vehicles can now be tested and deployed in many US states. The testing and deployment of autonomous vehicles was limited to a very few states just a few years ago. We think there is healthy competition among US states to provide relaxed regulatory frameworks to attract more AV startups.

While state and federal regulators have shown an eagerness to promote the development of this technology in the US, they have had to balance this support with public safety concerns. For instance, a serious accident in San Francisco in October 2023 resulted in Cruise grounding all its autonomous vehicles and announcing a third-party safety review of its robotaxis. The self-driving firm has not been able to fully emerge from the impacts of the accident and has not been able to resume testing in various cities where it previously operated. Building public trust and ensuring high safety standards are extremely important, but ideally this is balanced with the need to conduct more testing in real-life situations for the evolution of the technology.

Exhibit 69 US State Governments Are Increasingly Open to AV Testing and Deployment



Source: Morningstar, Autonomous Vehicle Industry Association. Data as of June 18, 2024. California only allows testing and deployment of AVs under 10,001 pounds. Louisiana and Alabama allow testing and deployment of commercial AVs only.

China has also been supportive of autonomous driving firms by establishing comprehensive safety standards, creating regulatory frameworks, enabling the development of supporting infrastructure, and providing economic incentives. The top-down structure of central planning gives China an edge over other countries in terms of the speed at which it can change regulation. Its centralized systems can move much faster compared with other countries where building public consensus is essential.

China's progress in this industry has been notable especially in the past couple of years. It is difficult to get precise data to replicate Exhibit 69 for China in terms of regulatory approvals, but upon the directives of the central government, local governments throughout the country are showing increasing eagerness to test and deploy autonomous systems. Regulatory approvals have gone up considerably in the past year for the deployment of fully driverless robotaxis in various cities, and at least 17 cities in China have allowed driverless vehicles to operate on public roads. Exhibit 70 shows the states where Baidu's Apollo robotaxis are currently operating.

Exhibit 70 Various Cities in China Already Have Permitted Level 4 Ride-Hailing Services to Become Operational

Source: Morningstar, Apollo. Data as of June 18, 2024.

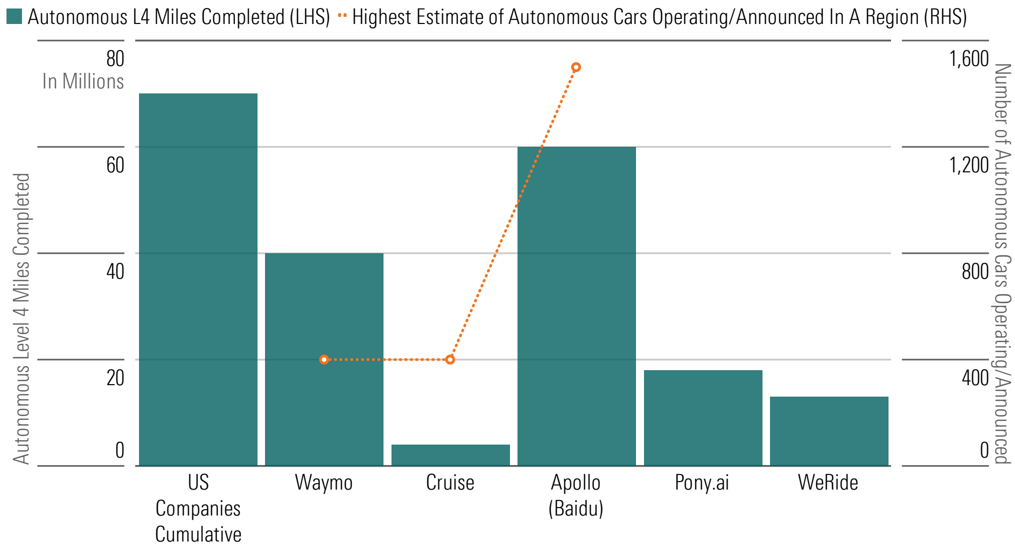
Absolutely key to the advancement of self-driving technology is extensive testing, especially in real-life conditions. Simulation testing, controlled-environment trials, and real-world testing reinforce the self-driving algorithms to deal with different scenarios, including extremely rare scenarios, that are essential to navigate in often chaotic traffic. More testing leads to more data, which leads to better algorithms, which leads to safer autonomous systems. Safer autonomous systems lead to more vehicles on the road, which leads to more data. There is a sort of reinforcing network effect in training autonomous systems.

In Exhibit 71, we attempt to compare the amount of testing in the US and China. The data comes from various sources with slightly varying dates and includes our best estimates. Therefore, the exhibit should only be analyzed from a high-level perspective. Having said this, it seems like China has leaped ahead of the US in terms of testing autonomous systems. Precisely comparable data on this is very hard to come by, but the difference is becoming more clear with every passing quarter.

We can attribute some of the recent divergence to regulation and competition. Relaxed regulation standards can go a long way, as they allow more testing and regulators can potentially look the other way when one-off accidents happen. *The New York Times* recently reported on Chinese authorities censoring and limiting discussion related to the safety of autonomous vehicles on online forums. This does suggest that Chinese authorities are going out of their way to support this sector.

The other factor leading to more testing is higher competition. By one estimate, at least 19 Chinese companies are fighting for share. The extent and the speed of China's Level 4 autonomous system deployment can be judged by the recent announcement from Apollo that it will take its active fleet of driverless robotaxis from 500 to 1,500 by the end of the year in Wuhan. In our opinion, this is significantly higher than any US company's driverless fleet.

Exhibit 71 China's Lead in Testing Autonomous Level 4 Systems Appears Poised to Widen



Source: Morningstar, The New York Times, San Francisco Chronicle, Waymo, Cruise, WeRide, Pony.ai, Baidu, Autonomous Vehicle Industry Association, California Department of Transportation. Data as of June 20, 2024. The data above is our best estimate for autonomous miles driven by various companies from various sources. We have attempted to find the latest publicly available figures for autonomous driving for various companies. Due to the irregularity of the data, the figures for different companies may be of different dates. Highest estimate of autonomous cars operating/announced in a region for Waymo and Cruise comes from California DMV data while for Apollo it comes from a recent NYT article.

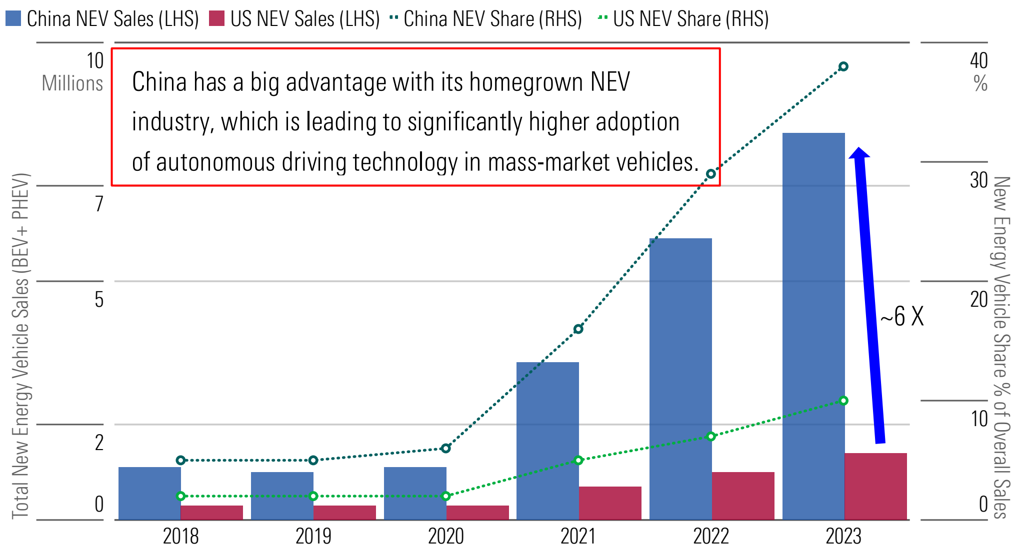
Autonomous Driving Hardware: Vibrant EV Sectors and Manufacturing Give China an Advantage

The technological advancement of the hardware stack associated with autonomous driving systems is also very important. Counterarguments suggest that cheap cameras and sensors coupled with great software can achieve full self-driving. While this is possible at some point in the future, we are a bit skeptical of these arguments and believe that a specialized hardware stack is essential for achieving Level 4 autonomy. As seen in Exhibit 7, the hardware stack in a self-driving vehicle helps in collecting data to feed into the software system, process the data, enable the timely flow of decision signals throughout the vehicle, and execute instructions through the control module. Ensuring high levels of accuracy and reliability in all these steps is important in achieving autonomy.

One of the biggest roadblocks in mass-market adoption of Level 4 systems has been the unaffordability and the difficult economics of operating these vehicles. We believe that achieving manufacturing scale for autonomous driving hardware can massively improve affordability, which is bound to have an exponential impact on the adoption of these systems.

China has an advantage in the development of autonomous driving hardware mostly because of its vibrant new energy vehicle ecosystem. Autonomous driving technology is better suited to electric vehicles, as electric motors can alter power with a much smaller lag. This is also one of the reasons upstart OEMs that specialize in EVs have taken a lead in developing and integrating autonomous driving technology into their vehicles. Exhibit 72 compares new energy vehicle sales in the US and China in the past six years. China's NEV sales were almost 6 times higher than the US' in 2023.

Exhibit 72 AV Technology Is Better Suited to EVs As Electric Motors Can Alter Power With a Much Smaller Lag

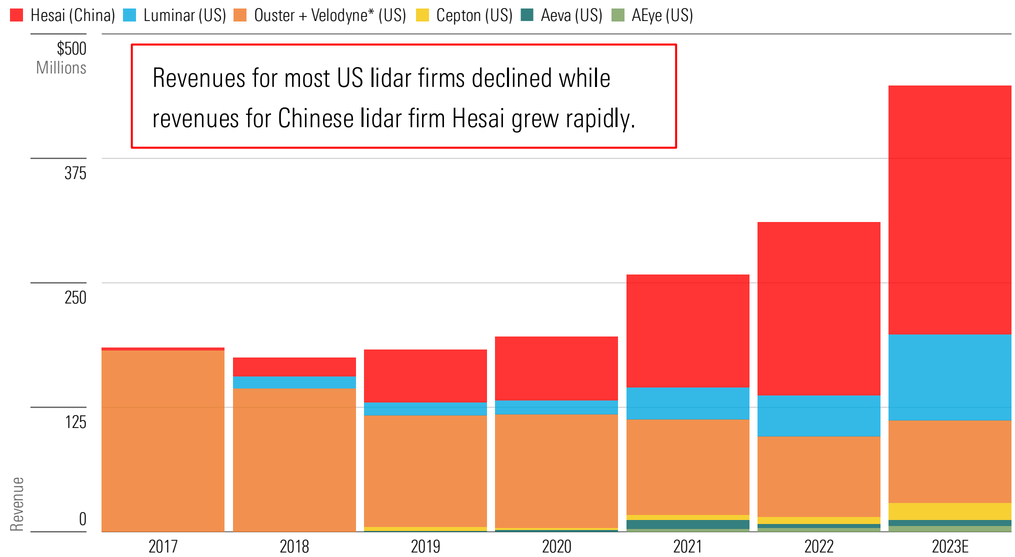


Source: Morningstar, International Energy Agency, The New York Times. NEV = new energy vehicle; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; NEV = PHEV + BEV.

Lidar—light detection and ranging—is an example of how a lead in NEVs translates into a lead in the hardware stack for autonomous driving technology. Lidar is a sensor that throws out a laser pulse and measures the time it takes to bounce back after hitting an object to calculate the accurate distance of the object. By sending out thousands of these laser pulses, lidar can create a three-dimensional view of the area around it. Lidar's applications are not limited to autonomous vehicles, but autonomous vehicles are the biggest market for lidar companies.

Exhibit 73 compares the revenues of various publicly listed lidar companies in the past seven years. We can see that Western companies dominated the lidar market until about 2017, but Chinese companies like Hesai gained significant share as lidar started being integrated into new energy vehicles. By 2023, it was estimated that Chinese manufacturers had cornered about 73% of the global market for lidar through scale advantages and technological breakthroughs.

Exhibit 73 US Firms Used to Dominate Lidar Market, but Chinese Firms Have Taken Over

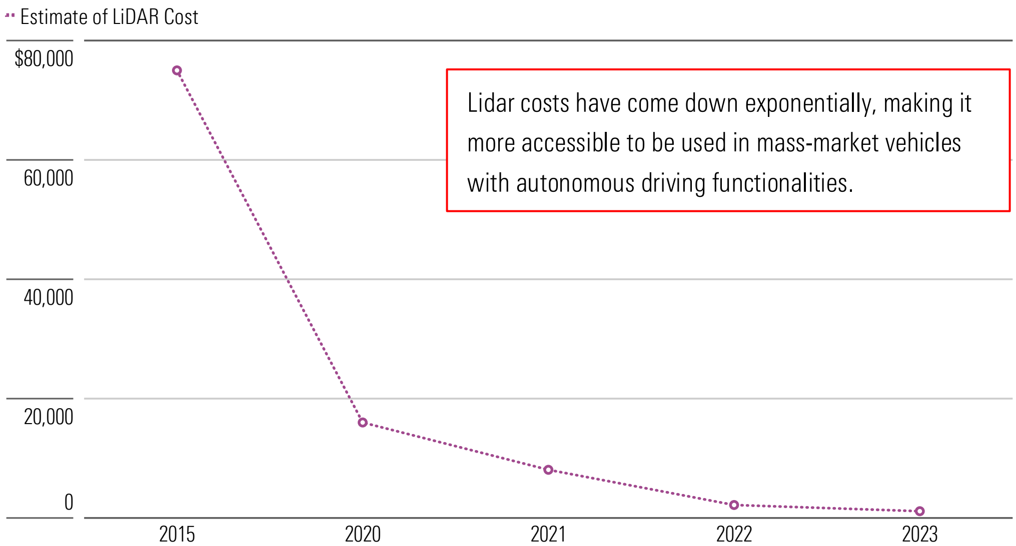


Source: Morningstar, Hesai, Luminar, Ouster, Cepton, Aeva, AEye. Velodyne and Ouster merged in 2023 and kept the Ouster name. This shows the combined revenue of Ouster and Velodyne before the merger.

Like most technologies at the leading edge, the cost can be cut dramatically by achieving manufacturing scale. Lidar's per unit costs have come down from an estimated $75,000 in 2015 to around $1,000 recently. The increasing affordability has made lidar accessible for use in mass-market NOA systems. In recent months, various EV models priced around $40,000 have been launched with lidar systems in the Chinese market.

The exponential decrease in the cost of autonomous driving hardware systems can be a big catalyst in the evolution of the technology. Until as recently as 2019, Tesla CEO Elon Musk was calling lidar "expensive sensors that are unnecessary." While there are different opinions on the effectiveness of lidar systems, the point is that technological advancement and manufacturing at scale can exponentially reduce the cost of various autonomous driving-related hardware components. The current economics of a Level 4 robotaxi can look unreasonable on paper, but when adopted at scale, the cost of these systems can fall faster than most people realize.

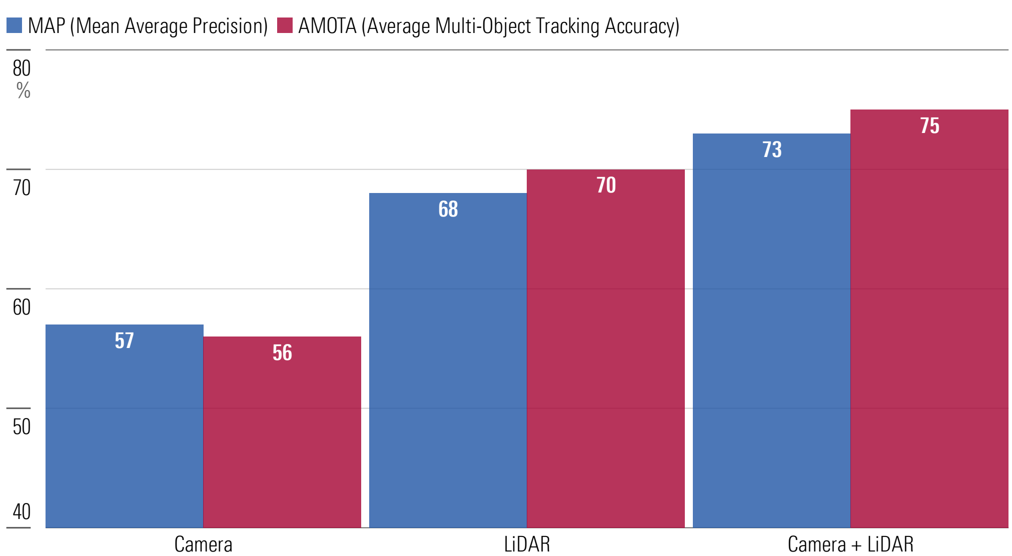
Exhibit 74 Manufacturing at Scale Can Often Dramatically Lower Costs for New Technologies



Source: Morningstar, Hesai, Forbes. Lidar cost from 2020 is estimated by dividing Hesai revenue by total lidar shipments. 2015 lidar cost estimate is from industry commentary and media articles.

Various industry studies have shown that lidar can materially improve perception capabilities of autonomous vehicles. Per a study published by nuScenes, the combination of lidar and cameras significantly outperforms only cameras when measured on industry metrics like mean average precision and average multi-object tracking accuracy.

Exhibit 75 Lidar Can Materially Improve Perception Capabilities of Autonomous Vehicles



Source: Morningstar, nuScenes 2023 Detection Challenge, Hesai. Data as of Dec. 31, 2023.

The discussion around sensor effectiveness will evolve with the technology, but our opinion is that combining data from various types of sensors can improve perception capabilities of autonomous vehicles, since every sensor type has its own set of advantages and disadvantages.

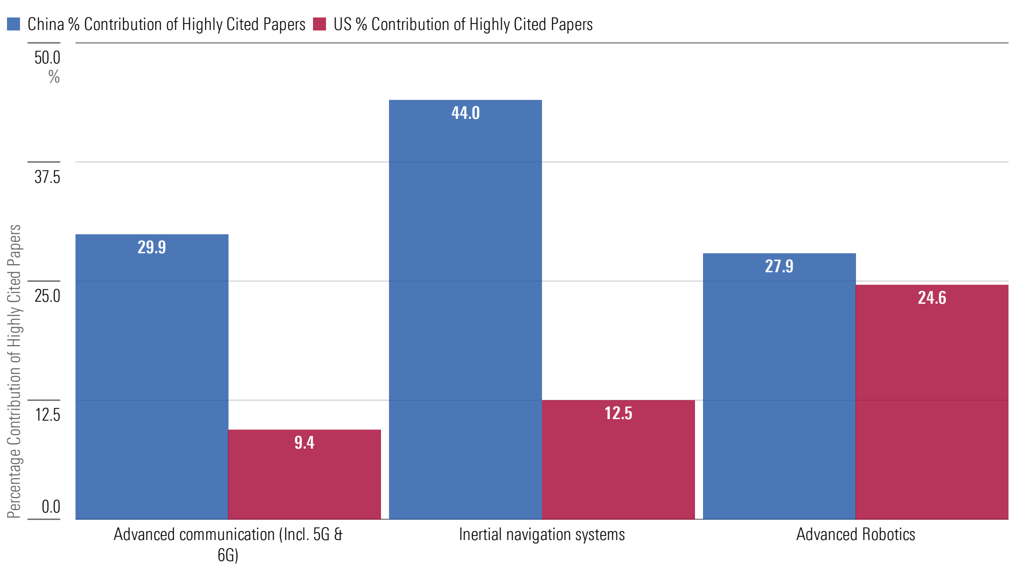
While we have focused on the example of lidar systems, the interplay of scale, adoption, and affordability is valid for the entire hardware stack. China's manufacturing prowess and vibrant NEV industry give it a leg up on other countries in terms of autonomous driving hardware.

Overall Maturity of Autonomous Driving Ecosystem: US Has Upper Hand in Talent and Funding While China Has Better Infrastructure and Faster Communications Technology

The speed and the scale of the adoption of autonomous driving technology will also depend on the maturity of the overall ecosystem, which includes factors like supportive infrastructure, deployment of advance communications networks, industry partnerships, funding, government incentives, availability of human capital, market size, and ease of deployment.

We do not think that either country has a sizable advantage in this pillar now. It will probably take a couple of more years to be clear on who is ahead in respect to the maturity of the overall ecosystem. In our current assessment, China benefits from better infrastructure and faster communications networks due to its lead in 5G and 6G technology, while the US has a considerable edge in funding and capital markets.

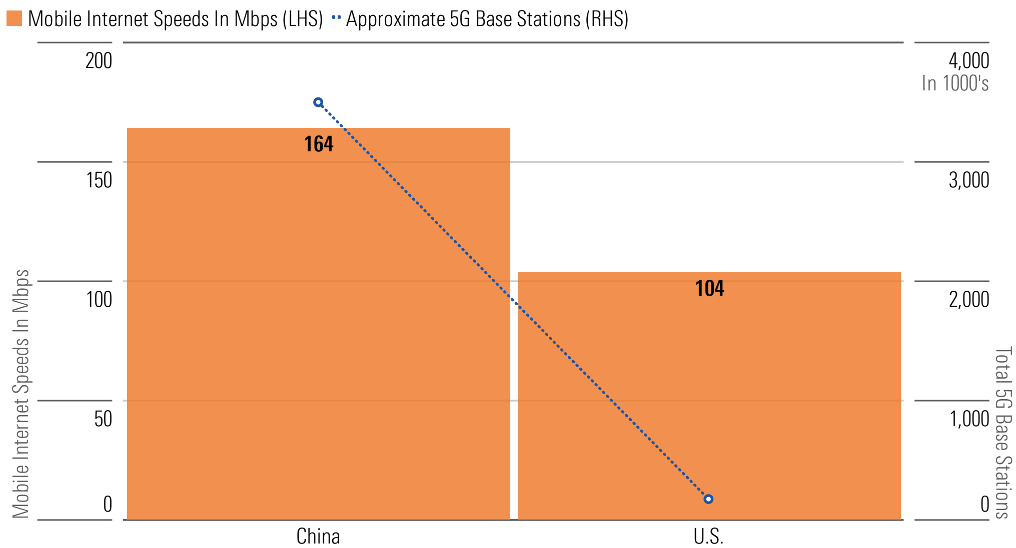
Exhibit 76 China Has Advantage in Various Supporting Technologies That Could Be Decisive in Self-Driving Era



Source: Morningstar, Australian Strategic Policy Institute. Data as of June 17, 2024. Bars show the weighted fraction of papers in the top 10% of highly cited papers in various fields published by a certain country.

Exhibit 76 compares the contributions of the US and China in technologies that we believe can play an important role in fostering the development of autonomous driving. This is done on the basis of contribution of high-quality research papers and the employment location of the authors of these papers. We can see that China seems to be a dominant force in advanced communication and inertial navigation systems while it is tied with the US in advanced robotics.

Exhibit 77 Better 5G Network Has Enabled Higher Mobile Internet Speeds in China



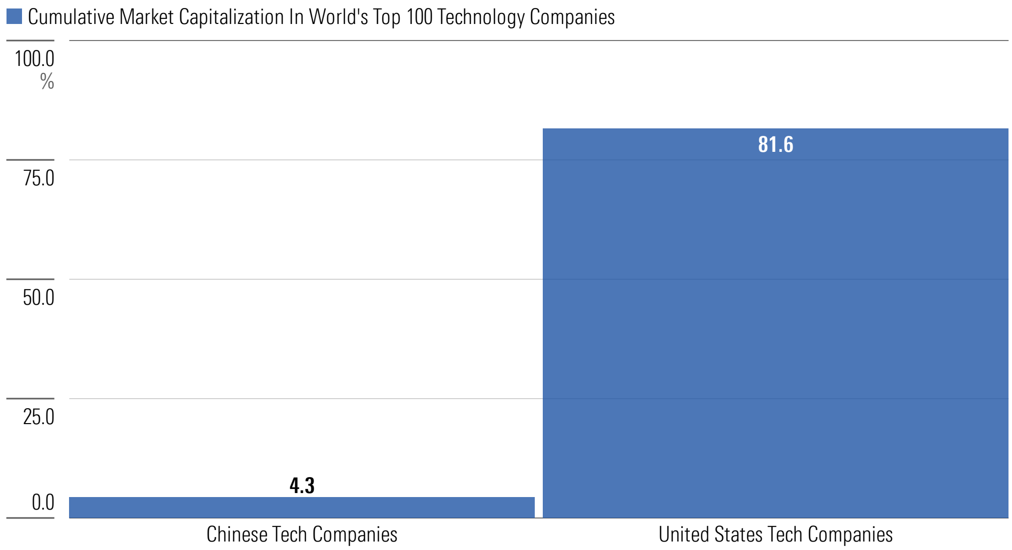
Source: Morningstar, Speedtest Global Index 2021, World Population Review, European 5G Observatory. Data as of June 17, 2024.

Exhibit 77 shows how leadership in a particular core technology can result in tangible benefits to a wide variety of use cases. Chinese companies have a lead in 5G and 6G technology which has resulted in faster deployment of 5G base stations in China compared with almost any other large country in the world. A better 5G network has enabled materially faster internet speeds in China compared with the US.

Advance communications systems can be integrated with a country's road infrastructure, enabling seamless communication between autonomous vehicles and other supporting systems like HD maps and also among various autonomous vehicles operating on the road. While the advantages of advanced communications networks are limited in the current fleet of deployed autonomous vehicles, they will become more tangible in an era of fully autonomous cars.

The US has its own advantages when it comes to development of new technologies. It has an incredible dominance in the world of tech companies and has done a much better job in scaling core technologies to build world-leading companies. We estimate that the cumulative market capitalization of US tech companies in the world's top 100 tech companies is around 19 times higher than Chinese companies. The maturity, scale, and reach of the US technology ecosystem give it a massive advantage over China. US Big Tech companies have a much bigger global footprint, more capital, more human capital resources, and perhaps a more geopolitically friendly environment to operate in.

Exhibit 78 US Has Incredible Dominance in Large Technology Companies



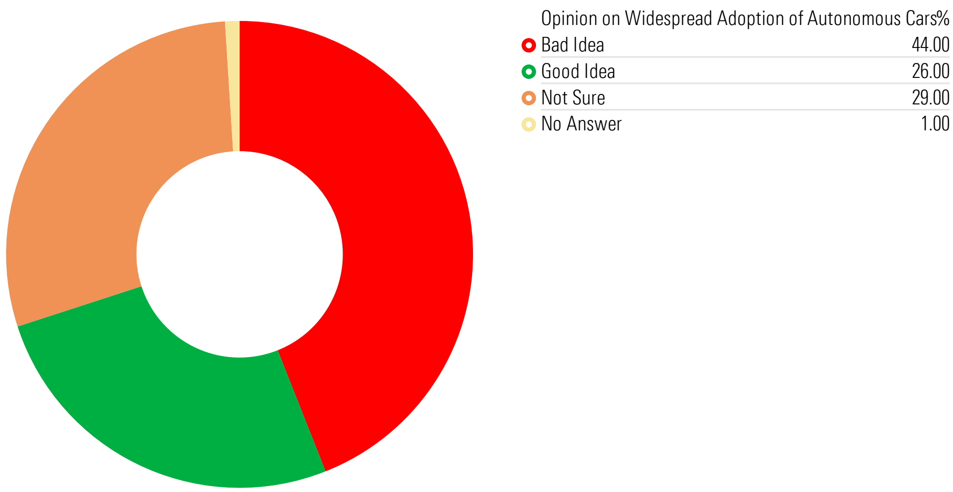
Source: Morningstar, Companiesmarketcap.com. Data as of June 17, 2024. Chinese and US tech companies' cumulative market capitalization is calculated by adding market caps of all tech companies in the country in the world's top 100 tech company list and dividing that by the sum of market caps for the world's top 100 tech companies.

Consumer Acceptance of Autonomous Driving Technology: Americans Are More Skeptical

The sixth pillar in our framework is based on the public acceptance of autonomous driving technology. While public trust and acceptance may not matter much in the early stages of development, it certainly has an impact on the pace of adoption. In the case of autonomous vehicles, consumer acceptance matters much more because the advancement of the technology depends on real-world testing, which can be seriously affected by the public perception on safety.

The US perception of autonomous vehicles can be described as mix of enthusiasm and skepticism. Skepticism is visible in the public reaction in cities where driverless autonomous vehicles are operational. In a survey conducted by Pew Research Center, the Americans who think that widespread adoption of autonomous vehicles will be a bad idea for society significantly outnumber those who see the technology as a good idea.

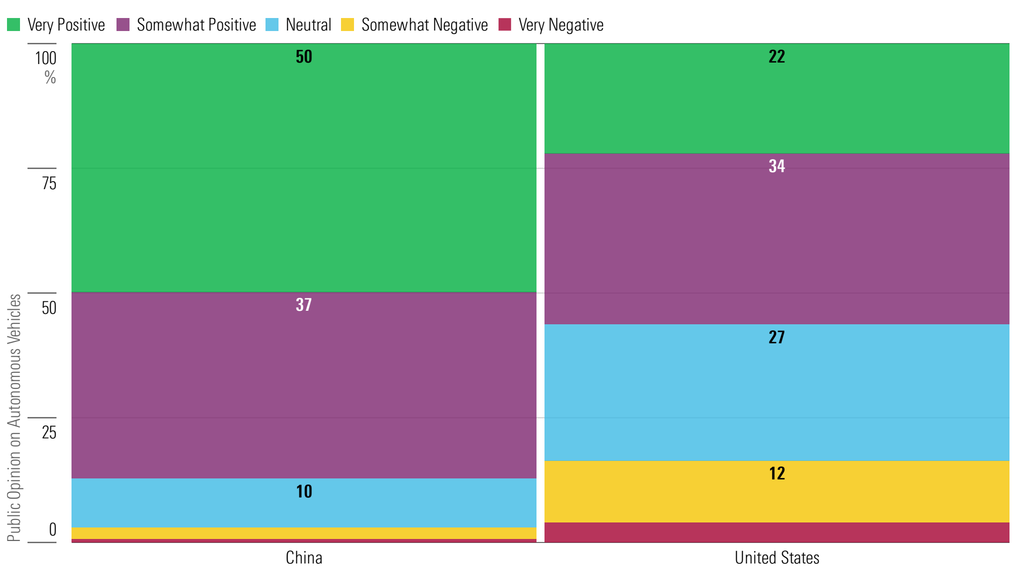
Exhibit 79 A Higher Percentage of Americans Say That Adoption of Autonomous Cars Would Be Bad



Source: Morningstar, Pew Research Center. Data as of March 17, 2022.

Chinese citizens have had a more accepting and favorable opinion on autonomous vehicles, at least as of now. Research suggests that this is partly because they have seen huge advancements in their quality of life in the last 45 years, which makes them more open to change. The top-down political system also plays a role in building public perception and encouraging the adoption of desired technologies. As referenced in Exhibit 80, 87% of Chinese citizens have a "very positive" or "somewhat positive" opinion of autonomous cars compared with just 56% of Americans.

Exhibit 80 Chinese Citizens Have a Much More Positive Opinion of Autonomous Cars



Source: Morningstar, Schoettle at al. "Public opinion about self-driving vehicles in China, India, Japan, the U.S., the U.K., and Australia." Data as of Oct. 31, 2014.

While public perception and acceptance may seem like distant factors, we believe they will play an increasingly important role in the competition between the US and China as they directly affect the pace of testing, deployment, and mass-market adoption.

Conclusion: We Think China Has a Slight Lead

The US clearly seems to be ahead in areas like software, processing power, talent, and funding, while China seems to have a material advantage in areas like competition, hardware, cost-competitiveness, testing, and consumer acceptance. There are other areas like policy support, regulatory frameworks, and the overall maturity of the autonomous vehicle ecosystem where it is not clear which country has a lead.

We are still in the relatively early stages of development in this technology, and predictions about nascent technologies are inherently uncertain. However, when all factors are considered, we think China is slightly ahead of the US in the race toward autonomy. It is important to emphasize the word *slightly*. In our opinion, China has developed a slight lead in the autonomous driving technology mostly in the last two years.

The next couple of years will be crucial. There is a possibility that the Chinese lead in this technology will become sizable on the back of fierce competition, government support, cost-competitive products, and most importantly, wider deployment. It is also possible that US champions will leverage their software prowess to surpass Chinese competitors. An all-in US policy and government support will be essential for this to happen, and we do not think that this field is necessarily getting the attention and the urgency from US policymakers that it requires.

Exhibit 81 China and US Both Have Areas of Strength, but Our Sense Is That China Is Slightly Ahead Overall

Pillar	Importance	Who is Ahead?	Extent of Lead?
Software Stack	Very Important	United States	Low
Competition & Dynamism	Very Important	China	Medium
Government & Policy Support	Very Important	No clear leader	
Hardware Stack	Moderately Important	China	High
Maturity of Ecosystem	Moderately Important	No clear leader	
Consumer Acceptance	Low Importance	China	Medium

Source: Morningstar estimates.

Research Methodology for Valuing Companies

Overview

At the heart of our valuation system is a detailed projection of a company's future cash flows, resulting from our analysts' research. Analysts create custom industry and company assumptions to feed income statement, balance sheet, and capital investment assumptions into our globally standardized, proprietary discounted cash flow, or DCF, modeling templates. We use scenario analysis, in-depth competitive advantage analysis, and a variety of other analytical tools to augment this process. We think analyzing valuation through discounted cash flows presents a better lens for viewing cyclical companies, high-growth firms, businesses with finite lives (mines, for example), or companies expected to generate negative earnings over the next few years. That said, we don't dismiss multiples altogether but rather use them as supporting cross-checks for our DCF-based fair value estimates. We also acknowledge that DCF models offer their own challenges (including a potential proliferation of estimated inputs and the possibility that the method may miss short-term market-price movements), but we believe these negatives are mitigated by deep analysis and our long-term approach.

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Four key components drive the Morningstar rating:

- our assessment of the firm's economic moat.
- our estimate of the stock's fair value.
- our uncertainty around that fair value estimate.
- the current market price.

This process ultimately culminates in our single-point star rating.

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Fair Value Estimate

Each stock's fair value is estimated by using a proprietary discounted cash flow model, which assumes that the stock's value is equal to the total of the free cash flows of the company is expected to generate in the future, discounted back to the present at the rate commensurate with the riskiness of the cash flows. As with any DCF model, the ending value is highly sensitive to Morningstar's projections of future growth.

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The Morningstar Uncertainty Rating represents the analysts' ability to bound the estimated value of the shares in a company around the fair value estimate, based on the characteristics of the business underlying the stock, including operating and financial leverage, sales sensitivity to the overall economy, product concentration, pricing power, exposure to material ESG risks, and other company-specific factors. Based on these factors, analysts classify the stock into one of several uncertainty levels: Low, Medium, High, Very High, or Extreme. Our recommended margin of safety—the discount to fair value demanded before we'd recommend buying or selling the stock—widens as our uncertainty of the estimated value of the equity increases.

Market Price

The market prices used in this analysis and noted in the report come from exchanges on which the stock is listed, which we believe is a reliable source.

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