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Forecasting uptake of driver assistance technologies in Australia

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Foreword

Vehicle automation is already underway with many new vehicles sold in Australia having multiple safety enhancing automation features. However, vehicles that are capable of operating fully autonomously on our road networks are not yet available commercially anywhere in the world.

In this report, BITRE constructs a conceptual framework, based on a literature review of existing studies and theories of how to forecast the development and likely future uptake of different levels of vehicle automation in Australia. The conceptual framework looks into key factors driving price, willingness to pay (including consumer sentiment), supply availability and enablers (including the regulatory and policy landscape). This conceptual framework, along with other studies on fully automated vehicles, informs key parameter values, such as the date of introduction; market saturation rate and speed of uptake.

The report also includes some scenario analysis to help provide an understanding of the uncertainty around the uptake of vehicles with high levels of automation. Given the uncertain nature of the higher levels of vehicle automation, such as those capable of achieving full autonomy, this model allows for modifying assumptions. This has allowed BITRE to test the sensitivity of its forecasts to key modelling assumptions, where a broader value range is explored for less certain inputs, such as the saturation rate. Allowing for modifying assumptions also presents the opportunity to revisit forecasts on a regular basis to track technological developments.

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Executive summary

This report illustrates historical trends and forecasts the potential uptake of selected active safety, driver support and connectivity features in light vehicles in Australia. It addresses gaps in the literature for Australia by forecasting to 2070:

- incremental levels of automation, including specific technologies that are available in the market, and new technologies that are expected to be made commercially available in coming years; and
- the uptake of 'fully automated vehicles' (AVs).

Automation is often made up of several different types of technology, which will come onto the market at different times. Separate technologies that assist drivers — including warning sensors for traffic and pedestrians; connectivity features; and telematics — are all expected to be ubiquitous in new car sales from around 2045.

Broader automation of vehicles is commonly expressed in terms of 'levels', with a higher degree representing more automation:

- Under Levels 0-2 of automation, vehicles have an increasing number of driver support features, all of which require a human to drive whenever the features are engaged.
- Level 3 vehicles are capable of self-driving in certain domains, but are not autonomous given a human driver is required to take control when needed.
- Level 4 automation features allow for autonomous driving under limited conditions.
- Level 5 automation is fully autonomous and requires zero human attention.

For simplicity, automated vehicles are often referred to in this report as levels 4 and 5.

The report uses an established modelling framework to forecast technology and AV uptake in Australian light vehicles. The forecasts are based on past and current penetration of technologies through Australia's new car/sports utility vehicle (SUV) and light commercial vehicle (LCV) sales. Historical uptake of safety features that reached around 100 per cent of sales penetration by 2019 were used as a proxy to estimate market diffusion of other safety features and vehicle automation technologies. The model provides forecasts for both the arrival of selected new technologies and levels of automation in the Australian market, the share of new sales, as well as the extent of penetration of AVs in the light vehicle fleet.

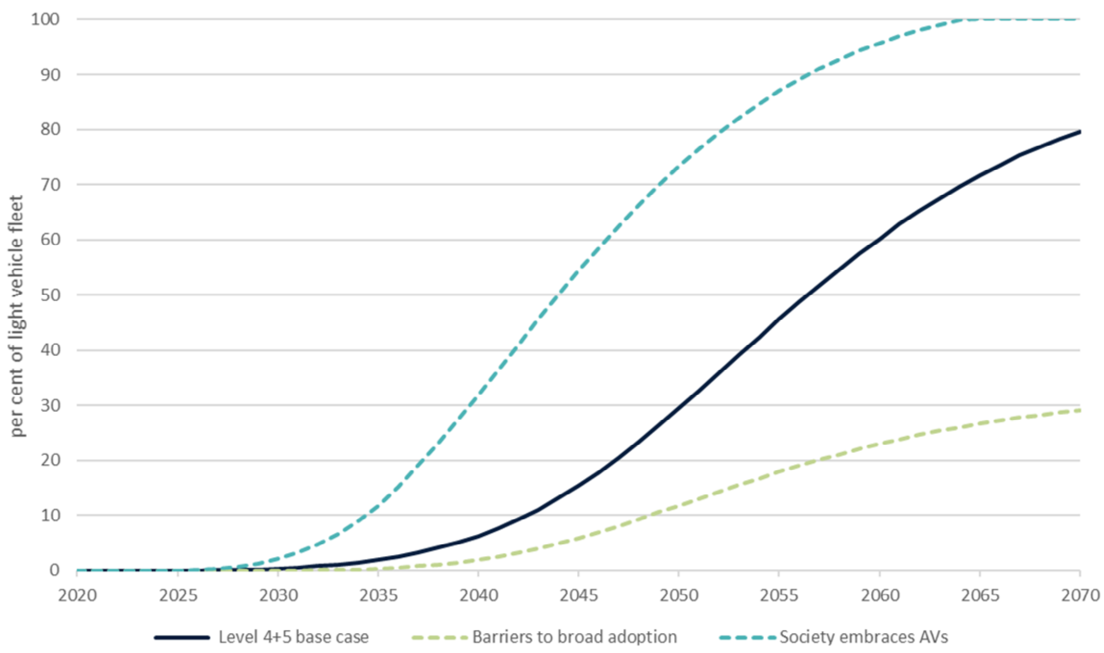
The base case scenario in forecasting the uptake of AVs represents the most likely outcome — assuming development of AV technology progresses as observed so far with no unforeseen setbacks and customers with high willingness to pay driving initial demand. Demand then increases as the benefits of AVs are more widely demonstrated. Under the base case:

- A maximum penetration rate of AVs of 85 per cent of new vehicles is assumed, which reflects expectations that this level of vehicle automation is unlikely to be mandated, a proportion of Australian consumers will continue to show minimal willingness to pay for the technology, and that new non-AV vehicles will still be commercially available in the future;

- Level 4 AVs become commercially available from 2026. The share of Level 4 and 5 AVs in new light vehicle sales reaches around 66 per cent by 2050 and 85 per cent by 2070. The share of Level 4 and 5 AVs in the light vehicle fleet reaches around 30 per cent by 2050 and 80 per cent by 2070; and
- Level 5 AVs become commercially available from 2031. The share of Level 5 AVs in new light vehicle sales reaches around 13 per cent by 2050 and 75 per cent by 2070. The share of Level 5 AVs in the light vehicle fleet reaches around four per cent by 2050 and 47 per cent by 2070.

These forecasts are not considered in isolation. The results are considered in the context of key factors that drive uptake of new technology, including prices, consumer sentiment, supply availability and other enablers. This includes exploring the sensitivity of forecasts to changes in individual parameters, including introduction dates, uptake speeds, and saturation rates. This is shown in figure 1, which illustrates the uncertainty of the proportion of Level 4 and Level 5 AVs in light vehicle fleet by presenting the base case and other scenarios considered in this report.

Figure 1: The share of AVs in the light vehicle fleet depends on the underpinning assumptions



BITRE will maintain a watch on AVs as they are deployed and use the modelling framework to update its estimates when new information to inform forecasts becomes available.

Background

Vehicle automation technology is currently a rapidly evolving space, with a number of features already incorporated into new vehicles and delivering a range of benefits, including safety. Similarly, though fully automated vehicles are yet to arrive, they have the potential to unlock a whole range of new use cases with further benefits, including around safety, accessibility and productivity.

Many previous forecasts have overestimated the arrival and uptake of AVs (see the discussion in Global Data 2020, for example). While expectations have been revised in recent years, there is still uncertainty around the arrival of AVs. Despite this, continued investment, trials and technological progress in AVs and supporting technology indicate that commercial availability is a matter of when and not if. Projections of willingness to pay and costs also suggest there will be a market for AVs once they are available.

Fully automated vehicles will bring about different challenges to our existing environment. The spread of AVs through the light vehicle fleet in coming decades has the potential to substantially alter the way transport and transport infrastructure is used, with implications that policy makers must consider.

In this context, it is valuable to understand when and how rapidly AVs are expected to arrive in Australia. This is important for understanding the potential benefits of investing in enabling infrastructure, and of ensuring our regulatory settings are able to accommodate the introduction of AVs.

Modelling uptake of vehicle features

Active safety, driver support and connectivity features are forecast to 2070, using data on vehicle safety technologies that have reached 100 per cent sales penetration in Australia as a proxy to estimate market diffusion.

Empirical sales data is used to estimate the market penetration of vehicles with features of interest over 1990 to 2019. The uptake of features beyond 2019 is forecast. For example, driver airbags were introduced around 1990 and are estimated to have reached 100 per cent sales penetration around 2010 and 2013 for new cars/SUVs and LCVs, respectively (see Figure 2). Sales data from 2020 was not relied on in this report, as the effects of the COVID–19 pandemic reduced its representativeness for the purposes of producing long-term forecasts.

Where there are no recorded sales at the time of drafting, an appropriate lag to a comparable feature is assumed to forecast the year of commercial introduction. For example, it is estimated that in 2019, about five per cent of new cars/SUVs and 23 per cent of new LCVs sold were equipped with adaptive cruise control. New vehicles sold with adaptive cruise control is forecast to reach 100 per cent in 2034 and 2035 for cars/SUVs and LCVs, respectively (see Figure 3). The connectivity technologies in Figure 3 are not exhaustive and were selected due to data availability (see Section 3.1 for further information).

Figure 2: Light vehicle sales penetration of vehicle safety technologies

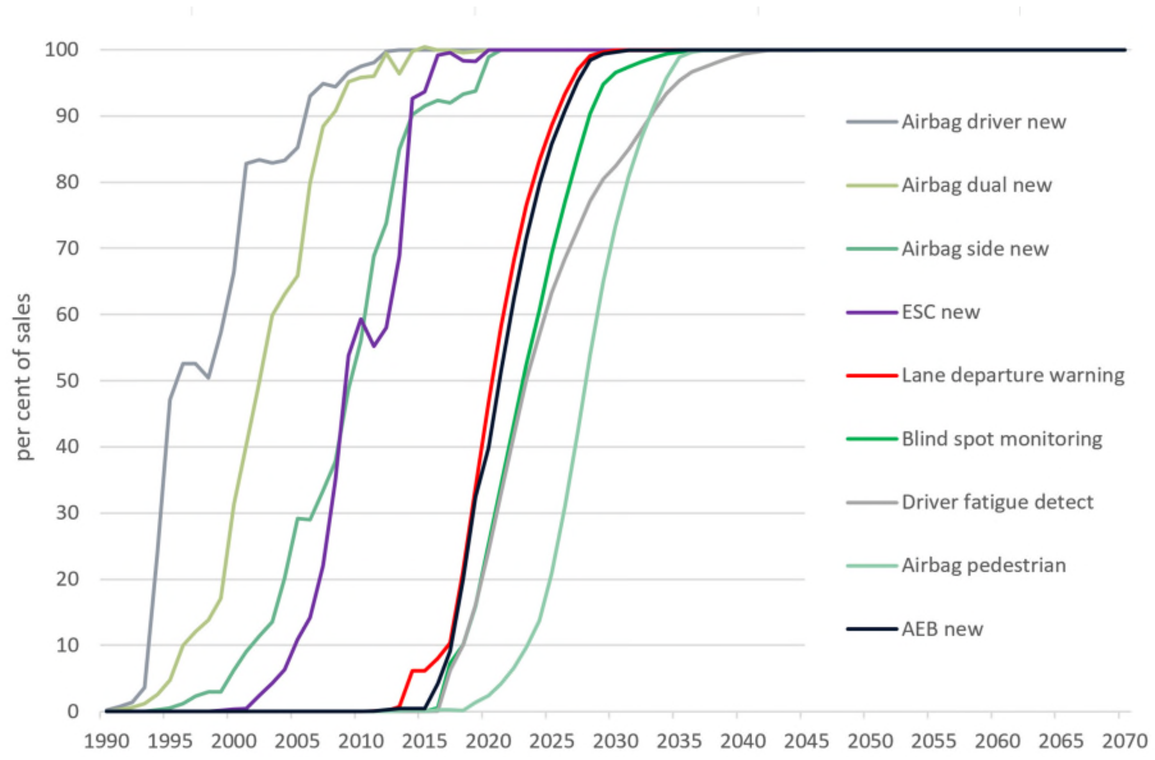
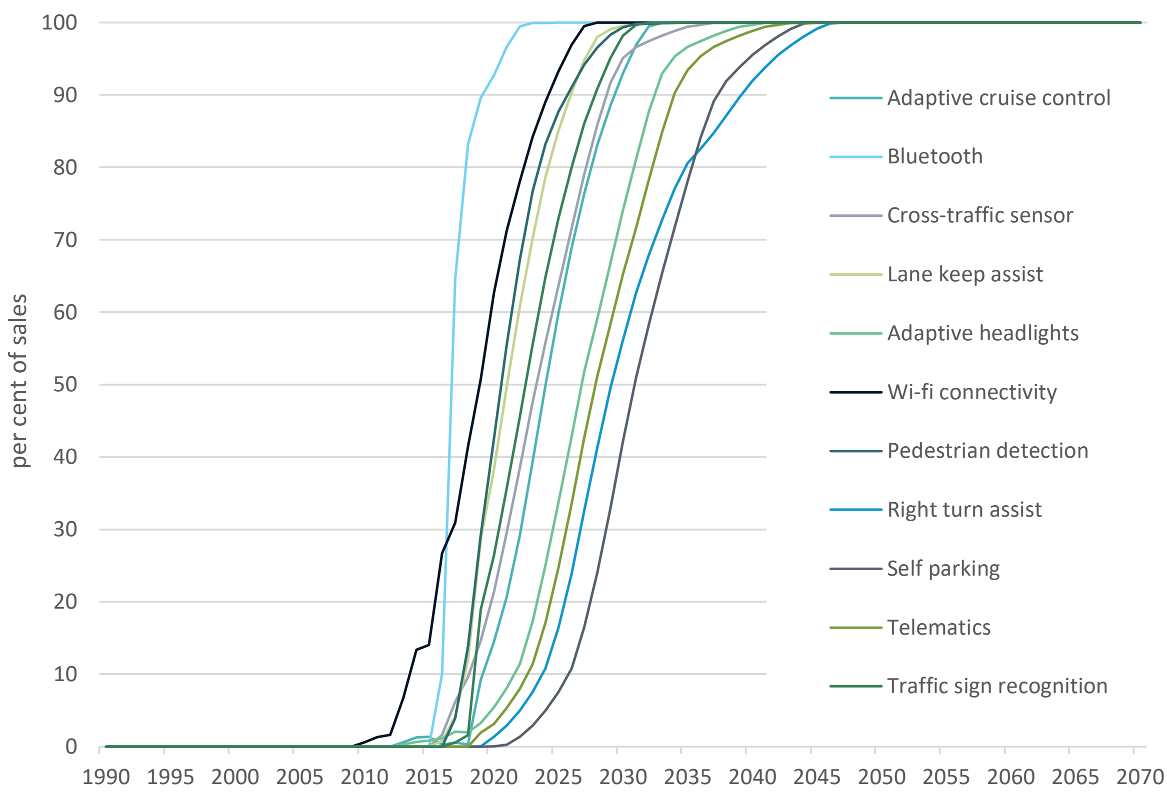


Figure 3: Light vehicle sales penetration of driver support features and connectivity technologies



Sales forecasts of active safety, driver support and connectivity technologies are then run through a fleet penetration model. This forecasts the penetration of these technologies in the light vehicle fleet through to 2070, which is provided in Figure 4 and Figure 5 below.

Figure 4: Light vehicle fleet penetration of vehicle safety technologies

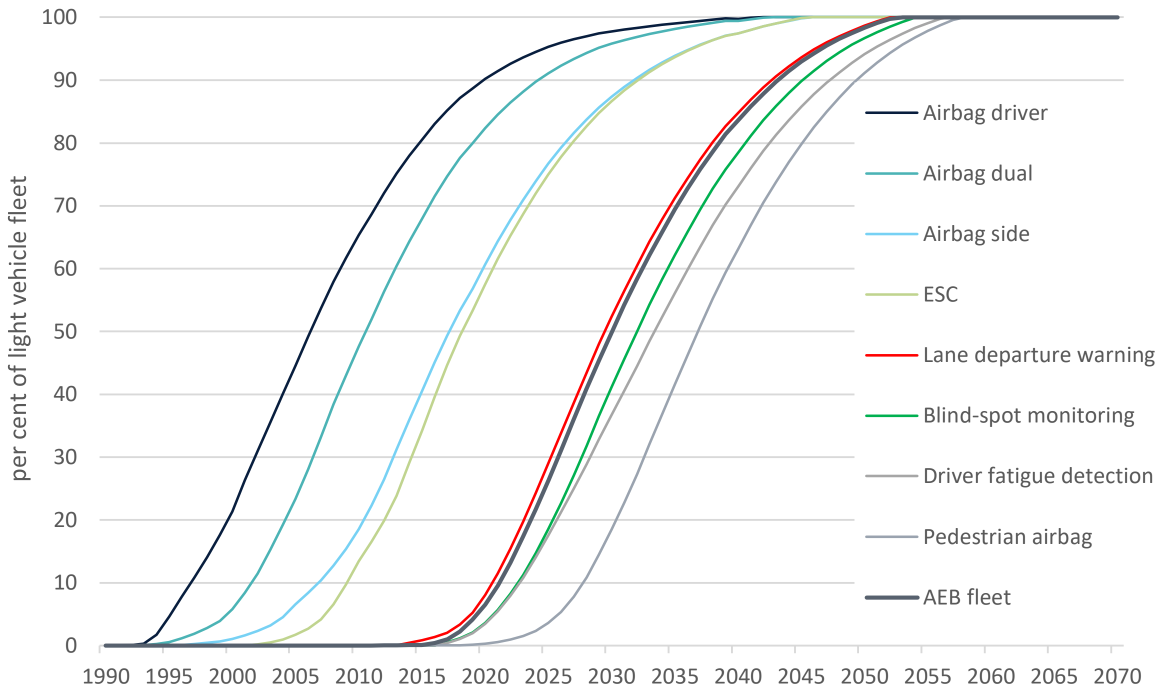
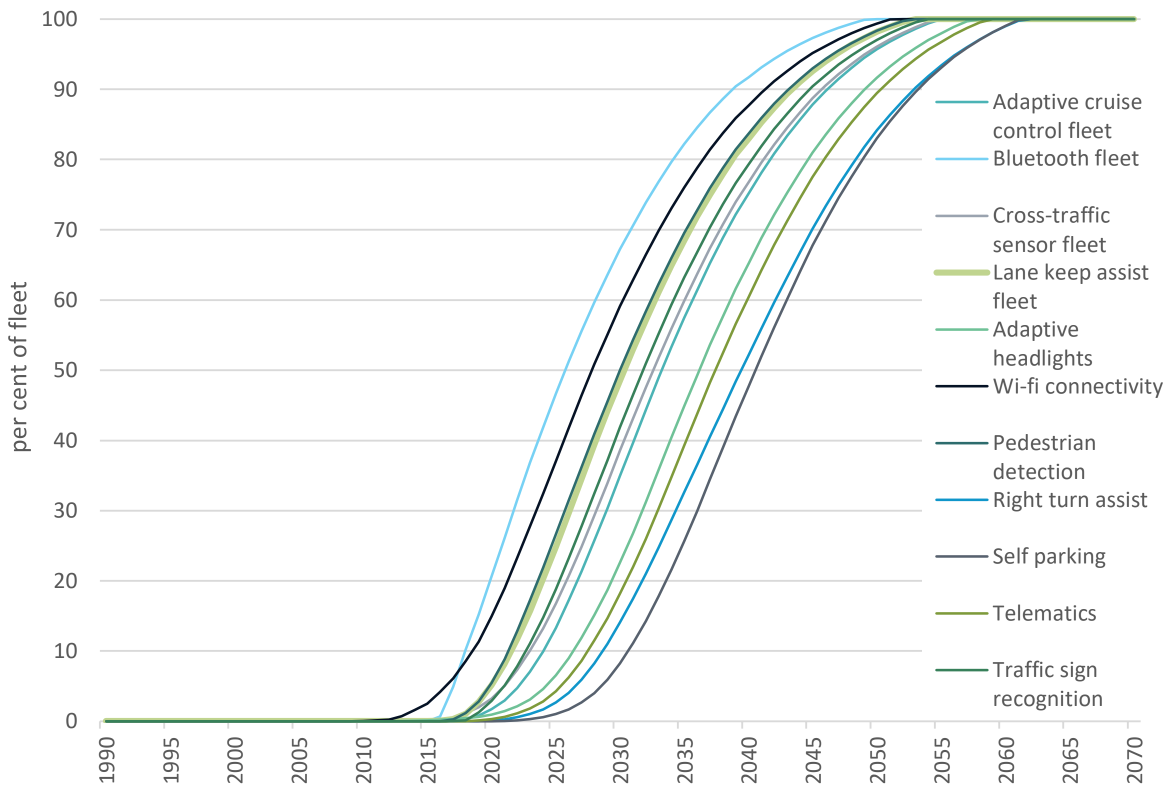


Figure 5: Light vehicle fleet penetration of driver support features and connectivity technologies



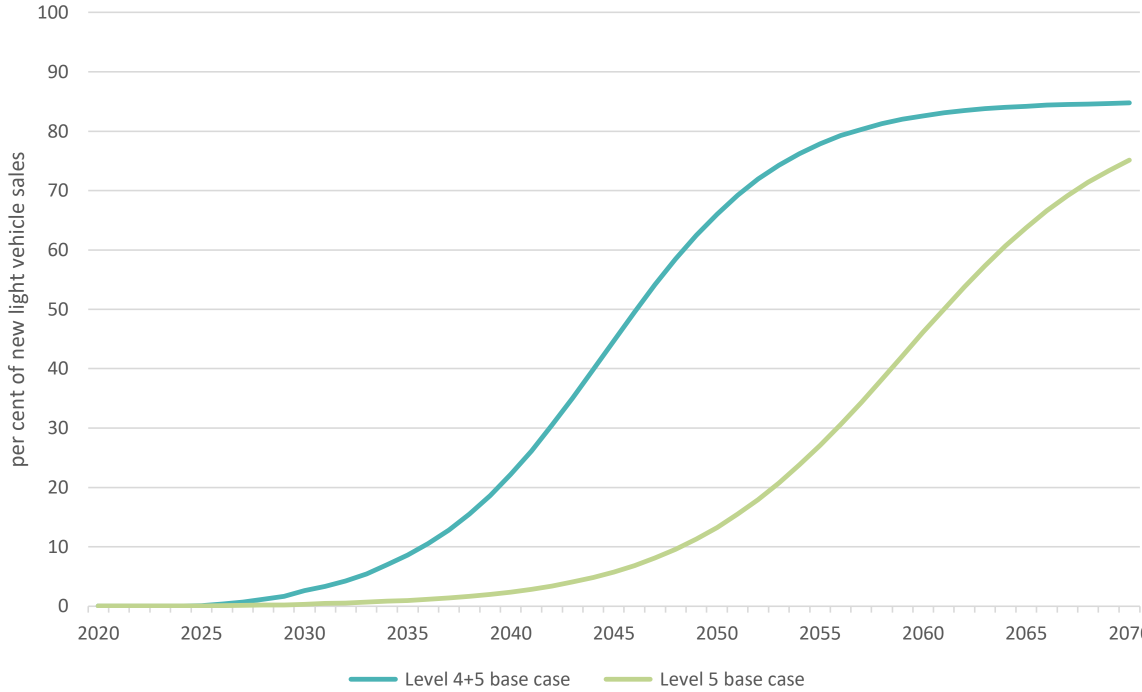
Modelling uptake of fully automated vehicles

Sales forecasts of SAE Level 4+5 and SAE Level 5 automation levels in light vehicles to 2035 are based on the average of seven existing studies, noting AVs are still in the development stage so sales data does not yet exist.

Sales forecasts from 2035 to 2070 are based on a logistic function, recognising that technology uptake generally takes the form of an S-curve. In the base case (or the 'best guess' forecasting scenario), forecasts assume that AV sales will reach 85 per cent market saturation by 2070.

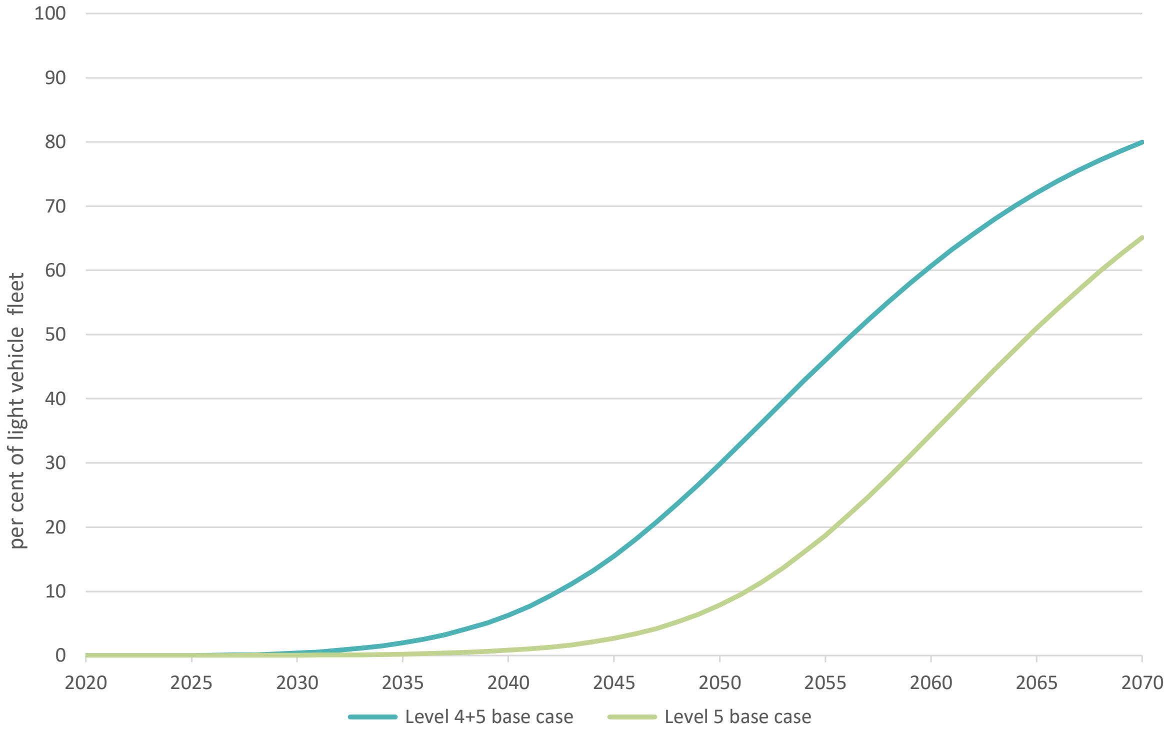
This modelling methodology produces the forecasts in Figure 6. SAE Level 4+5 AVs are forecast to reach just over 65 per cent of new light vehicle sales by 2050 and 85 per cent by 2070. In contrast, SAE Level 5 AVs are forecast to reach around 10 to 15 per cent of new light vehicle sales by 2050 and 75 per cent by 2070.

Figure 6: Base case projections of SAE Level 4+5 and SAE Level 5 AVs as share of light vehicle sales



The diffusion of AVs through the light vehicle fleet is then modelled using a fleet penetration model. The share of SAE Level 4+5 AVs in the light vehicle fleet is estimated to reach 30 per cent by 2050 and 80 per cent by 2070, with just under five and fifty per cent in 2050 and 2070 respectively comprising of SAE Level 5 AVs (Figure 7).

Figure 7: Base case projections of SAE Level 4+5 and SAE Level 5 AVs as share of the light vehicle fleet



Following the base case forecasts, several sensitivities are tested by changing particular input parameters (introduction date, uptake speed and saturation rate). This analysis illustrates the sensitivity of the modelling results to particular input assumptions. Several scenarios are also explored where multiple parameters are varied to understand what different states of the world might look like. Using fairly wide scenario assumptions, a broad range of possibilities can be explored to better understand how the rate of AV uptake can be influenced by various factors.

Policy implications and conclusion

An understanding of the speed and extent of AV uptake is important for policy makers for several reasons. The forecasts estimated by the models can help policy makers understand the impact of AVs, and where this may benefit from new policies, updated regulatory frameworks, and greater targeted public investment and planning. Moreover, the qualitative analysis in Chapter 4 illustrates the role that policymakers can have in influencing consumer sentiment towards AVs. This role may include, among other things, increasing people's familiarity with the technology through trials and addressing uncertainties around potential security and legal risks.

As AVs spread throughout the fleet, their impact will be realised to a greater extent. For instance, road safety is a top priority for road managers at all levels of government, and technology uptake is an important part of government strategy. To this end, the Infrastructure and Transport Ministers Meeting (ITMM)[1], of which the Australian Government is a member, sets nationally consistent

[1] Formerly the Transport and Infrastructure Council.

priorities and makes decisions in preparation for AVs, informed by work from bodies such as the National Transport Commission (NTC) and Austroads. The forecasts in this report will help decision-makers understand likely future safety technology uptake without government intervention and therefore, inform the safety benefits of regulation.

Similarly, understanding the likely timing of the introduction of vehicle automation technologies and the rate of uptake by Australian consumers will assist the government in decision-making to ensure all vehicle needs (traditional and new) are provided for on Australian roads. For example, the faster the increase and spread of AVs in the vehicle fleet, the faster the growth in demand for new digital and physical infrastructure, and the more urgent need for system reconfiguration.

CHAPTER 1

Introduction

In this report, BITRE estimates the historical and future uptake of selected active safety, driver support and connectivity features in Australia's light vehicle sales and fleet from 1990 to 2070. BITRE also forecasts the future uptake of AVs - which are interpreted as vehicles with SAE Levels 4 or 5 automation.

In developing AV forecasts for Australia, BITRE draws on other available forecasts, and sense-checks these estimates against a conceptual framework based on a literature review. The literature review analyses how a wide range of interrelated supply and demand factors will affect the development and uptake of AVs. These factors include price, consumer willingness to pay, the cost of technology, available supply, enabling infrastructure, and the regulatory and policy landscape.

As well as providing best estimates (consistent with the 'base case' scenario), other forecast scenarios are explored to examine a range of uncertainties. These forecast scenarios explore deviations from BITRE's best estimates of the commercial introduction date, market saturation rate and uptake speed. Combined, the base case forecasts and scenario analysis illustrate some of the forces underlying AV forecasts, providing rich insights into the speed at which AV sales are expected to replace those of human-driven vehicles.

This report is structured as follows:

- Chapter 2 estimates the uptake of active safety systems over 1990 to 2070.
- Chapter 3 estimates the uptake of driver support features and connectivity technologies over 1990 to 2070.
- Chapter 4 reviews literature to provide a qualitative analysis of factors expected to affect the uptake of AVs.
- Chapter 5 projects the uptake of AVs to 2070.
- Chapter 6 summarises the conclusions.

A full description of the forecasting models, including parameter estimates is given in Appendix A. The modelling draws on previous BITRE analysis of uptake of new vehicle technologies and their diffusion across the passenger vehicle fleet (BITRE 2019, BITRE 2015, Gargett et al. 2011). Given the high uncertainty around AVs, the models allow for modifying of assumptions to test sensitivities. This presents the opportunity to revisit the forecasts on a regular basis to track the development of vehicle automation.

1.1. Vehicle automation and active safety systems

Vehicle automation involves a collection of automation features that relieve the driver of parts of the driving task. Australia uses SAE's global standard definitions for Levels of Driving Automation. The six levels, shown in Figure 8, are defined in terms of the roles of the human and the vehicle rather than specific technologies.

Figure 8: SAE levels of vehicle automation

<table>
<tr><th>Level 0</th><th>Level 1</th><th>Level 2</th><th>Level 3</th><th>Level 4</th><th>Level 5</th></tr>
<tr><td colspan="3">You are driving whenever these automation features are engaged.</td><td colspan="3">You are not driving when these automation features are engaged.</td></tr>
<tr><td colspan="3">These are driver support features.</td><td colspan="3">These are automated driving features.</td></tr>
<tr><td colspan="3" rowspan="2">You must constantly supervise the automation features.</td><td>When requested…</td><td colspan="2" rowspan="2">These automated features will not require you to drive.</td></tr>
<tr><td>…you must drive.</td></tr>
<tr><td>Features provide warnings and momentary assistance.</td><td>Features provide steering OR brake / acceleration assistance to the driver.</td><td>Features provide steering AND brake / acceleration assistance to the driver.</td><td colspan="2">These features can drive the vehicle under limited conditions.</td><td>These features can drive under ALL conditions.</td></tr>
</table>

Source: BITRE, adapted from SAE International (2018b)

Under SAE Levels 0–2, the person is driving the vehicle with increasing levels of sustained assistance from automation features. In SAE Level 3–4, the vehicle is driving under specific circumstances and can monitor and react to the road environment. At SAE Level 3 automation, the vehicle can drive under certain conditions, with the human driver required to be able to take over when requested. Vehicles with SAE Level 4 automation can handle highly complex driving situations without human assistance. However, the human still has the option to manually override the vehicle. Vehicles with SAE Level 5 automation are fully self-driving cars that require zero human attention. SAE Level 5 automation is associated with autonomy, as well as SAE Level 4 automation (although, only in limited conditions).

The phrase 'sustained assistance' is important to understanding the definition of automation. Certain active safety systems and driver assistance systems that provide momentary assistance to drivers are not considered automation features and therefore, fall into the SAE Level 0 category (SAE International 2018c). These features include autonomous emergency braking (AEB) and lane departure warning.[2]

[2] For avoidance of doubt, lane departure warning differs from lane keeping, for which this report provides separate forecasts.

Box 1: Autonomous vehicles, automated vehicles and vehicle automation explained

The terms *autonomous vehicles*, *automated vehicles* and *vehicle automation* are all used, to varying degrees, to describe vehicles and technology systems that enable the vehicle to undertake activities currently performed by a human vehicle operator.

The SAE clearly defines vehicles as having different levels of vehicle automation, which is where vehicle systems follow orders to control the operation of part or all of its function. This is consistent with traditional automated systems that reduce human intervention in systems and processes.

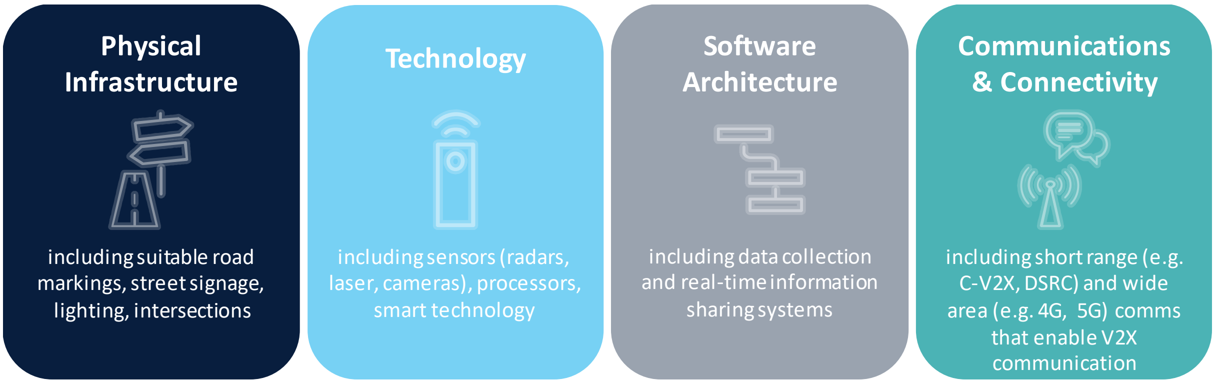
The term '*autonomous vehicles*' is generally used to describe the broad range of automated vehicle technologies, particularly SAE Level 5 vehicles (and SAE Level 4 vehicles in limited conditions), which will be fully automated, or fully driverless. The SAE defines fully autonomous vehicles as being self-aware and capable of makings its own decisions (Synopsys n.d.).

In keeping with this broader use, this report adopts the convention of using the term '*autonomous vehicles*' in general discussion, but using the terms '*vehicle automation'* and '*automated vehicles*' when referencing particular technologies and standards – for example, the SAE levels of vehicle automation. The use of '*AVs*' in this report refers to '*fully automated vehicles*', defined as vehicles with SAE Levels 4 or 5 automation.

1.2. Building blocks of fully automated vehicles

Vehicle automation is developing in an uncertain and dynamic space. Despite this uncertainty, there are building blocks (new technology, software architecture, communications and connectivity networks) that are needed to successfully deliver and facilitate AVs (Figure 9). Existing physical infrastructure will also require upgrades, which is discussed further in Section 4.4.2.

Figure 9: Building blocks of AVs



1.2.1. Technology

The safe, accurate and reliable operation of human-driven vehicles is currently largely the responsibility of the human driver, who must continuously observe and analyse road conditions and make decisions. Drivers not only follow road rules, but also communicate with other road users through signaling, gestures and other cues, particularly in ambiguous and sometimes out of the ordinary situations. AVs will require technology to match the performance of an attentive human driver to navigate similar scenarios. AVs will require many sensors (such as radars and cameras) to provide 360-degree information of the vehicle's surroundings to identify objects and road conditions accurately without false alerts (SAE International 2018a). Technology continues to develop to provide better performance. For instance, advanced techniques for sending and receiving signals are currently helping radars identify objects rather than just providing range information. For example, Light Detection and Ranging (LiDAR) combines laser and camera technology.

The ability to successfully combine and process data inputs from the technology to create a highly accurate view of a vehicle's surroundings and make informed decisions (such as steering, braking and vehicle speed) is key to ensuring the safety of AVs. AVs will require a range of processors to carry out multiple tasks simultaneously in response to the information feeding through. As more technology is available and included in a vehicle, the volume of data to be processed rises. Processors need to be capable of increasing computation functionality to keep up with this evolution. Companies developing AV systems rely heavily on artificial intelligence in the form of machine learning and deep learning to process the vast amount of data efficiently, and to train and validate their autonomous driving systems (AutoTechInsight 2020).

1.2.2. Software architecture

Software architecture is the foundation that supports and brings all elements of AVs together (SAE International 2018a). While hardware must be able to accurately collect and store information, the software must be capable of combining information from multiple sources, analysing data, and computing and cross-checking decisions in real-time to avoid crashes. Poorly designed automation could make AVs as vulnerable as inattentive human drivers.

It can be difficult to create software architecture that will respond accurately to the limitless possible scenarios that can arise in a system as dynamic and fast moving as on road driving. For example, many types of currently-available vehicle automation technology use visible light to navigate, which can be a challenge when driving conditions are poor, such as in glaring sun, fog and snow (Massachusetts Institute of Technology 2018). In the Australian context, existing animal detection systems designed for primarily detecting medium to large quadrupeds struggle to identify animals such as kangaroos, which not only look different to what the algorithms are programed to detect, but also behave quite differently (ABC 2017). There is an opportunity to design these systems to evolve and 'learn through experience' over time as AV activity accumulates and vehicles encounter more and varying situations.

1.2.3. Communications and connectivity

AVs must be able to continuously capture and interpret information to ensure they operate safely on the road. Ideally, AVs should also be able to securely exchange data with external systems to improve vehicle awareness of potential dangers and road safety (such as indicating location, speed, direction and other properties). With the growing challenges of handling large amounts of data in real-time, AVs will rely on high-speed networks and interoperability to connect and communicate with their surroundings. One aspect of this is cooperative perception, where a vehicle is able to augment the information it has about it surroundings with information from other vehicles and roadside infrastructure.

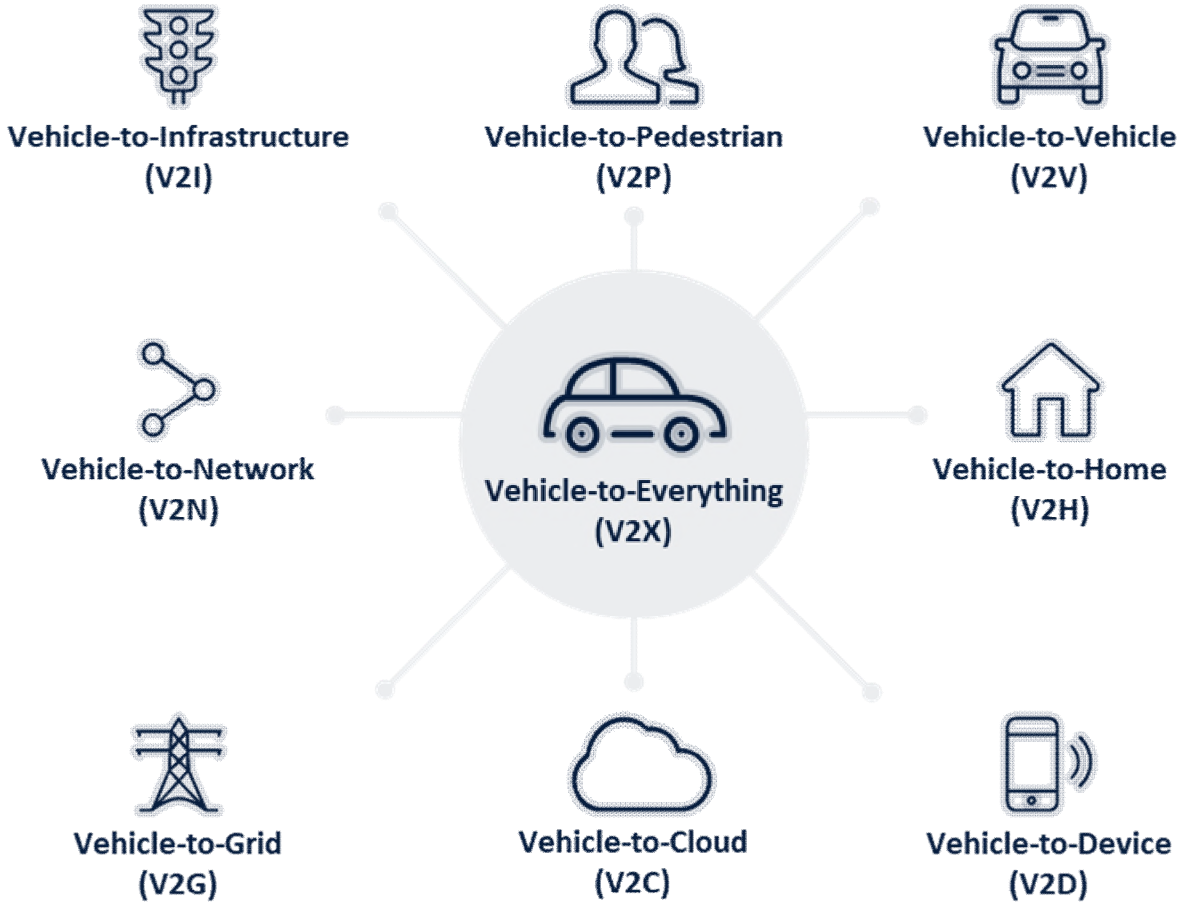
On this basis, AVs will also be 'connected vehicles' and therefore, are sometimes referred to as 'connected and automated vehicles'. However, a connected vehicle need not have automation features.

Vehicle-to-Everything (V2X) is a form of technology that allows vehicles to efficiently and accurately communicate with the surrounding environment. This includes communicating with infrastructure (V2I), pedestrians (V2P) and other vehicles (V2V), using short-range wireless signals (Figure 10). While V2X is not a necessary requirement to enable the functionality of AVs, it is a useful tool that can enhance road safety and user experience. Connectivity plays an important role in the integration of V2X.

In order for the various parts of a V2X systems to be able to cooperate, it is necessary for them to operate in a compatible manner, including in terms of hardware, software and data standards – this is known as Cooperative Intelligent Transport Systems (C-ITS).

The benefit of V2X technology is it can capture information that on-board sensors may not be able to detect. For example, emergency braking by a car hidden by a trailer can be shared through V2V, while information exchange between roadside beacons through V2I can aid with safety and traffic flow (SAE International 2018a). As the technology becomes more sophisticated, its capability will expand. While there are many benefits, V2X relies on the ability to communicate with many vehicles on the roads, which will take time as the fleet transitions from traditional to AVs.

Figure 10: Vehicle-to-Everything (V2X) communication



Source: BITRE, adapted from SAE International (2018a) and IPA (2017)

Note: Definitions are provided in the Glossary.

1.3. The current state of play

SAE Levels 0–2 automation features are regularly incorporated into new cars, and some SAE Level 3 technologies are emerging in high end vehicles. Figure 11 lists examples of automation features at different levels of automation. Examples in the grey section of the table are commercially available now, while the green are not yet commercially available but may be in or nearly passed the trial phase. For example, the cruising chauffer feature has been undergoing on-road testing since 2017 and has been expected to go into series production in the early 2020s (SAE International 2017).

Figure 11: Examples of automation features from SAE Levels 0–4

Level 0	Level 1	Level 2	Level 3	Level 4
Autonomous emergency braking (AEB)*	At least one advanced driver-assistance system (ADAS) feature such as active lane centring or adaptive cruise control*	Two or more ADAS features such as active lane centring and adaptive cruise control	Traffic jam chauffer*	Local driverless taxi
Blind spot and lane departure warning*			Cruising chauffeur*	Self-driving vehicles in designated areas, such as motorways[3]

Source: BITRE, adapted from SAE International (2018b). * Definitions are provided in the Glossary.

1.4. Government interest in technology uptake

Road safety is a top priority for road managers at all levels of government, and technology uptake is an important part of governments' road safety strategies. In November 2019, the then Transport and Infrastructure Council (2019a) agreed to 'implement rapid deployment and accelerated uptake of proven vehicle safety technologies and innovation'. The forecasts in this report will help decision-makers understand likely safety technology uptake without government intervention and therefore inform the safety benefits of regulation.

The National Land Transport Technology Action Plan, agreed by Australia's Commonwealth, state and territory infrastructure and transport ministers, includes work to support, among other things, the development and uptake of vehicle automation features. The Action Plan covers changes in regulation and legislation, digital and road infrastructure investment, research and AV trials (Transport and Infrastructure Council 2019b).

Accommodating vehicles with SAE Levels 3–5 automation features will involve significant changes to the role of drivers, resulting in necessary changes to driver licensing and training. Additionally, vehicles with SAE Level 3 and 4 automation will operate in specific environments, or operational design domains (ODDs) (such as environments with more line markings). Governments will need to

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[3] A SAE Level 4 vehicle will stop itself in the event of system failure, whereas SAE Level 3 features (such as cruising chauffeur) will require the driver to take over when requested.

understand and define these ODDs and provide suitable digital and physical infrastructure. Drivers will need information to adapt to a new road environment.

According to the 2018 Motor Vehicle Census, almost 20 per cent of passenger vehicles are more than ten years old and 42 per cent are more than five years old (ABS 2018). Given vehicle needs are likely to vary depending on their level of automation, governments will need to provide infrastructure and regulation to support the simultaneous operation of all vehicles.Understanding the likely timing of the introduction of automation technologies and the rate of uptake by Australian consumers will help government decision-making.

CHAPTER 2

Uptake of active safety systems

2.1. Types of active safety systems

Active safety systems comprise technologies that improve vehicle safety by providing momentary intervention, including warning alerts, during potentially hazardous situations. Due to the momentary nature of the actions of active safety systems, they are not considered vehicle automation (SAE 2018c). However, they improve road safety and, in some cases, form part of the suite of technologies that will allow vehicle automation. Technologies in this category include:

1. **Electronic stability control (ESC):** Uses sensors to monitor the direction of travel and steering wheel position. ESC automatically activates the brakes, including by braking individual wheels to help steer the vehicle back on track. ESC activates if the driver loses control when turning a corner, braking sharply or making a sudden manoeuvre.
2. **Autonomous emergency braking (AEB):** Uses radar and/or cameras to measure the distance from the vehicle in front, and reacts if that distance gets shorter at too fast a rate. AEB activates the brakes or increasing the braking force, if needed, to prevent collision. As well as detecting vehicles, many AEB systems can also detect pedestrians and cyclists.
3. **Lane departure warning:** Uses a camera near the rear-view mirror to monitor the lane markings on the road ahead. The driver is alerted when the vehicle is about to veer out of the lane.
4. **Blind spot monitoring:** Uses sensors and/or a camera to detect vehicles in the adjacent lanes and informs the driver by providing an audio and/or visual warning. Active blind spot monitoring systems also manipulate the steering and brakes to avoid collision if the driver does not act in time, using lane-keeping technology.
5. **Driver fatigue detection:** Monitors driver behaviour relative to the start of the journey, alerting the driver to take a break after detecting signs of fatigue. Common indirect systems use a road-facing front camera to monitor changes such as more erratic steering movements, pedal use and lane deviations. More advanced systems use driver-facing cameras and face-tracking technology to look directly for signs of fatigue, such as blinking and nodding.

This chapter also presents the uptake of airbags (driver, passenger, side and pedestrian), which are passive safety systems. While airbags are a passive safety system, they have often reached 100 per cent market saturation. The uptake of this technology can therefore provide a proxy for forecasting the rate of market diffusion of other safety features and vehicle automation technologies.

2.2. Forecasts of active safety systems

Uptake of various active safety systems are forecast to 2070. Estimates of past and current penetration of active safety systems through Australia's new car/SUV and LCV sales are based on sales data over 1990 to 2019. The uptake of features beyond 2019 is forecast. Sales data from 2020 was not relied on in this report, as the effects of the COVID–19 pandemic reduced its representativeness for the purposes of producing long-term forecasts.

Sales forecasts to 2070 for active safety systems that are yet to become ubiquitous are informed by a proxy for the uptake of new technologies in light vehicles over time. This proxy is based on movements in the median rate of adoption in four base-line technologies over time, that have reached around 100 per cent of new vehicle sales by 2019. This median rate of uptake is used as a proxy to project the uptake rate of technologies that either have just started or are materially less than 100 per cent of sales. The base-line technologies are driver airbags, dual airbags, side airbags and ESC. Where these technologies are an optional feature in the base vehicle model, it is assumed the technology is adopted 15 per cent of the time. Appendix A outlines the forecast methodology in detail.

Figure 12 to Figure 21 show the historical and forecast uptake of each safety system feature listed in Section 2.1 above. Generally, adoption of safety features is often faster in cars/SUVs than LCVs, although this trend does not necessarily hold for all features. Each figure shows the uptake in new light vehicle sales for cars/SUVs and LCVs, with:

- Figure 12 to Figure 15 showing the progressive uptake over time of safety systems that have reached around 100 per cent market penetration. These figures illustrate the rate and pattern of market diffusion for these safety features, from their introduction to market saturation. The uptake pattern for these features (including ESC and driver, dual and side airbags) provides a proxy for forecasting the market diffusion of other safety features and vehicle automation technologies explored in this report; and
- Figure 16 to Figure 20 showing estimates of the historical and forecast uptake of active safety systems that are yet to reach market saturation.

Figure 12 shows estimates of the uptake of driver airbags in new car/SUV and LCV sales. Driver airbags were introduced around 1990 and are estimated to have reached 100 per cent sales penetration around 2010 and 2013 for new cars/SUVs and LCVs, respectively.

Figure 12: Uptake of driver airbags in new vehicle sales

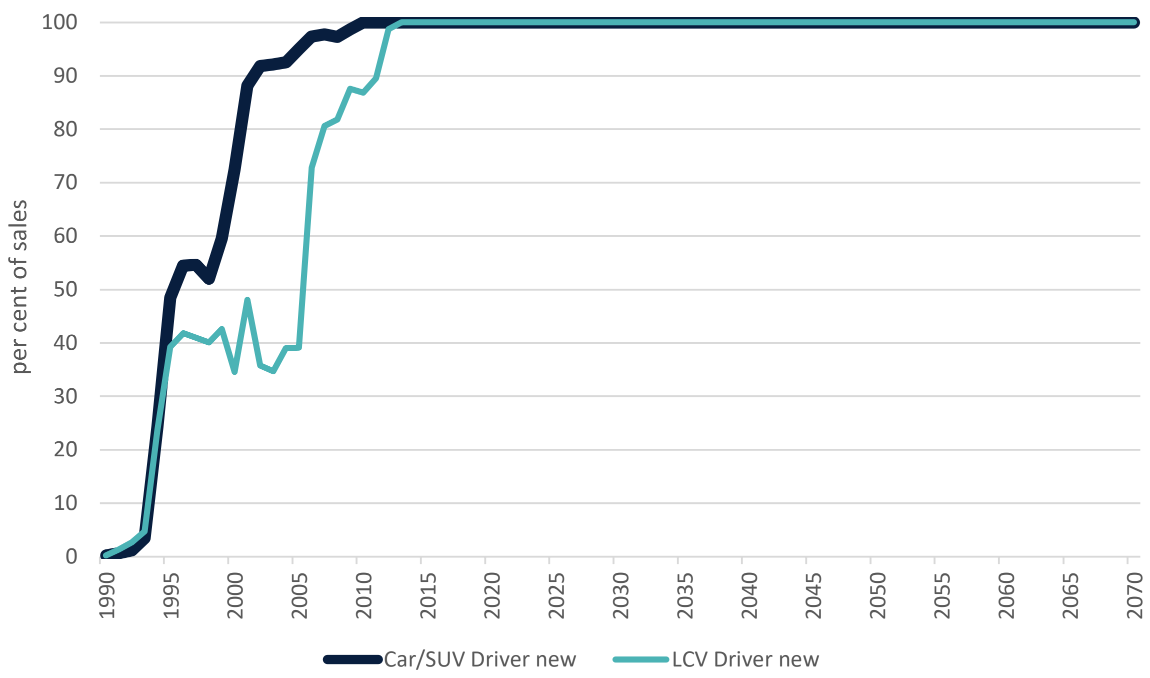


Figure 13 shows estimates of the uptake of dual airbags in new car/SUV and LCV sales. Dual airbags were introduced around 1991 and are estimated to have reached 100 per cent sales penetration around 2012 and 2014 for new cars/SUVs and LCVs respectively.

Figure 13: Uptake of dual airbags in new vehicle sales

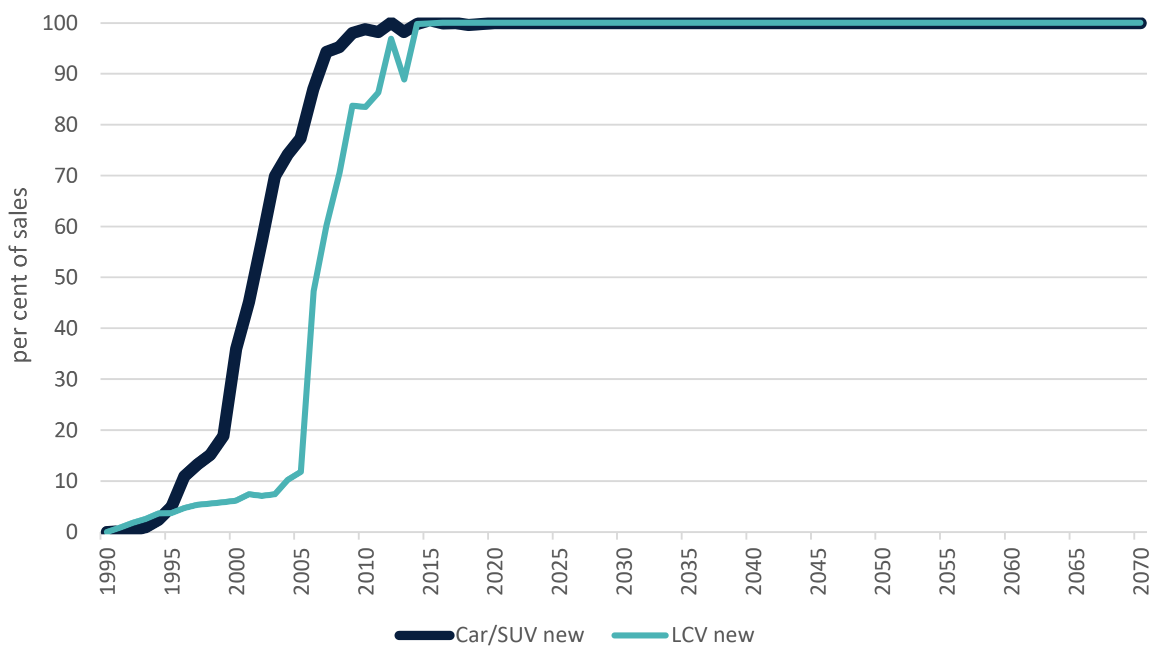


Figure 14 shows estimates of the uptake of side airbags in new car/SUV and LCV sales. Side airbags were introduced around 1994 and 2005 in cars/SUVs and LCVs respectively. BITRE estimates nearly 100 per cent of new cars/SUVs and LCVs were sold with side air bags in 2019. BITRE estimates that 100 per cent sales penetration will be reached in 2021.

Figure 14: Uptake of side airbags in new vehicle sales

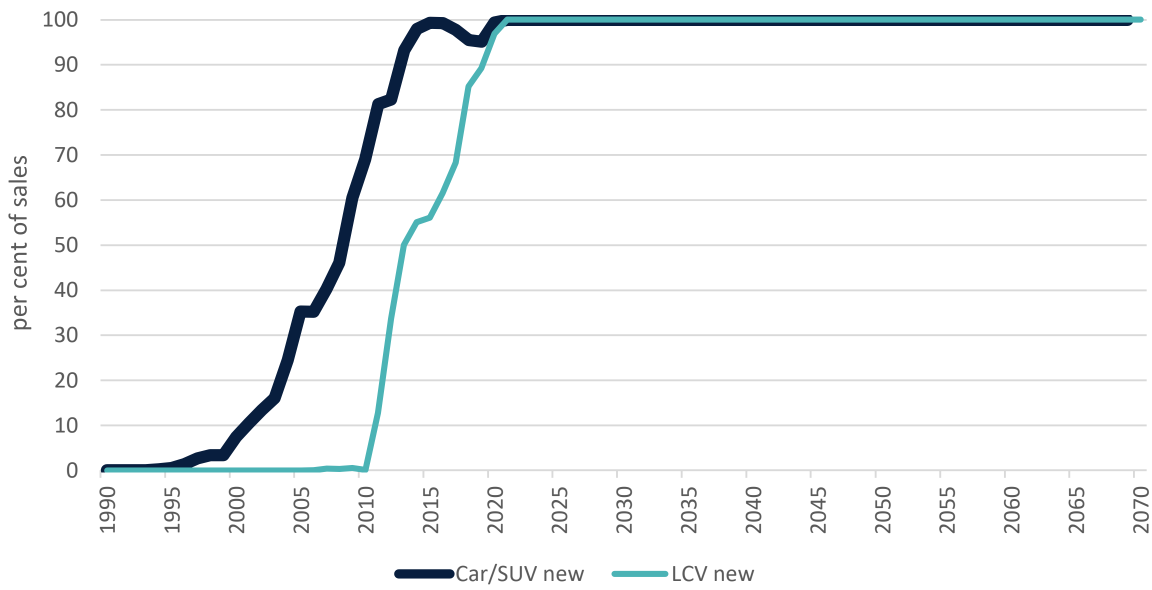


Figure 15 shows estimates of the uptake of ESC in new car/SUV and LCV sales. ESC was introduced around 1999 and 2005 in cars/SUVs and LCVs respectively. In 2013, ESC was mandated for all new passenger cars under the Australian Design Rules (ADRs). All cars/SUVs were estimated to be sold with ESC in 2015. BITRE estimates nearly 100 per cent of LCVs were sold with ESC in 2019, and that this would reach 100 per cent in 2020.

Figure 15: Uptake of ESC in new vehicle sales

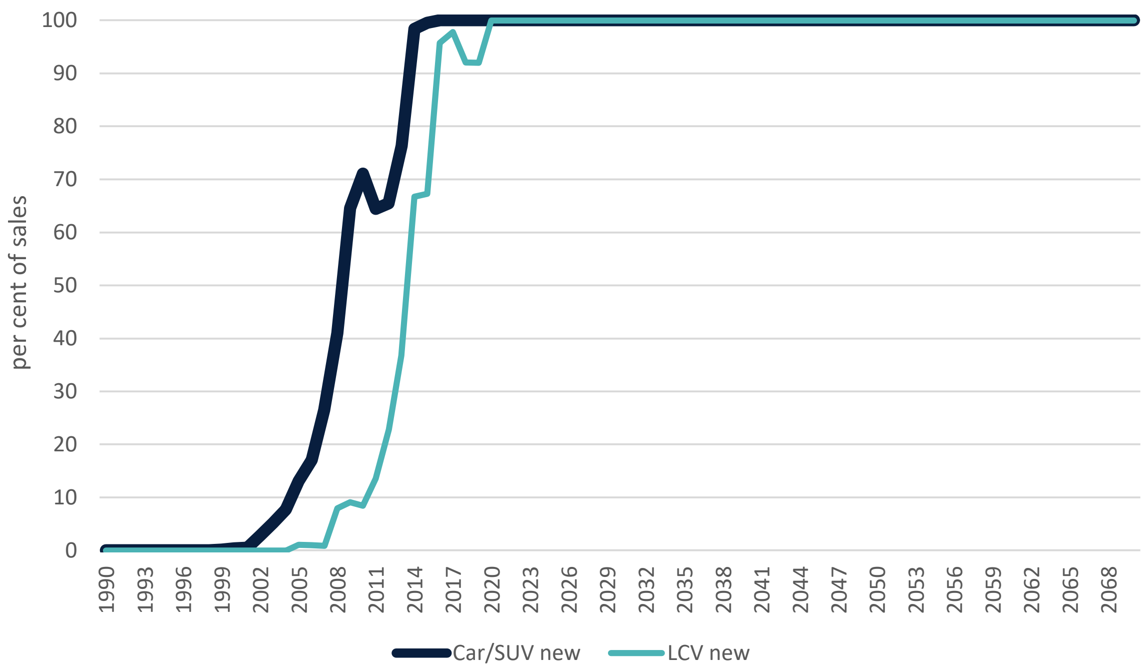


Figure 16 shows estimates of the uptake of pedestrian airbags in new car/SUV and LCV sales. New cars/SUVs and LCVs in Australia were sold with pedestrian airbags from 2013 and 2019 respectively after the first pedestrian airbag was developed in 2012 (Volvo 2012). BITRE estimates that in 2019, under one and four per cent of new cars/SUVs and LCVs, respectively were sold with pedestrian airbags. Pedestrian airbags are forecast to be in 100 per cent of new cars/SUVs and LCVs sold from 2036 and 2041, respectively.

Figure 16: Uptake of pedestrian airbags in new vehicle sales

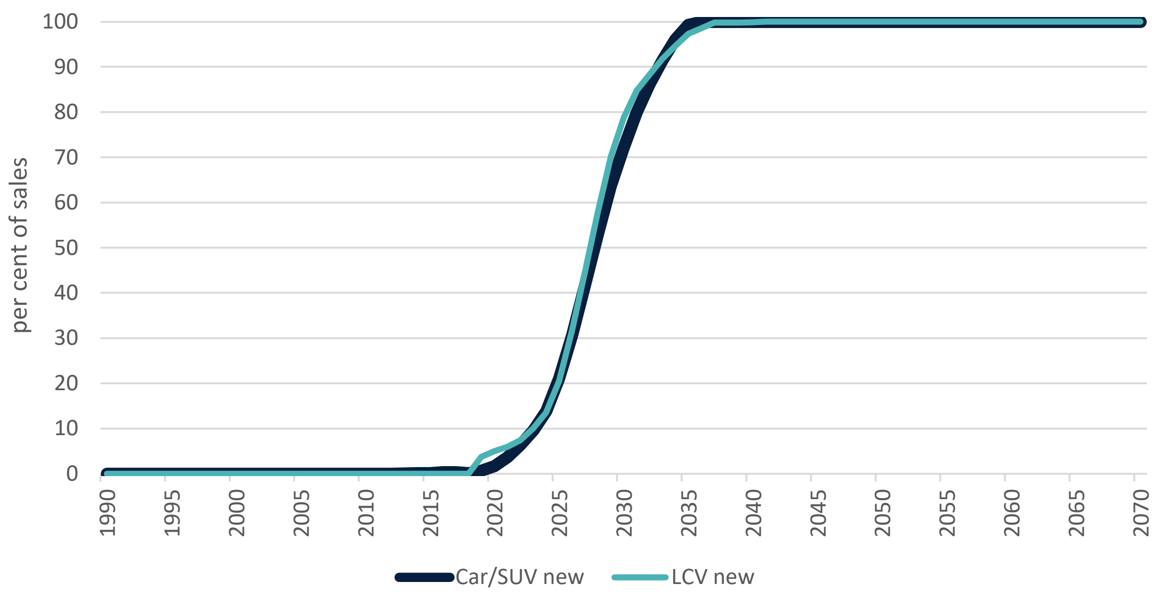


Figure 17 shows estimates of the uptake of AEB in new car/SUV and LCV sales. New cars/SUVs and LCVs in Australia were sold with AEB from 2013 and 2017, respectively. BITRE estimates 34 per cent percent of new cars/SUVs and 24 per cent of new LCVs were sold with AEB in 2019. AEB is forecast to be in 100 per cent of new cars/SUVs and LCVs sold from 2029 and 2031, respectively.

Figure 17: Uptake of AEB in new vehicle sales

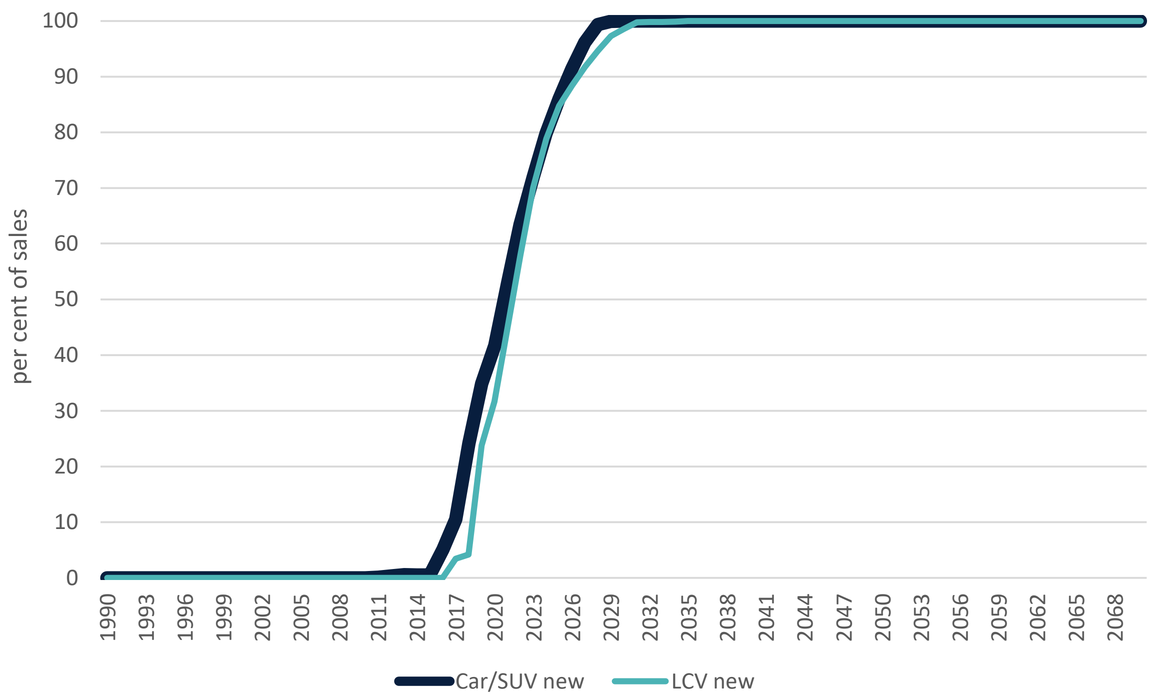


Figure 18 shows estimates of the uptake of lane departure warning in new car/SUV and LCV sales. New cars/SUVs and LCVs in Australia were sold with lane warning from 2010 and 2013, respectively. BITRE estimates 35 per cent of new cars/SUVs and 30 per cent of new LCVs were sold with lane warning in 2019. Lane warning features are forecast to be in 100 per cent of new cars/SUVs and LCVs sold from 2029 and 2034, respectively.

Figure 18: Uptake of lane warning in new vehicle sales

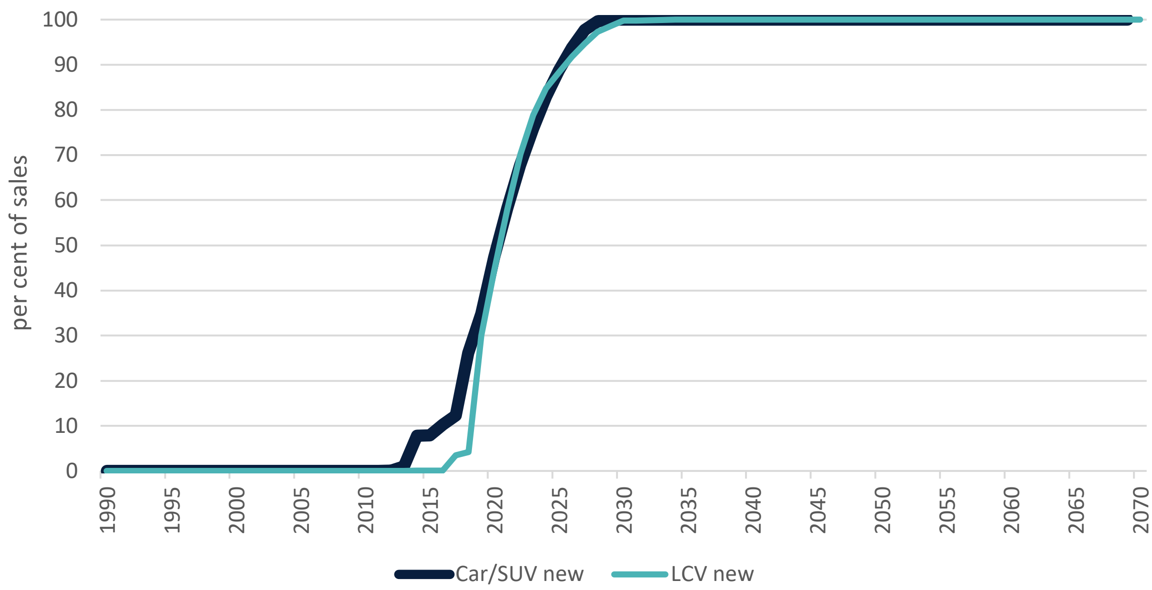


Figure 19 shows estimates of the uptake of blind spot monitoring in new car/SUV and LCV sales. Blind spot monitoring was available in new cars/SUVs and from 2016 and 2018, respectively. BITRE estimates about 19 per cent of new cars/SUVs and five per cent of new LCVs were sold with blind spot monitoring in 2019. Blind spot monitoring is forecast to be in 100 per cent of new cars/SUVs and LCVs sold from 2030 and 2040, respectively.

Figure 19: Uptake of blind spot monitoring in new vehicle sales

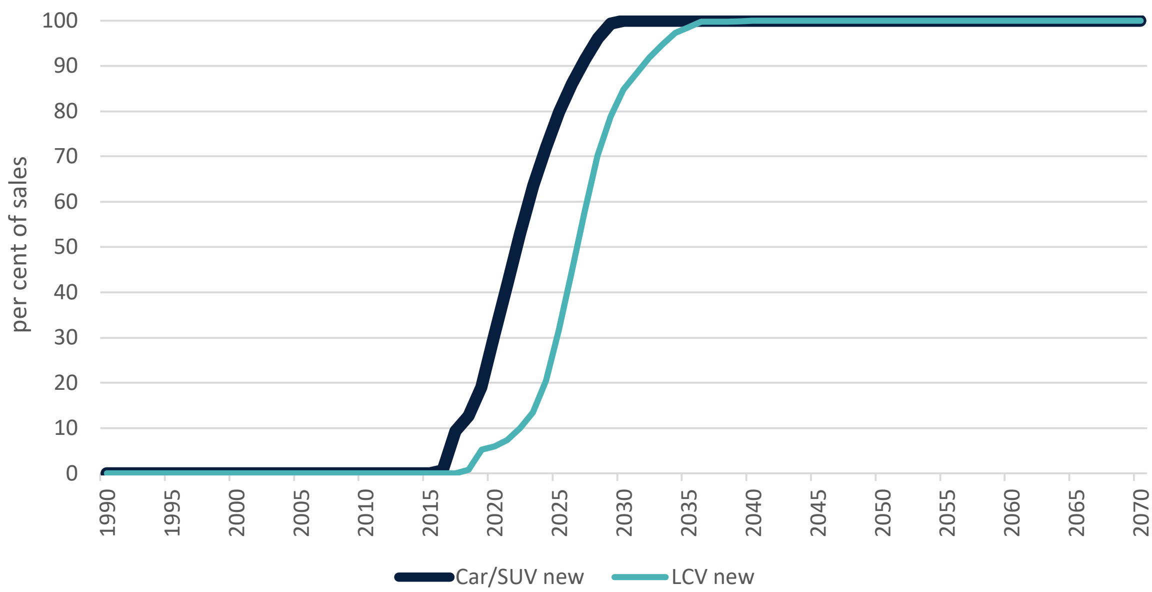


Figure 20 shows estimates of the uptake of driver fatigue detection systems in new car/SUV and LCV sales. Driver fatigue detection was available in new cars/SUVs and LCVs from 2016 and 2017, respectively. BITRE estimates about 21 per cent percent of new cars/SUVs and one per cent of new LCVs were sold with driver fatigue detection in 2019. Driver fatigue detection systems are forecast to be in 100 per cent of new cars/SUVs and LCVs sold from 2031 and 2046, respectively.

Figure 20: Uptake of driver fatigue detection in new vehicle sales

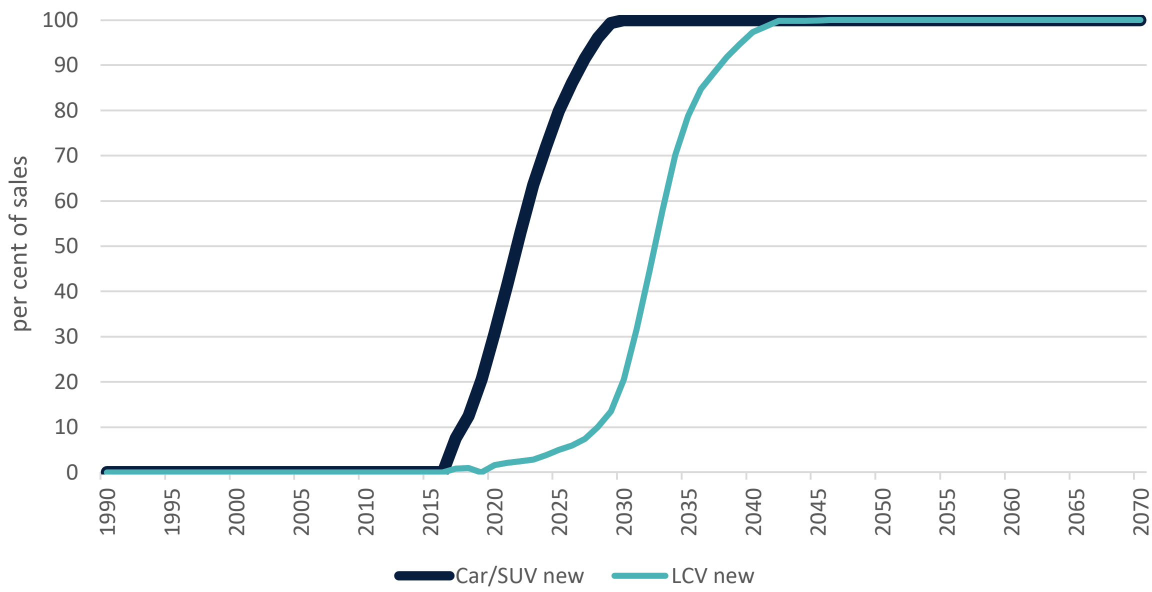


Figure 21 shows estimates of the percentage uptake of driver, dual and side airbags in new light vehicle sales. Light vehicles include cars/SUVs and LCVs.

Figure 21 also shows estimates of how these features have penetrated through the light vehicle fleet. Fleet penetration was estimated using the methodology in Appendix A.2, which takes the current fleet, forecast sales and scrappage into account. Fleet penetration lags behind the sales penetration of new technologies as existing vehicles can survive decades before going into scrappage.

Figure 21: New sales and fleet uptake rates for airbag technologies

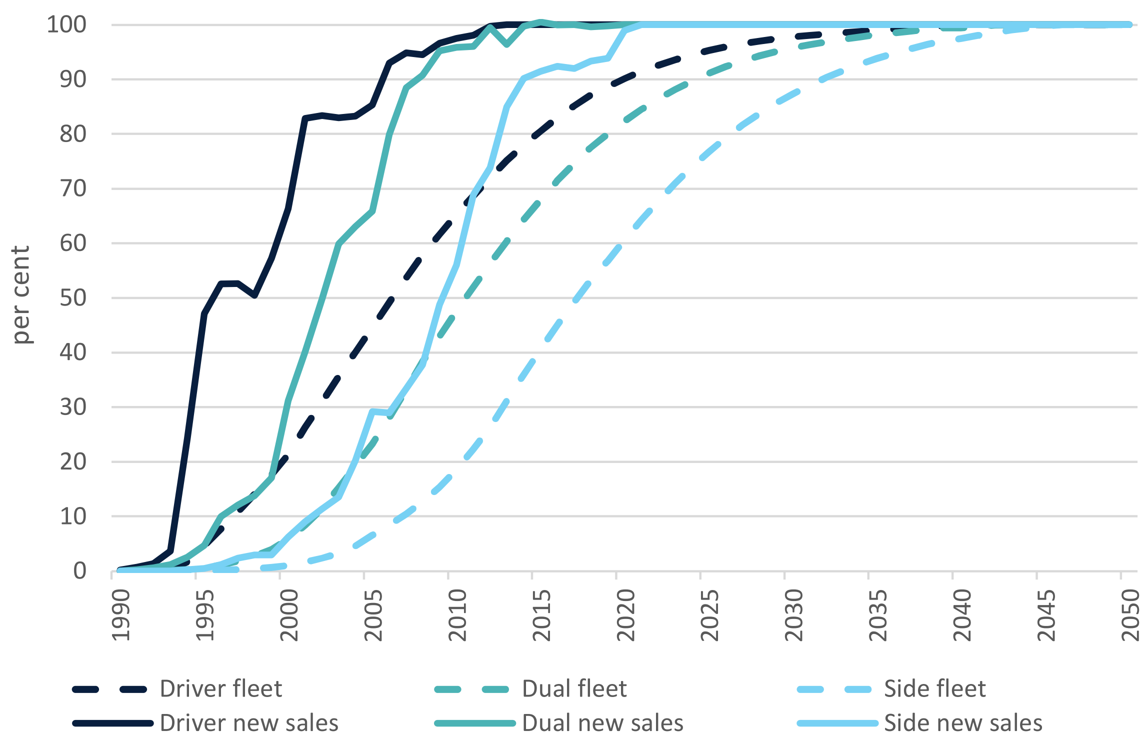


Figure 22 shows estimated new light vehicle sales penetration of all safety system technologies explored in this report.

Figure 22: Light vehicle sales penetration of active safety system technologies

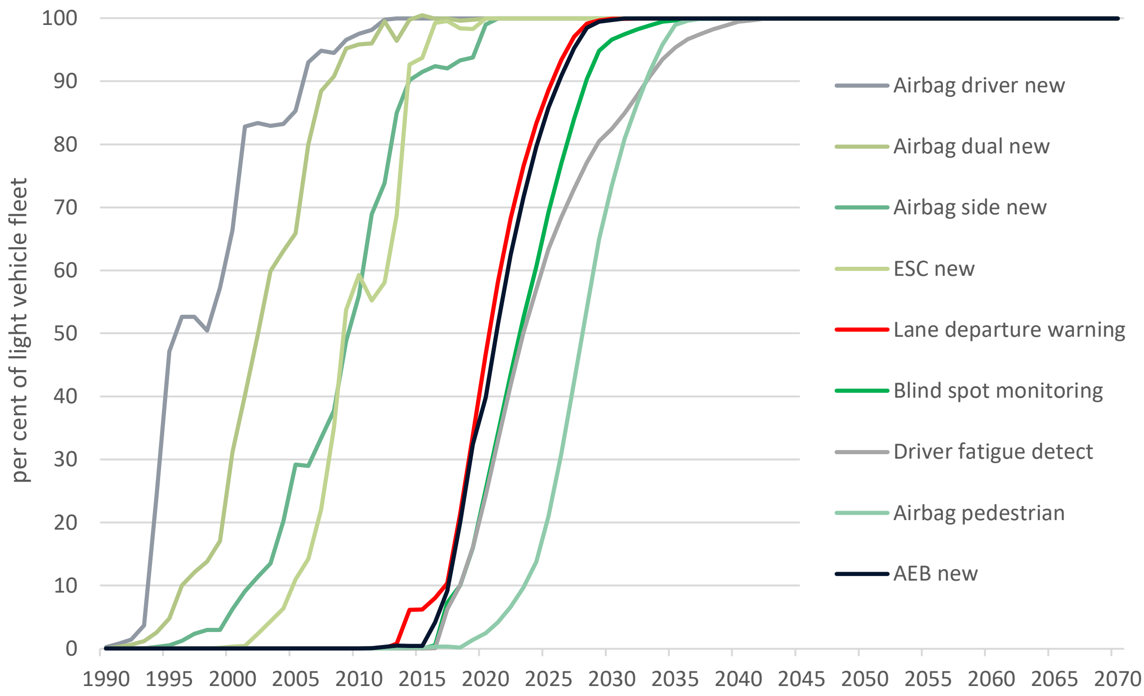
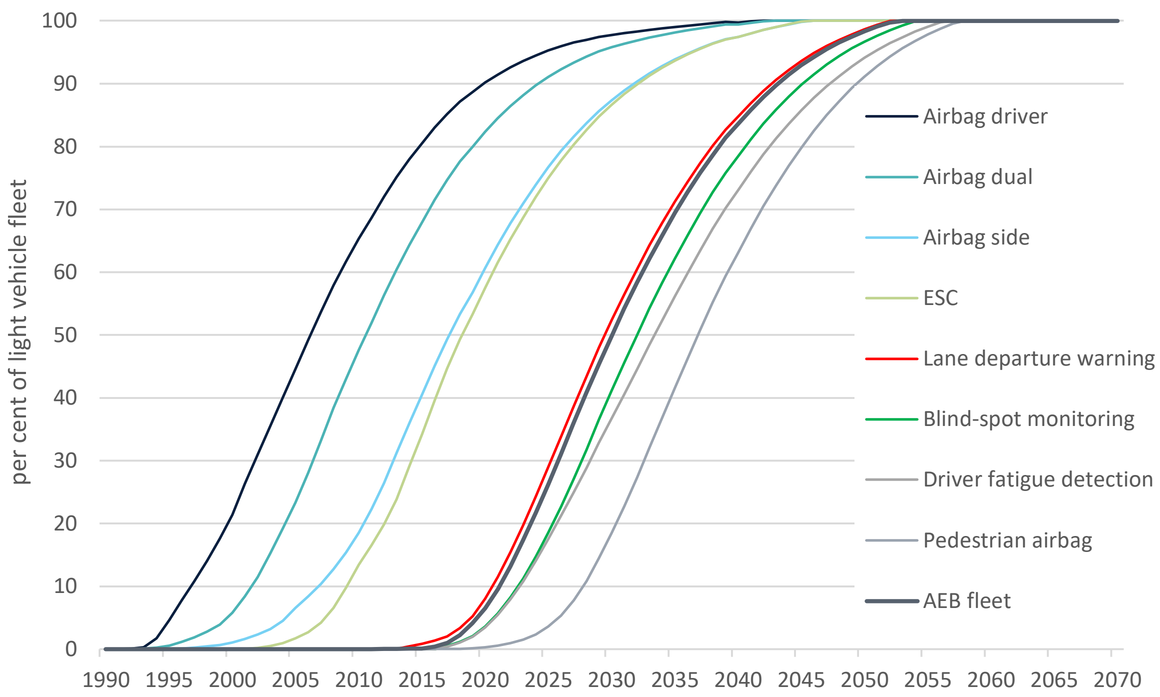


Figure 23 shows estimated light vehicle fleet penetration of all safety system technologies explored in this report.

Figure 23: Light vehicle fleet penetration of active safety systems



The above forecasts assume that all of the above active safety systems will eventually penetrate 100 per cent of the light vehicle fleet. This is consistent with the uptake of previous safety features considered in this report, all of which became ubiquitous even when they were not legally mandated. Not only are safety features generally considered highly desirable, but the economics of mass production means that once a technology is almost universally adopted, it becomes almost impossible to purchase vehicles without that technology. For example, while airbags are not legally required in Australia and many other countries, they have become ubiquitous.

CHAPTER 3

Uptake of driver support features and connectivity technologies

3.1. Types of driver support features and connectivity technologies

This chapter provides forecasts for several types of driver support features, which fall under SAE Levels 0–2 of automation. These include features that provide warnings and momentary assistance (SAE Level 0), and features that allow certain vehicle operations (such as steering, braking and acceleration) to occur independently of the human driver in defined situations (SAE Levels 1–2). Forecasts in this chapter cover:

1. **Adaptive cruise control:** An enhancement of conventional cruise control systems that allow the equipped vehicle to follow a leading vehicle at a pre-selected time gap, up to a driver-selected speed, by controlling the engine, power train, and/or service brakes.
2. **Lane keeping:** An ADAS that provides electronic steering and/or braking control inputs to keep the vehicle in its original travel lane upon detecting an unintended lane departure. These systems provide a momentary intervention, but do not automate this part of the dynamic driving task on a sustained basis.
3. **Adaptive headlights:** Headlights that respond to changing conditions to provide drivers with better visibility. These can include headlights that pivot depending on the direction of travel, as well as headlights that switch between high and low beams in the presence of traffic.
4. **Self-parking:** Uses parking sensors upon activation to locate a parallel (and in some cases, a perpendicular or diagonal) parking spot. After the driver selects an identified parking spot, the vehicle issues instructions to shift into the proper gear. The driver usually operates the accelerator and brake (although some systems automate this function) as the vehicle steers itself into the parking space.
5. **Right-turn assist:** Uses short-range radar to detect cyclists and other vulnerable road users approaching from behind the vehicle on the right-hand side. This system was designed for right-hand-traffic markets and would not assist with right-hand turns in left-hand traffic markets, such as Australia. Forecasts do, however, provide insight into the uptake of similar technologies suited to left-hand traffic markets.
6. **Pedestrian detection:** Uses one or a combination of forward-facing camera, radar and laser sensor to detect pedestrians and other objects in the vehicle's path, and provides an alert upon detection. Some systems are also combined with automatic braking. This functionality works best for vehicles travelling at slow speeds.

7. **Traffic sign recognition:** Uses a forward-facing camera to detect road signs and project messages onto the driving display. Some vehicles provide a vibration or audible warning if the driver does not adhere to the sign instructions (or recommendations).

8. **Cross-traffic sensor:** Uses radar sensors that send radio waves to detect oncoming objects. Examples include rear cross-traffic systems and blind spot detection systems.

Forecasts in this chapter also include features that support vehicles in sending and receiving information, which provide the connectivity that enable vehicle automation technologies to function. Connectivity forecasts in this chapter cover:

1. **Bluetooth:** A wireless technology that connects devices within short distances to allow for data exchange. It uses a low radio wavelength and hops between frequencies.

2. **V2X connectivity:** A connected vehicle has its own connection to the internet, usually via a wireless local area network. This allows the vehicle to share internet access and data with other devices.

3. **Telematics:** Telematics systems feature a vehicle tracking device that collects Global Positioning System (GPS) data, as well as a large range of vehicle-specific data that may be gathered from on-board sensors and/or engine diagnostics. The data is temporarily stored in a telematics device plugged into the on-board diagnostics or a Controller Area Network bus (CAN-BUS) port. A SIM card and modem in the device enables the data to be transmitted over private cellular networks to a centralised server for interpretation.

The above technologies do not reflect a comprehensive list of connectivity technologies. For instance, separate forecasts for DSRC and cellular connectivity would be particularly relevant for AV-enabling connectivity. The technologies explored in this section reflect the standard features that BITRE was able to estimate by matching pre-2020 vehicle sales to vehicle information from Glass's Research Data.

3.2. Forecasts of driver support features and connectivity technologies

The forecast methodology for driver support features is similar to that described for active safety systems (see Chapter 2). Appendix A outlines the forecast methodology in detail.

Figure 24 to Figure 34 show the estimated historical and future uptake of each driver support feature and connectivity technology listed in Section 3.1 above. Each figure shows uptake in new vehicle sales for cars/SUVs and LCVs.

Figure 24 shows the estimated uptake of adaptive cruise control in new cars/SUVs and LCVs. BITRE estimates about five per cent of new cars/SUVs and 23 per cent of new LCVs sold were equipped with adaptive cruise control in 2019. New vehicles sold with adaptive cruise control is forecast to reach 100 per cent in 2034 and 2035 for cars/SUVs and LCVs, respectively.

Figure 24 Uptake of adaptive cruise control in new light vehicle sales

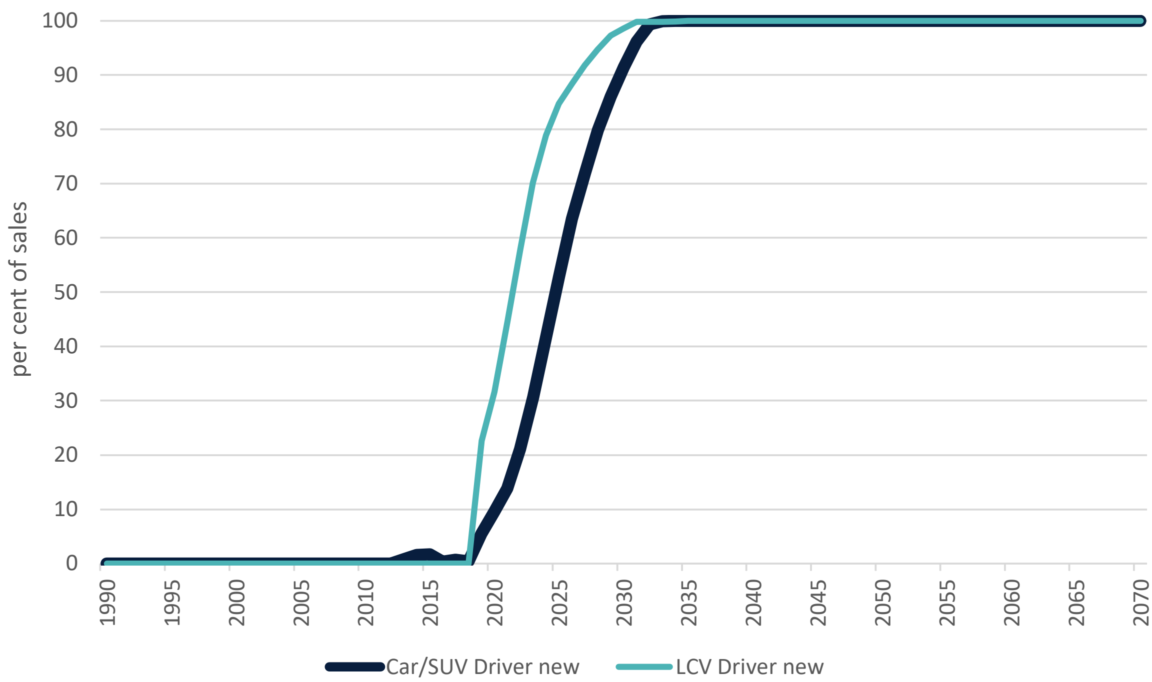


Figure 25 shows the estimated uptake of lane keeping driver support systems in new cars/SUVs and LCVs. BITRE estimates about 32 per cent of new cars/SUVs and 16 per cent of new LCVs sold were equipped with lane keeping systems in 2019. New vehicles sold with lane keeping features is forecast to reach 100 per cent in 2030 and 2036 for cars/SUVs and LCVs, respectively.

Figure 25: Uptake of lane keeping in new light vehicle sales

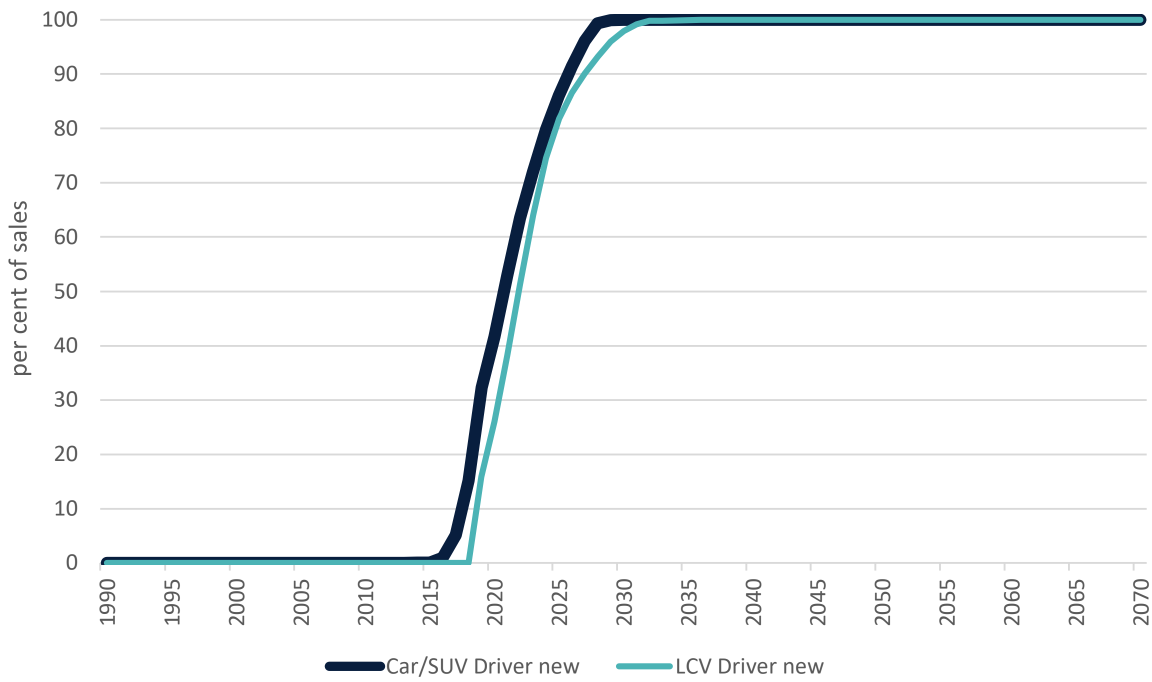


Figure 26 shows the estimated uptake of adaptive headlights in new cars/SUVs and LCVs. BITRE estimates about four per cent of new cars/SUVs and one to two per cent of new LCVs sold were equipped with adaptive headlights in 2019. New vehicles sold with adaptive headlights are forecast to reach 100 per cent in 2034 and 2045 for cars/SUVs and LCVs, respectively.

Figure 26: Uptake of adaptive headlights in new light vehicle sales

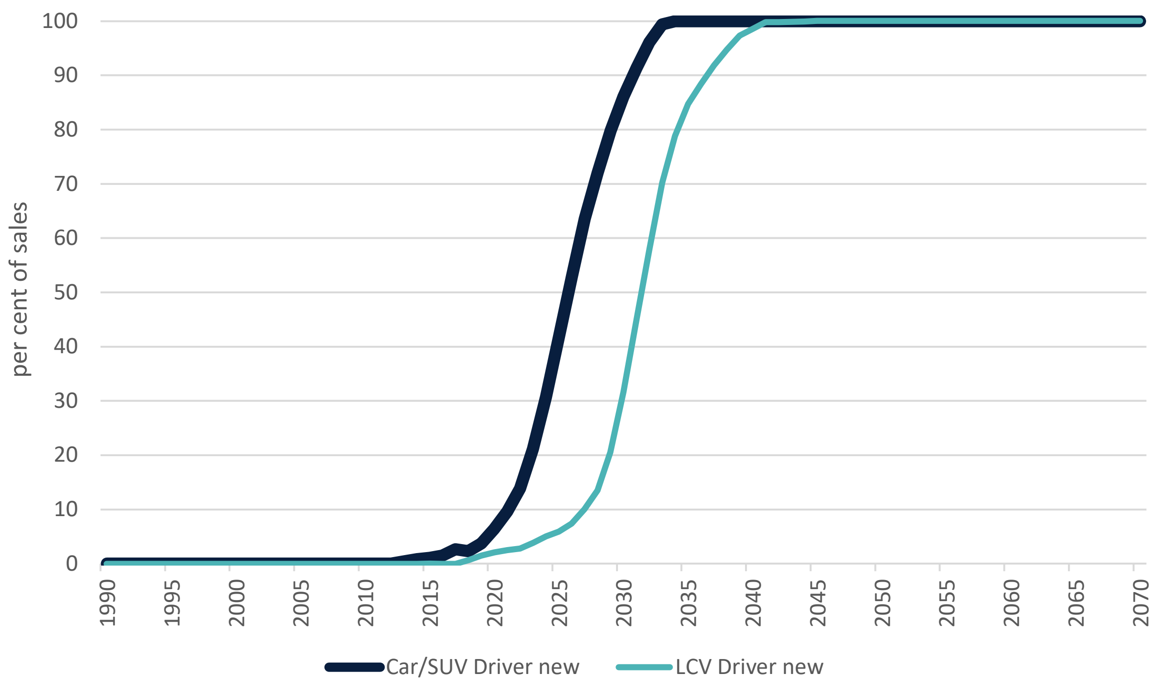


Figure 27 shows the estimated uptake of right turn assist systems in new cars/SUVs and LCVs. BITRE estimates less than 0.04 per cent of new cars/SUVs and no new LCVs sold were equipped with right turn assist systems in 2019. It is forecast that 100 per cent of new cars/SUVs sold in 2036 will be equipped with right turn assist. Right turn assist is forecast to start featuring in new LCVs sales from 2030, rising to reach 100 per cent of new LCV sales in 2048.

Figure 27: Uptake of right turn assist in new light vehicle sales

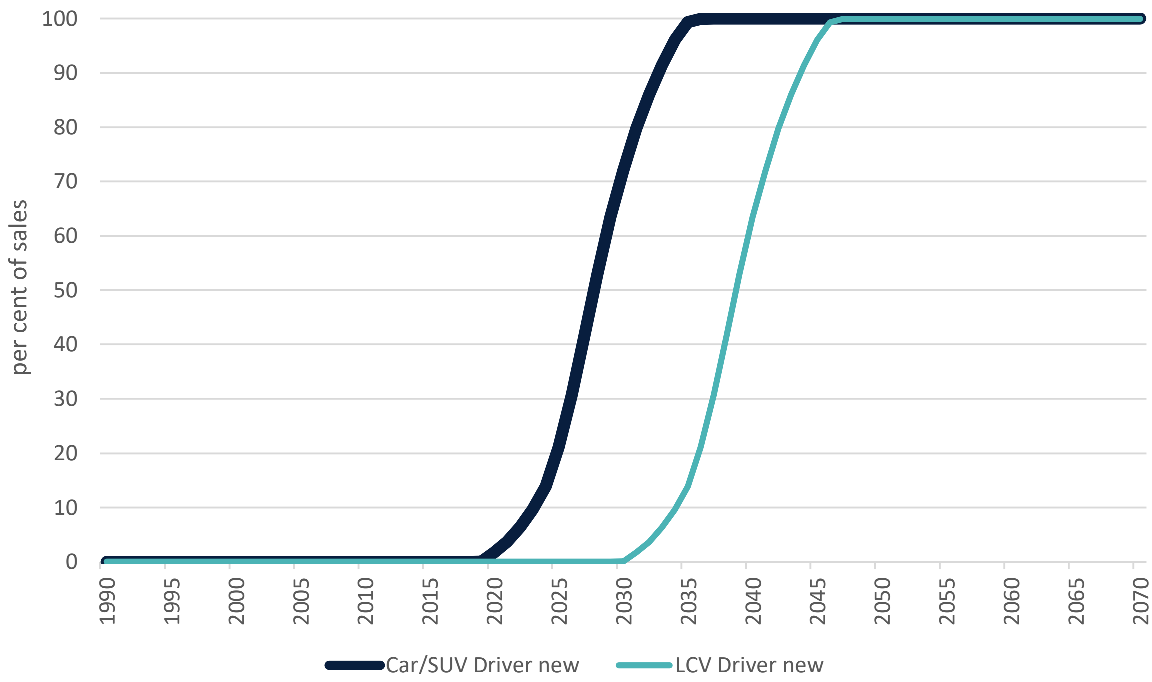


Figure 28 shows the estimated uptake of self-parking systems[4] in new cars/SUVs and LCVs. BITRE estimates no new cars/SUVs or LCVs sold were equipped with self-parking systems in 2019. Self-parking systems are forecast to start featuring in new car/SUV sales from 2020 and LCV sales from 2027, rising to 100 per cent of new sales in 2038 and 2045, respectively.

Figure 28: Uptake of self-parking in new light vehicle sales

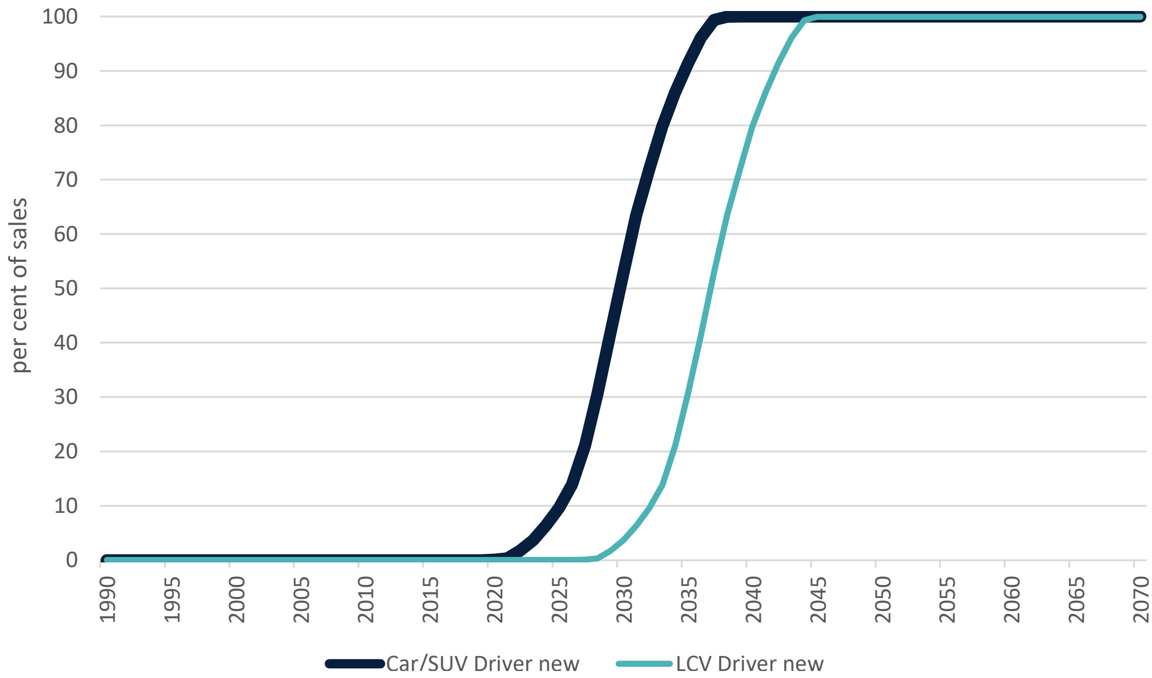


Figure 29 shows the estimated uptake of pedestrian detection systems in new cars/SUVs and LCVs. BITRE estimates about 25 per cent of new cars/SUVs and 46 per cent of new LCVs sold were equipped with pedestrian detection systems in 2019. New vehicles sold with pedestrian detection are forecast to reach 100 per cent in 2035 and 2033 for cars/SUVs and LCVs, respectively.

[4] Note that self-parking technology does not include more common park-assist technology, such as reversing sensors and reverse-parallel assist technology.

Figure 29: Uptake of pedestrian detection in new light vehicle sales

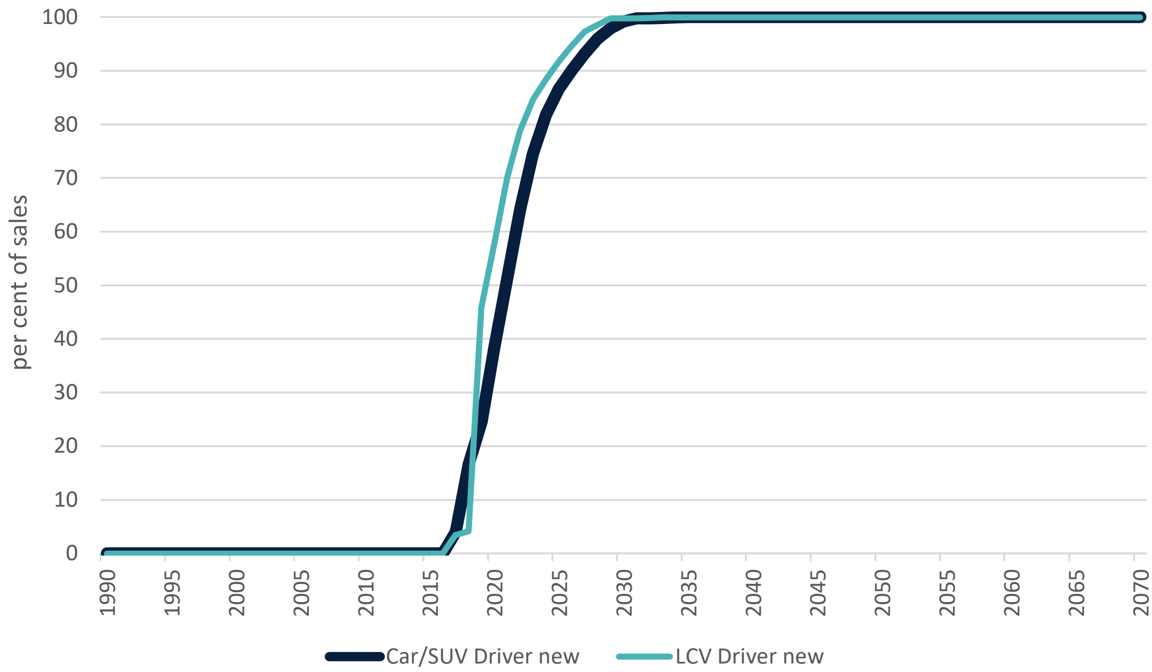


Figure 30 shows the estimated uptake of traffic sign recognition systems in new cars/SUVs and LCVs. BITRE estimates about 13 per cent of new cars/SUVs and 42 per cent of new LCVs sold were equipped with traffic sign recognition systems in 2019. New vehicles sold with traffic sign recognition are forecast to reach 100 per cent in 2032 and 2033 for cars/SUVs and LCVs, respectively.

Figure 30: Uptake of traffic sign recognition in new light vehicle sales

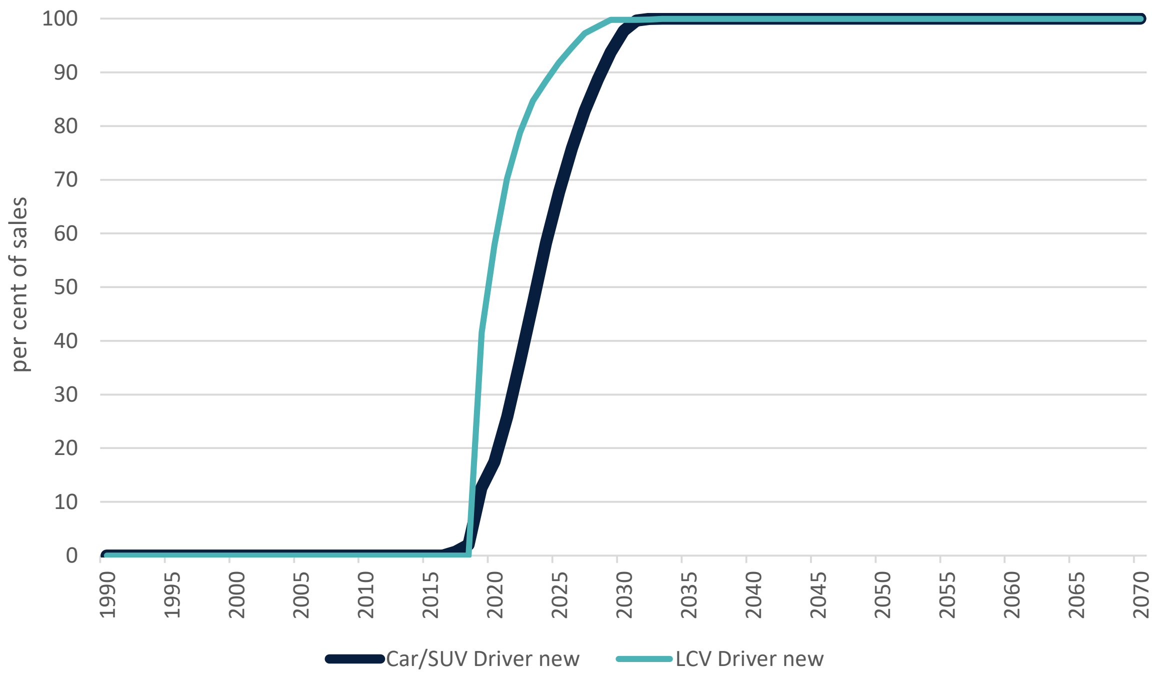


Figure 31 shows the estimated uptake of cross-traffic sensors in new cars/SUVs and LCVs. BITRE estimates about 18 per cent of new cars/SUVs and 4 per cent of new LCVs sold were equipped with traffic sign recognition systems in 2019. New vehicles sold with traffic sign recognition are forecast to reach 100 per cent in 2032 and 2041 for cars/SUVs and LCVs, respectively.

Figure 31: Uptake of cross-traffic sensor in new light vehicle sales

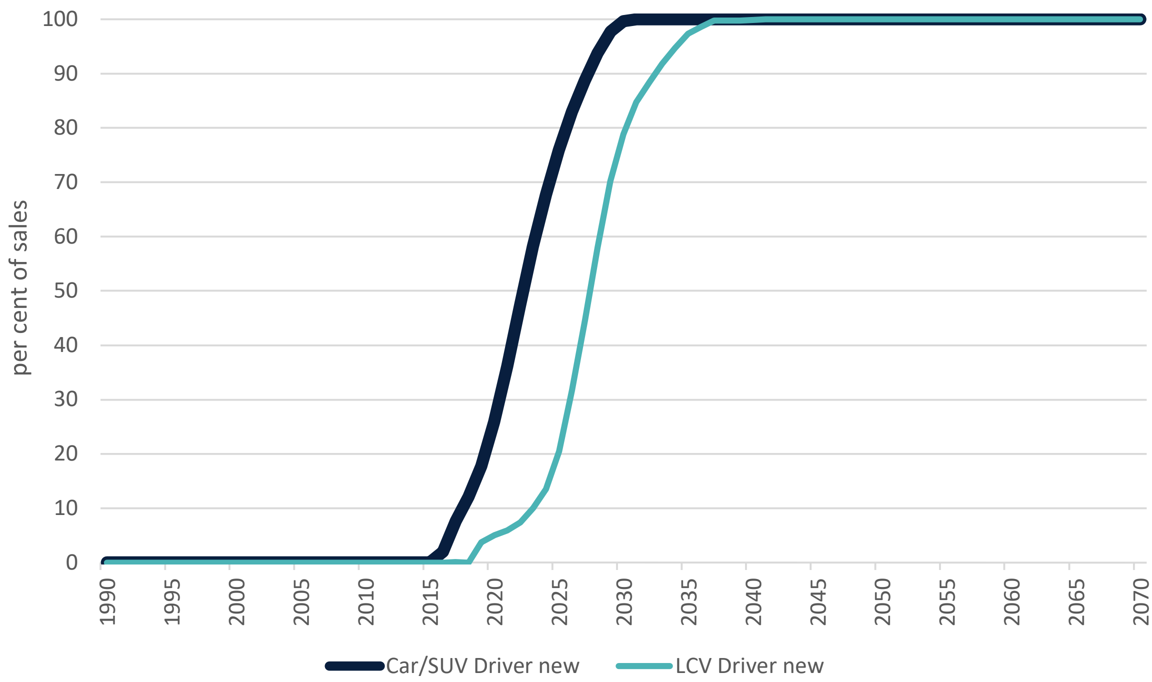


Figure 32 shows the estimated uptake of Bluetooth in new cars/SUVs and LCVs. Bluetooth is already well-established for in-vehicle infotainment, but also has other applications, such as vehicle management (Keeping 2021). BITRE estimates about 89 per cent of new cars/SUVs and 93 per cent of new LCVs sold were equipped with Bluetooth in 2019. New vehicles sold with Bluetooth are forecast to reach 100 per cent in 2024 and 2026 for cars/SUVs and LCVs, respectively.

Figure 32: Uptake of Bluetooth in new light vehicle sales

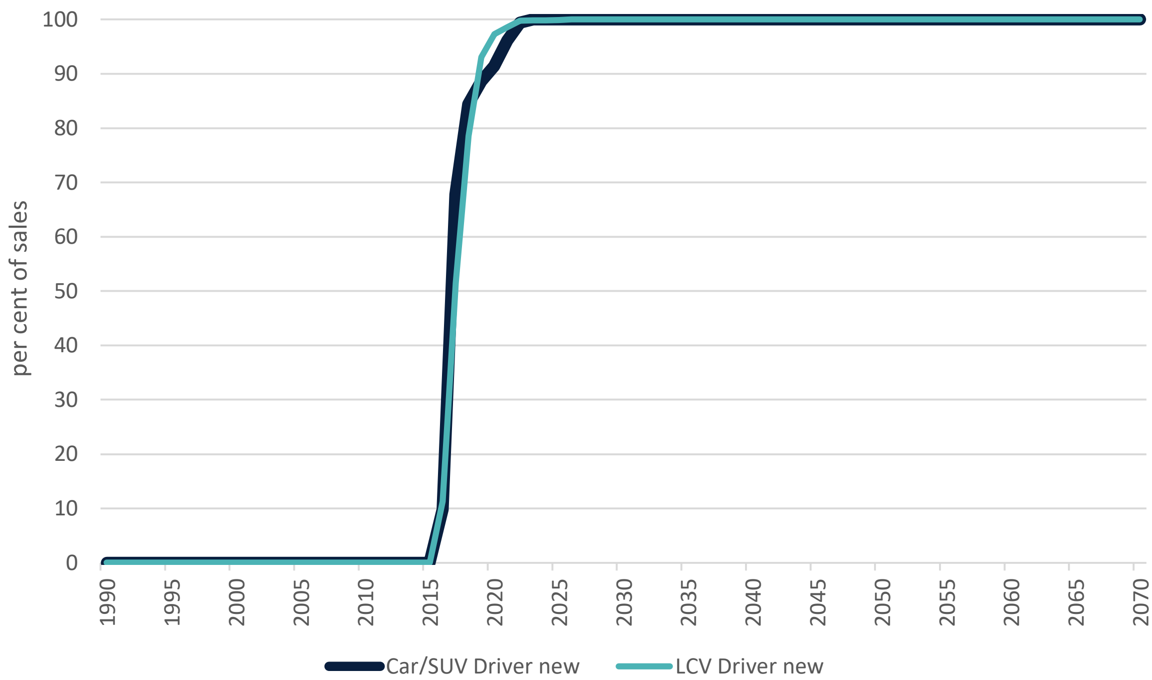


Figure 33 shows the estimated uptake of Wi-Fi connectivity in new cars/SUVs and LCVs based on features defined by the manufacturer. It is likely that some Wi-Fi features include connectivity between vehicles and infrastructure (V2X), but will also include other features such as connectivity for audio-visual devices unrelated to automation. The broad nature of the data prevents a more targeted analysis of just the V2X connectivity features. BITRE estimates about 38 per cent of new cars/SUVs and 94 per cent of new LCVs sold had Wi-Fi connectivity in 2019. New vehicles sold with Wi-Fi connectivity are forecast to reach 100 per cent in 2028 and 2026 for cars/SUVs and LCVs, respectively.

Figure 33: Uptake of Wi-Fi connectivity in new light vehicle sales

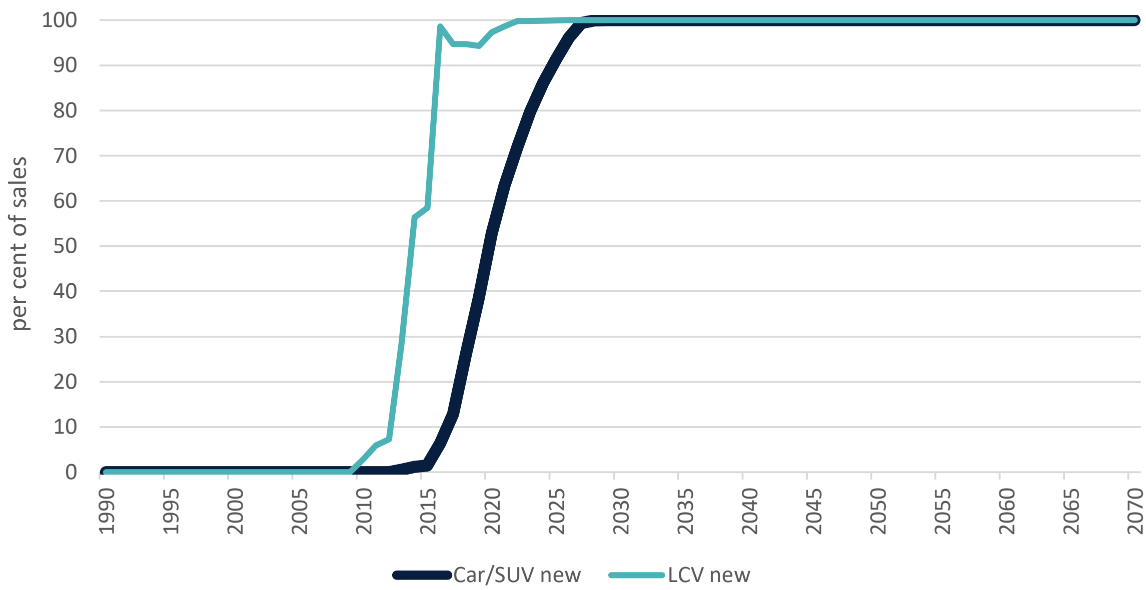


Figure 34 shows the estimated uptake of telematics in new cars/SUVs and LCVs. BITRE estimates about 2.3 per cent of new cars/SUVs and 0.6 per cent of new LCVs sold with in-vehicle telematics capability in 2019. New vehicles sold with in-vehicle telematics capability are forecast to reach 100 per cent in 2035 and 2047 for cars/SUVs and LCVs, respectively.

Figure 34: Uptake of in-vehicle telematics capability in new light vehicle sales

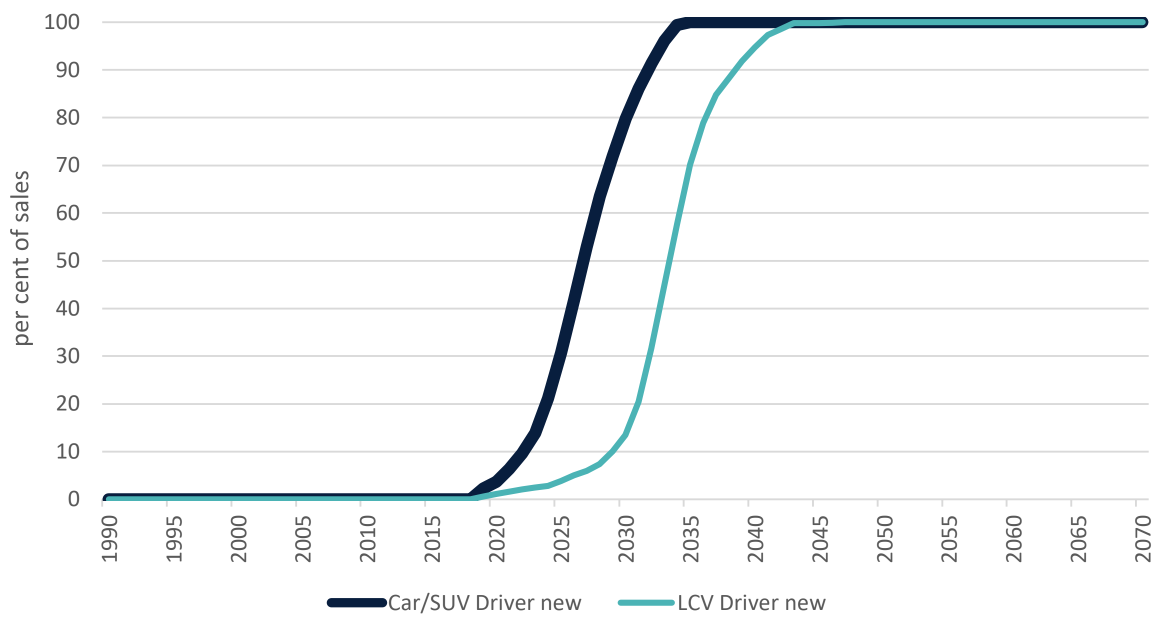


Figure 35 shows estimated historical and forecast new light vehicle sales penetration of the driver support features and connectivity technologies explored in this report.

Figure 35: Light vehicle sales penetration of driver support features and connectivity technologies

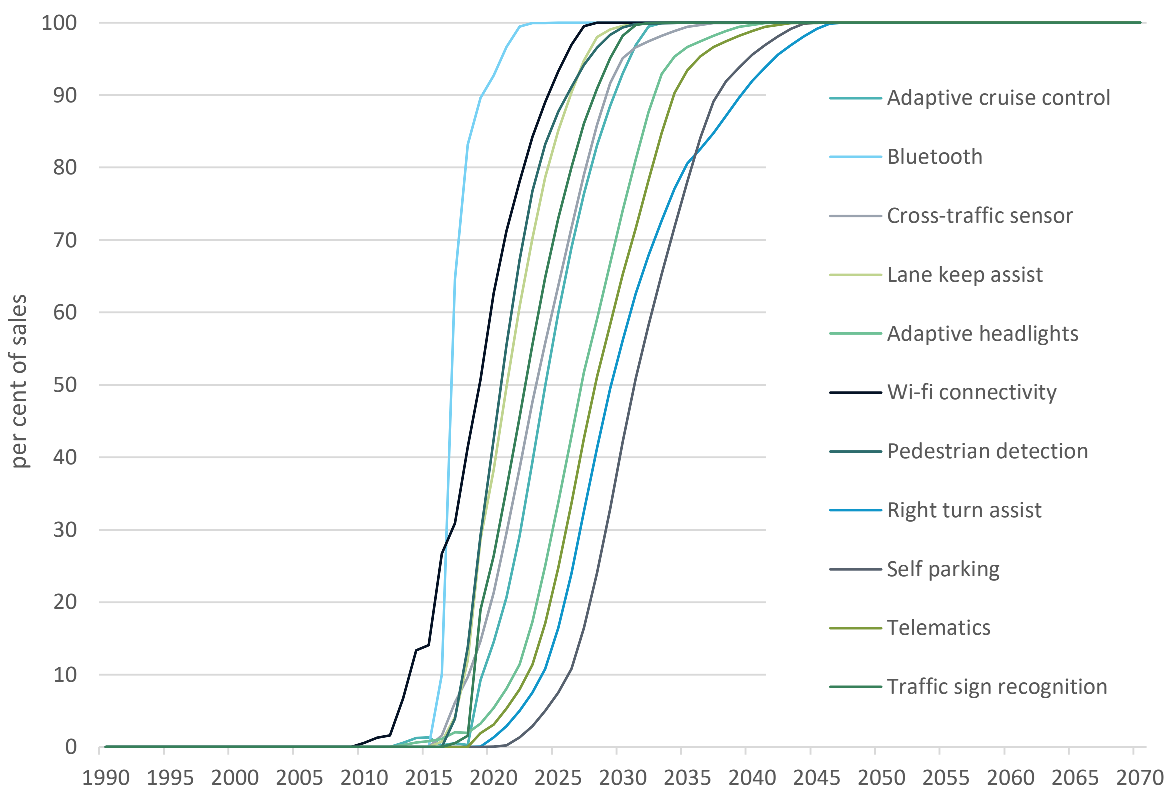
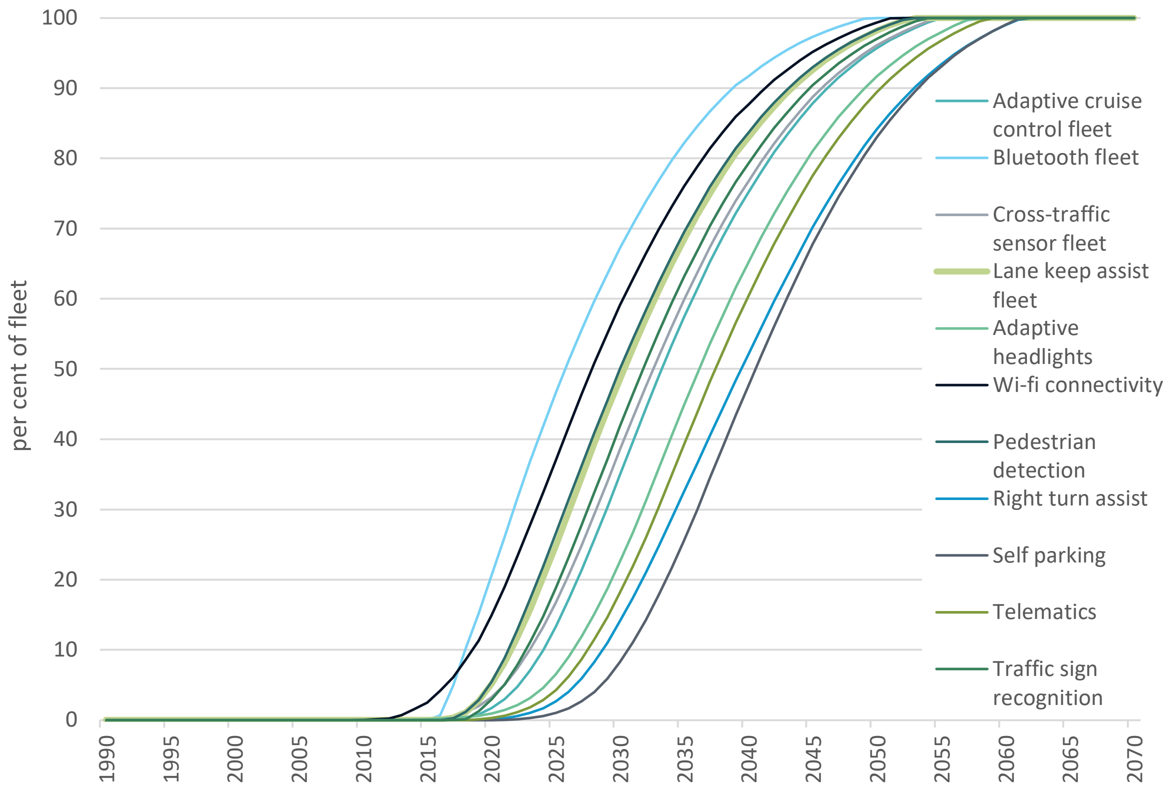


Figure 36 shows the estimated historical and forecast fleet penetration of the driver support features and connectivity technologies explored in this report.

Figure 36: Light vehicle fleet penetration of driver support features and connectivity technologies



These forecasts assume that the above driver support features and connectivity technologies will eventually penetrate 100 per cent of the light vehicle fleet, although this will be a long time away for some features (around 2060). It is stronger to assume 100 per cent fleet penetration for these features than for active safety systems (discussed in Chapter 2), given the proxy technologies used in this report all have clear safety benefits. Nevertheless, many driver support features rely on similar technologies to active safety systems (cameras and lasers to monitor the surrounds, and capability to automate braking and steering), and also often have safety benefits. Connectivity features are highly desirable as they often enable driver support, active safety and vehicle automation more broadly.

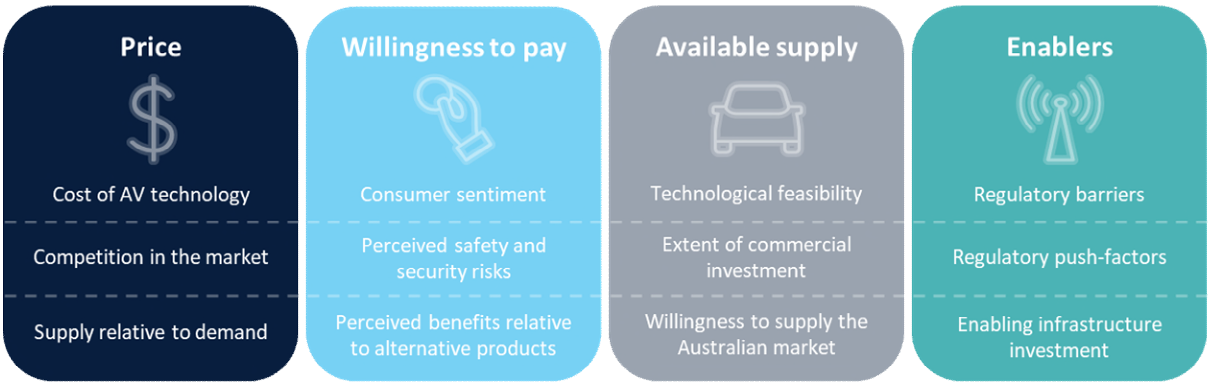
CHAPTER 4

Factors affecting uptake of fully automated vehicles

This chapter discusses factors that are expected to influence the forecasts of AV uptake in Chapter 5. These include light vehicle forecasts for SAE Level 5 vehicles, as well as the sum of SAE Level 4 and SAE Level 5 vehicles (SAE Level 4+5). These conceptual considerations inform key parameter values, such as the date of introduction, market saturation rate and speed of uptake (summarised in Section 0). This chapter also considers how several major automotive technologies have diffused empirically, which provides a sense-check on the speed of uptake implied by the forecasts in Chapter 5. The likely pattern for AV uptake is discussed separately in Appendix A.[5]

Figure 37 summarises the factors discussed in this chapter. These factors align with other research and analysis. For instance, McKinsey&Company (2016) finds if the uptake of ADAS can be taken as an example, the primary challenges impeding faster market penetration are pricing, consumer understanding, safety and security issues. Strategy& (2020) suggests the key factors for the tipping point of exponential technological adoption for AVs relate to technology, consumer sentiment, regulation and economic value.

Figure 37: Factors affecting uptake of AVs



[5] The uptake pattern is assumed to accord with the diffusion of innovation theory, pioneered in Rogers (1962).

Many of the factors in Figure 37 are interrelated and overlap. For example, low demand for AVs in Australia will reduce manufacturers' willingness to supply the Australian market, which in turn will reduce supply available in Australia.

4.1. Price/upfront costs of fully automated vehicles

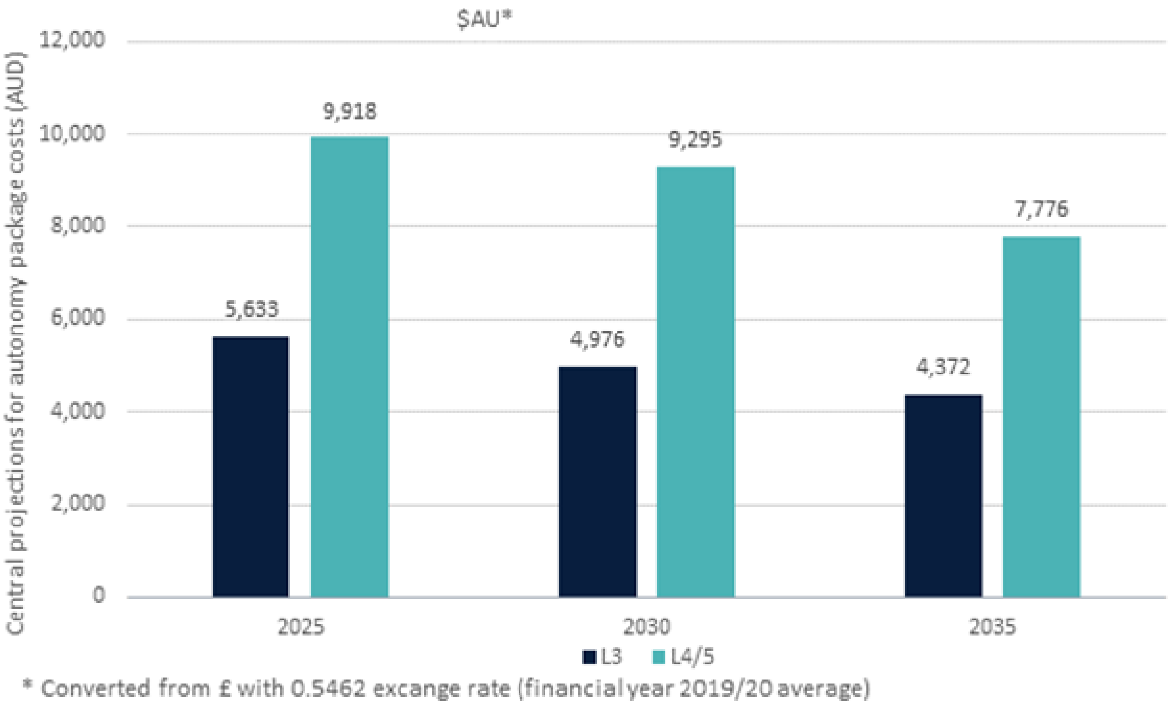
Original equipment manufacturers (OEMs) developing AV systems are facing challenges in creating these systems while keeping component costs down (Forrester 2019). Technology being developed and used, such as LiDAR sensors and cameras, is expensive. This results in significant price premiums in excess of what many consumers would be willing to pay. For instance, in the Australian context, Tesla's Full Self Driving package in 2020 is an additional AUD10,100 for a single vehicle (Cartwright 2020), noting that this is only SAE Level 3 and therefore not capable of self-driving. Tesla expects the price of its packages will continue to increase with additional functions as it moves towards full automation.

While these upfront costs are high, they have been declining over time. For instance, LiDAR sensors, while still expensive at around USD7,500 (AUD10,900) per sensor in 2019, had retailed for USD75,000 (AUD109,000) just over a decade ago (Moreno 2021; Lee 2020).[6] LiDAR costs are expected to decrease further, particularly in anticipation of mass-market adoption across the technology sector. For example, Apple's iPhone 12 Pro (and Pro Max) and iPad Pro are equipped with LiDAR (IDTechEx 2021). Velodyne, an AV technology company, expects to commence mass manufacturing of a new automotive-grade LiDAR unit, the 'Velarray H800', by the second half of 2021 at a sub-USD500 price-point (Nellis 2020).

Moreover, some OEMs are exploring alternatives to LiDAR and other radar sensors to overcome some of their limitations whilst achieving more accessible prices (Cantu 2021). For example, self-driving car start-up, Comma.ai combines an aftermarket dash-cam and wiring harness to provide self-driving capabilities in competition with Tesla and Cadillac's SAE Level 2 offerings for around USD1,000 (Vanderwerp 2020). Costs are expected to become less prohibitive as market share increases, in part due to economies of scale and efficiencies from learning-by-doing. Connected Places Catapult (2021) forecasts that the incremental cost of SAE Level 4+5 automation packages will fall from AUD9,918 to AUD7,776 between 2025 to 2035 (Figure 38). This forecast cost reduction is over 20 per cent, and corresponds with a forecast of global SAE Level 4+5 sales reaching 8.9 per cent in 2035.

[6] AUD to USD conversion calculated with a 0.6878 exchange rate (year 2019/20 average), rounded to the nearest $100.

Figure 38: Forecast costs of autonomy packages



Source: Connected Places Catapult (2021).

Similarly, Fragnant and Kockelman (2015) estimate that a self-driving car may cost an additional USD10,000 (AUD14,500) in up-front capital costs when it has 10 per cent market share, compared to USD3,000 (AUD4,400) at 90 per cent market saturation – representing a 70 per cent cost reduction.[7] While significant cost reductions are expected over time, this may take a number of decades. Litman (2021) anticipates that AVs are unlikely to become common and affordable globally until the 2050s to 2060s.

While BITRE's forecasts in Chapter 5 focus on Light vehicles, it is worth noting that automation in heavy commercial vehicles are expected to attract even higher costs. Fully automated commercial vehicles are estimated to cost an additional over USD23,000 (AUD33,400) compared to a standard truck operated by a human driver (Roland Berger 2016).[8] The bulk of the additional cost lies in the need for advanced software programs, while under one fifth of costs is expected to come from incremental hardware needs. The incremental cost takes into account new sensors and cameras, telematics upgrades, human-machine interface connections, driveline enhancements, and software algorithms. Incremental costs are expected to range from USD1,800 (AUD2,600) to USD6,200 (AUD9,000) per automated commercial vehicle with every level of automation.

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7 AUD to USD conversion calculated with a 0.6878 exchange rate (year 2019/20 average), rounded to the nearest $100.

8 AUD to USD conversion calculated with a 0.6878 exchange rate (year 2019/20 average), rounded to the nearest $100. Note. McKinsey&Company (2018) predicts a minimum USD30,000 for a basic AV, to an upwards of USD100,000 for a high-end AV.

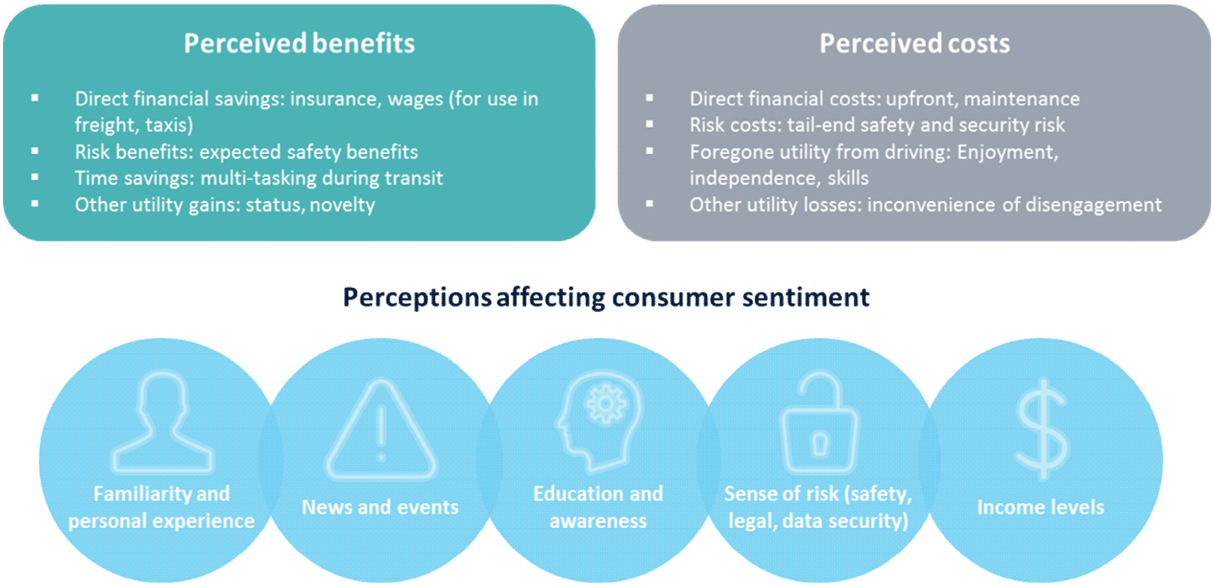
4.2. Willingness to pay

Willingness to pay is the maximum amount a consumer is willing to pay for a product or service. This maximum amount is influenced by the consumer's perception of the costs and benefits of that product or service. When deciding whether to purchase an AV, the potential customer will have a view on the incremental costs and benefits of purchasing the AV relative to alternative options (which may include purchasing an equivalent human-driven vehicle or not purchasing a vehicle at all).

Willingness to pay typically varies between consumers and consumer types. For instance, a taxi company purchasing an AV would expect benefits from reduced wages. In contrast, consumers purchasing an AV for personal use might expect time-saving benefits from being able to undertake more activities while commuting.

Figure 39 summarises the determinants of willingness to pay for AVs discussed in this section. This aligns with Austroads' (2020a) finding that a major influence of how quickly (and how far) technologies progress through the life cycle is the balance between perceived costs and benefits.

Figure 39: Determinants of willingness to pay for AVs



There have been several quantitative estimates of willingness to pay based on surveys (given AV sales data does not yet exist to estimate revealed willingness to pay). Cunningham et al. (2019) surveyed Australian consumers to understand what they would be willing to pay for a fully automated car compared to the same vehicle with no automated driving capabilities,[9] and found the following:

> Approximately 43 per cent of respondents would pay more for an AV. Of respondents willing to pay more, they would pay a median amount of AUD5,000 (~USD3,780) more. This is lower than willingness to pay estimates derived from US-based studies (e.g. USD4,900-7,253). This is also

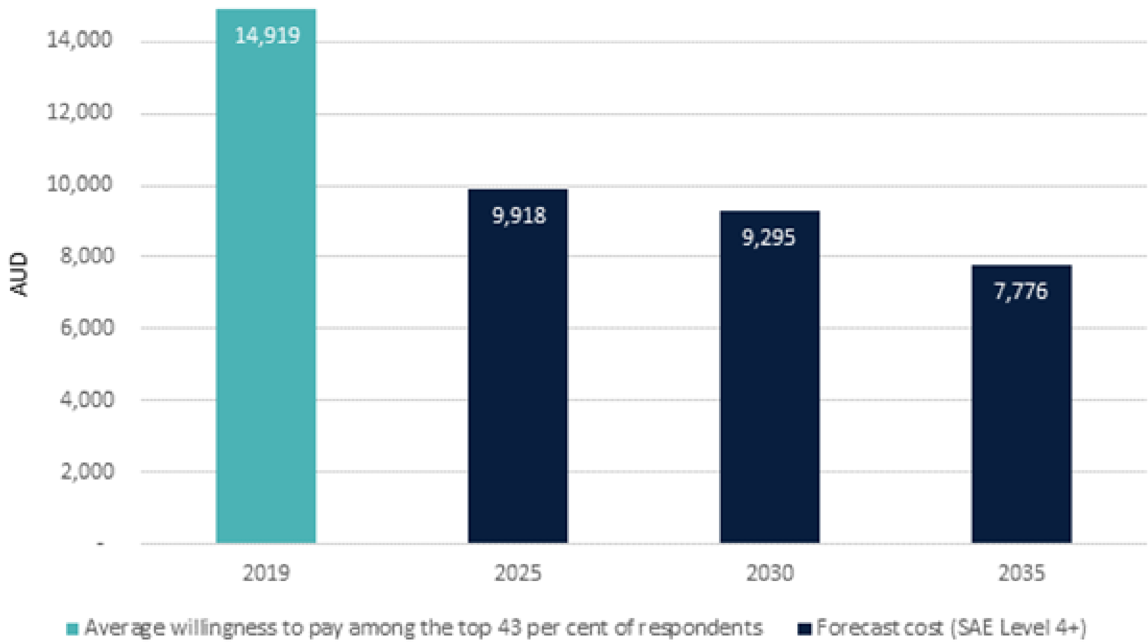
[9] Note that Elvik (2020) did not consider Cunningham et al. (2019) to strictly be a willingness to pay study as it aimed to identify factors influencing willingness to pay. See Elvik (2020), p. 7.

lower than AV cost projections for the next couple of decades, which is consistent with Litman's observation that AVs are unlikely to become common and affordable until the 2050s to 2060s (see Section 4.1).

Respondents were willing to pay on average AUD14,919 (~USD11,250) more for a fully-automated car. Given estimates typically suggest that SAE Level 4+5 technology will cost less than this in the early years (see Figure 40), these results suggest there will be sufficient demand for AVs to push the technology along the diffusion of innovation curve.[10]

Compared to the US, a larger proportion of Australian individuals were willing to pay significantly more for fully-automated vehicle technology at the higher end of the Australian market. Approximately 9 per cent of Australian respondents were willing to pay over AUD39,800. This indicates that, even if price projections for SAE Level 4+5 vehicles are very optimistic, demand for AVs in the Australian market should be sufficient to warrant supplying the Australian market (notwithstanding that this information is based on preferences stated in surveys, so are hypothetical rather than market-based).

Figure 40: Forecast costs over time versus willingness to pay for full automation in Australia (AUD)

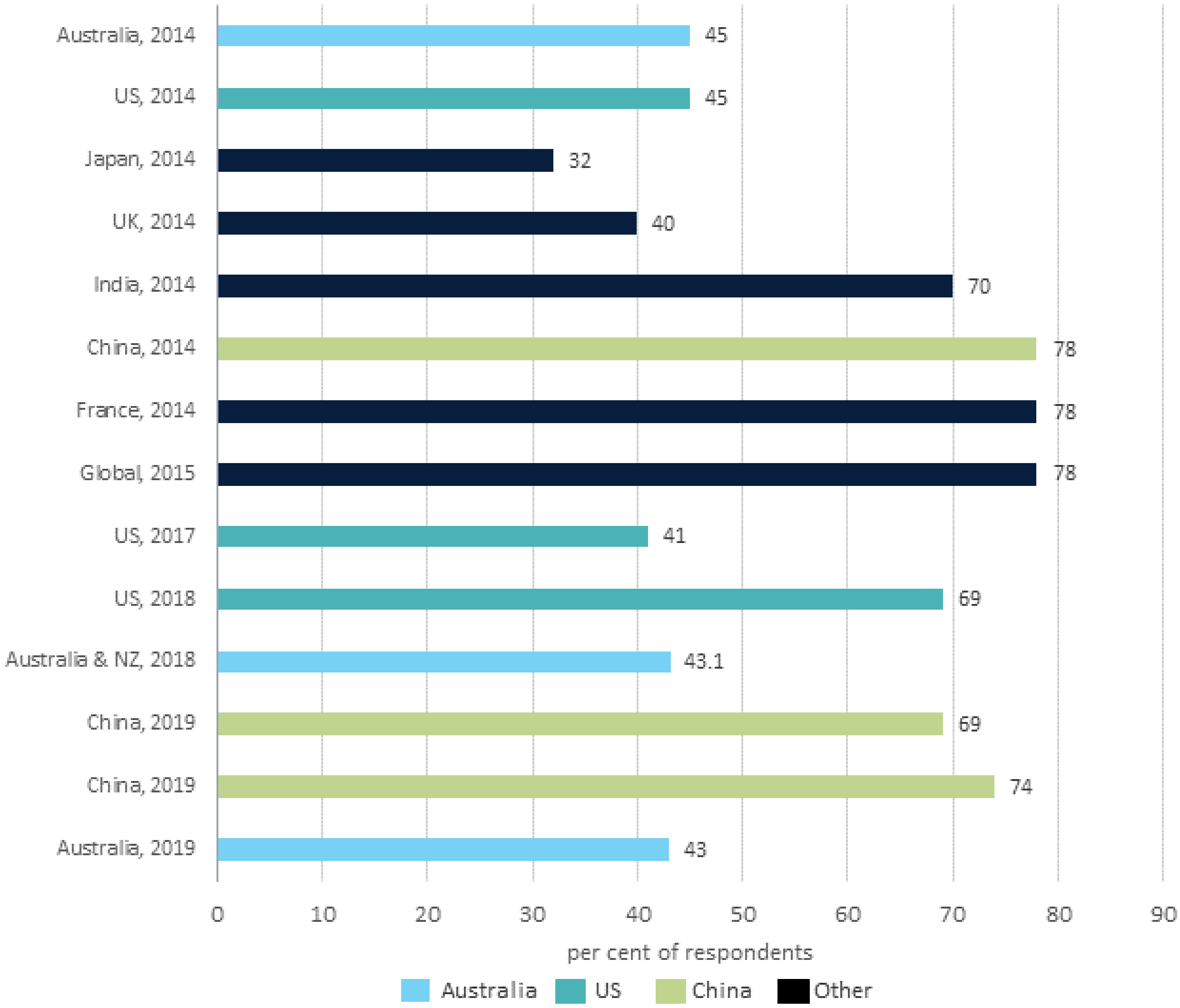


Source: Cunningham et al (2019) (willingness to pay); Connected Places Catapult (2021) (forecast cost)

Figure 41 summarises several AV willingness to pay surveys. While the proportion of respondents willing to pay for SAE Level 4 or full automation varies across surveys, regions and time, data shows relatively consistent results of 43-45 per cent of Australian respondents willing to pay for automation. Surveys also indicate there will be substantial demand for AVs globally, which shows promise for commercial investment to support large-scale production, driving technological improvements and cost reductions.

10 The diffusion of innovation curve (discussed in Appendix A) describes the pattern in which new technologies diffuse throughout the market from their introduction to market saturation.

Figure 41: Percentage of respondents willing to pay for SAE Level 4 or full automation



Source: Cunningham et al. (2019); Liu et al. (2019a, 2019b); Ledger et al. (2018); Balsal and Kockelman (2018); Kyriakidis et al. (2015); Payre et al. (2014); Schoettle and Sivak (2014)

4.2.1. Perceived ongoing benefits and costs

Different factors influence whether the ongoing operational and maintenance costs of AVs will be higher or lower than those incurred by comparable human-driven vehicles. While the net-impact is unclear, it appears likely that these will be a net-financial cost if AVs are for personal use. This is driven by the following financial factors:

Insurance savings: tangential to their safety benefits, AVs are expected to provide financial savings from reduced insurance premiums. For instance, Accenture (2017) estimates that auto insurance premiums could drop by as much as USD25 billion in the US by 2035 (when it forecasts that just under 25 million registered vehicles on US roads will be fully autonomous).

Fuel savings: Some projections indicate that AVs will lower fuel costs by 10 per cent due to more balanced driving, and are expected to require less maintenance for traditional vehicle components (Harvard Business Review 2019). However, Litman (2021) considers fuel cost savings are likely to be small, and may be more than offset by additional equipment and larger vehicles to serve as mobile offices and bedrooms. Engholm et al. (2020) consider fuel savings associated with AVs will likely be minor for commercial vehicles, and rather would gain far more from savings on driver costs. Moreover, if fuel costs reduce as the vehicle fleet becomes increasingly electrified, the incremental fuel efficiency savings of AVs could be even more marginal.

Maintenance costs: AVs are expected to incur higher service, maintenance and repair costs.

Net impact: Litman (2021) estimates that cost reductions associated with insurance savings will likely be marginal relative to the other incremental operating costs of AVs. Bosch et al. (2018) predict autonomous private car depreciation will be 6 per cent higher per passenger kilometre compared to a traditional car.

When providing commercial services, AVs will offer operating cost savings. Various research has commented on this, including with regards to:

Truck freight: Cost analysis finds the use of drivers will have the highest potential for cost savings (Engholm et al. 2020). Currently, driver costs are around 40 per cent of truck operating costs in a high wage country.

Ride-sourcing: Assuming AVs available around 2030-2035 cost about USD10,000 more than traditional vehicles, the net savings from eliminating the driver will make ride-sourcing about 30 per cent cheaper than driving one's own vehicle in the US (Compostella et al. 2020). Even if the manufacturing costs of AVs remain high, this cost will be minor when amortised over a service life of 400,000 miles. MacroPlan Dimasi (2018) suggest these cost reductions will grow the mobility industry significantly, given recent improvements to mobility service costs and quality has already resulted in modal shift and increased propensity to travel.

Last-mile delivery: AVs are expected to be well suited to providing last kilometre delivery services, given the short distances and shortages of drivers available to provide these increasingly sought-after services (MacroPlan Dimasi 2018).

In addition to changes in ongoing financial costs, consumers are likely to view AVs as having a range of other costs and benefits, which will affect consumer perceptions in different ways. For example:

- **Safety risks:** AVs are expected to have strong safety benefits due to the elimination of human factors in the crash risk. However, forgone control and scope for tail-end risks may cause some consumers to perceive AVs as posing safety risks as well as benefits.
- **Disengagement risk:** Given SAE Level 4 AVs will not be fully automated in all domains, they may disengage in certain locations or in certain weather events. The likelihood of the AV functionality disengaging will likely create perceived costs of inconvenience and can even result in ‘access anxiety’, where travellers fear their vehicle cannot reach all desired destinations (Grush 2016).
- **Increased mobility:** A major benefit of AVs is they will allow mobility for people with driving impairments or restrictions, such as medical conditions and vision impairments (Ledger et al 2018).
- **Other utility changes:** Some attributes of AVs may be perceived as a cost to some consumers and as a benefit to others (for example, some people enjoy driving).

Consumer perceptions of the above benefits relative to the costs and benefits should improve with consumer sentiment improves (see Section 4.2.2 below).

4.2.2. Consumer sentiment towards fully automated vehicles

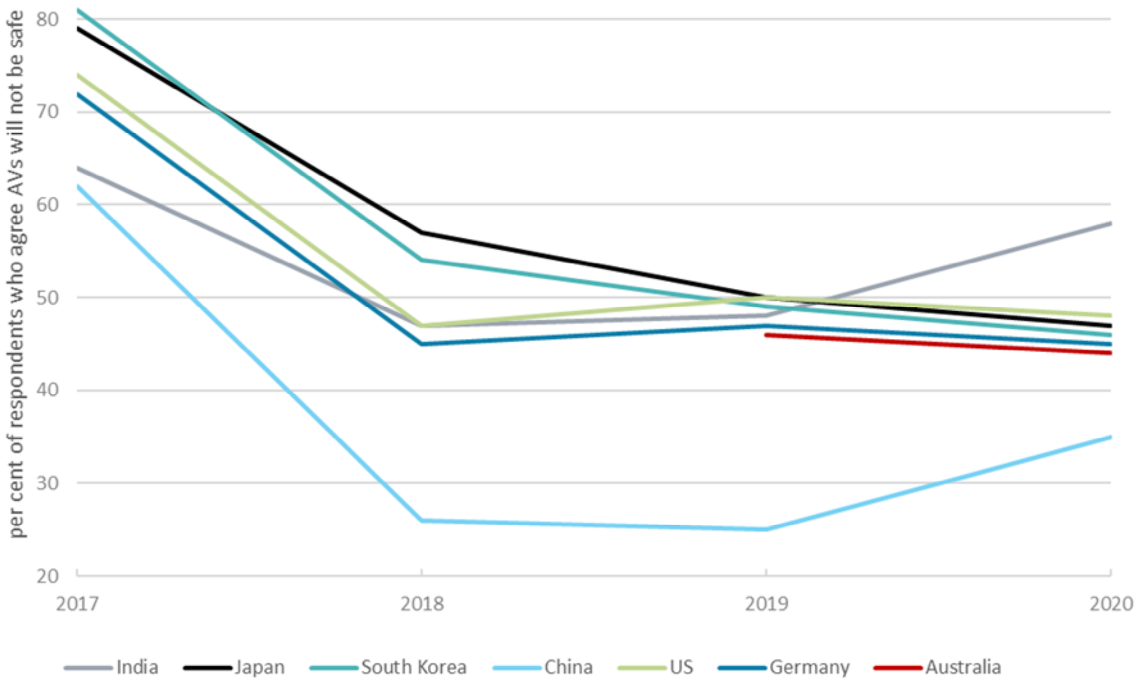
Consumer sentiment is an important factor to understand when forecasting AV uptake as it is a useful indicator of the likelihood of uptake. This is because consumer sentiment towards AVs affects:

- **Willingness to pay:** Consumer sentiment affects how consumers perceive benefits, costs and risks, and therefore their willingness to pay for the technology. For instance, if consumers perceive AVs as being less safe than human-driven vehicles, this will reduce their willingness to pay for (or even use) AVs, even if the technology offers a significant net-safety benefit.
- **Enabling factors:** Given AVs have the potential to create communal risks, if a significant proportion of the population is concerned with the risks they pose, there will be an onus on policymakers to take a more conservative approach to enabling the technology.

Consumer sentiment towards AVs is very responsive to various factors (such as personal experience and knowledge) and changes rapidly. The importance of consumer exposure and experience to AV technology in influencing future uptake will be discussed below.

Some measures indicate that consumer sentiment in Australia (as well as other countries, like the US and Germany) has stalled in the last couple of years, after having improved between 2017 and 2019. Some countries (such as China and India), have even seen a recent decline in sentiment, albeit still higher than in 2017 (Figure 42).

Figure 42: Change over time of global distrust in AVs



Source: Deloitte (2020)

Understanding current consumer sentiment

While recent survey data indicates less than half of Australians trust AVs (Figure 42), there is decent scope for this to improve. AV knowledge remains relatively low, and this lack of understanding acts as a barrier to adopting the technology, contributing to the relatively low acceptance threshold. Greater awareness and understanding of AVs in communities can address some of the hesitancies around consumer trust and acceptance.

Understanding the extent to which personal and contextual factors may influence consumer attitudes provides important information for decision-makers. Favourable attitudes towards AVs are associated with younger individuals, those who do not drive as often, and are more open to sharing a vehicle (ITLS 2018). These consumers are often more exposed and open minded to new technology, are more welcoming, and willing to pay more for AVs (Capgemeni Research Institute 2019).

Trust in AVs has changed over time. Globally, while three in five consumers feel a sense of anticipation about the future of self-driving cars, almost half say AVs invoke fear, while over two in five are anxious and feel a sense of losing control (46 and 43 per cent respectively) (Capgemeni Research Institute 2019). Only 32 per cent of respondents feel trusting of AVs. In 2020, almost one third of experts identified gaining consumer trust as one of the leading challenges in the field (JD Power 2020).

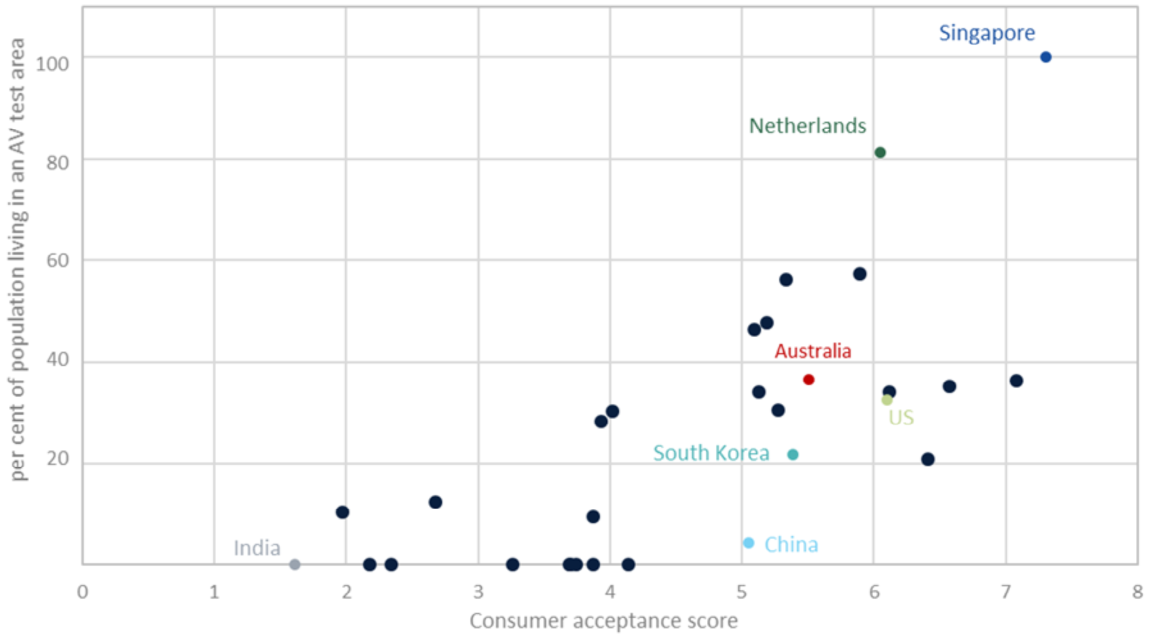
Operational safety and data confidentiality and security are also drivers related to trust. Following a series of AV crashes from 2018 to 2019, the US saw an increase in those afraid to ride in fully self-driving vehicles from 64 per cent in 2018 to 71 per cent in 2019 (Rumery 2019). Prior to this, around 75 and 78 per cent of Americans reported feeling afraid to ride in a self-driving car in 2016 and 2017 respectively, further highlighting the instability in consumer sentiment (AAA 2017).

Safety and familiarity are key to improved consumer sentiment

Personal experience in emerging technologies has proven to improve consumer sentiment when it comes to lower levels of AVs. A majority of drivers who have experienced ADAS technologies firsthand generally have favourable impressions of the technology in their vehicles and trust it more (McDonald et al. 2018). This suggests that consumer sentiment is likely to improve with AV penetration, creating a positive force as the technology moves along the diffusion of innovation curve.

Empirical evidence indicates that increasing public awareness through live demonstrations improves consumer sentiment and acceptance (Figure 43). The more consumers see AVs on the road, the more comfortable and likely they are to use them when they become available (KPMG 2019). The opportunity to personally interact with AVs provides a pathway to increasing awareness, education and in turn, trust in the technology.

Figure 43: Relationship between consumer acceptance and population living in AV test area



Source: KPMG (2020)

For example, since 2018, Singapore has had the highest overall consumer acceptance of 30 countries (KPMG 2018, 2019, 2020). KPMG (2019) analysis indicates this is partly driven by the city-state's population living in AV test areas. The country continues to take significant steps to encourage testing, development and adoption of AVs, including opening one tenth of its roads for AV testing and embedding AVs into wider goals, such as greater use of public transport (KPMG 2020).

Over 70 per cent of South Korean and Indian respondents stated media coverage relating to AV crashes made them more cautious about AVs (Deloitte 2020). The Indian government has taken a clear stance against introducing AVs due to infrastructure constraints and not wanting to compete with employment opportunities for skilled drivers (Dataquest 2021). Meanwhile, although South Korea has one of the highest consumer information technology adoption rates, its government only introduced a national AV strategy in 2019 (KPMG 2020).

There is an opportunity for decision-makers to take the lead and positively influence consumer sentiment. In contrast to South Korea and India, 55 per cent of those surveyed in China agreed media coverage on AV crashes made them more cautious (Deloitte 2020). In 2019, the Chinese government made it easier to test AVs on public roads, allowing testing to occur in more cities (KPMG 2020). China has also been trialling free SAE Level 4 automated taxi services in various districts around Beijing to promote the technology in the community (Global Times 2021).

Australian sentiment towards AVs is presently lower than some other jurisdictions, with a general view that consumers are not yet ready to embrace this technology. Few Australians have experienced AVs firsthand, contributing to the lower levels of consumer acceptance of the technology (Ledger et al. 2018). Two thirds of Australians feel media reports involving AV crashes have made them more cautious (Deloitte 2020).

Consumer acceptance is lower for higher levels of automation that are still in development

A survey conducted by the Queensland Government (2018) observed that willingness to use automated vehicles has a negative correlation with the level of automation. This likely reflects how higher automation comes with newer technology that may be less developed and tested. In the state, three in four respondents considered vehicles with SAE Level 3 automation to be safer than their current vehicle, and were willing to use one in the future, while only 54 per cent were willing to use vehicles with SAE Level 5 automation.

Consumer favourability varies with the general level of personal familiarity and exposure to vehicle automation technology at all levels of automation. While more motorists are using the latest driver assistance functions each year, appetite for fully self-driving vehicles was significantly lower in 2019 than it was in 2017 among Victorian motorists (Eastlink 2017, 2018, 2020). The proportion of motorists who would be willing to ride in a fully self-driving vehicle even where there is a driver in the vehicle constantly monitoring and ready to take control has decreased (Eastlink 2020).

Consumer favourability is likely to increase as AV penetration increases. In Victoria, the number of motorists who want their next vehicle to offer full self-driving on freeways (provided the driver must continuously monitor the vehicle at all times) increased from 2018 to 2019 (Eastlink 2020). However, demand for full self-driving on all roads remains much lower compared to 2017. This is a good indication that motorists’ expectations remain in the Gartner (2019) ‘trough of disillusionment’ when it comes to AVs on all roads (see Box 2).

Box 2: Gartner Hype Cycle explained

The Gartner Hype Cycle provides a graphic representation of the maturity, adoption and social application of technologies and applications. It is a concept that aims to provide insight into how a technology or application will evolve over time. The Hype Cycle is broken into five key phases of a technology's life cycle:

Innovation trigger: A new technology gains significant interest. Often no usable product exists and commercial viability is unproven.

Peak of inflated expectations: Early publicity produces a number of success stories and failures.

Trough of disillusionment: Interest declines as experiments and implementation fails to deliver. Investments continue if some providers improve products to the satisfaction of early adopters.

Slope of enlightenment: More instances of the technology's benefit seen. Second and third generation products appear with further development.

Plateau of productivity: Mainstream adoption starts to take off.

Source: Gartner (2019)

Consumers lack trust in the possibility of AVs being able to navigate through unexpected situations without confusion (Capgemini 2019).[11] Almost three quarters of Americans would feel safer if they had the ability to take control if something goes wrong (AAA 2020). In 2017, only 43 per cent of Australians and New Zealanders agreed AVs would be safer than a car driven by an experienced human driver (Ledger et al. 2018).

Even with automated vehicles, consumers may still wish to disengage the automated functionality and 'drive' their vehicle from time to time. Over four in five drivers would still prefer to drive manually occasionally even if they owned an AV (Infrastructure Partnerships Australia 2017). In a hypothetical situation where a consumer's future car offers fully automated driving functions that can be switched on and off, over one third of respondents do not intend to use self-driving functions at all, reflecting a lack of trust in AVs (Otto 2017).

Meanwhile, while China has seen a recent decrease in consumer sentiment around AVs (Figure 42), it remains one of the most accepting countries. One reason for this positivity is as China's traffic continues to worsen, many consumers prefer not to drive themselves given the nature of the roads. In other markets, such as the US and some European countries, many consumers still enjoy driving (Capgemini Research Institute 2019).

Role of government, legal clarity and data security in positive sentiment

Globally, there is significant disparity between industry and consumer sentiment when it comes to perceived barriers to AV uptake. The Capgemini Research Institute (2019) found the top three barriers identified by industry professionals are around understanding and learning to use the

[11] 71 per cent of respondents agreed AVs getting confused by unexpected situations as one of the main barriers to adoption.

technology, while consumers see safety and vehicle security as key constraints. They also found that while 78 per cent of industry thinks consumers would be comfortable sharing personal data with original equipment manufacturers, only 49 per cent of consumers trust traditional automakers with their personal data.

Consumers concerned with data and privacy issues are less likely to be interested in AVs. A global survey in 2017 found a quarter of consumers with low or no privacy concerns rated fully autonomous driving functions as the most preferred future mobility feature (Otto 2017). In comparison, 17 per cent of those with privacy concerns were significantly less interested in AVs.

In Ledger et al.'s (2018) survey of Australia and New Zealand, over two thirds of respondents expressed a level of concern about data privacy and security. Consumers are particularly worried about cyber security threats (79 per cent) and privacy of data (72 per cent) when it comes to issues of trust (Infrastructure Partnerships Australia 2017).

In the Asia-Pacific region, a majority of consumers in countries, including India (80 per cent), China (77 per cent), South Korea (74 per cent) and Australia (63 per cent) would feel more comfortable riding in an AV if it were government-certified (Deloitte 2020). This shows there is opportunity for decision-makers to address legal and privacy issues to encourage and improve consumer sentiment.

Box 3: Case study on building AV trust in the Mcity Driverless Shuttle research project

Trust drives consumer interest in AVs. Research shows trust can be built by facilitating positive personal experiences to provide greater exposure, interest and understanding of AV technology. The Mcity Driverless Shuttle research project ran from 2018 to 2019 at the University of Michigan with a goal to understand acceptance, trust and behaviour when riding in driverless shuttles, or interacting with one on the road.

The study found outreach and education were key to engaging with the community and promoting ridership. Around 86 per cent of shuttle riders expressed trust in the service, after having used the service, while 66 per cent of non-riders expressed trust in the service. The personal experience in interacting with the service improved consumer sentiment on AVs.

Lessons learned from this successful trial show that there is opportunity to positively influence and shape consumer sentiment and in turn, the uptake of AVs in the future.

Source: University of Michigan (2020)

4.3. Availability of supply

As well as demand-side drivers and non-market enablers, supply-side factors will also affect the uptake of AVs. These factors are particularly important in determining the date of commercial introduction, given that AVs are not yet technically feasible to the point they can be safely and legally driven outside the trial context.

Investment, trials and technological progress in AVs indicate that supply will become available. Several signs of progress include:

- 'Miles per disengagement', the metric describing the average distance an AV can travel without human intervention, has more than doubled each year since 2015 (IDTechEx 2021);
- A mobility-as-a-service (MaaS) company in California was granted the world's first driverless testing license in July 2020. Since then, six other MaaS companies have obtained driverless

testing licenses in California, and others have gained similar licenses in parts of China (IDTechEx 2021);

- A fully automated truck has been successfully piloted on a US motorway under human supervision. There are plans to remove human supervision in a subsequent pilot towards the end of 2021 (Brann 2021); and
- A prototype AV has been developed to match the highest international driving automation classification level (that is, SAE Level 5), and is currently being tested on closed tracks (Sber 2021).

Despite recent progress, AVs still have obstacles to overcome, such as testing in more urbanised areas and establishing cost-effective sensor suites (IDTechEx 2021). There is some uncertainty as to when the technology will be demonstrated as being sufficiently reliable, safe and secure for commercial production. Since 2019, AV forecasts have been pushed back and revised downwards. Around 38 per cent of industry experts say prospects for AVs have become worse during the COVID-19 pandemic, noting that the focus of innovation has shifted towards shorter term and battery electric alternatives, while delaying the development of self-driving systems (JD Power 2020).

It is also valuable to consider whether international forecasts will reasonably indicate when supply will likely be available in Australia. For instance, PwC (2020) considers businesses' willingness to supply AVs to the Australian market could be hampered if Australia adopts nationally inconsistent or restrictive regulations, particularly given Australia only comprises 1-2 per cent of the international vehicle market. This risk appears unlikely given Australia's current commitment to harmonising international vehicle standards and adopting a nationally consistent approach to AV regulations (see Table 1). However, Australia's relatively small automotive market, along with its right-hand drive requirements and preference towards SUVs may mean that AVs arrive a couple of years later than in larger markets, such as Europe and North America.

4.4. Impact of policy, regulatory and infrastructure factors

Policy, regulatory and infrastructure factors will affect uptake of AVs on Australian roads. For instance, if limited road and communications infrastructure prevents AV benefits from being realised, this would likely lower consumer willingness to pay for the technology.

Given the vehicles rely on public infrastructure and impose external costs, AVs require greater public planning and regulation than other technologies (Litman 2021). For example:

- Public infrastructure planning includes decisions such as whether to build dedicated AV lanes to allow for platooning (that is, where numerous vehicles drive close together at relatively high speeds, possibly using electronic or mechanical coupling).
- New technologies and services driven by AVS are likely to affect road, parking and transit needs. Infrastructure costs may increase as a result of higher road design requirements and maintenance standards.
- AVs may stimulate increased vehicle travel, particularly with non-drivers, due to increased accessibility, convenience and comfort. This may lead to increased congestion, pollution and

sprawl-related[12] costs. On the contrary, AVs may facilitate greater vehicle sharing, allowing households to reduce vehicle ownership and travel. The net impact of AVs will depend on transport and land use policies.

4.4.1. Regulatory and policy-based enablers

Deloitte (2020) forecasts large-scale adoption of AVs beyond selected use cases will be especially dependent on regulatory factors, and finds this is the potential predominate driver between its base case and disruptive case scenarios. Similarly, Research and Markets (2021) considers global regulations favouring testing and deployment will determine the adoption timeline for consumer markets. A number of the regulatory and policy-based drivers likely to affect AV uptake in Australia are discussed in Table 1.

Table 1: Potential regulatory and policy-based drivers of AV uptake

Policy or regulatory driver	Potential impact on AV uptake
Australasian New Car Assessment Program (ANCAP): Sets safety ratings for cars and currently provides higher ratings for autonomous safety technologies.[13] Empirically, ANCAP has found its ratings encourage the swift adoption of technologies ahead of regulation. For instance, ANCAP has been encouraging the fitting of AEB, which has increased from around 35 per cent in 2015 to over 75 per cent of the Australian new car market in 2019.	If AVs are clearly demonstrated to be safer than human-driven vehicles, it is expected ANCAP would encourage this level of automation and make it a requirement for a five star ANCAP rating. A higher ANCAP rating for AVs should increase consumers' willingness to pay (and therefore demand) for AVs.
Australian Design Rules (ADRs): Set the requirements for new cars coming into Australia, and are administered by DITRDC.[14]	If specific automation features are set in the ADRs, cars imported into Australia will need to have those features.
United Nation's vehicle regulations: Set international regulations, in which many governments (including the Australian Government) seek to harmonise their standards.	Likely to influence the ADRs, which will determine requirements for new cars coming into Australia.

[12] That is, costs associated with urban-sprawl. For instance, increased travel costs, decreased economic vitality of urban centres, natural habitat losses, increased tax burdens for greater per capita infrastructure needs.

[13] Including driver assistance (collision avoidance), blind spot monitoring, autonomous emergency breaking, lane keep assist/lane support systems, and intelligent speed adaptation/speed assistance systems.

[14] The *Motor Vehicle Standards Act 1989* requires all road vehicles, whether they are newly manufactured in Australia or are imported as new or second hand vehicles, to comply with the relevant ADRs at the time of manufacture and supply to the Australian market.

Policy or regulatory driver	Potential impact on AV uptake
Other countries' manufacturing requirements: Australia imports its new cars. In 2019-20, Australia's largest passenger vehicle importing countries/regions (based on import value) were Japan (38 per cent), the EU (20 per cent), Republic of Korea (13 per cent), and the US (10 per cent).	If the manufacturing requirements of countries that Australia imports its vehicles from encourage or require vehicles to include particular automation features, these features will make their way into the Australian fleet. Australia's imports of vehicles could also be impacted by trade agreements.
The National Transport Commission's Automated Vehicle Program: The program focusses on achieving nationally consistent reforms that support the safe commercial deployment of AVs. Reforms include updates to driving laws, motor accident injury insurance, and government access to vehicle-generated data (National Transport Commission 2020).	Updates to driving laws will be required to allow AVs on Australian roads. Clarity around responsibility when an AV is involved in a crash will be important for improving consumer sentiment. For example, in 2017, 86 per cent of Australians and New Zealanders reported they would have concerns over the legal and financial implications if an AV is involved in a collision or makes mistakes (Ledger et al. 2018).
The National Policy Framework for Land Transport Technology and National Land Transport Technology Action Plan: These policy instruments support an integrated policy approach to developing and adopting emerging transport technologies. This work includes considering the safety, security and privacy implications on the deployment of AVs (DITRDC 2020a).	An integrated policy approach, including towards the safety, security and privacy, will be important for improving consumer sentiment towards AVs (see Section 4.2.2).

4.4.2. Enabling infrastructure

Austroads (2019) identified what infrastructure changes would likely be required to support AVs on rural and metropolitan highways and freeways. In doing so, it recognised that some infrastructure gaps may also be addressed by improvements in vehicle technologies. Given AV technology is still being developed, uncertainty remains around what standards of infrastructure are required to enable AVs. Nevertheless, Austroads (2019) was able to identify three types of infrastructure that would be key to enabling AVs: infrastructure that assists on-board sensors to interpret the road, high-definition mapping and continuous data connectivity (particularly cellular networks). The enabling role of these infrastructure types is described in Table 2 below.

Table 2: Key infrastructure for enabling AVs

Infrastructure that assists sensors to interpret the road	Infrastructure that assists on-board sensors to interpret the road predominately relate to line markings (suitable line types, line quality, curve radius) and traffic signs that can be interpreted by machine vision systems (suitable position, visual quality). In addition to appropriate line markings and traffic signs, in general, roads must be well-maintained to enable AVs; with potholes and other maintenance issues presenting challenges to AVs (Duvall et al, 2019).
High definition mapping	Prior high definition maps expand the situational awareness of AVs by encoding road-level features, allowing the vehicle to verify the data received by its sensors against the prior map and fill gaps where sensor data is limited due to obstructions, such as rain. While high definition maps can be avoided, alternatives can be restrictive (such as geo-bounding the driving area).
Continuous data connectivity	Austroads (2020a) found that AVs will require cloud connectivity, and that while beneficial, cooperative intelligent transport systems (C-ITS) would not be essential. Enabling communications infrastructure is required to support cloud connectivity, with Austroads (2020a) noting that cellular networks are particularly important for enabling continuous data connectivity. Austroads (2019) found access to mobile data would enable AVs to access base map information and receive live updates, with consulted AV manufacturers viewing continuous 4G or better data communications as being strongly desirable or essential.

Infrastructure to assist sensors

There is some reason to expect there will be infrastructure to enable on-board sensors on AVs to interpret the road by the time AVs arrive on Australian roads. There are already benefits in providing the infrastructure as this also improves the performance of active safety systems, which have already entered the market and are forecast to increase at a fast rate (discussed in Chapter 2). However, given AVs will likely require higher road standards than what is needed to support active safety systems, foresight will be required if these earlier investments will also meet the needs of AVs. Fortunately, work is already underway that seeks to provide such foresight – for instance, Austroads (2021).

Despite these promising signs, persistent efforts to keep roads well maintained will be required. For instance, Austroads (2020b) research finds that while many recent harmonisation design standards for pavement markings meet or exceed machine-vision requirements, road agencies can have poor maintenance processes and limited information on pavement markings and asset conditions.

It is also worth noting that work in this area is still being explored, and some researchers identify that a broader range of infrastructure upgrades may be needed to enable AVs. Duvall et al (2019) observe there has been increasing debate around how much should be invested in enabling V2I systems (such as sensors in roads or street signs that send signals to AVs) to enable AVs. For example, Infrastructure Partnerships Australia (2017) indicate that more investment would be required, so that infrastructure can clearly communicate with and guide AVs. This includes debate about which V2I short range communication standards are more appropriate – DSRC or C-V2X (Duvall et al, 2019).

High-definition mapping

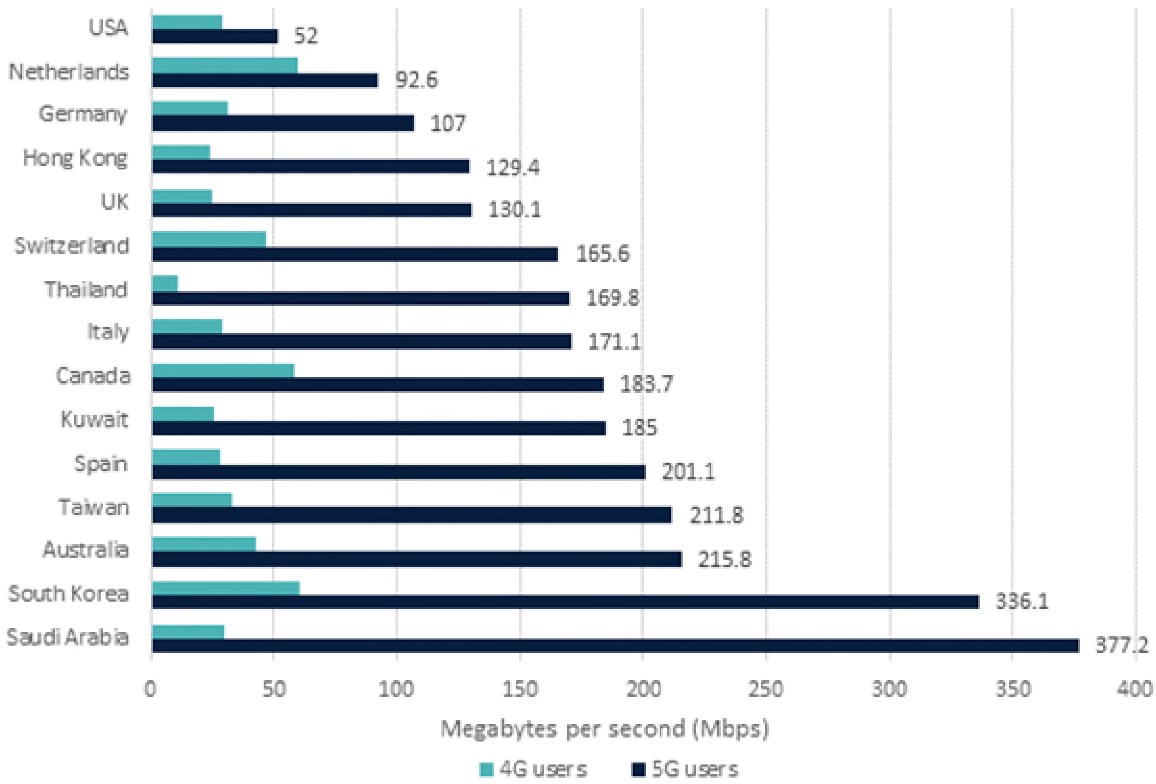
The timely arrival of high-definition maps also has promise. Austroads (2019) finds that while high-definition maps do not exist in Australia beyond demonstration and prototype examples, some companies have collected the data required to build the maps, but are waiting for customer demand before processing it into maps that would then require ongoing updates.

The exact role of the government relative to the market in providing this infrastructure is not clear-cut. Hausler and Milford (2020) consider the task of providing reliable high-definition maps will likely require collaboration between car manufacturers, map makers and governments. They observe that assumptions being made by governments vary globally, from a strong government role in the EU, to a market-led approach in the US (with a greater reliance on crowd-sourced data, which is reactive in nature to features like roadworks). High-level positioning accuracy is also likely to be among the technology enablers for AVs, along with high definition maps built for AVs. Australia is in the process of upgrading its satellite-based positioning system to provide 10cm level accuracy across Australia (Geoscience Australia n.d.).

Continuous data connectivity

Australia appears to be tracking well in providing infrastructure to enable continuous data connectivity, although connectivity in regional and remote areas remains variable (DITRDC 2021). Australia is performing well with rolling out 5G and providing 4G, with Australians experiencing strong average download speeds by international comparison (Figure 44). Other metrics also tell a positive story, with Opensignal finding the average proportion of time its users spend with a 4G or better connection to be around 94 per cent across the three main network providers (Fenwick 2021). Australian Opensignal 5G users are found to spend 10.1 per cent of their time connected to 5G, and experience 5G in almost one-third of locations, which is impressive given the large geographic area of the Australian market (Fogg 2021).

Figure 44: Average download speeds experienced by 4G and 5G users



Note. Data collection period 1 July–28 September 2020. Canada, Hong Kong, Taiwan and Thailand 5G services launched in 2020. Source: Fogg (2020)

Other enabling infrastructure

In addition to the key enabling factors identified by Austroads (2019), additional infrastructure will likely also play an important role in enabling AVs. This might be by enabling use-cases (for example, shared mobility) or other features associated with AVs (electrification).

If demand for AVs is driven by demand for shared autonomous mobility, investments will also be needed to support shared autonomous mobility. Duvall et al (2019) identify that this might include support facilities, staging areas, curb modifications and mobility hubs. Similarly, Infrastructure Partnerships Australia (2017) identifies that curbs and existing street parking space may be redefined to reflect the change in road use following the introduction of AVs.

If AVs are developed as electric vehicles (EVs), EV charging infrastructure will be important for enabling AVs – noting that demand for EVs is forecast to increase in any case (BITRE 2019).

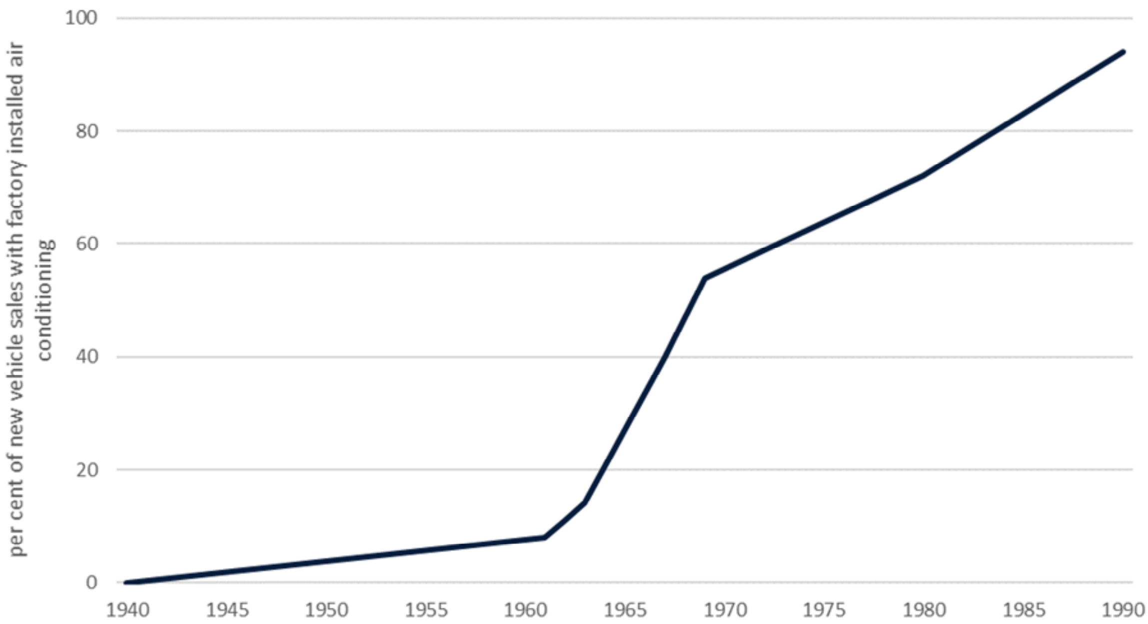
4.5. Diffusion of previous automotive innovations

In forming assumptions around AV deployment, it is valuable to consider how previous vehicle innovations have progressed. Litman (2021) notes new vehicles generally require three to five decades to penetrate 90 per cent of the vehicle fleet given they are costly, durable and highly regulated. Due to the complex and costly nature of AV technology, market acceptance and penetration is likely to take longer than previous vehicle technologies. On this basis, and noting that fleet turnover reduces as new vehicles become more durable, AVs are more likely to take greater than five decades to reach market saturation. Future changes in consumer behaviour are anticipated through tailored scenario testing, including the impact of faster penetration of AVs (see Chapter 5). In forming this view, the following vehicle innovations are considered:

- **Automobiles:** While mass production of automobiles started in 1908, widespread vehicle ownership only eventuated in the 1960s, with vehicle ownership not approaching saturation until around 1980. This represents a period of about 75 years between commercial introduction to market saturation.
- **Automatic transmissions:** While automatic transmissions were first developed in the 1930s, they did not become reliable and affordable until the 1980s. When optional, they cost around USD1,500 and are currently included in 90 per cent of new vehicles in North America (as well as Australia), and 50 per cent in Europe and Asia. This represents a period of about 50 years between commercial introduction to market saturation.
- **Factory installed air conditioning:** While factory installed air conditioning was first offered in cars in the 1940s, it took around five decades for this technology to reach over 90 per cent market saturation (Figure 45). This represents a period of about 50 years between commercial introduction to market saturation.
- **Hybrid vehicles:** These became commercially available in 1997. They typically add USD5,000 to prices and represented two per cent of total vehicle sales in 2016. While the market saturation rate is uncertain, market share is currently about four per cent. This represents a period of at least 25 years between commercial introduction to market saturation.
- **Electric vehicles:** While electric cars were developed in the late-1800s, major manufacturers produced improved electric vehicles in the 1990s (Litman 2021). By 2020, many companies sold

high quality electric cars. The typical cost premium is about USD10,000 for high performance electric vehicles, and about one per cent of total vehicle sales are currently electric. While the market saturation rate is currently unknown, Litman (2021) expects it will reach over 80 per cent. BITRE (2019) has adopted a 65 per cent market saturation rate in its electric vehicle forecasts.

Figure 45: Uptake of factory installed air conditioning in new vehicle sales



Source: The Australian Institute of Refrigeration (2008)

While previous diffusion can inform uptake, there is also considerable uncertainty in that AV features may be so different to previous technologies that the adoption pattern is also different. For example, the potential of AVs to enable a shared fleet of vehicles may reduce the total number of vehicles on the roads in the future, which may accelerate the rate of penetration. Alternatively, the enabling infrastructure is so different in scope that it could take greater coordination and time to achieve saturation. A range of sensitivity analyses (section 5.2.1) are presented in this report to reflect the uncertainty associated with the take-up of AV technologies.

4.6. Overall effect on input assumptions

This section summarises the parameter values used to produce the AV forecasts in Chapter 5 (see Table 3), along with the degree of confidence around those values. This is where lower confidence calls for a broader set of inputs to be explored as sensitivities and across scenarios.

Table 3: Parameters used in AV forecasts

Parameter	Value	Confidence level
Date that SAE Level 4 vehicles become commercially available	2026 in the base case. 2031 as a slow sensitivity.	Moderate to high. While there is a general consistency between many of the current forecasts, forecasts have been revised downwards by material amounts in recent years. This reflects uncertainty around new technological developments. Given uncertainty is likely to result in delays rather than early delivery, a fast commencement date is not explored as a sensitivity.
Date that SAE Level 5 vehicles become commercially available	2031 in the base case. 2026 and 2036 as fast and slow sensitivities respectively.	Moderate to low. There are few SAE Level 5 forecasts available. While some forecasts indicate that SAE Level 4 and SAE Level 5 vehicles are likely to become commercially available around similar times, other forecasts suggest otherwise. The late date of 2036 as a slow sensitivity reflects scope for delays given the incremental complexity in achieving SAE Level 5 automation.
Market saturation rate for SAE Level 4+5 vehicles	Market saturation of 85 per cent in the base case (which the model indicates will be reached around 2070 for SAE Level 4+5 forecasts). The same rate is applied for SAE Level 4+5 and SAE Level 5 forecasts, consistent with SAE Level 4 AVs eventually becoming redundant in favour of SAE Level 5 technology. A market saturation rate of 30 per cent as a low saturation sensitivity, 100 per cent as a high saturation sensitivity.	Low. Market saturation of 85 per cent reflects a reasonably likely market saturation based on the qualitative factors discussed in Section 4.6.2 below. However, this is ultimately an assumption around what the world will look like in 50 years’ time with respect to a technology that is still being developed.

Parameter	Value	Confidence level
Uptake speed for SAE Level 4+5 and SAE Level 5 vehicles	The central uptake speed, used in the base case, is a function of: (a) the rate of change implied from available forecasts; (b) the logarithmic uptake function;[15] and (c) the central market saturation rate discussed above. A slow and fast rate of change was explored as sensitivities by halving and doubling the rate of change implied by the available forecasts respectively. In scenarios, a growth rate that triples the rate of change implied by available forecasts was explored.	Moderate to low. There is reasonable confidence around the logarithmic uptake pattern, based on the uptake of new technologies empirically. However, there is a low level of confidence around the rate of change implied by available forecasts as forecasting the uptake of technologies that are currently in the development phase is innately difficult. This high rate of uncertainty is reflected by exploring a materially slower and faster rate of change than what has been considered in the base case.

15 As discussed in Appendix A.

4.6.1. Rationale for dates of commercial availability

BITRE assumes that SAE Level 4 AVs will become commercially available in Australia from 2026 in the base case. BITRE also explores a slow introduction date of 2031. These choices are informed by the following considerations:

- A commercial availability date of 2026 reflects that the earlier forecasts used in this report are generally from 2025 onwards, and these tend to focus on global uptake rather than being Australia-specific (see Global Data 2020, Accenture 2017). Where forecasts commence later (for example, several commence from 2030), SAE Level 4 AVs typically reach two per cent of vehicle sales by that point, indicating an earlier introduction date (see Deloitte Global 2020, Strategy& 2020, Litman 2021, Grand View Research 2020, Reid-Cleveland 2021).[16]
- While a 2031 introduction date as a slow sensitivity is later than the introduction date in the central scenario, this is reasonably likely to occur. This aligns with Litman's (2021) view that AVs will optimistically be safe and reliable by 2025, and may be commercially available in many places by 2030. While 2031 is later than when many forecasts indicate that SAE Level 4 AVs will become available, it is reasonably likely that the technology may arrive later in Australia given our small population and geographic separation to OEMs.

BITRE assumes that SAE Level 5 AVs will become commercially available in Australia from 2031 in the base case. BITRE also explores a fast introduction date of 2026 and a slow introduction date of 2036 as sensitivities. These choices are informed by the following considerations:

- Global Data (2020) predicts there will be 8,000 SAE Level 5 vehicles globally in 2025. Prognos (2018) also forecasts that SAE Level 5 vehicles will be available in 2025. Given these numbers are very low, and it is likely that AVs will arrive later in Australia than in larger markets, a 2026 introduction date is adopted as a fast sensitivity.
- Other information indicates the fast sensitivity is likely to be quite optimistic. For instance, Austroads (2020a) does not expect SAE Level 5 vehicles to be available in Australia before 2030, informing a central estimate of 2031.
- Strategy& (2020) forecasts SAE Level 5 vehicles will comprise one per cent of vehicle sales in the EU and China in 2035, and zero per cent in the US. While Strategy&'s (2020) forecasts would likely align with commercial availability before 2035, analysis of country-specific factors does not suggest that take-up rates in Australia would exceed those in the US, informing BITRE's slow sensitivity of 2036.

4.6.2. Rationale for market saturation rates

The saturation rate of a technology is the maximum market penetration it achieves. Historically, saturation rates have varied due to differences in government regulation, consumer preferences and available alternatives. For instance, mandated technologies, such as seatbelts, reached 100 per cent

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16 For example, while Deloitte Global (2020) only provides forecasts at 2035, these range from 5-10 per cent of vehicle sales at that point, indicating initial sales would commence earlier.

market saturation. Where there is strong consumer preference to use non-mandatory technologies, market saturation is also likely to be high.

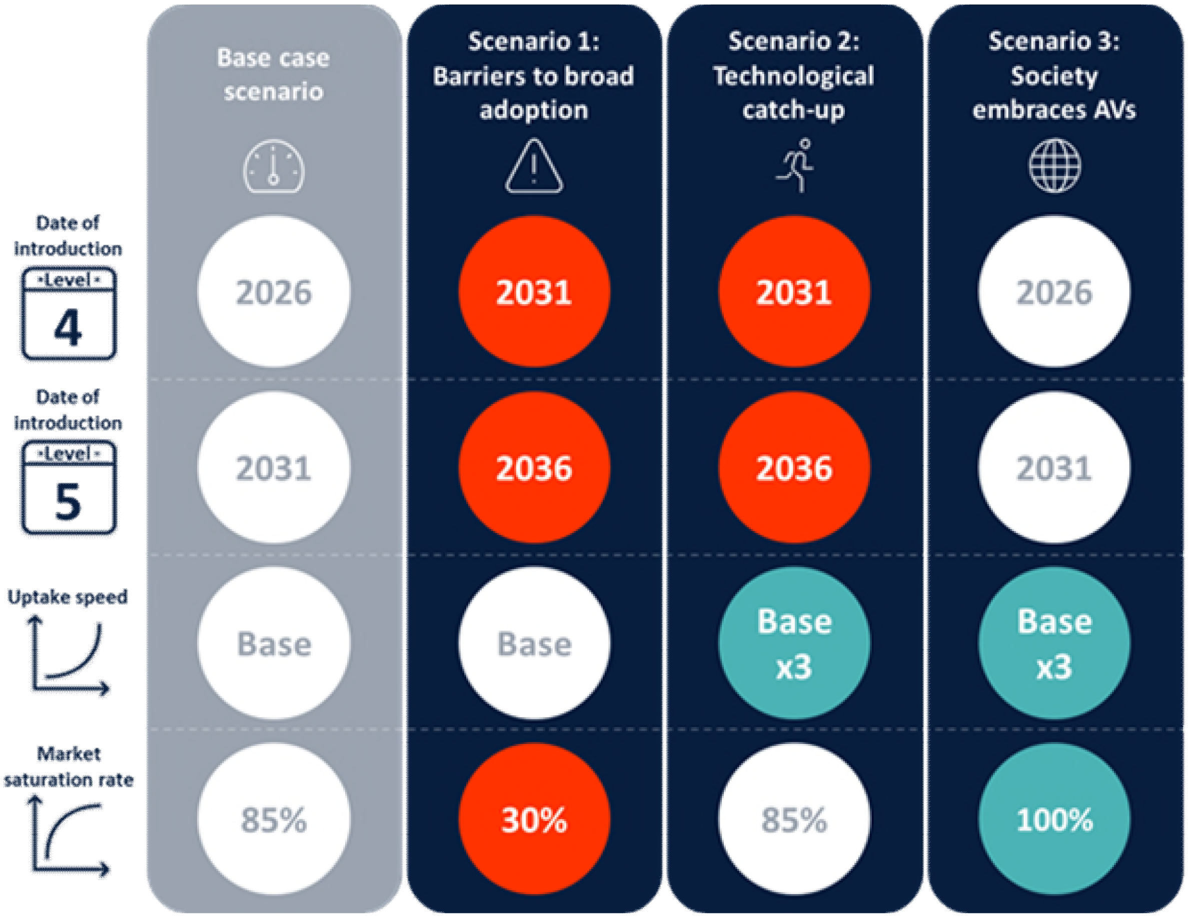
BITRE’s rationale for adopting the following market saturation rates for SAE Level 4+5 and SAE Level 5 AVs are set out below. Saturation rates of 30, 85 and 100 per cent are adopted as low, central and high saturation sensitivities respectively. This choice has regard to the following factors:

- A central saturation rate of 85 per cent has regard to the empirical preference of Australian consumers to adopt automatic transmission, as well as technologies that have safety benefits. A sub-100 per cent rate reflects an expectation that this level of automation is unlikely to be mandated, a proportion of Australian consumers will continue to show minimal willingness to pay for the technology, and that new non-AV vehicles will still be commercially available in the future. This proportion may include people who enjoy driving, have limited financial resources, or remain concerned with the technology’s tail-end risks (that is, the chance of a loss occurring due to a rare event).
- A high saturation rate of 100 per cent reflects the possibility of a world where, after reaching a critical mass and becoming ‘normalised’, AVs demonstrate high levels of safety relative to human-driven vehicles, which prompts a regulatory response to eliminate human-driven vehicles.
- A low saturation rate of 30 per cent reflects the possibility that, if a sufficient number of tail-end risks materialise (such as major failures causing security or safety incidents), demand may only come from consumers with particularly high willingness to pay. These consumers are likely to include (among others) providers of commercial services (e.g. last-mile delivery and ride-hailing), time-poor commuters who are unable to use public transport, individuals unable to drive and those who are attracted to the novelty or status of owning an AV.

4.6.3. Scenarios explored

In addition to testing the sensitivity of forecasts to changes in individual parameters, BITRE also explores different scenarios where multiple parameters are changed relative to the base scenario. Figure 46 summarises the parameters adopted in each scenario.

Figure 46: Key parameters adopted in scenarios



The base case scenario draws on central estimates and could be reasonably interpreted as BITRE's 'best estimate' of the future state of the world. However, the combination of parameter values shown in Figure 46 were selected so each scenario is internally-consistent and represents a plausible state of the world. Table 4 presents a narrative around how each of these scenarios might develop, thereby providing a logical explanation as to their plausibility.

Table 4: Description of scenarios explored

Base case scenario	The development of AV technology progresses as expected, with no unforeseen set-backs. High willingness to pay customers drive initial demand for AVs. As costs decrease and benefits are demonstrated, demand for AVs increases as projected. A small proportion of consumers continue to show minimal willingness to pay for AVs for various reasons (costs, enjoy driving, perceived risks).
Scenario 1: Barriers to broad adoption	AVs face a slow start. Unforeseen security and safety issues are identified at the trial stage, delaying the ability of policymakers to agree AVs are secure and safe. While many consumers doubt the benefits of AVs when they arrive, there is still some demand as high willingness to pay customers (such as commercial service providers) drive technological uptake. Many consumers continue to doubt whether the benefits of AVs outweigh the costs, particularly as initial scepticism undermines investment in enabling infrastructure and consumer sentiment.
Scenario 2: Technological catch-up	AVs face a slow start. A high level of caution is exercised in proving the technology is sound, secure and safe. By the time AVs arrive, enabling institutional and physical infrastructure is reasonably established. This, along with efforts to prove AVs are sound, safe and secure, allows the benefits of AVs to be quickly demonstrated, driving a fast rate of uptake. A small proportion of consumers continue to show minimal willingness to pay for AVs for various reasons (costs, enjoyment of manual driving, perceived risks).
Scenario 3: Society embraces AVs	**The** development of AV technology progresses as expected, with no unforeseen set-backs. Policy foresight meant enabling institutional and physical infrastructure is reasonably established when AVs arrive. Public awareness campaigns have strengthened consumer sentiment, promoting high willingness to pay among many customers. The benefits of AVs are quickly demonstrated, driving a fast rate of uptake. AVs reach a critical mass and demonstrate high levels of safety relative to human-driven vehicles, prompting SAE Level 5 automation under the Australian Design Rules.

It is worth noting that the scenarios described in Table 4 are non-exhaustive. These were selected to illustrate a broad range of what is possible, and to understand the circumstances under which they might occur.

CHAPTER 5

Uptake of fully automated vehicles

Self-driving vehicles, those with SAE Level 5 automation technology, do not need human input under any circumstances. SAE Level 4 vehicles can assume driving under specific circumstances in specific areas. Operating in more defined environments (spatial and traffic), these vehicles are expected to be the first vehicles to emerge with full self-driving capabilities. Therefore, estimating the date at which SAE Level 4 technology becomes commercially available is the first step in forecasting the uptake of AVs.

An article in the Australian on 14 January 2021 (Swan 2021) quoted Edzard Overbeek, the chief executive of Here Technologies, as saying that an expectation reset is needed on self-driving technology. Mr Overbeek observed that while advanced driver assistance systems are kicking in (see Figure 3.13 in Chapter 4), solving the regulatory issues around self-driving vehicles to the point where AVs are common on our roads is about a decade away.

Steps are being taken to craft a regulatory environment that can support AVs. In May 2021, the National Transport Commission released a policy paper, calling for a new national regulator with the power to ensure that in-service automated vehicle safety risks are comprehensively addressed by 2026. The reform program aims to develop end-to-end regulation to support the safe commercial deployment and operation of automated vehicles at all levels of automation in Australia, in collaboration with Commonwealth, state and territory governments and Austroads (National Transport Commission 2021).

In examining the prospects for self-driving SAE Level 4+5 and SAE Level 5 vehicle uptake in the new vehicle fleet, BITRE surveyed recent articles that had numeric forecasts out to at least 2035. Seven studies were found, dating from 2018 onwards. While the areas forecast could not be completely standardised, these seven studies were drawn on to approximate a reasonable global forecast.

While Austroads also provides forecasts for automated vehicles in Australia (Austroads 2021), these forecasts are based more closely around operational design domains (ODDs) rather than SAE levels of automation. BITRE and Austroads have liaised with each other when developing their respective forecasts. While Austroads' forecasts provide different information (that is, forecasts around ODDs and out to 2031), the overall findings are broadly consistent to those found in this report.

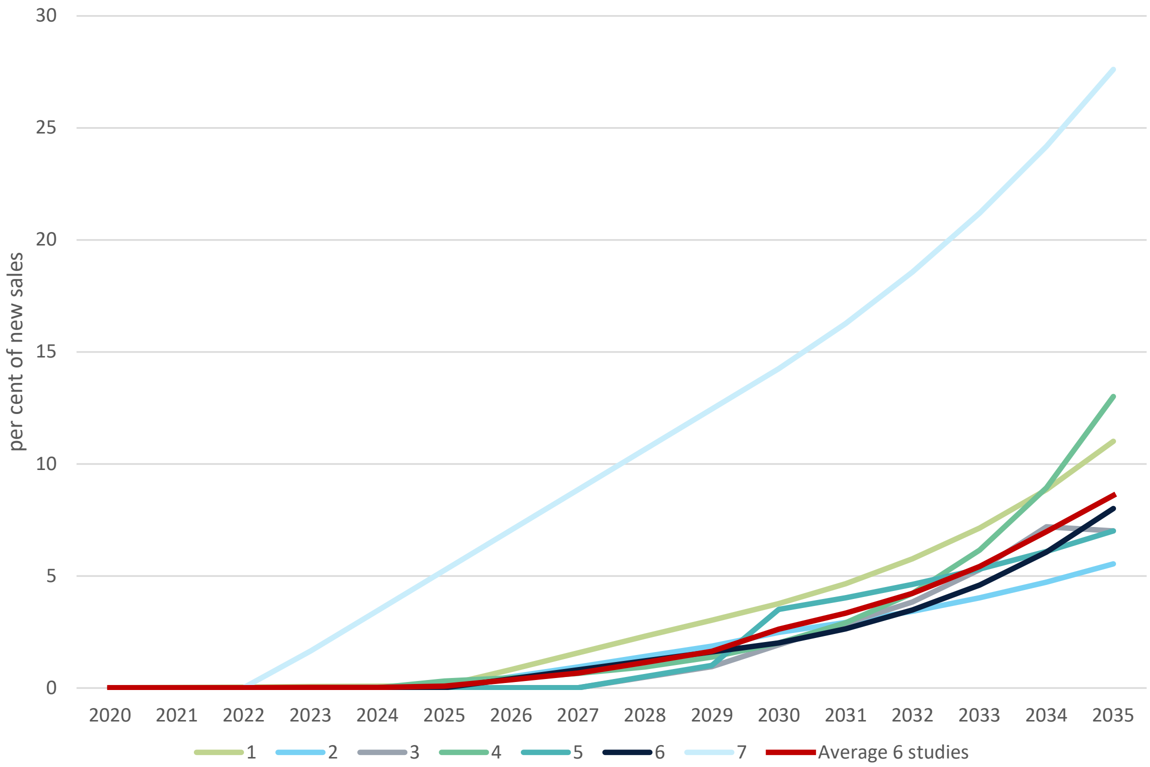
Table 5 gives details of the seven studies drawn upon, as well as how BITRE incorporates the forecasts provided in the studies.

Table 5: Studies projecting uptake of SAE Level 4+5 AVs

#	Source	Forecasts provided	Use in BITRE forecasts
1	Strategy& (2020)	Forecasts share of new vehicle sales by SAE Levels (0-2, 3, 4, 5) for years 2020, 2025, 2030, 2035. Separate forecasts for Europe, US and China. Forecasts cover all 'new vehicle' sales.	BITRE uses SAE Level 4 and SAE Level 5 forecasts for new vehicles to inform its SAE Level 4+5 and SAE Level 5 forecasts for light vehicles. A simple average is calculated across countries/regions. Given the level of imprecision around AV forecasts, a rough proxy for a global forecast informs an Australian forecast.
2	Global Data (2020)	Forecasts global AV volumes by SAE Level (4, 5) up to 2035. Forecasts cover all units produced.	BITRE converts forecast sales quantities into sale shares. SAE Level 4 and SAE Level 5 forecasts inform SAE Level 4+5 and SAE Level 5 forecasts for light vehicles in Australia.
3	Deloitte Global (2020)	Forecasts share of new vehicle sales as SAE Level 4+5 AVs in 2035. Provides separate forecasts for 'base case' and 'disruptive case'. Forecasts cover all new vehicle sales. Separate forecasts for the US, Japan, China and 'Euro5' (Germany, France, Spain, Italy and the United Kingdom).	BITRE uses the base case SAE Level 4+5 forecast to inform its SAE Level 4+5 forecast for light vehicles in Australia. The disruptive case was not used as updated information indicates that AVs are not on that trajectory. BITRE calculates a simple average across countries/regions. Given the level of precision around AV forecasts, a rough proxy for a global forecast should be sufficient to inform an Australian forecast.
4	Litman (2021)	Forecasts global share of new vehicle sales as AVs up until 2080. Also forecasts share of fleet and travel. Provides 'upper' and 'lower' forecasts.	BITRE uses the lower share of new vehicle sales forecast to inform its SAE Level 4+5 forecast for light vehicles in Australia.
5	Grand View Research (2020)	Forecasts global demand for AVs in 2030 in units.	BITRE converts forecast sales units into share of sales, and uses global AV forecast to inform its SAE Level 4+5 forecast for light vehicles in Australia.
6	Reid-Cleveland (2021)	Forecasts global sales of SAE Level 4 AVs.	BITRE combines the SAE Level 4 forecast with Global Data's SAE Level 5 forecast to derive a SAE Level 4+5 forecast. BITRE uses global sales projections to convert the SAE Level 4+5 forecast into share of new sales, informing its SAE Level 4+5 forecast for light vehicles in Australia.
7	Prognos (2018)	Separate forecasts for share of vehicles capable of highway pilot, city pilot and door-to-door pilot. Separate forecasts for optimistic and pessimistic scenarios.	BITRE uses a simple average of optimistic and pessimistic forecasts. Door-to-door forecasts inform BITRE's SAE Level 5 forecast. Highway and city pilots were considered for inclusion to inform BITRE's SAE Level 4+5 forecast, but these forecasts were excluded as an outlier.

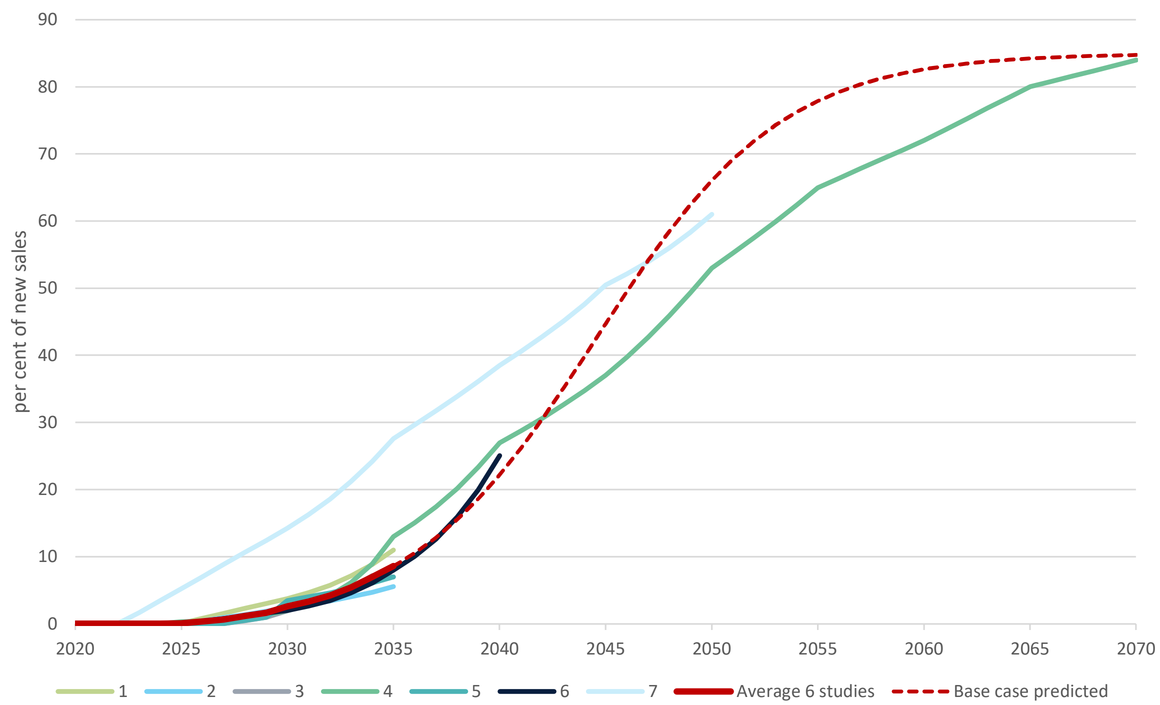
Figure 47 shows the projected share of new vehicle sales with SAE Level 4+5 automation to 2035 from across these seven recent studies. The forecasts provided in all but one of the studies are consistent with SAE Level 4 AVs being commercially available from around 2025 and SAE Level 4+5 sales penetration increasing to between 5 to 12 per cent by 2035.

Figure 47: Projections to 2035 – share of new light vehicle sales with SAE Level 4+5 automation



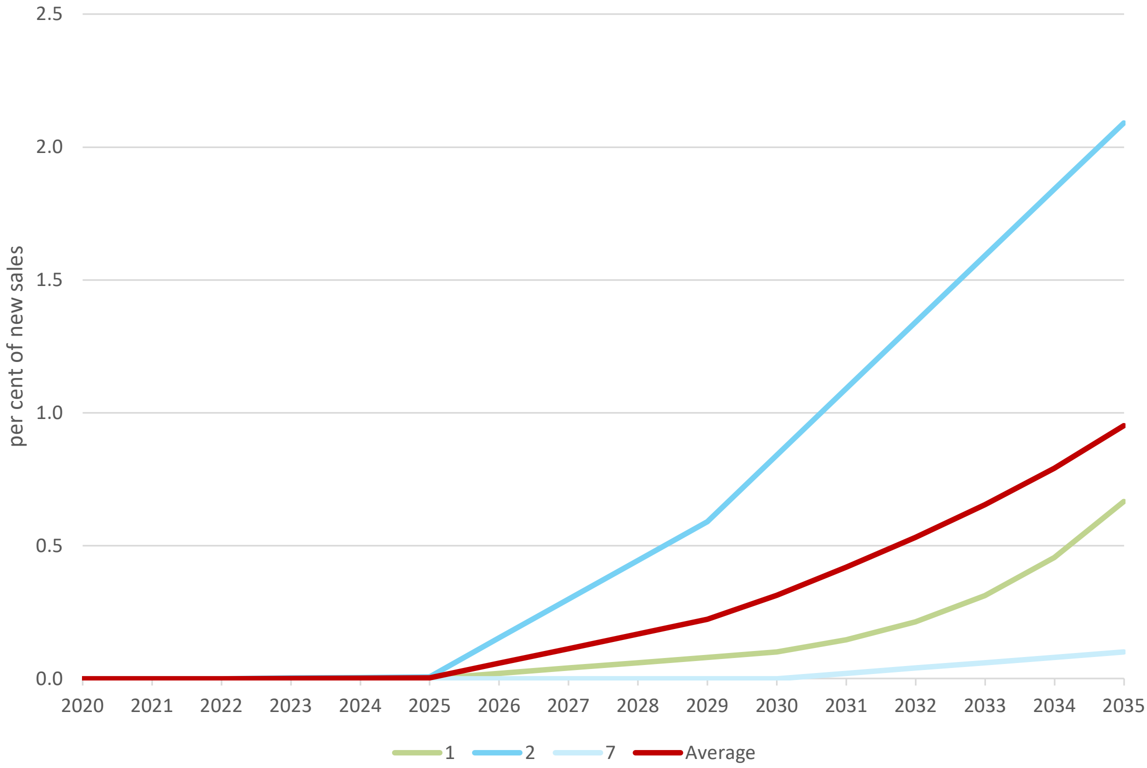
Projections of SAE Level 4+5 sales to 2070 draw on the average of the lowest six studies and assume a saturation level of 85 per cent. This is shown in Figure 48 and forms the base SAE Level 4+5 forecast in Section 5.1.

Figure 48: Projected share of new light vehicles sold with SAE Level 4+5 automation



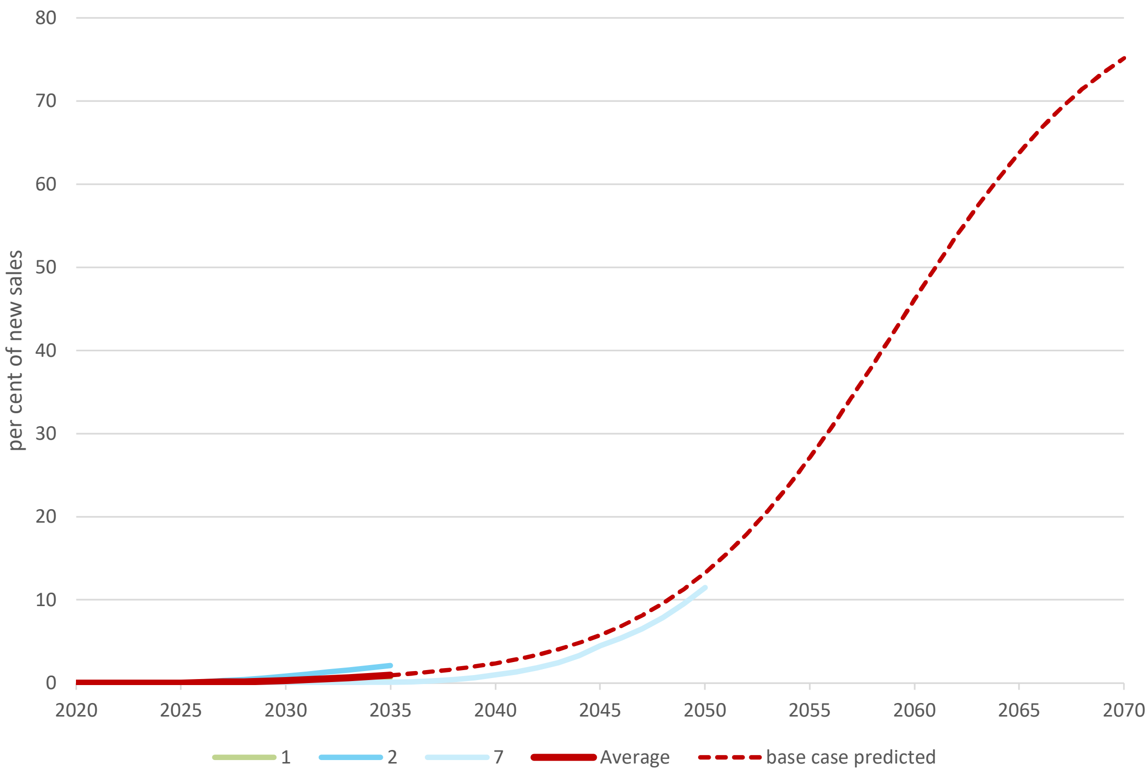
A similar analysis can be done for SAE Level 5 automation. Three of the above studies provide a specific SAE Level 5 forecast to 2035 (shown in Figure 49).

Figure 49: Projections to 2035 – share of new vehicle sales with SAE Level 5 automation



Projections of the share of SAE Level 5 AVs in new vehicle sales to 2070 (with an assumed saturation level of 85 per cent) are shown in Figure 50. This forms the base SAE Level 5 forecast for the analysis in Section 5.2.

Figure 50: Projected share of new light vehicles sold with SAE Level 5 automation



5.1. Uptake of vehicles with SAE Level 4+5 automation

The base case forecast for SAE Level 4+5 AV uptake (Figure 48) is the product of multiple guesses by experts in the field. This section examines how these forecasts would change under different assumptions.

Table 6 shows the six scenarios examined for Level 4+5 AV uptake. The base case forecast is based on the central parameters for the introduction date, growth rate and saturation level. Sensitivities are also tested by varying one of the three parameters listed, with the other two held constant. The tailored scenarios explore a combination of the assumptions tested as sensitivities.

Table 6: Six scenarios for forecasting SAE Level 4+5 AV uptake

Scenarios for SAE Level 4+5 AV uptake	Introduction date*	Growth rate	Saturation rate
Central (base case)	2026	medium**	85 per cent
Sensitivities			
Slow	2031	1/2 medium	30 per cent
High	2026	2 x medium	100 per cent
Tailored scenarios			
Scenario 1: Barriers to broad adoption (late introduction date, low saturation)	2031	medium	30 per cent
Scenario 2: Technological catch-up (late introduction date, faster growth)	2031	3 x medium	85 per cent
Scenario 3: Society embraces AVs (faster growth, high saturation)	2026	3 x medium	r cent

* Note that the introduction date here refers to L4 vehicles, with L5 vehicles occurring later. Under the SAE Level 4+5 scenarios, the earlier introduction (and uptake) of L4 vehicles means that L4 vehicles make up a larger proportion of sales and fleet relative to L5. ** 'medium' refers to the average growth rate implied by the studies drawn upon (Table 5).

5.1.1. Sensitivity analysis

Figure 51 and Figure 52 show the base case projections for SAE Level 4+5 AV sales as a proportion of light vehicle sales and the light vehicle fleet respectively. These forecasts show the penetration of AVs through the light vehicle fleet lags about 10 years behind the penetration of light vehicle sales.

Figure 51: Base case projected share of new light vehicles sold as SAE Level 4+5 AVs

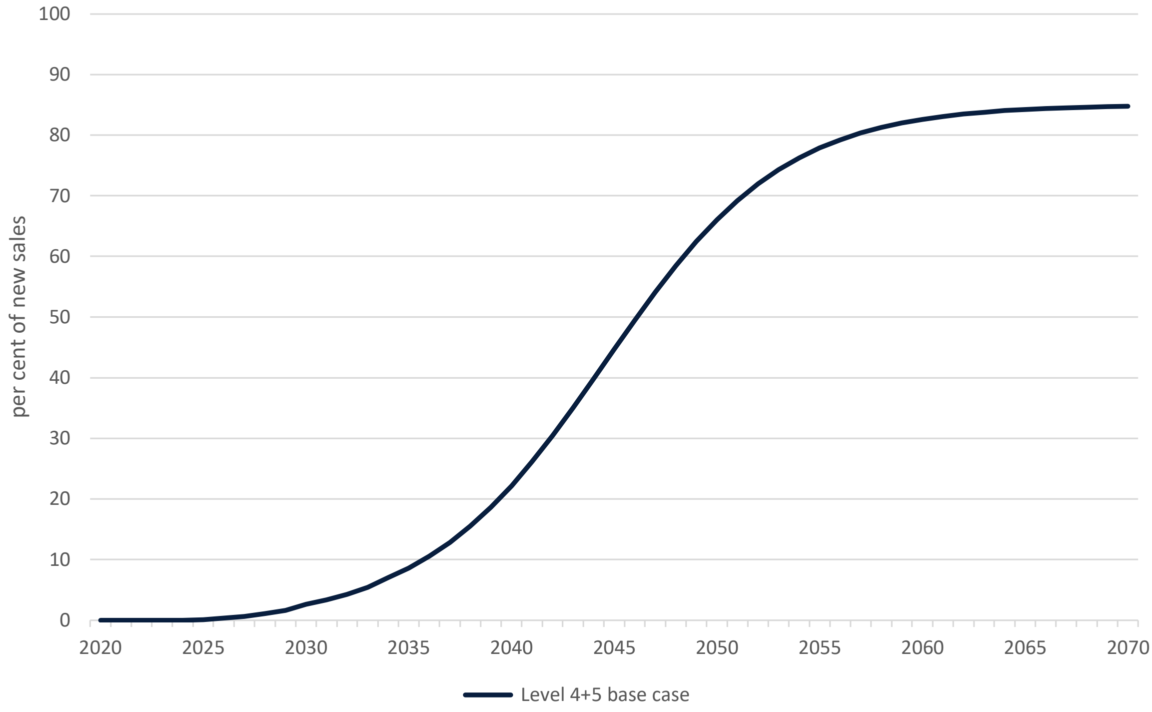


Figure 52: Base case projected share of light vehicle fleet as SAE Level 4+5 AVs

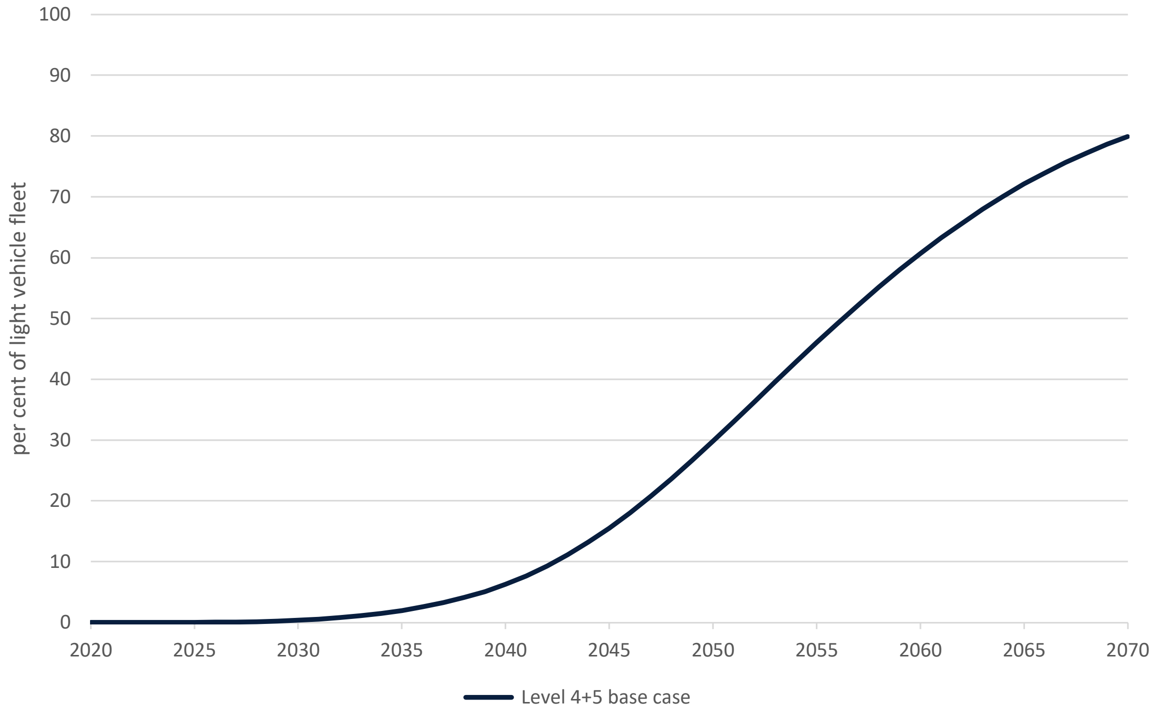


Figure 53 shows the base case and late introduction date of 2031 sensitivity for SAE Level 4+5 AV uptake in new light vehicle sales. An earlier introduction date was not considered realistic and was therefore not explored.

Figure 53: Introduction date sensitivity – projected share of new light vehicles sold as SAE Level 4+5 AVs

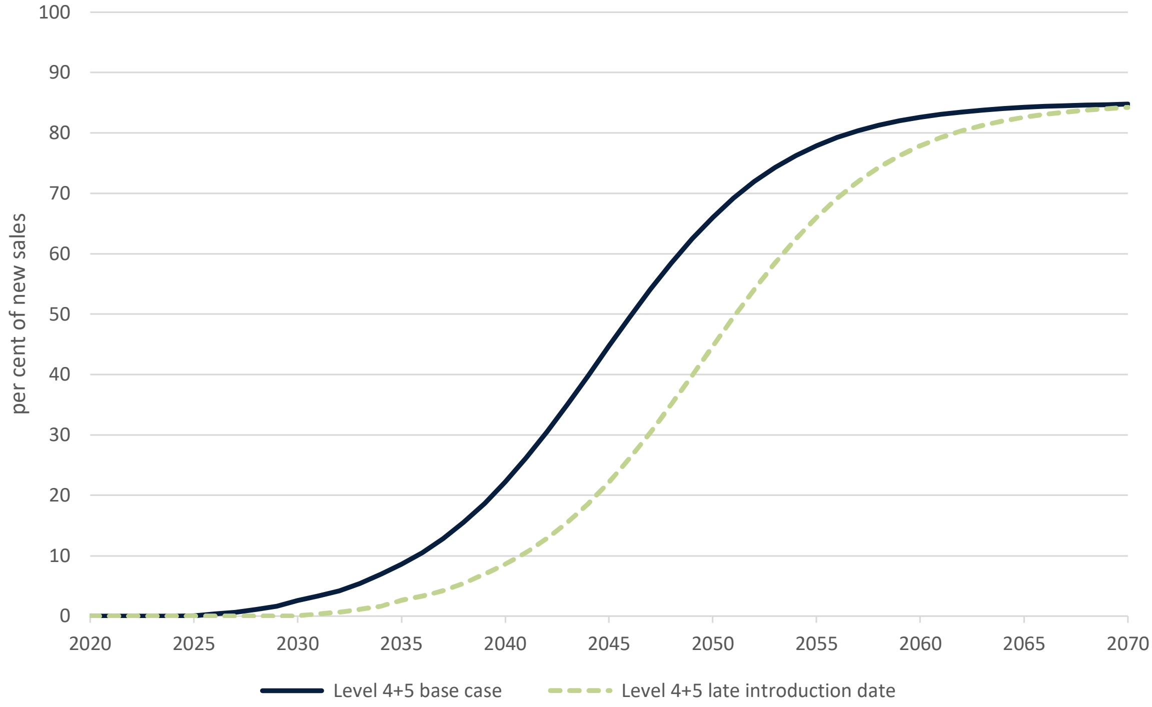


Figure 54 shows the sensitivity of fleet penetration to the introduction date.

Figure 54: Introduction date sensitivity – projected share of light vehicle fleet as SAE Level 4+5 AVs

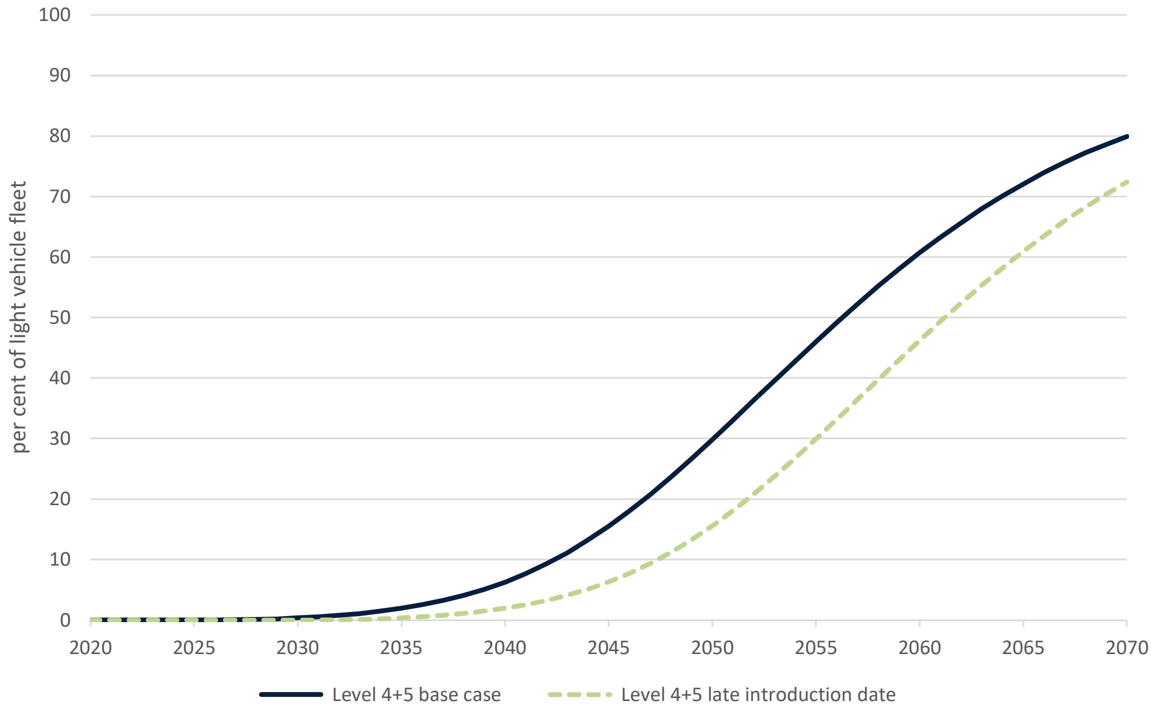


Figure 55 shows the base case against low and high sales growth sensitivities. The high growth sensitivity shows twice the rate of the base case uptake to 2035, while the low growth sensitivity shows half the rate.

Figure 55: Sales growth sensitivity – projected share of new light vehicles sold as SAE Level 4+5 AVs

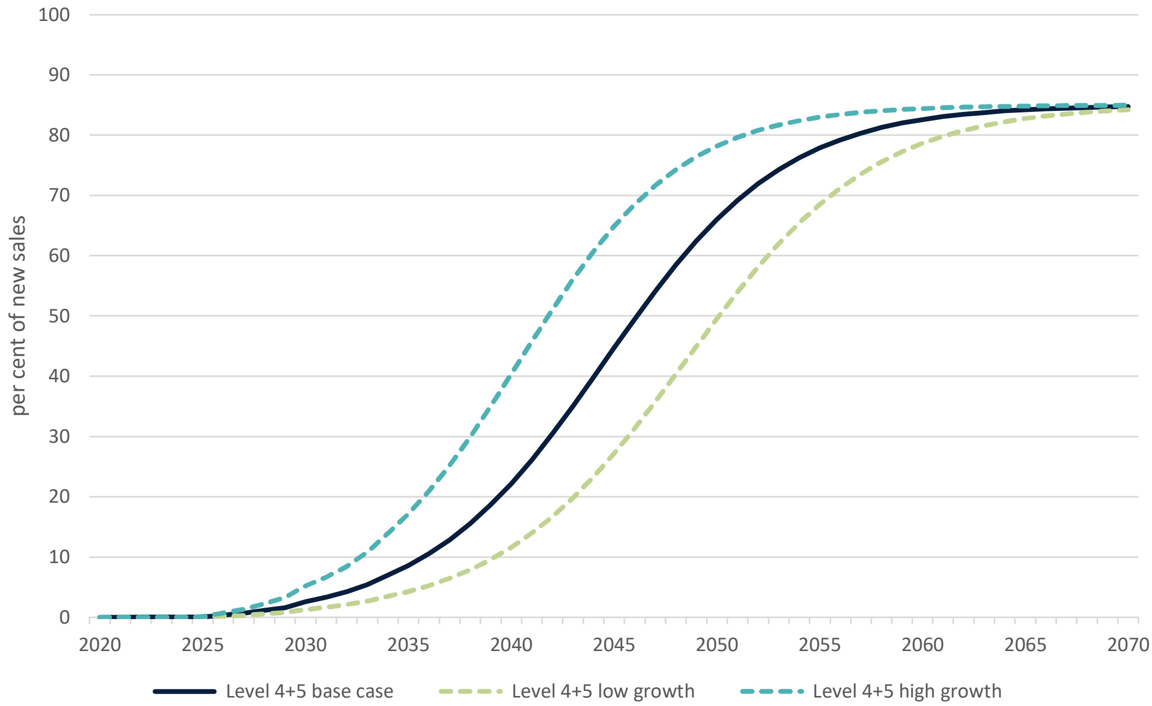


Figure 56 shows the sensitivity of fleet penetration to sales growth.

Figure 56: Sales growth sensitivity – projected share of light vehicle fleet as SAE Level 4+5 AVs

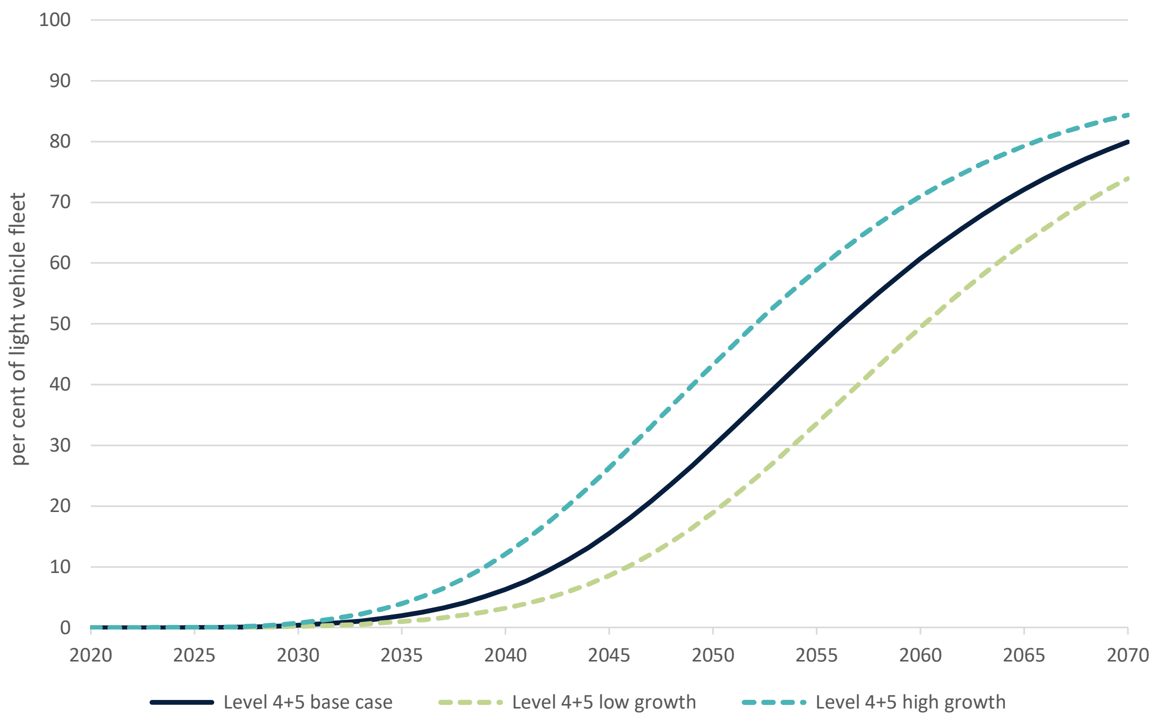


Figure 57 shows the sensitivity of projected SAE Level 4+5 AV sales to the assumed market saturation rate by showing the base rate (which assumes 85 per cent market saturation) against a rate of 30 per cent and 100 per cent.

Figure 57: Market saturation sensitivity – projected share of new light vehicles sold as SAE Level 4+5 AVs

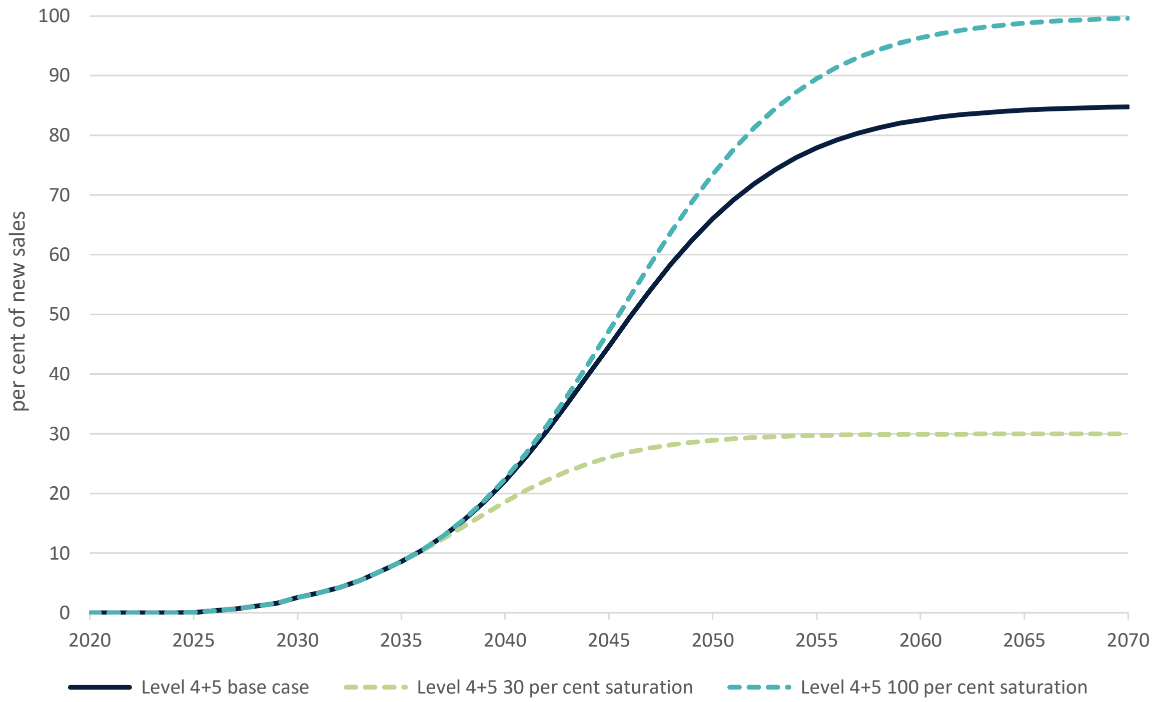
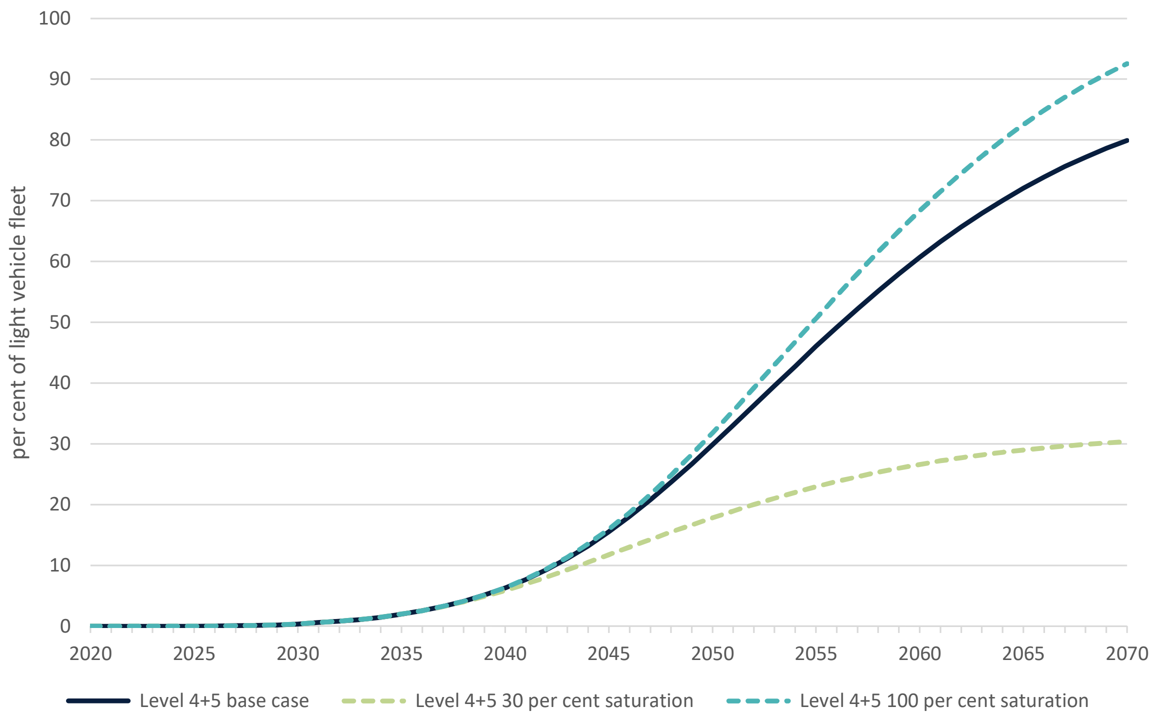


Figure 58 shows the sensitivity of fleet penetration to market saturation rates.

Figure 58: Market saturation sensitivity – projected share of light vehicle fleet as SAE Level 4+5 AVs



5.1.2. Tailored scenarios

As shown in Table 6, BITRE explores three tailored scenarios for SAE Level 4+5 AV uptake. The key parameters adopted in tailored scenarios are also summarised in Figure 46.

Scenario 1: Barriers to broad adoption involves a late introduction date of 2031, central uptake speed and a low saturation rate of 30 per cent. Figure 59 and Figure 60 show that these assumptions significantly lower the expectation of AVs penetrating new light vehicle sales and the light vehicle fleet.

Figure 59: Scenario 1 (Barriers to broad adoption) – projected share of new light vehicles sold as SAE Level 4+5 AVs

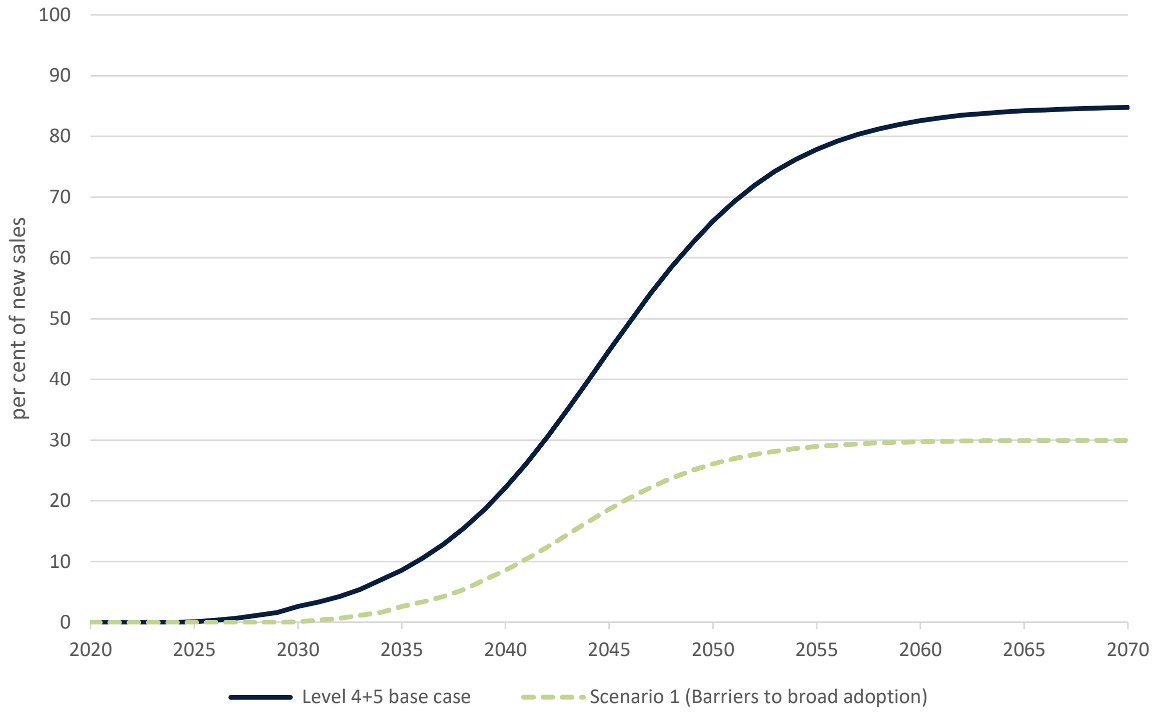
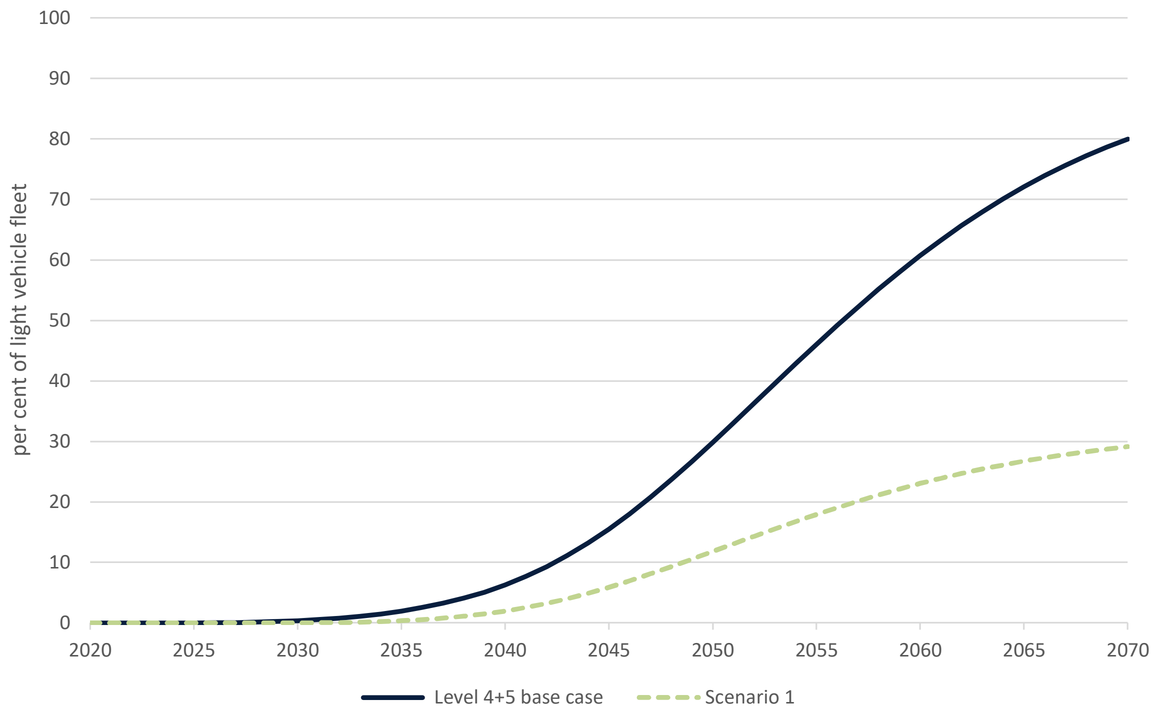


Figure 60: Scenario 1 (Barriers to broad adoption) – projected share of light vehicle fleet as SAE Level 4+5 AVs



Scenario 2: Technological catch-up involves a late introduction date of 2031, very high growth rate (three times the base case) and a central saturation rate of 85 per cent. Figure 61 and Figure 62

show the results for uptake in new light vehicle sales and fleet. The higher growth largely makes up for the late introduction date.

Figure 61: Scenario 2 (Technological catch-up) – projected share of new light vehicles sold as SAE Level 4+5 AVs

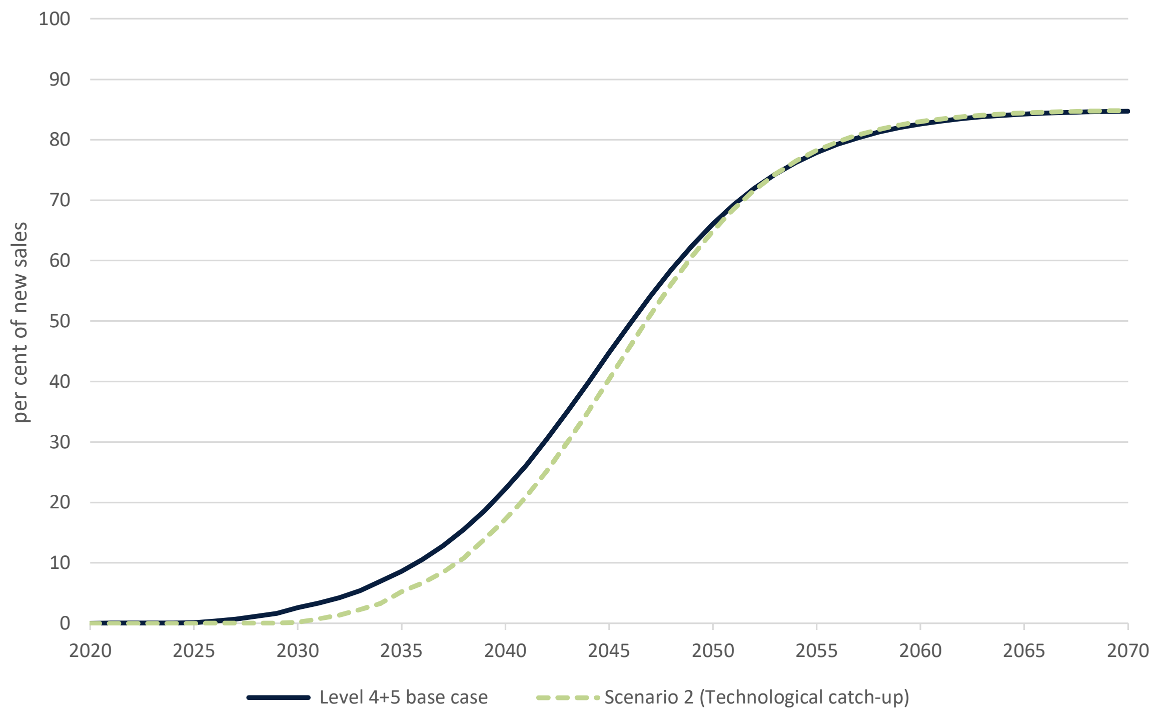
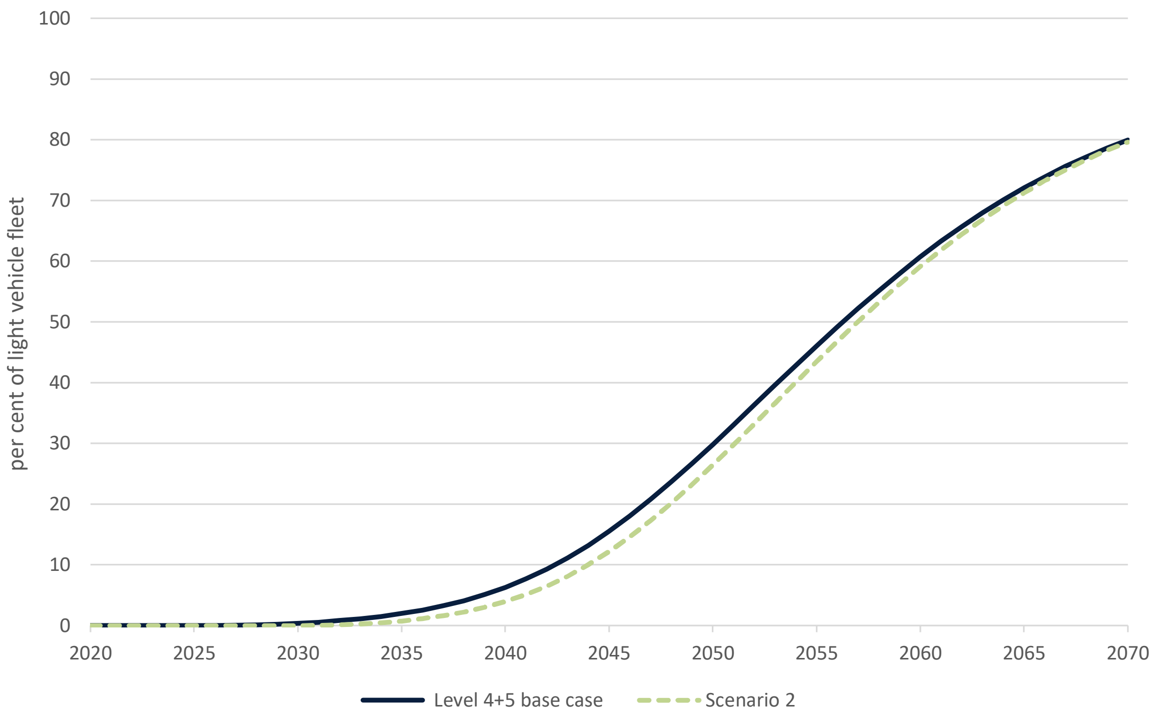


Figure 62: Scenario 2 (Technological catch-up) – projected share of light vehicle fleet as SAE Level 4+5 AVs



Scenario 3: Society embraces AVs involves a central introduction date of 2026, very high growth rate (three times the base case) and a high saturation rate of 100 per cent. Figure 63 and Figure 64 show that these assumptions significantly raise the expectation of AVs penetrating new light vehicle sales and fleet.

Figure 63: Scenario 3 (Society embraces AVs) – projected share of new light vehicles sold as SAE Level 4+5 AVs

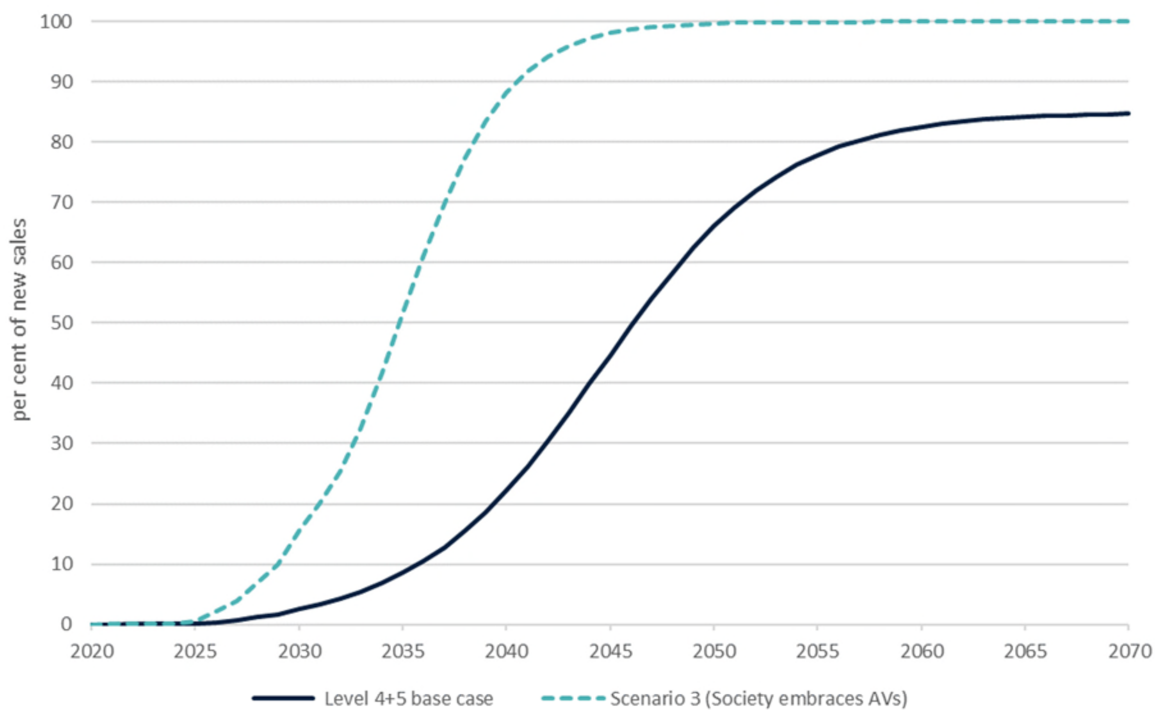


Figure 64: Scenario 3 (Society embraces AVs) – projected share of light vehicle fleet as SAE Level 4+5 AVs

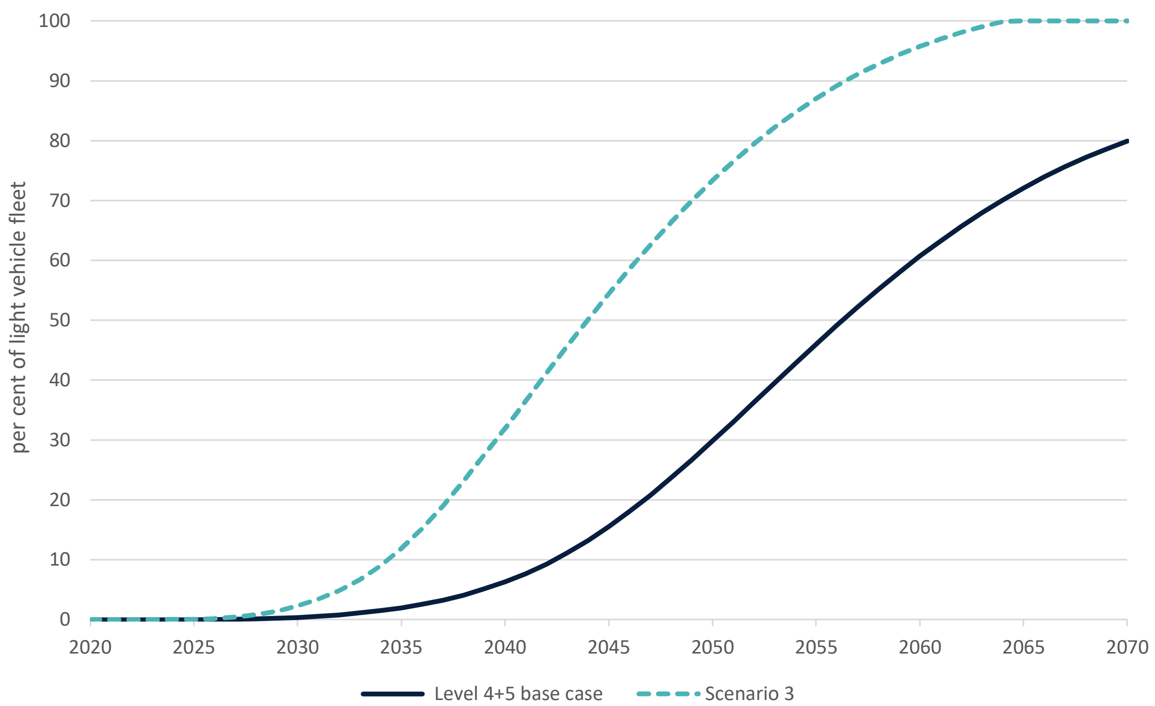


Table 7 shows the variation between scenarios in the dates at which 50 per cent of new light vehicle sales and the light vehicle fleet are SAE Level 4+5 AVs.

The fastest uptake of SAE Level 4+5 AVs is seen in Scenario 3, with AVs reaching 50 per cent of light vehicle sales and the light vehicle fleet in 2035 and 2044 respectively.

The base case scenario sees SAE Level 4+5 AVs reach 50 per cent of light vehicle sales in 2047 and 50 per cent of the light vehicle fleet in 2057.

Leaving aside all low saturation (30 per cent) scenarios, the slowest uptake of SAE Level 4+5 AVs is seen in the late introduction scenario, reaching 50 per cent of light vehicle sales and the light vehicle fleet in 2052 and 2062 respectively.

The full details of all the sensitivity and scenario projections of the share of SAE Level 4+5 AVs in new light vehicle sales and in the light vehicle fleet can be found at Appendix B.1.

Table 7: When SAE Level 4+5 AVs are forecast to reach half of light vehicle sales and fleet

Scenarios for SAE Level 4+5 AV uptake	Date to reach 50 per cent sales	Date to reach 50 per cent fleet
Base case	**2047**	**2057**
Sensitivities		
Low growth	2051	2061
High growth	2042	2052
30 per cent saturation rate	Beyond 2070	Beyond 2070
100 per cent saturation rate	2046	2055
Late introduction date	2052	2062
Tailored scenarios		
Scenario 1: Barriers to broad adoption (late introduction date, low saturation)	Beyond 2070	Beyond 2070
Scenario 2: Technological catch-up (late introduction date, faster growth)	2047	2057
Scenario 3: Society embraces AVs (faster growth, high saturation)	2035	2044

5.2. Uptake of vehicles with SAE Level 5 automation

The base case forecast for SAE Level 5 AV uptake (Figure 50) is the product of multiple guesses by experts in the field. This section examines how these forecasts would change under different assumptions. Table 8 shows the six scenarios examined for SAE Level 5 AV uptake. The base case forecast is based on the central parameters for the introduction date, growth rate and saturation level. Sensitivities are also tested by varying one of the three parameters listed, with the other two held constant. The tailored scenarios explore a combination of the assumptions tested as sensitivities.

Table 8: Six scenarios for forecasting SAE Level 5 AV uptake

Scenarios for SAE Level 5 AV uptake	Introduction date	Growth rate	Saturation Rate
Central (Base case)	**2031**	**medium**	**85 per cent**
Sensitivities			
Slow	2036	1/2 medium	30 per cent
High	2026	2 x medium	100 per cent
Tailored scenarios			
Scenario 1: Barriers to broad adoption (late introduction date, low saturation)	2036	medium	30 per cent
Scenario 2: Technological catch-up (late introduction date, faster growth)	2036	3 x medium	85 per cent
Scenario 3: Society embraces AVs (faster growth, high saturation)	2031	3 x medium	100 per cent

5.2.1. Sensitivity analysis

Figure 65 and Figure 66 show the base case projections for SAE Level 5 AV sales as a proportion of light vehicle sales and light vehicle fleet numbers, respectively. These forecasts show the penetration of AVs through the light vehicle fleet lags about 10 years behind the penetration of light vehicle sales.

Figure 65: Base case projected share of new light vehicles sold as SAE Level 5 AVs

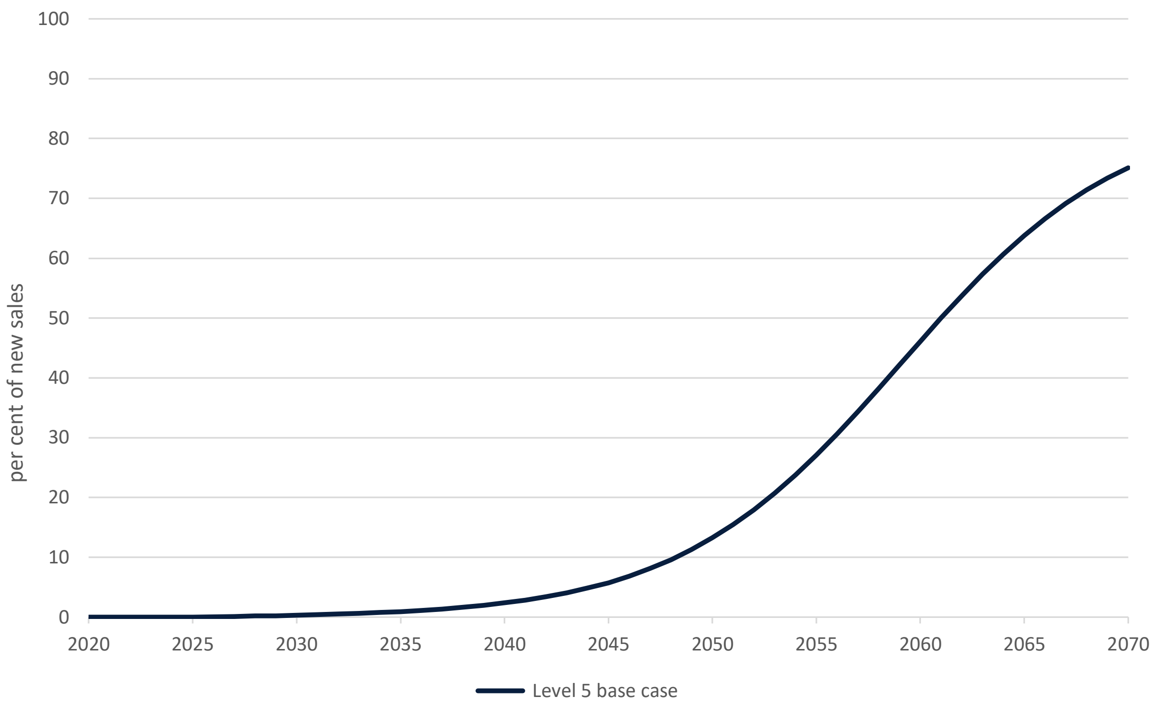


Figure 66: Base case projected share of light vehicle fleet as SAE Level 5 AVs

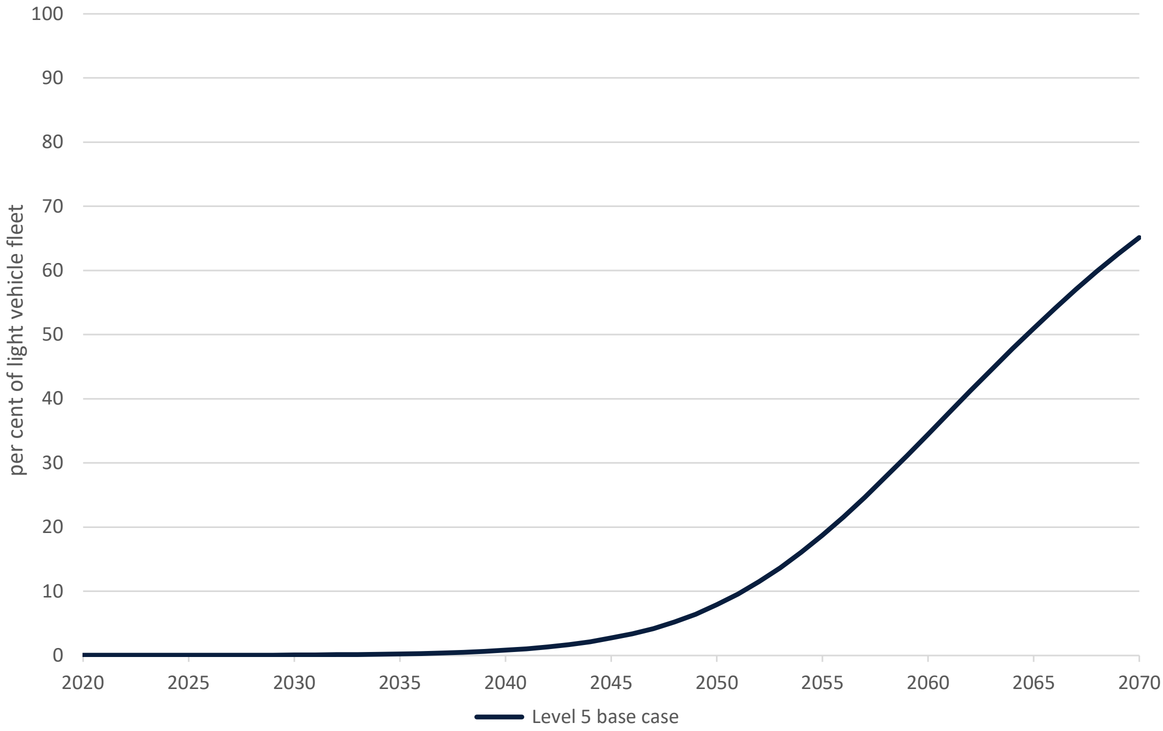


Figure 67 shows the base case, early and late introduction date (2026 and 2036 respectively) scenarios for SAE Level 5 AV uptake in new light vehicle sales.

Figure 67: Introduction date sensitivity – projected share of new light vehicles sold as SAE Level 5 AVs

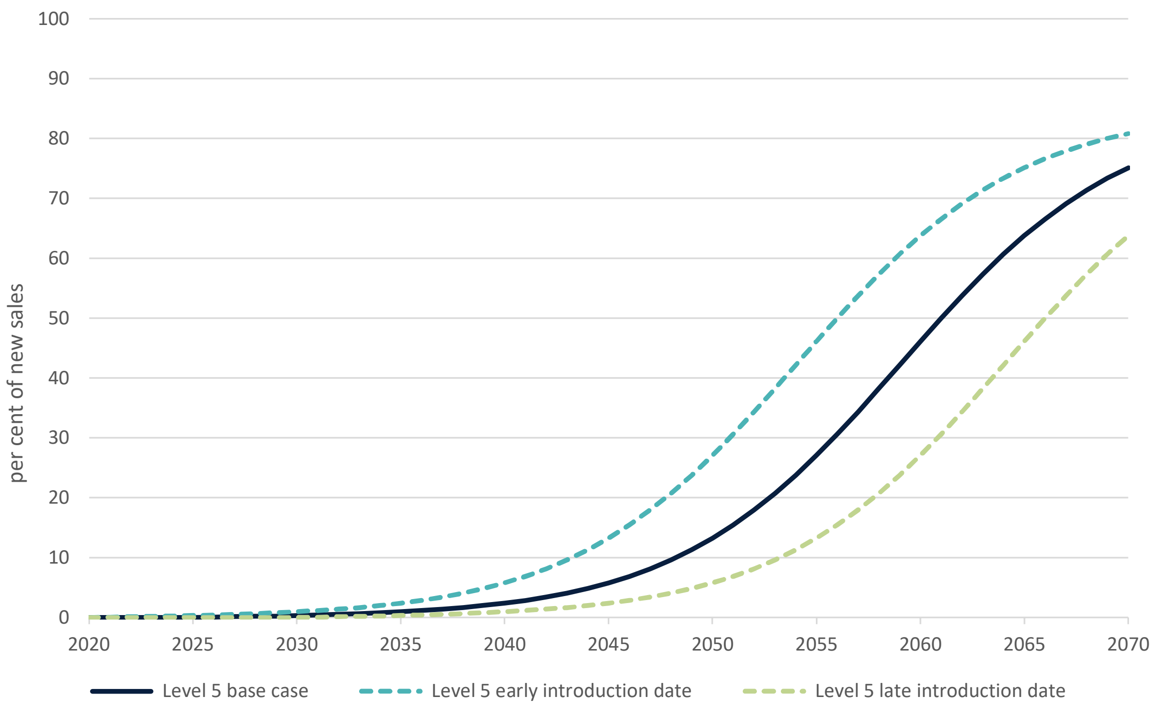


Figure 68 shows the sensitivity of fleet penetration to the introduction date.

Figure 68: Introduction date sensitivity – projected share of light vehicle fleet as SAE Level 5 AVs

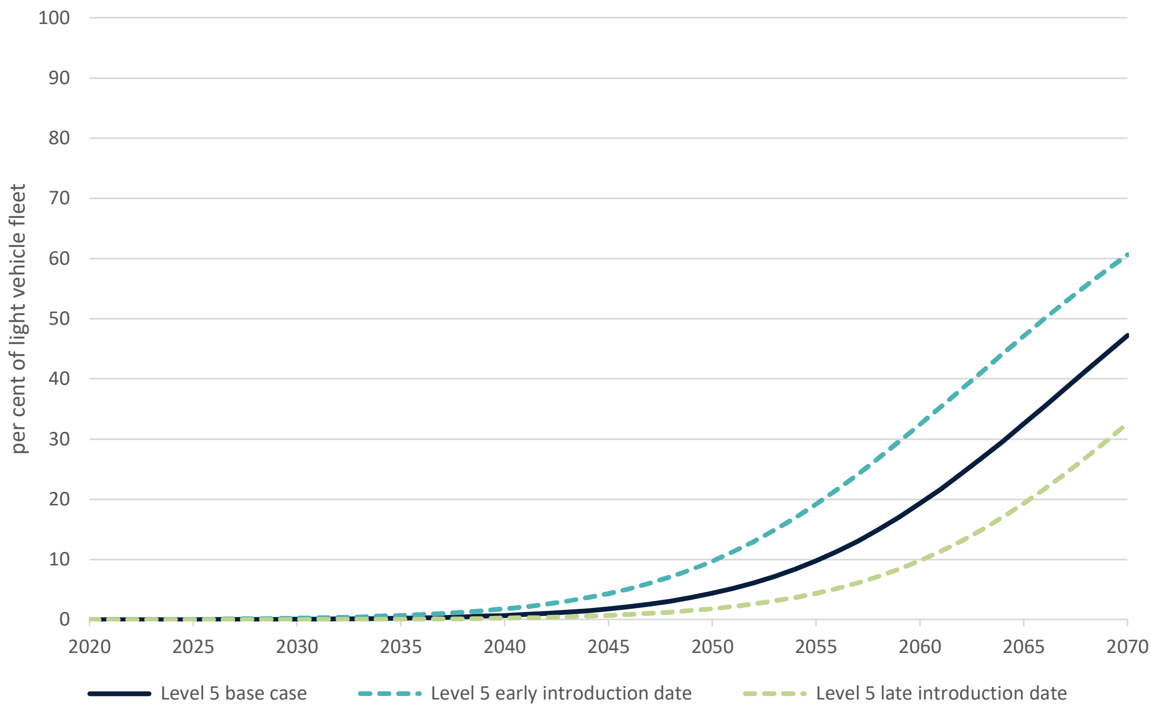


Figure 69 shows the base case, low and high growth sensitivities for SAE Level 5 AV uptake in new light vehicle sales. The high growth sensitivity shows twice the rate of the base case uptake to 2035, while the low growth scenario shows half the rate of the base case uptake.

Figure 69: Sales growth sensitivity – projected share of new light vehicles sold as SAE Level 5 AVs

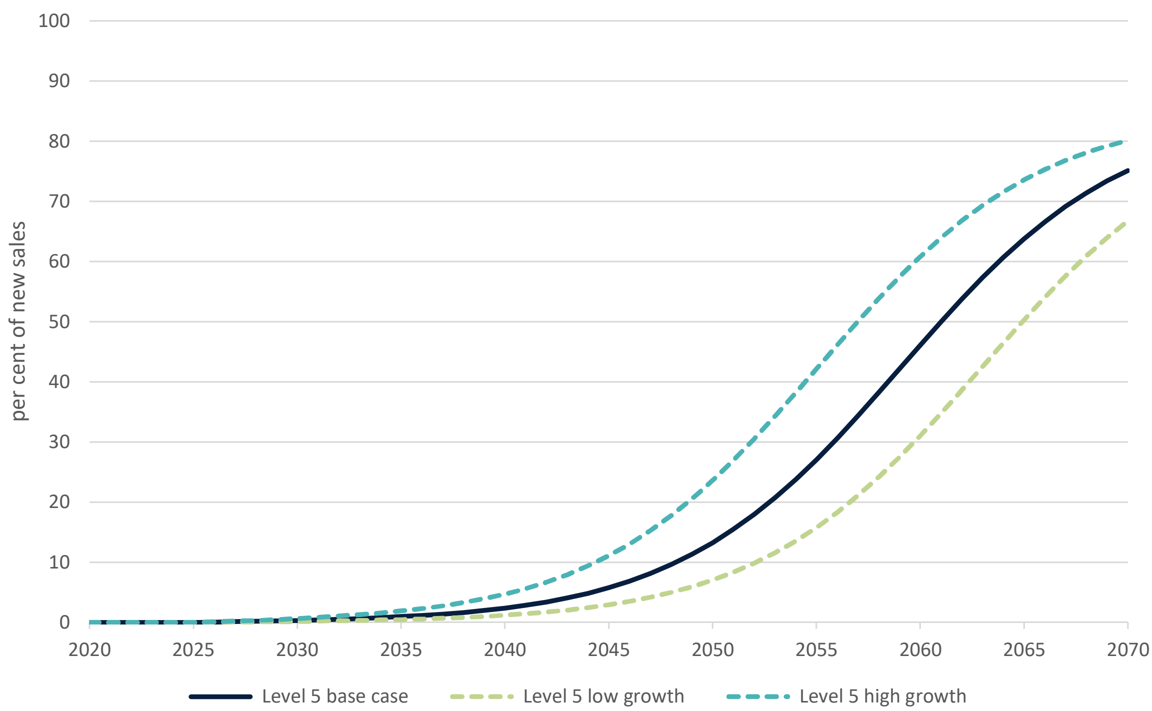


Figure 70 shows the sensitivity of fleet penetration to sales growth.

Figure 70: Sales growth sensitivity – projected share of light vehicle fleet as SAE Level 5 AVs

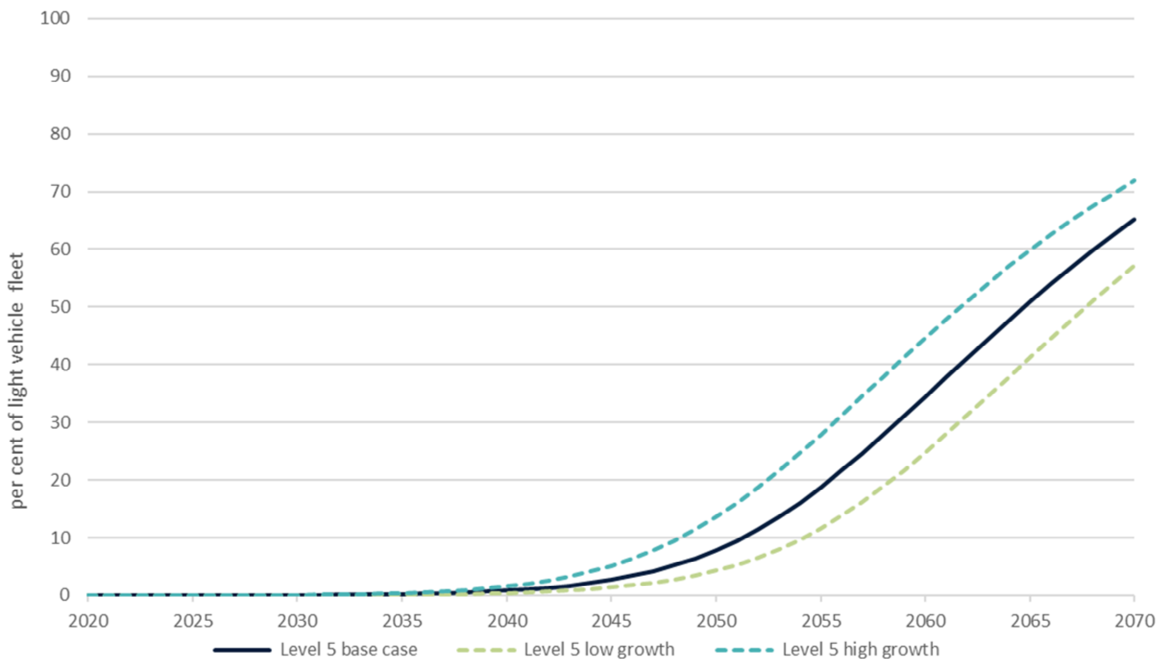


Figure 71 shows the sensitivity of projected SAE Level 5 AV sales to the assumed market saturation rate by showing the base rate (which assumes 85 per cent market saturation) against a rate of 30 per cent and 100 per cent.

Figure 71: Market saturation sensitivity – projected share of new light vehicles sold as SAE Level 5 AVs

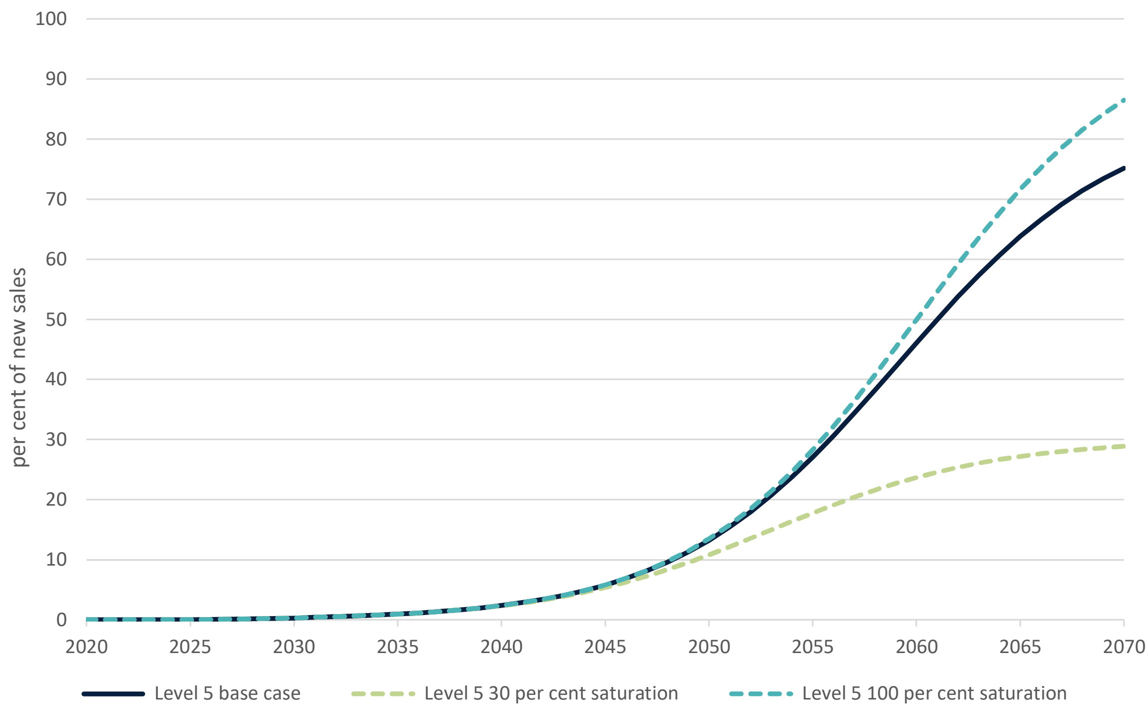
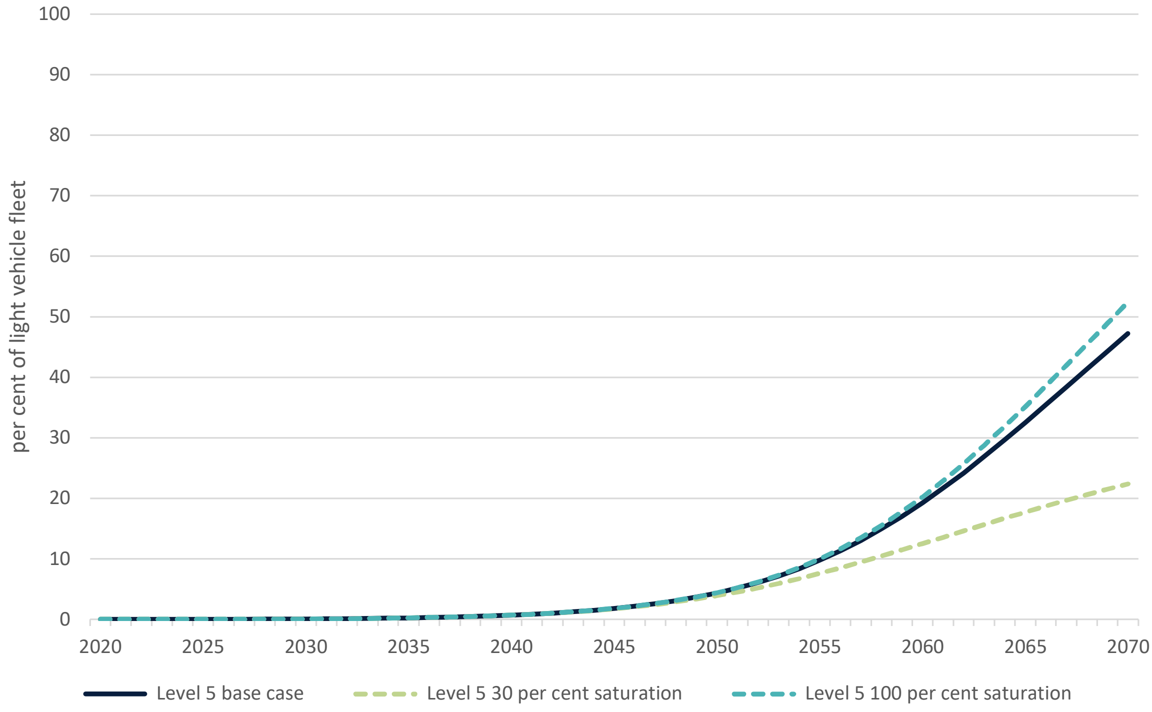


Figure 72 shows the sensitivity of fleet penetration to the market saturation rate.

Figure 72: Market saturation sensitivity – projected share of light vehicle fleet as SAE Level 5 AVs



5.2.2. Tailored scenarios

As shown in Table 8, BITRE explores three tailored scenarios for SAE Level 5 AV uptake.

Scenario 1: Barriers to broad adoption involves a late introduction date of 2036, central uptake speed and a low saturation rate of 30 per cent. Figure 73 and Figure 74 show that these assumptions significantly lower the expectation of AVs penetrating new light vehicle sales and the fleet.

Figure 73: Scenario 1 (Barriers to broad adoption) – projected share of new light vehicles sold as SAE Level 5 AVs

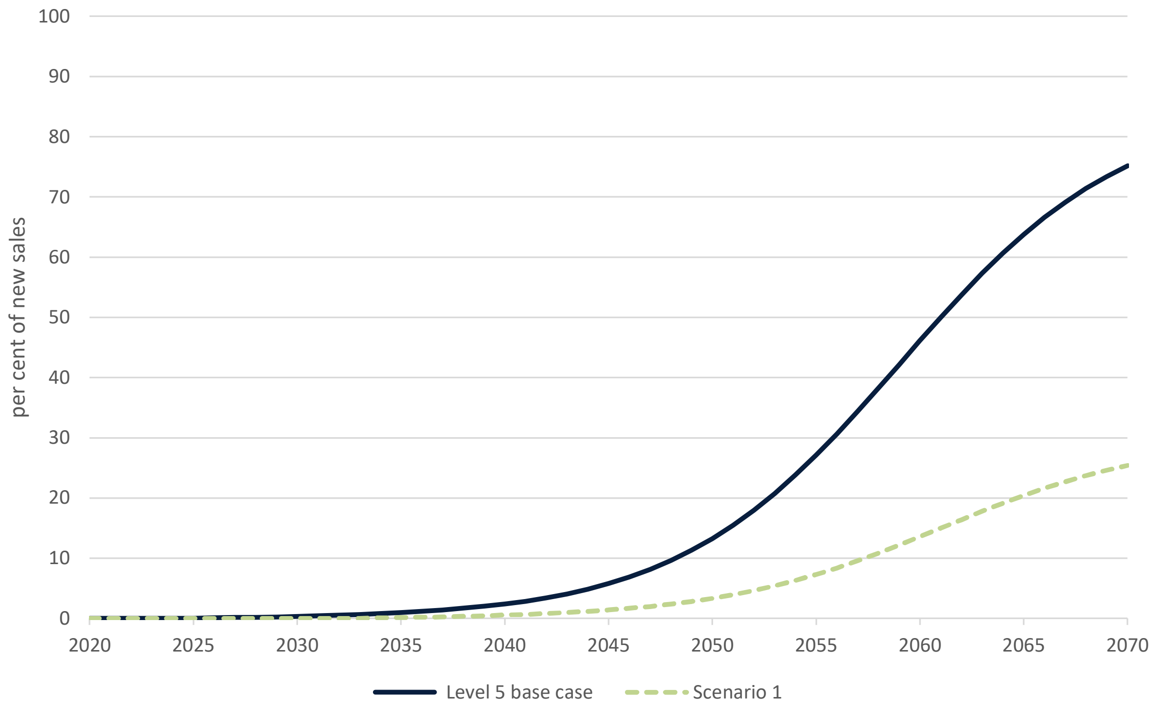
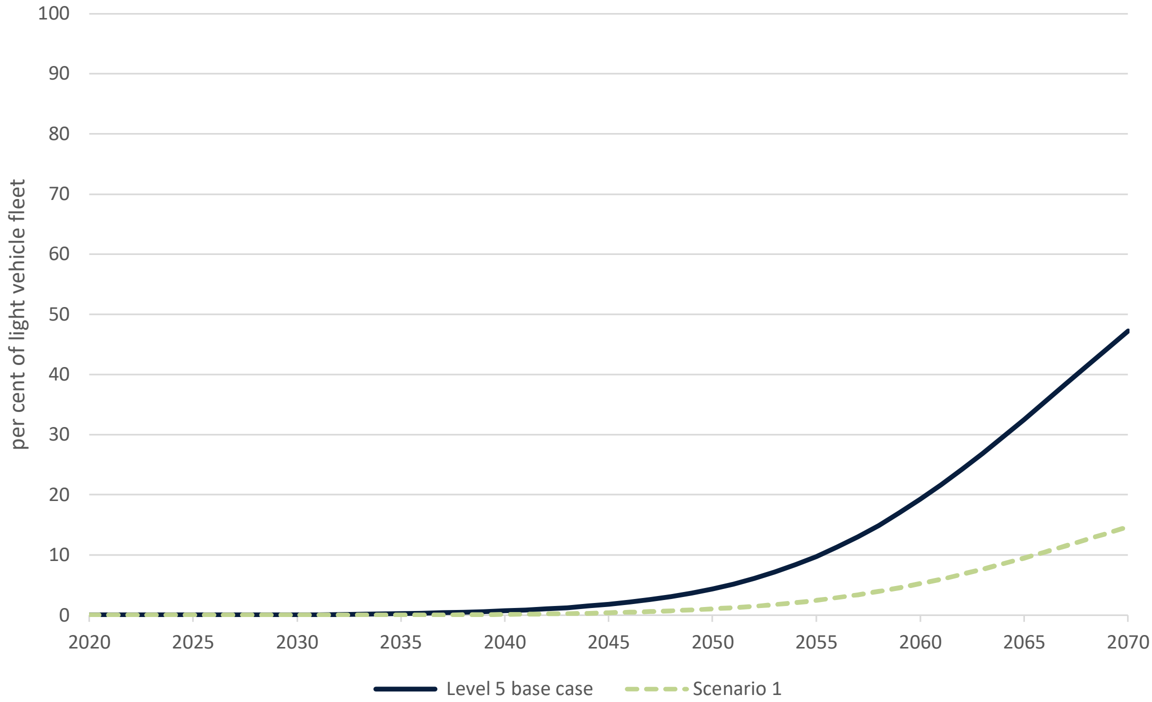


Figure 74: Scenario 1 (Barriers to broad adoption) – projected share of light vehicle fleet as SAE Level 5 AVs



Scenario 2: Technological catch-up involves a late introduction date of 2036, very high growth rate (three times the base case) and a central saturation rate of 85 per cent. Figure 75 and Figure 76 show the results for uptake in new light vehicle sales and fleet. It can be seen that the higher growth partially makes up for the late introduction date.

Figure 75: Scenario 2 (Technological catch-up) – projected share of new light vehicles sold as SAE Level 5 AVs

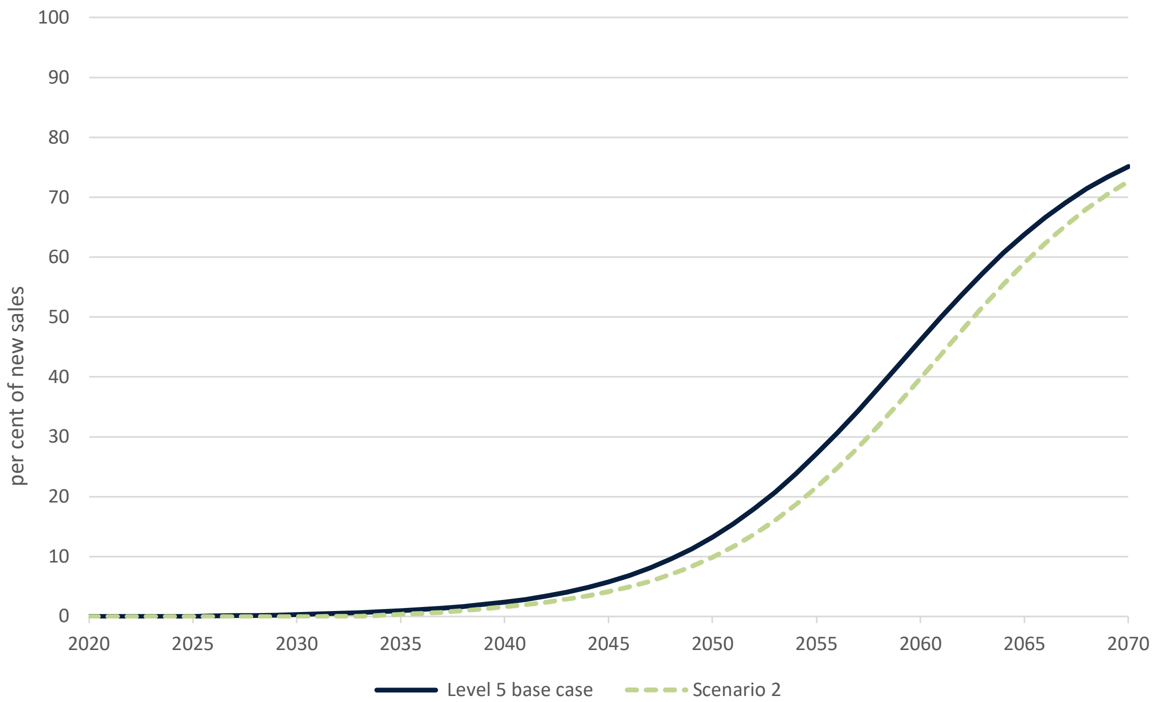
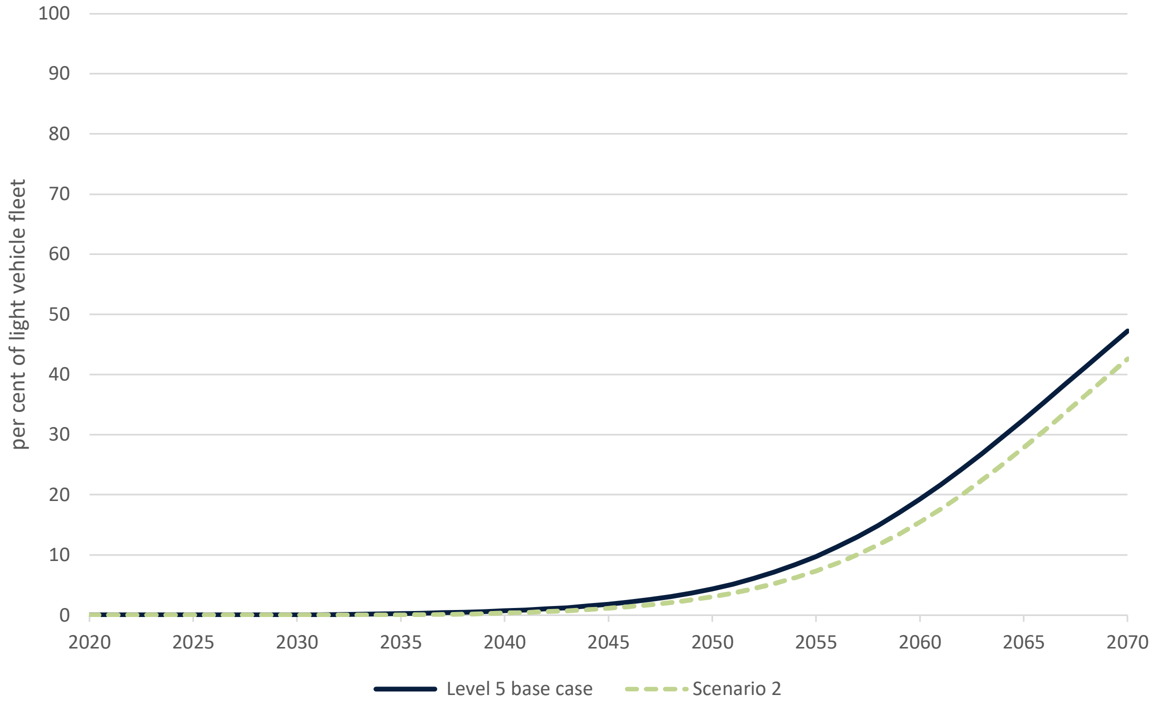


Figure 76: Scenario 2 (Technological catch-up) – projected share of light vehicle fleet as SAE Level 5 AVs



Scenario 3: Society embraces AVs involves a central introduction date of 2031, very high growth rate (three times the base case) and a high saturation rate of 100 per cent. Figure 77 and Figure 78 show that these assumptions significantly raise the expectation of AVs penetrating new light vehicle sales and fleet.

Figure 77: Scenario 3 (Society embraces AVs) – projected share of new light vehicles sold as SAE Level 5 AVs

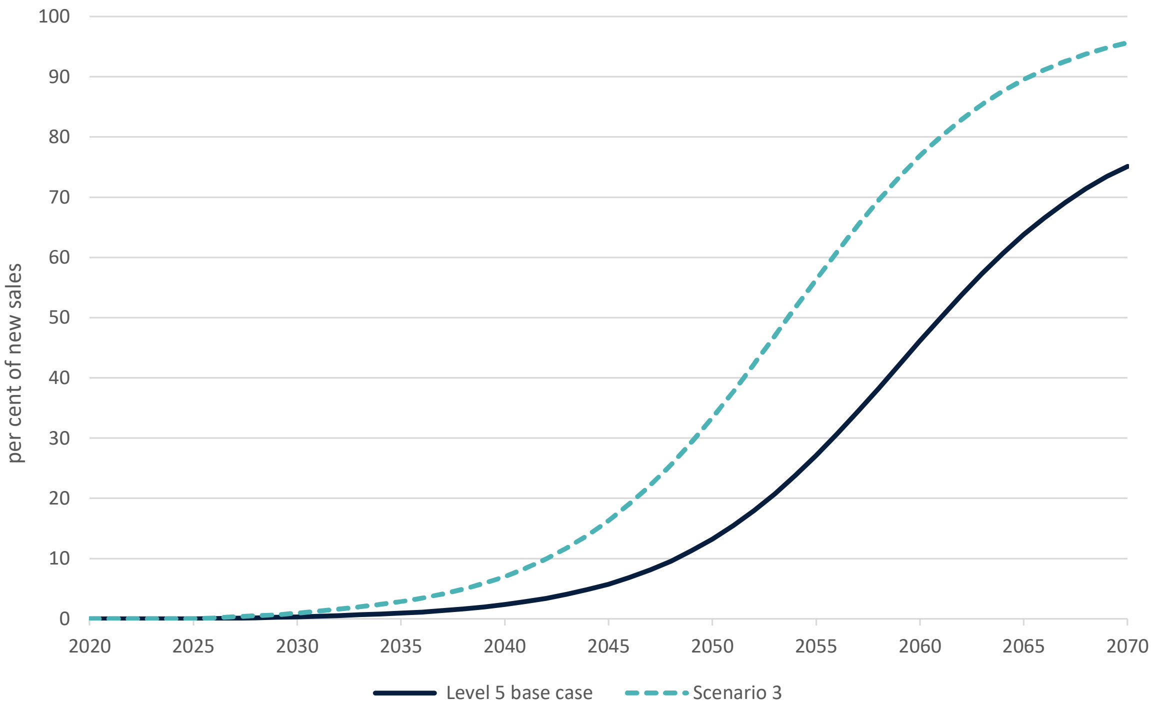


Figure 78: Scenario 3 (Society embraces AVs) – projected share of light vehicle fleet as SAE Level 5 AVs

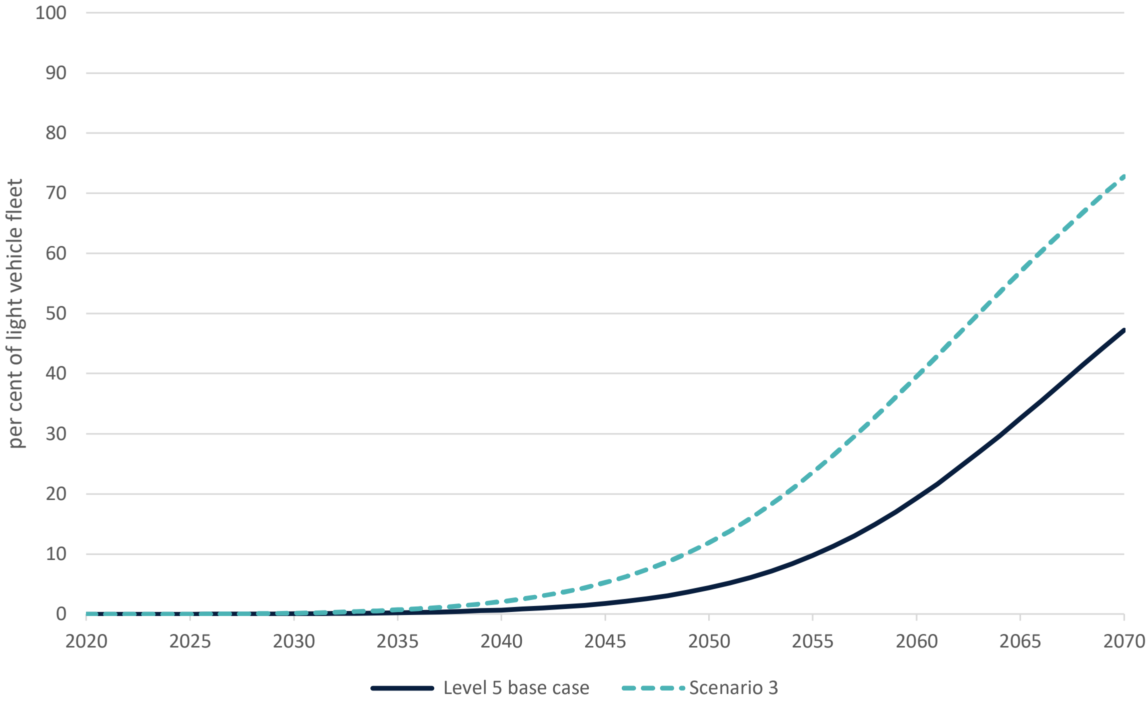


Table 9 shows the variation between scenarios in the dates at which 50 per cent of new light vehicle sales and fleet are SAE Level 5 AVs.

The fastest uptake of SAE Level 5 AVs is seen in Scenario 3, with AVs reaching 50 per cent of light vehicle sales in 2054 and the fleet in 2063.

The base case scenario sees SAE Level 5 AVs reach 50 per cent of light vehicle sales by 2062 and 47 per cent of the light vehicle fleet in 2070.

Leaving aside all low saturation (30 per cent) scenarios, the slowest uptake of SAE Level 5 AVs is seen in the late introduction sensitivity, reaching 50 per cent of light vehicle sales by 2067 and less than 33 per cent of the light vehicle fleet in 2070.

The full details of all the sensitivity and scenario projections of the share of SAE Level 5 AVs in new light vehicle sales and in the light vehicle fleet can be found at Appendix B.2.

Table 9: When SAE Level 5 AVs are forecast to reach half of light vehicle sales and fleet

Scenarios for SAE Level 5 AV uptake	Date to reach 50 per cent sales	Date to reach 50 per cent fleet
Base case	2062	Beyond 2070
Sensitivities		
Low growth	2065	Beyond 2070
High growth	2057	2067
30 per cent saturation rate	Beyond 2070	Beyond 2070
100 per cent saturation rate	2061	2070
Early introduction date	2057	2067
Late introduction date	2067	Beyond 2070
Tailored scenarios		
Scenario 1: Barriers to broad adoption (late introduction date, low saturation)	Beyond 2070	Beyond 2070
Scenario 2: Technological catch-up (late introduction date, faster growth)	2063	Beyond 2070
Scenario 3: Society embraces AVs (faster growth, high saturation)	2054	2063

CHAPTER 6

Conclusions

This report has constructed a conceptual framework, based on a literature review of existing studies and theories to explore the development and forecast the uptake of selected active safety, driver support and connectivity features in Australia’s light vehicle sales and fleet from 1990 to 2070. It has also forecast the uptake of AVs to 2070 in Australia, and has considered some of the factors that may influence uptake.

The active safety, driver support and connectivity features investigated in this report are all forecast to follow an ‘S-curve’ uptake pattern, eventually reaching 100 per cent of new light vehicle sales. This pattern is similar to that seen in several vehicle safety technologies, including ESC and several types of airbags. Some of these technologies are forecast to reach full market penetration earlier than others, with technologies like Bluetooth already featuring in around 90 per cent of new light vehicles sold, while other technologies feature in less than five per cent of new light vehicles sold (e.g. telematics, self-parking systems, right turn assist, adaptive headlights and pedestrian airbags).

While AVs have the potential to unlock benefits that human-driven vehicles do not offer, there are many factors expected to influence their uptake, including price, consumer willingness to pay, the cost of technology, available supply, enabling infrastructure and the regulatory and policy landscape. These factors are interrelated and their interaction plays a part in driving the uptake of AVs.

Projected willingness to pay (including consumer sentiment on perceived safety, security risks and benefits), the cost of technology and the extent of commercial investment suggests there will be a market for AVs.

Policymakers have a role in ensuring information on the safety, security and other performance features, and opportunities to be exposed to AVs is made available to consumers to improve consumer sentiment, including increasing trust in the technology, and helping the community to understand actions by governments and others to manage a number of social concerns, including security risks, privacy and data ownership issues, and liability and other legal issues.

The resulting forecasts predict that, under the central scenario:

- Around half of new light vehicles sold in Australia by 2047 will have at least SAE Level 4 automation. This will reach around 65 per cent by 2050 and 85 per cent by 2070. The share of the vehicle fleet with at least SAE Level 4 automation is projected to reach 30 per cent by 2050, 50 per cent by 2057 and 80 per cent by 2070; and
- Around 10–15 per cent of new light vehicles sold in Australia by 2050 will have SAE Level 5 automation. This will reach around 50 per cent by 2062 and 75 per cent by 2070. The share

of the vehicle fleet with SAE Level 5 automation is projected to reach just under five and 50 per cent by 2050 and 2070, respectively.

The model allows predictions of how these base case forecasts would change with modified assumptions (saturation rate, uptake speed and introduction date). Scenario testing has shown how AV uptake may vary across different states of the world, informing policy makers of uncertainties to bear in mind.

Abbreviations

Short form	Long form
ABS	Australian Bureau of Statistics
ADAS	Advanced driver-assistance systems
AEB	Autonomous emergency braking
ADRs	Australian Design Rules
ANCAP	Australasian New Car Assessment Program
ASS	Active safety systems
AV	Automated vehicle
BITRE	Bureau of Infrastructure Transport and Research Economics
DITRDC	Department of Infrastructure, Transport, Regional Development and Communications
DSRC	Dedicated short-range communication
ESC	Electronic stability control
EV	Electric vehicle
GPS	Global Positioning System
LCV	Light commercial vehicle
LiDAR	Light detection and ranging
LTE	Long-term evolution
ODD	Operational design domain
OEM	Original equipment manufacturer
SAE	The Society of Automotive Engineers International
SAE Level 4+5	The sum of SAE Level 4 and SAE Level 5 vehicles
SUV	Sports utility vehicle
V2C	Vehicle-to-Cloud
V2D	Vehicle-to-Device
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home

Short form	Long form
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything

Glossary

Term	Definition
Autonomous emergency braking (AEB)	An active safety system that measures the distance from the vehicle in front, and reacts if that distance gets shorter at a fast rate by activating the brakes or increasing the braking force if needed to prevent a collision.
Adaptive cruise control	An enhancement of conventional cruise control systems that allows the equipped vehicle to follow a leading vehicle at a pre-selected time gap, up to a driver-selected speed, by controlling the engine, power train, and/or service brakes.
Adaptive headlights	Headlights that respond to changing conditions to provide drivers with better visibility. These can include headlights that pivot depending on the direction of travel, as well as headlights that switch between high and low beams in the presence of traffic.
Blind spot monitoring	An active safety system that detects vehicles in the adjacent lanes and warns the driver. Active blind spot monitoring systems also manipulate the steering and brakes to avoid collisions if the driver does not act in time.
Bluetooth	A wireless technology that connects devices within short distances to allow for data exchange, using a low radio wavelength that hops between frequencies.
Cellular Vehicle-to-Everything (C-V2X)	A LTE chip technology designed to facilitate real-time V2X communication using the 4G and 5G network. C-V2X technology uses the 5.9 GHz band of the radio frequency spectrum to communicate. C-V2X currently cannot communicate with DSRC and vice versa.
Cross-traffic sensor	A type of active safety system/driver support feature that uses radar sensors that send radio waves to detect oncoming objects. Examples include rear cross traffic systems and blind spot detection systems.
Cruising Chauffeur	An automated driving feature that enables vehicles to take over the driving task on highways, adjusting speed to traffic conditions and regulations and staying within the lane. The vehicle alerts the driver to take over before exiting the highway, and otherwise automatically stops safely (Continental 2021).
Dedicated short-range communication (DSRC)	A wireless communication technology designed to facilitate V2X. DSRC enables direct communication between vehicles and other road users, without involving cellular or other communication infrastructure. DSRC technology operates on the 5.9 GHz band of the radio frequency spectrum and is effective over short to medium distances. DSRC has low latency and high reliability, is secure and supports interoperability. DSRC currently cannot communicate with C-V2X and vice versa.
Driver fatigue detection	Monitors driver behaviour relative to the start of the journey, alerting the driver to take a break after detecting signs of fatigue. More common indirect systems use a road-facing front camera to monitor changes such as more erratic steering movements, pedal use and

Term	Definition
	lane deviations. More advanced systems use driver-facing cameras and face-tracking technology to look directly for signs of fatigue, such as blinking and nodding.
Electronic stability control (ESC)	Uses sensors to monitor the direction of travel and steering wheel position. ESC activates if the driver loses control when turning a corner, braking sharply or making a sudden manoeuvre. ESC automatically activates the brakes, including by braking individual wheels to help steer the vehicle back on track.
Lane (departure) warning	An active safety system that monitors the lane markings on the road ahead and alerts the driver if/when the vehicle is about to veer out of the lane.
Lane keeping (lane keep assist)	An ADAS/active safety system that makes electronic steering and/or braking control inputs to keep the vehicle in its original travel lane upon detecting an unintended lane departure. These systems provide a momentary intervention, but do not automate this on a sustained basis.
Light commercial vehicle (LCV)	Vehicles primarily constructed for the carriage of goods, and which are less than or equal to 3.5 tonnes GVM. This includes utilities, panel vans, cab-chassis and forward-control load carrying vehicles (whether four-wheel drive or not).
Light vehicles	Passenger vehicles plus LCVs.
Long-term evolution	Long-term evolution, more commonly known as LTE, is a wireless standard that delivers lower data latency and increased bandwidth, resulting in greater speed and capacity of wireless cellular networks.
Passenger vehicles	Motor vehicles constructed primarily for the carriage of persons and containing up to nine seats (including the driver's seat). This category includes cars, station wagons, four-wheel drive passenger vehicles, sports utility vehicles and forward-control passenger vehicles. Campervans are excluded.
Pedestrian airbag	A passive safety system that deploys an external airbag when the vehicle comes in contact with an object that the control unit interprets as a human leg.
Pedestrian detection	Uses one or a combination of forward-facing cameras, radars and laser sensors to detect pedestrians and other objects in the vehicle’s path, providing an alert upon detection. Some systems are also combined with automatic braking. This functionality works best for vehicles travelling at slow speeds.
Right turn assist	Uses short-range radar to detect cyclists and other vulnerable road users approaching from behind the vehicle on the right-hand side. While this system was designed for right-hand-traffic markets, it would still prevent Australian drivers from hitting vulnerable road users on the vehicle’s left-hand-side. However, it would not assist with right-hand turns in left-hand traffic markets, like Australia.
Self-parking	Uses parking sensors upon activation to locate a parallel (and in some cases, a perpendicular or diagonal) parking spot. After the driver selects an identified parking spot, the vehicle issues instructions to shift into the proper gear. The driver usually operates the accelerator and brake (although some systems automate this function) as the vehicle steers itself into the parking space.
Telematics (as a vehicle feature)	Telematics systems feature a vehicle tracking device that collects GPS data, as well as a large range of vehicle-specific data that may be gathered from in-vehicle sensors and/or engine diagnostics. The data is temporarily stored in a telematics device (plugged into the on-board diagnostics or CAN-BUS port). A SIM card and modem in the devise enables the data to then be transmitted over private cellular networks to a centralised server for interpretation.

Term	Definition
Traffic jam chauffeur	An automated driving feature that allows vehicles to drive autonomously on motorways up to a defined speed by adapting vehicle speed to the surrounding traffic and speed limit. The system asks the driver to take back control of the vehicle before a manoeuvre is necessary (PSA Groupe 2016).
Traffic sign recognition	A forward-facing camera that detects road signs, and projects messages onto the driving display. Some vehicles provide a vibration or audible warning if the driver does not adhere to the signed instruction / recommendation.
Vehicle-to-Cloud (V2C)	A form of technology that allows vehicles to connect and communicate with the cloud.
Vehicle-to-Device (V2D)	A form of technology that allows vehicles to communicate with devices, including transport (such as e-bicycles and e-scooters) and personal devices.
Vehicle-to-Everything (V2X)	A form of technology that allows vehicles to communicate with its surrounding environment using short-range wireless signals. Benefits of V2X include increased traffic safety and efficiency. V2X may use DSRC technologies or cellular networks. V2X includes V2I, V2V and V2N communications.
Vehicle-to-Grid (V2G)	A form of technology that allows electric vehicles to communicate with the electricity grid and enable vehicle energy to be pushed back to the power grid to balance variations in energy production and consumption.
Vehicle-to-Home (V2H)	A form of technology that allows vehicles to connect and communicate with the home network.
Vehicle-to-Infrastructure (V2I)	A form of technology that allows vehicles to communicate with infrastructure systems, including traffic lights, signage, roadside beacons and buildings.
Vehicle-to-Network (V2N)	A form of technology that allows vehicles to communicate with external networks, including the cloud.
Vehicle-to-Pedestrian (V2P)	A form of technology that allows vehicles to communicate with pedestrians.
Vehicle-to-Vehicle (V2V)	A form of technology that allows vehicles to communicate with other vehicles.
Wi-Fi connectivity (as a vehicle feature)	Synonymous with the 'connected vehicle', which refers to a vehicle with its own connection to the internet, usually via a wireless local area network. This allows the vehicle to share internet access and data with other devices.

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Appendix A
Forecast methodology

The vehicle technology uptake scenarios presented in this report are forecast in two phases:

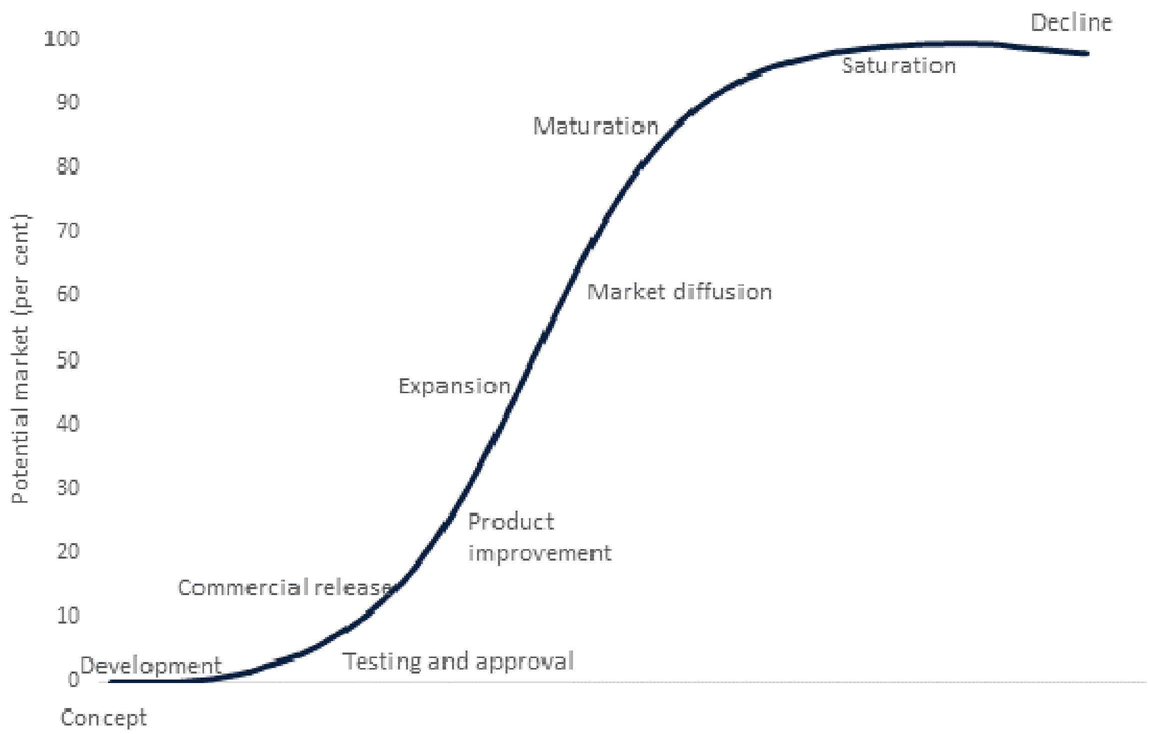
A. Forecasting the uptake of technology in new vehicle sales.

B. Modelling the diffusion of technology through the vehicle fleet.

A.1. Technology uptake in new vehicles

Technology uptake in new vehicles generally takes the form of an S-curve or logistic function. This pattern has been shown empirically, and aligns with Rogers' (1962) diffusion of innovation theory (as depicted in Figure 79).

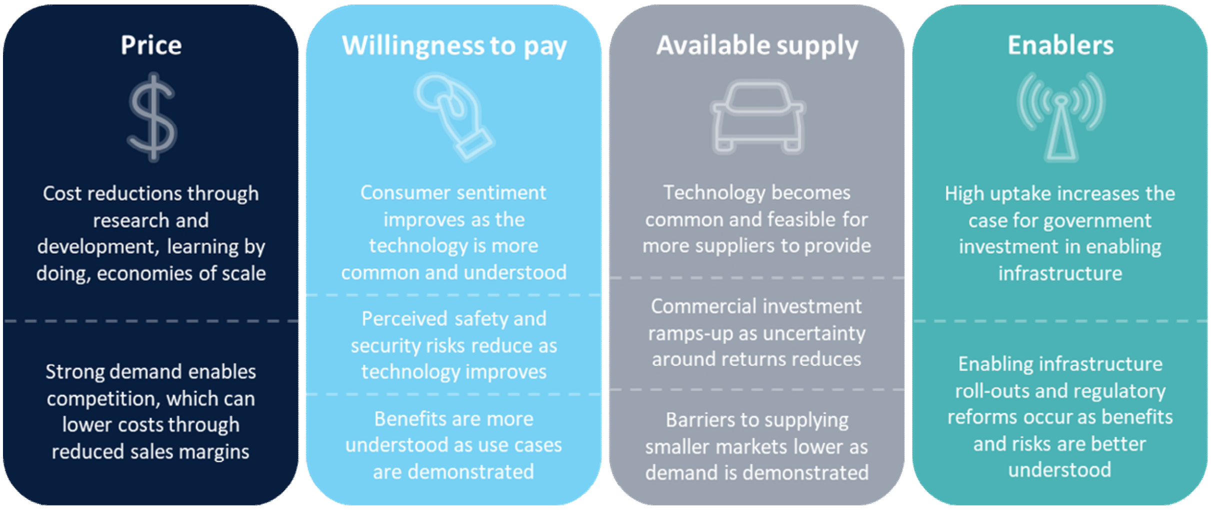
Figure 79: Innovation S-curve



Source: BITRE, adapted from Litman (2021)

The S-curve implies that after a technology is introduced, there tends to be slow uptake in the first few years. This slow uptake reflects low consumer understanding of the technology and/or high costs and low quality. Once costs fall below what a greater proportion of consumers are willing to pay, uptake can rapidly increase before levelling off as technology uptake nears the point of market saturation. This uptake pattern also reflects the positive relationship between the factors that influence uptake (as discussed in Chapter 4) and movement along the diffusion of innovation curve. The factors outlined in Figure 80 provide a conceptual basis for this positive relationship.

Figure 80: Technological diffusion and factors affecting demand for AVs

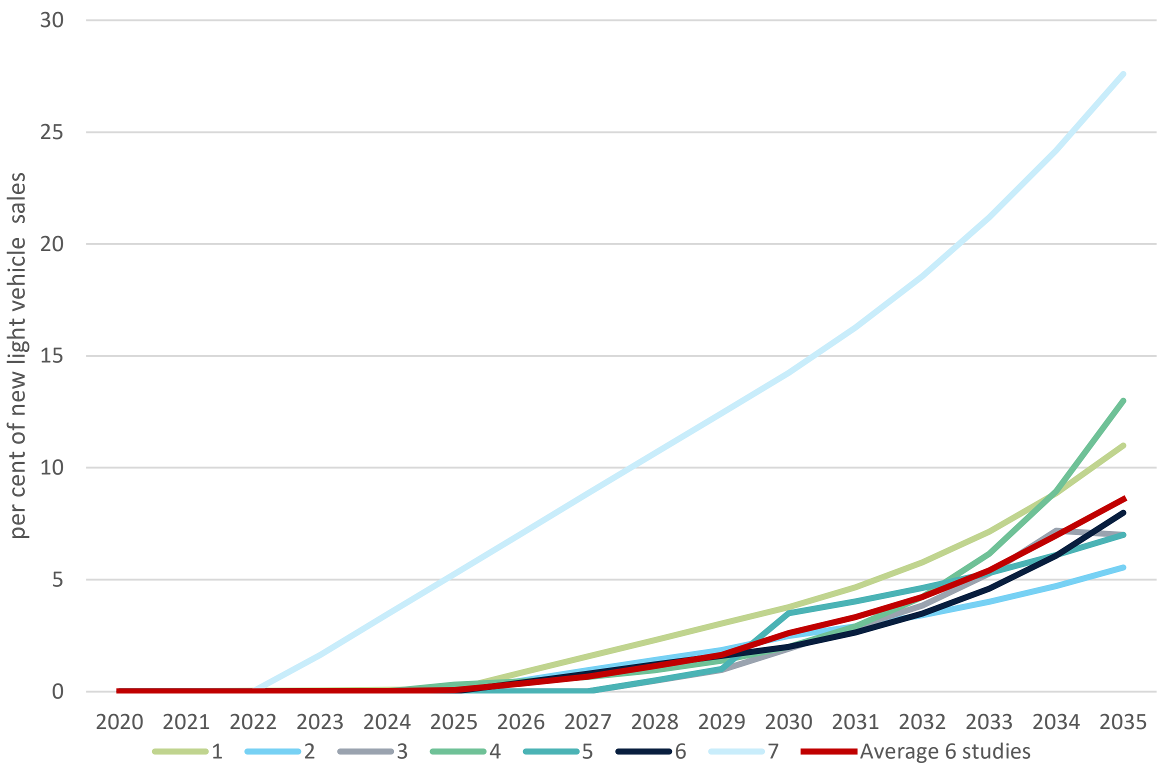


A.1.1. Uptake of fully automated vehicles

BITRE uses the same methodology for projecting the uptake of both SAE Level 4+5 and SAE Level 5 AVs. The base forecasts to 2035 for SAE Level 4+5 AVs are based on the average of the first six studies presented in Table 5, with study seven excluded as an outlier.

Figure 81 shows the seven studies against the base-case average growth forecasts to 2035 for SAE Level 4+5 AVs.

Figure 81: Projections to 2035 – share of new vehicle sales with SAE Level 4+5 automation



The base forecasts to 2035 for SAE Level 5 AVs are based on the average of the three studies that provide separate forecasts for SAE Level 5 AVs. These are studies 1–3 and eight, as illustrated in Figure 49.

To produce an S-shaped uptake curve saturating at a rate of 85 per cent, a log-linear formula is applied to the average sales forecasts to generate a linearised logistic curve (loglin).

Figure 82 shows the loglin curve for the SAE Level 4+5 forecast, which becomes linear after an initial non-linear period.

Figure 82: Linearised logistic curve and straight line extrapolation for SAE Level 4+5 forecast

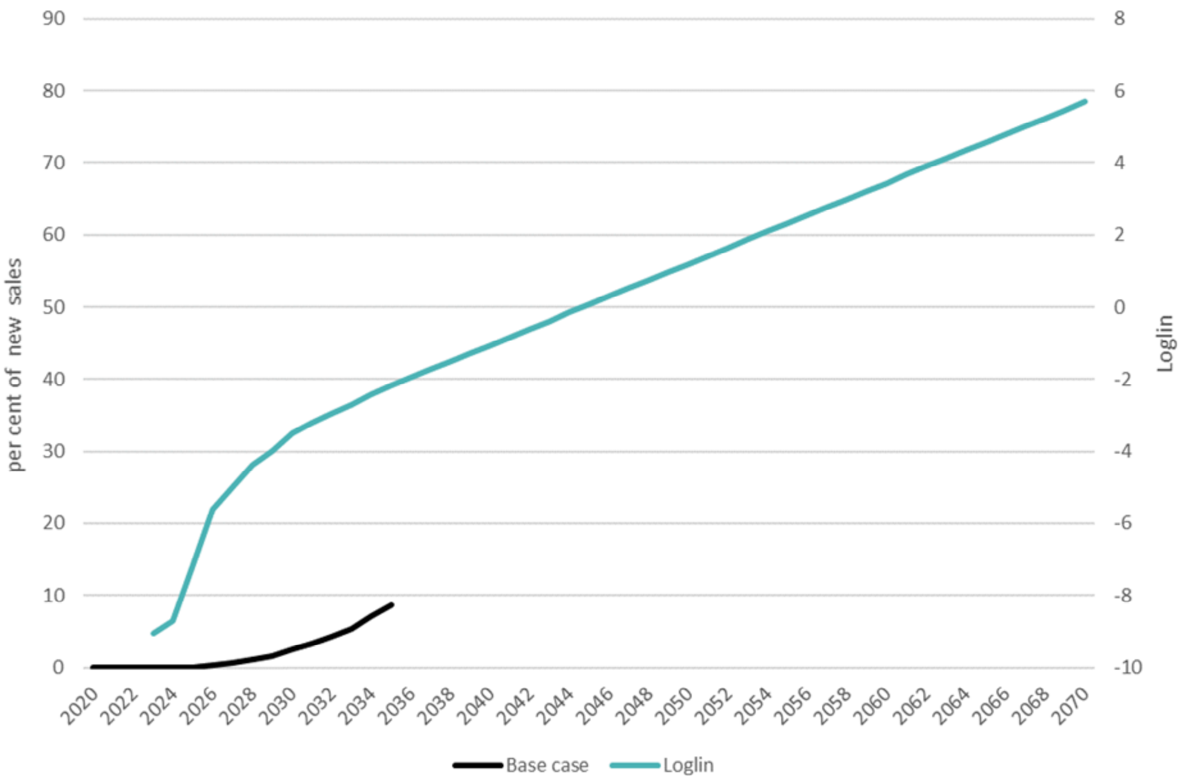


Figure 82 also shows the straight-line extrapolation of the login to 2070. This extrapolation forms the basis for constructing an S-shaped projection of the base forecasts to 2070. This is done by re-converting the extrapolated loglin to predict the base forecasts in each year, *t*, over the projection horizon (Equation 1).

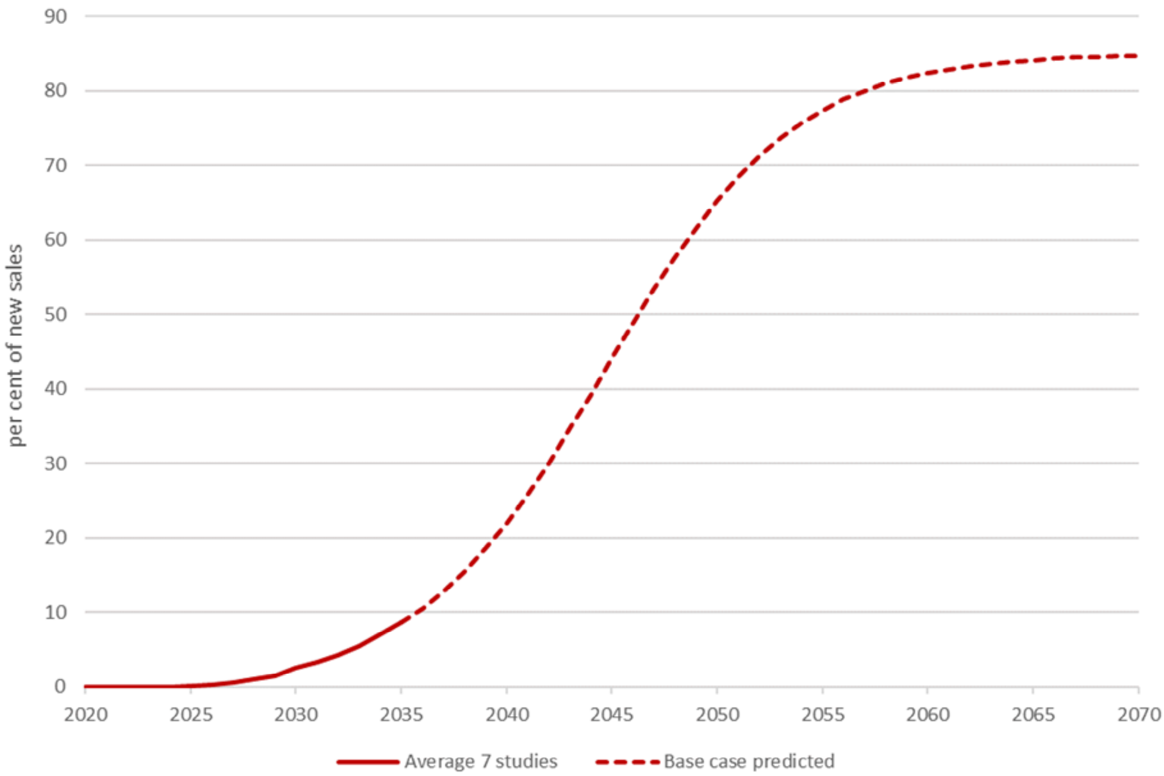
Equation 1: Predicted sales penetration in year t

$$\hat{x}_t = 85 \times \frac{e^{l_t}}{1 + e^{l_t}}$$

where $\hat{x}_t$ is the predicted sales forecast and l_t is the loglin in year *t*.

Figure 83 shows the forecast sales penetration of light vehicles with SAE Level 4+5 automation, separated by average forecasts from studies relied upon in this report (bold line) and predicted sales penetration using Equation 1 (broken line).

Figure 83: Base case projected share of new light vehicles sold with SAE Level 4+5 automation



Key parameters for forecasting the uptake of SAE Level 4+5 and SAE Level 5 light vehicles include:

- **Date of introduction:** Given SAE Level 4 and SAE Level 5 vehicles are still in early development, there is no firm empirical data on the likely date of commercial introduction. The introduction date is therefore informed by the best available forecasts (summarised in Table 5). Forecasts are informed by various factors, including the empirical lag between when a technology is technically feasible to when it becomes available in the new vehicle model. This lag reflects that manufacturers tend to introduce new passenger vehicle models every five years and new light commercial vehicle models every eight years. The degree of forecasting uncertainty also informs how the introduction date varies between scenarios (explained in Table 3). The start date scenarios are generated by simply shifting to the base case curves forward or backwards.
- **Saturation rate:** The saturation rate of a technology is the maximum market penetration it achieves. Historically, saturation rates have varied due to differences in government regulation, consumer preferences and available alternatives. For instance, mandated technologies, such as seatbelts, typically reach 100 per cent market saturation. Where there is strong consumer preference to use non-mandatory technologies, market saturation is also likely to be high. For instance, Australian drivers have shown a strong preference for automatic transmission vehicles, which now comprise 90 per cent 90 per cent of new vehicle sales. Consumer preferences for available alternatives are also a relevant consideration. For instance, when selecting a market saturation rate of 65 per cent for electric vehicles, BITRE considered that many drivers would continue to prefer fossil fuel powered vehicles or switch to hydrogen powered vehicles (BITRE 2019). An 85 per cent market saturation rate has been applied when forecasting sales for SAE Level 4+5 vehicles in the base case. This high saturation rate has regard to the empirical preference of Australian consumers to adopt automatic transmission technology, as well as technologies that have safety benefits. A sub-

100 per cent rate reflects an expectation that this level of automation is unlikely to be mandated, a proportion of Australian consumers will continue to show minimal willingness to pay for the technology, and that new non-AV vehicles will still be commercially available in the future. The high and low saturation level sensitivities are generated by replacing 85 in the loglin formula with 100 and 30 respectively.

- **Speed of uptake:** The uptake speed is a product of the loglin model and reflects both the rate of change implied from the forecasts drawn upon (see Table 5) and the market saturation rate. Additionally, the rate at which technologies improve or costs fall will also affect the speed of uptake. To reflect uncertainty in the available forecasts, the model also explores different uptake speeds by halving, doubling or tripling the average rate of uptake drawn upon in this report before the loglin series is calculated.

A.1.2. Uptake of active safety, driver assistance and connectivity features

Sales penetration of active safety, driver assistance and connectivity features also follow an S-curve. Rather than deriving the sales penetration trajectory by applying a structural equation, these forecasts are formed using the following method:

- Pre-2020 sales data inform current sales penetration estimates of light vehicles with features of interest. Standard feature estimates are based on matching vehicle information from Glass's Research Data with new light passenger vehicle sales figures from various VFACTS issues. Where a feature is optional in the base model rather than being a standard feature, BITRE assumes the feature will be adopted 15 per cent of the time.
- Where there are no recorded sales at the time of drafting, BITRE forms an assumption around when sales would commence by applying an appropriate lag to a comparable feature. Given this absence of sales only applies to right turn assist and self-parking features in LCVs, BITRE can draw on the uptake of these features in cars and SUVs. The model assumes that right turn assist and self-parking will be adopted in LCVs with an 11-year and 7-year lag, respectively.
- For technologies where sales penetration before 2020 is either at or near 100 per cent, a 100 per cent penetration rate is applied over the forecasting period. This applies to driver airbags, dual airbags, side airbags and ESC
- For technologies where sales penetration is materially below 100 per cent pre-2020 forecasts are based on the median of the four technologies that have reached 100 per cent (that is, driver airbags, dual airbags, side airbags and ESC). The four technology takeups are shifted in time to align as closely as possible, and then a median is taken. This is shown in Figure 84 for cars/SUVs and in Figure 85 for LCVs.

Figure 84: Technologies with 100 per cent uptake in cars and SUVs

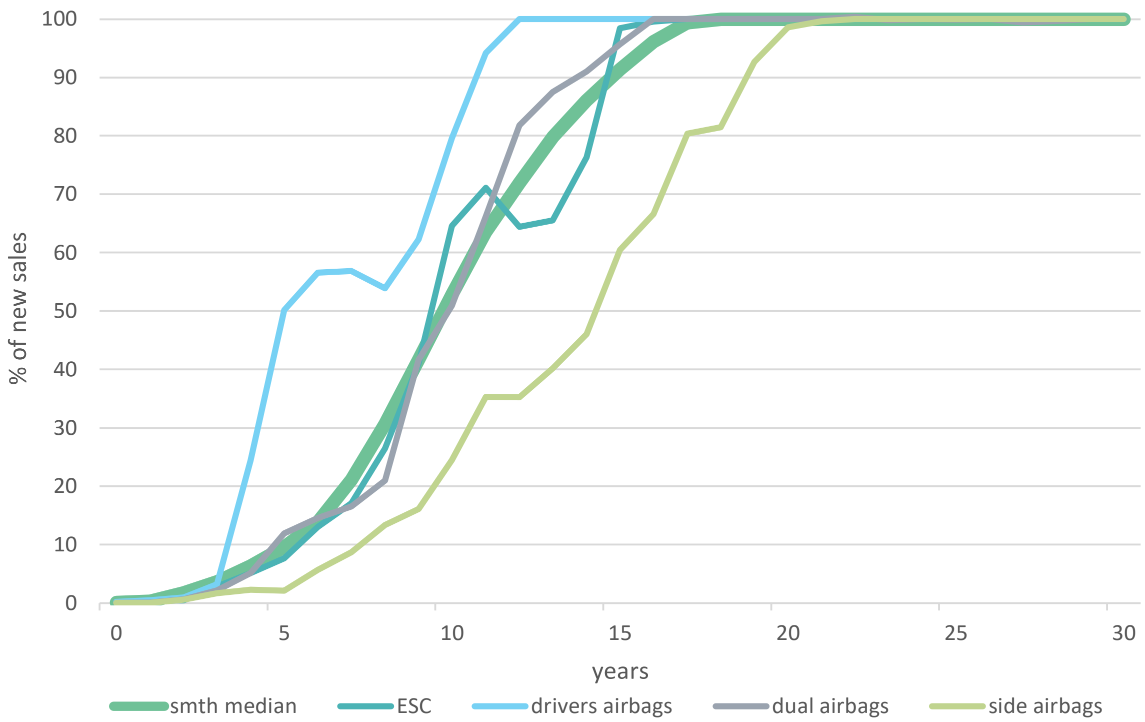
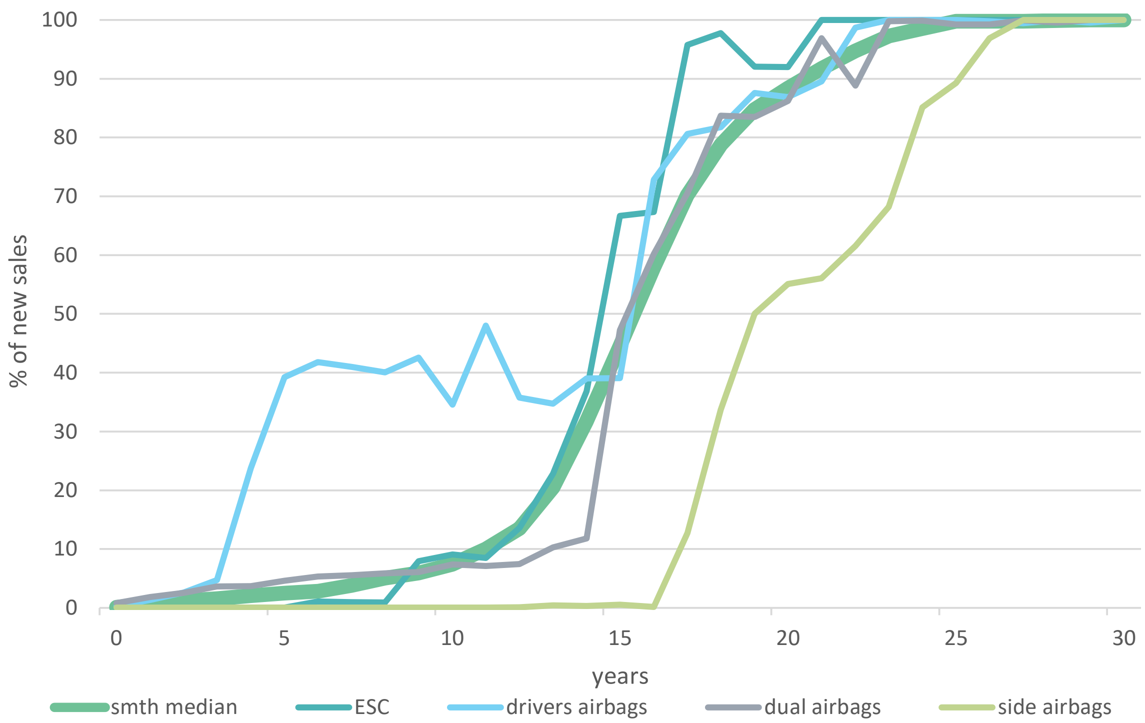


Figure 85: Technologies with 100 per cent uptake in LCVs



It can be seen that technological uptake in LCVs generally initially lags behind that in cars/SUVs, but then increases faster a little later on.

BITRE then uses the median uptakes to forecast the rest of the safety and automation technologies by linking the uptake percentage at 2019 to a corresponding number (or average of numbers) in the median series. The future uptake numbers from the median series are then used to forecast the uptake of the technologies that have not reached 100 per cent.

After forecasting the uptake of technology in the new vehicle fleet, fleet penetration rates are modelled.

A.2. Fleet penetration model

A fleet penetration model determines what percentage of the light vehicle fleet will be AVs or include technologies of interest. The model does this by taking the current fleet, forecast sales and scrappage into account.

For each sales forecast, the model calculates the number of vehicles with a characterisic of interest (*i*) in the fleet. Equation 2 derives the number of vehicles sold in year *t* with characteristic *i* that will be in the fleet in year *y*.

Equation 2: Fleet penetration of vehicles sold in year t with characteristic i

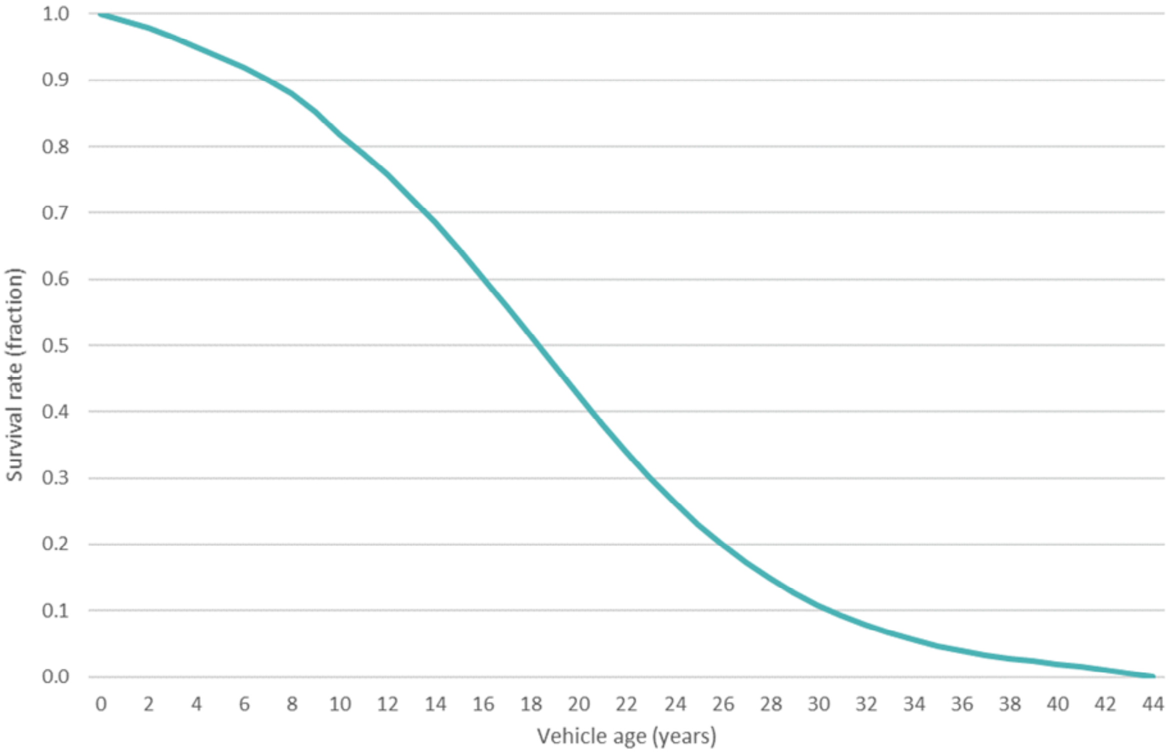
$$f_{y,t,i} = S_t \times \alpha_{t,i} \times r_{y,t}$$

Where:

- S_t *= forecast vehicle sales for year t*
- $\alpha_{t,i}$ *= forecast percentage of sales with characteristic i sold in year t*
- *t = year of vehicle sales and can be between 1930–2070*
- *y = is the year, which can be can be between 1930–2070*
- $r_{y,t}$ *= survival rate for vehicles in year y that were sold in year t*

The survival rate varies between 0 (0 per cent) and 1 (100 per cent), and declines as vehicle age ($y - t$) moves from zero to 44 years (see Figure 86).

Figure 86: Survival rate of vehicles over vehicle age



The fleet penetration of vehicles sold in year *t* with characteristic *i* is then added to vehicles sold over all years (that is, all values of *t*). This derives the fleet penetration of vehicles with characteristic *i* in year *y* (as per Equation 3).

Equation 3: Fleet penetration of vehicles with characteristic i

$$F_{y,i} = \sum_{t=1930}^{141} F_{y,t,i}$$

$F_{y,i}$ can then be divided by vehicle sales in year *y* to get the proportion of the vehicle fleet with characteristic *i* for that year.

Appendix B

Fully automated vehicle forecasts

The full details of the AV forecasts presented in this report are found in this Appendix.

B.1. Uptake of vehicles with SAE Level 4+5 automation

Table 10 and Table 11 present the sensitivity and scenario projections of vehicles with SAE Level 4+5 automation as a share of new light vehicle sales and the light vehicle fleet, respectively.

Table 10: Forecast share of new light vehicles sold with SAE Level 4+5 automation across scenarios (2020-2070)

	Base	Sensitivities					Tailored scenarios		
Year	Base case	Low growth	High growth	30% saturation	100% saturation	Late start	Scenario 1	Scenario 2	Scenario 3
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02
2022	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.04
2023	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.07
2024	0.02	0.01	0.03	0.02	0.02	0.00	0.00	0.00	0.10
2025	0.07	0.04	0.15	0.07	0.07	0.00	0.00	0.00	0.44
2026	0.36	0.18	0.72	0.36	0.36	0.00	0.00	0.01	2.17
2027	0.66	0.33	1.32	0.66	0.66	0.01	0.01	0.01	3.96
2028	1.14	0.57	2.28	1.14	1.14	0.01	0.01	0.02	6.83
2029	1.64	0.82	3.28	1.64	1.64	0.02	0.02	0.03	9.83
2030	2.61	1.31	5.22	2.61	2.61	0.07	0.07	0.15	15.66
2031	3.34	1.67	6.67	3.34	3.34	0.36	0.36	0.72	20.01
2032	4.22	2.11	8.45	4.22	4.22	0.66	0.66	1.32	25.35
2033	5.41	2.71	10.83	5.41	5.41	1.14	1.14	2.28	32.48
2034	6.98	3.49	13.95	6.98	6.98	1.64	1.64	3.28	41.86
2035	8.59	4.30	17.18	8.59	8.59	2.61	2.61	5.22	51.55
2036	10.53	5.28	20.94	10.41	10.54	3.34	3.34	6.67	61.11
2037	12.83	6.46	25.20	12.39	12.86	4.22	4.22	8.45	69.89
2038	15.52	7.89	29.94	14.47	15.60	5.41	5.41	10.83	77.42
2039	18.64	9.60	35.04	16.57	18.81	6.98	6.98	13.95	83.51
2040	22.18	11.62	40.37	18.61	22.50	8.59	8.59	17.18	88.21
2041	26.14	13.98	45.77	20.51	26.67	10.53	10.41	20.94	91.70

	Base	Sensitivities					Tailored scenarios		
Year	Base case	Low growth	High growth	30% saturation	100% saturation	Late start	Scenario 1	Scenario 2	Scenario 3
2042	30.45	16.71	51.06	22.23	31.30	12.83	12.39	25.20	94.23
2043	35.05	19.84	56.10	23.74	36.34	15.52	14.47	29.94	96.02
2044	39.84	23.34	60.74	25.02	41.70	18.64	16.57	35.04	97.27
2045	44.70	27.20	64.90	26.08	47.27	22.18	18.61	40.37	98.14
2046	49.51	31.38	68.54	26.94	52.90	26.14	20.51	45.77	98.73
2047	54.13	35.81	71.66	27.63	58.46	30.45	22.23	51.06	99.14
2048	58.48	40.39	74.28	28.17	63.81	35.05	23.74	56.10	99.41
2049	62.46	45.01	76.45	28.60	68.84	39.84	25.02	60.74	99.60
2050	66.05	49.58	78.21	28.93	73.46	44.70	26.08	64.90	99.73
2051	69.20	53.99	79.64	29.18	77.62	49.51	26.94	68.54	99.82
2052	71.94	58.14	80.79	29.38	81.29	54.13	27.63	71.66	99.88
2053	74.27	61.98	81.70	29.53	84.48	58.48	28.17	74.28	99.92
2054	76.24	65.45	82.42	29.64	87.22	62.46	28.60	76.45	99.94
2055	77.89	68.54	82.98	29.73	89.53	66.05	28.93	78.21	99.96
2056	79.24	71.24	83.43	29.80	91.46	69.20	29.18	79.64	99.97
2057	80.36	73.57	83.78	29.85	93.07	71.94	29.38	80.79	99.98
2058	81.26	75.56	84.05	29.88	94.39	74.27	29.53	81.70	99.99
2059	82.00	77.24	84.26	29.91	95.47	76.24	29.64	82.42	99.99
2060	82.60	78.65	84.43	29.93	96.35	77.89	29.73	82.98	99.99
2061	83.08	79.82	84.55	29.95	97.07	79.24	29.80	83.43	100.00
2062	83.46	80.78	84.65	29.96	97.64	80.36	29.85	83.78	100.00
2063	83.77	81.57	84.73	29.97	98.11	81.26	29.88	84.05	100.00
2064	84.02	82.22	84.79	29.98	98.49	82.00	29.91	84.26	100.00
2065	84.22	82.75	84.84	29.98	98.79	82.60	29.93	84.43	100.00
2066	84.38	83.18	84.87	29.99	99.03	83.08	29.95	84.55	100.00
2067	84.51	83.53	84.90	29.99	99.22	83.46	29.96	84.65	100.00
2068	84.61	83.82	84.92	29.99	99.38	83.77	29.97	84.73	100.00
2069	84.69	84.05	84.94	29.99	99.50	84.02	29.98	84.79	100.00
2070	84.75	84.23	84.95	30.00	99.60	84.22	29.98	84.84	100.00

Table 11: Forecast share of light vehicle fleet with SAE Level 4+5 automation across scenarios (2020-2070)

	Base	Sensitivities					Tailored scenarios		
Year	Base case	Low growth	High growth	30% saturation	100% saturation	Late start	Scenario 1	Scenario 2	Scenario 3
2020	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Base	Sensitivities					Tailored scenarios		
Year	Base case	Low growth	High growth	30% saturation	100% saturation	Late start	Scenario 1	Scenario 2	Scenario 3
2023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
2024	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
2025	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.04
2026	0.03	0.01	0.06	0.03	0.03	0.00	0.00	0.00	0.17
2027	0.07	0.03	0.14	0.07	0.07	0.00	0.00	0.00	0.41
2028	0.14	0.07	0.27	0.14	0.14	0.00	0.00	0.00	0.82
2029	0.23	0.12	0.46	0.23	0.23	0.00	0.00	0.00	1.39
2030	0.38	0.19	0.76	0.38	0.38	0.01	0.01	0.01	2.29
2031	0.57	0.29	1.14	0.57	0.57	0.03	0.03	0.06	3.43
2032	0.81	0.41	1.62	0.81	0.81	0.07	0.07	0.13	4.86
2033	1.11	0.56	2.23	1.11	1.11	0.13	0.13	0.27	6.68
2034	1.50	0.75	3.01	1.50	1.50	0.23	0.23	0.46	9.02
2035	1.98	0.99	3.96	1.98	1.98	0.38	0.38	0.76	11.87
2036	2.56	1.28	5.11	2.55	2.56	0.57	0.57	1.14	15.22
2037	3.26	1.63	6.48	3.23	3.26	0.81	0.81	1.62	19.01
2038	4.10	2.06	8.10	4.01	4.11	1.11	1.11	2.23	23.14
2039	5.11	2.58	9.99	4.89	5.13	1.51	1.51	3.01	27.51
2040	6.29	3.20	12.11	5.86	6.32	1.98	1.98	3.96	31.96
2041	7.68	3.95	14.52	6.93	7.75	2.56	2.55	5.11	36.55
2042	9.30	4.85	17.17	8.06	9.41	3.27	3.23	6.50	41.15
2043	11.14	5.90	20.05	9.26	11.33	4.11	4.02	8.12	45.68
2044	13.21	7.14	23.12	10.49	13.51	5.12	4.91	10.02	50.12
2045	15.52	8.57	26.33	11.74	15.96	6.32	5.89	12.17	54.43
2046	18.04	10.21	29.66	12.99	18.68	7.72	6.96	14.59	58.58
2047	20.76	12.07	33.05	14.24	21.64	9.34	8.11	17.26	62.56
2048	23.65	14.14	36.47	15.47	24.83	11.19	9.30	20.15	66.36
2049	26.69	16.43	39.89	16.67	28.22	13.27	10.54	23.23	69.95
2050	29.83	18.92	43.28	17.84	31.77	15.59	11.80	26.46	73.34
2051	33.04	21.60	46.60	18.96	35.45	18.12	13.06	29.79	76.51
2052	36.30	24.44	49.83	20.04	39.21	20.84	14.31	33.20	79.47
2053	39.57	27.40	52.96	21.06	43.02	23.74	15.55	36.64	82.21
2054	42.82	30.48	55.97	22.03	46.83	26.79	16.75	40.07	84.74
2055	46.03	33.62	58.84	22.94	50.63	29.94	17.92	43.47	87.06
2056	49.16	36.80	61.57	23.79	54.37	33.17	19.05	46.80	89.17
2057	52.21	40.00	64.15	24.59	58.04	36.43	20.13	50.05	91.08
2058	55.16	43.18	66.57	25.32	61.60	39.71	21.16	53.19	92.81
2059	57.98	46.32	68.84	26.00	65.05	42.97	22.13	56.20	94.35
2060	60.69	49.40	70.95	26.62	68.35	46.19	23.04	59.09	95.74
2061	63.25	52.39	72.91	27.19	71.51	49.34	23.90	61.83	96.97

Year	Base case	Low growth	High growth	30% saturation	100% saturation	Late start	Scenario 1	Scenario 2	Scenario 3
	Base	Sensitivities					Tailored scenarios		
2062	65.68	55.29	74.71	27.71	74.52	52.40	24.70	64.42	98.06
2063	67.96	58.08	76.36	28.18	77.36	55.36	25.44	66.86	99.03
2064	70.09	60.75	77.87	28.60	80.03	58.20	26.12	69.14	99.88
2065	72.08	63.29	79.25	28.98	82.53	60.92	26.75	71.26	100.00
2066	73.93	65.70	80.50	29.32	84.86	63.50	27.32	73.23	100.00
2067	75.63	67.97	81.63	29.62	87.02	65.94	27.84	75.05	100.00
2068	77.19	70.09	82.65	29.89	89.02	68.23	28.31	76.71	100.00
2069	78.62	72.07	83.56	30.14	90.86	70.38	28.74	78.23	100.00
2070	79.93	73.91	84.37	30.35	92.54	72.37	29.12	79.61	100.00

B.2. Uptake of vehicles with SAE Level 5 automation

Table 12 and

Table 13 presents the sensitivity and scenario projections of vehicles with SAE Level 5 automation as a share of new light vehicle sales and the light vehicle fleet, respectively.

Table 12: Forecast share of new light vehicles sold with SAE Level 5 automation across scenarios (2020-2070)

Year	Base case	Low growth	High growth	30% saturation	100% saturation	Early start	Late start	Scenario 1	Scenario 2	Scenario 3
	Base	Sensitivities						Tailored scenarios		
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.01
2026	0.06	0.03	0.12	0.06	0.06	0.42	0.00	0.00	0.00	0.17
2027	0.11	0.06	0.23	0.11	0.11	0.53	0.00	0.00	0.00	0.34
2028	0.17	0.08	0.34	0.17	0.17	0.65	0.00	0.00	0.00	0.51
2029	0.22	0.11	0.45	0.22	0.22	0.79	0.00	0.00	0.00	0.67
2030	0.31	0.16	0.63	0.31	0.31	0.95	0.00	0.00	0.00	0.94
2031	0.42	0.21	0.84	0.42	0.42	1.14	0.06	0.00	0.00	1.26
2032	0.53	0.27	1.06	0.53	0.53	1.37	0.11	0.00	0.00	1.59
2033	0.65	0.33	1.31	0.65	0.65	1.65	0.17	0.00	0.01	1.96
2034	0.79	0.40	1.58	0.79	0.79	1.98	0.22	0.06	0.17	2.38
2035	0.95	0.48	1.91	0.95	0.95	2.37	0.31	0.11	0.34	2.86
2036	1.14	0.57	2.29	1.14	1.14	2.84	0.42	0.17	0.51	3.43

	Base	Sensitivities						Tailored scenarios		
Year	Base case	Low growth	High growth	30% saturation	100% saturation	Early start	Late start	Scenario 1	Scenario 2	Scenario 3
2037	1.37	0.69	2.75	1.37	1.38	3.40	0.53	0.22	0.67	4.12
2038	1.65	0.83	3.29	1.64	1.65	4.06	0.65	0.31	0.94	4.93
2039	1.98	0.99	3.94	1.96	1.98	4.85	0.79	0.42	1.26	5.90
2040	2.37	1.19	4.71	2.34	2.38	5.77	0.95	0.53	1.59	7.04
2041	2.84	1.43	5.62	2.78	2.85	6.85	1.14	0.65	1.96	8.38
2042	3.40	1.71	6.69	3.30	3.41	8.12	1.37	0.79	2.38	9.95
2043	4.06	2.05	7.95	3.90	4.08	9.59	1.65	0.95	2.86	11.77
2044	4.85	2.46	9.41	4.59	4.87	11.29	1.98	1.14	3.43	13.88
2045	5.77	2.94	11.10	5.38	5.80	13.24	2.37	1.37	4.11	16.30
2046	6.85	3.52	13.04	6.26	6.91	15.46	2.84	1.64	4.92	19.05
2047	8.12	4.19	15.25	7.26	8.20	17.95	3.40	1.96	5.88	22.14
2048	9.59	5.00	17.75	8.35	9.71	20.72	4.06	2.34	7.01	25.56
2049	11.29	5.94	20.53	9.54	11.46	23.77	4.85	2.78	8.34	29.32
2050	13.24	7.05	23.60	10.81	13.49	27.09	5.77	3.30	9.88	33.39
2051	15.46	8.34	26.93	12.16	15.81	30.63	6.85	3.90	11.66	37.72
2052	17.95	9.84	30.50	13.55	18.44	34.36	8.12	4.59	13.70	42.25
2053	20.72	11.57	34.27	14.96	21.39	38.22	9.59	5.38	16.03	46.91
2054	23.77	13.55	38.17	16.38	24.68	42.16	11.29	6.26	18.65	51.64
2055	27.09	15.79	42.15	17.78	28.29	46.11	13.24	7.26	21.56	56.33
2056	30.63	18.31	46.13	19.12	32.21	49.99	15.46	8.35	24.76	60.91
2057	34.36	21.10	50.06	20.40	36.39	53.75	17.95	9.54	28.22	65.31
2058	38.22	24.17	53.85	21.59	40.79	57.32	20.72	10.81	31.90	69.46
2059	42.16	27.50	57.46	22.69	45.34	60.68	23.77	12.16	35.77	73.31
2060	46.11	31.05	60.83	23.69	49.97	63.77	27.09	13.55	39.75	76.85
2061	49.99	34.78	63.95	24.58	54.60	66.60	30.63	14.96	43.78	80.04
2062	53.75	38.63	66.78	25.37	59.15	69.14	34.36	16.38	47.79	82.89
2063	57.32	42.55	69.33	26.07	63.55	71.40	38.22	17.78	51.71	85.41
2064	60.68	46.47	71.59	26.67	67.73	73.39	42.16	19.12	55.46	87.61
2065	63.77	50.33	73.58	27.19	71.65	75.13	46.11	20.40	59.01	89.52
2066	66.60	54.05	75.31	27.64	75.27	76.64	49.99	21.59	62.31	91.16
2067	69.14	57.60	76.81	28.02	78.56	77.94	53.75	22.69	65.32	92.57
2068	71.40	60.91	78.10	28.34	81.52	79.06	57.32	23.69	68.05	93.77
2069	73.39	63.98	79.20	28.62	84.16	80.01	60.68	24.58	70.48	94.79
2070	75.13	66.77	80.14	28.85	86.48	80.81	63.77	25.37	72.63	95.65

Table 13: Forecast share of light vehicle fleet with SAE Level 5 automation across scenarios (2020-2070)

	Base	Sensitivities						Tailored scenarios		
Year	Base case	Low growth	High growth	30% saturation	100% saturation	Early start	Late start	Scenario 1	Scenario 2	Scenario 3
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.01	0.00	0.00	0.08	0.00	0.00	0.00	0.01
2027	0.01	0.01	0.02	0.01	0.01	0.11	0.00	0.00	0.00	0.03
2028	0.02	0.01	0.04	0.02	0.02	0.14	0.00	0.00	0.00	0.06
2029	0.03	0.02	0.07	0.03	0.03	0.19	0.00	0.00	0.00	0.10
2030	0.05	0.03	0.10	0.05	0.05	0.24	0.00	0.00	0.00	0.15
2031	0.08	0.04	0.15	0.08	0.08	0.30	0.00	0.00	0.00	0.23
2032	0.11	0.05	0.21	0.11	0.11	0.38	0.01	0.00	0.00	0.32
2033	0.14	0.07	0.28	0.14	0.14	0.46	0.02	0.00	0.00	0.42
2034	0.19	0.09	0.37	0.19	0.19	0.57	0.03	0.00	0.01	0.56
2035	0.24	0.12	0.48	0.24	0.24	0.69	0.05	0.01	0.03	0.71
2036	0.30	0.15	0.60	0.30	0.30	0.84	0.08	0.02	0.06	0.90
2037	0.37	0.19	0.75	0.37	0.37	1.02	0.11	0.03	0.10	1.12
2038	0.46	0.23	0.93	0.46	0.46	1.24	0.14	0.05	0.15	1.39
2039	0.57	0.28	1.14	0.57	0.57	1.49	0.19	0.08	0.23	1.70
2040	0.69	0.35	1.38	0.69	0.69	1.79	0.24	0.11	0.32	2.07
2041	0.84	0.42	1.68	0.84	0.85	2.15	0.30	0.14	0.43	2.52
2042	1.03	0.51	2.04	1.01	1.03	2.57	0.37	0.19	0.56	3.04
2043	1.24	0.62	2.46	1.22	1.24	3.07	0.46	0.24	0.72	3.66
2044	1.50	0.75	2.95	1.46	1.50	3.66	0.57	0.30	0.90	4.39
2045	1.80	0.91	3.53	1.74	1.80	4.34	0.70	0.38	1.13	5.24
2046	2.16	1.09	4.21	2.06	2.17	5.14	0.85	0.46	1.39	6.23
2047	2.58	1.31	5.00	2.44	2.60	6.06	1.03	0.57	1.71	7.38
2048	3.08	1.57	5.92	2.87	3.10	7.12	1.25	0.70	2.09	8.70
2049	3.67	1.89	6.98	3.36	3.70	8.34	1.50	0.84	2.53	10.20
2050	4.36	2.25	8.19	3.91	4.40	9.71	1.81	1.02	3.06	11.90
2051	5.16	2.69	9.57	4.52	5.22	11.26	2.17	1.23	3.67	13.81
2052	6.09	3.20	11.11	5.19	6.18	12.98	2.59	1.47	4.39	15.93
2053	7.15	3.80	12.83	5.93	7.28	14.87	3.09	1.75	5.23	18.27
2054	8.37	4.51	14.74	6.74	8.55	16.95	3.68	2.08	6.20	20.81
2055	9.74	5.32	16.82	7.59	9.99	19.19	4.37	2.45	7.32	23.54

	Base	Sensitivities						Tailored scenarios		
Year	**Base case**	**Low growth**	**High growth**	**30% saturation**	**100% saturation**	**Early start**	**Late start**	**Scenario 1**	**Scenario 2**	**Scenario 3**
2056	11.29	6.27	19.07	8.50	11.63	21.59	5.17	2.88	8.60	26.46
2057	13.02	7.35	21.48	9.45	13.47	24.13	6.10	3.37	10.04	29.55
2058	14.92	8.58	24.04	10.44	15.51	26.79	7.17	3.92	11.67	32.77
2059	17.00	9.98	26.72	11.46	17.77	29.56	8.39	4.54	13.47	36.10
2060	19.24	11.55	29.51	12.50	20.23	32.42	9.77	5.22	15.46	39.52
2061	21.65	13.29	32.38	13.55	22.88	35.33	11.32	5.96	17.62	43.00
2062	24.19	15.21	35.31	14.61	25.73	38.27	13.05	6.76	19.96	46.50
2063	26.87	17.31	38.27	15.66	28.74	41.23	14.95	7.63	22.45	50.01
2064	29.65	19.57	41.25	16.69	31.89	44.18	17.04	8.54	25.09	53.49
2065	32.51	21.99	44.22	17.71	35.17	47.09	19.29	9.50	27.84	56.93
2066	35.43	24.55	47.15	18.71	38.54	49.97	21.70	10.49	30.70	60.30
2067	38.39	27.24	50.04	19.68	41.98	52.77	24.26	11.52	33.62	63.58
2068	41.36	30.02	52.86	20.61	45.46	55.49	26.94	12.56	36.60	66.76
2069	44.31	32.89	55.60	21.50	48.95	58.13	29.73	13.62	39.60	69.82
2070	47.24	35.81	58.24	22.36	52.43	60.66	32.60	14.68	42.61	72.75

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