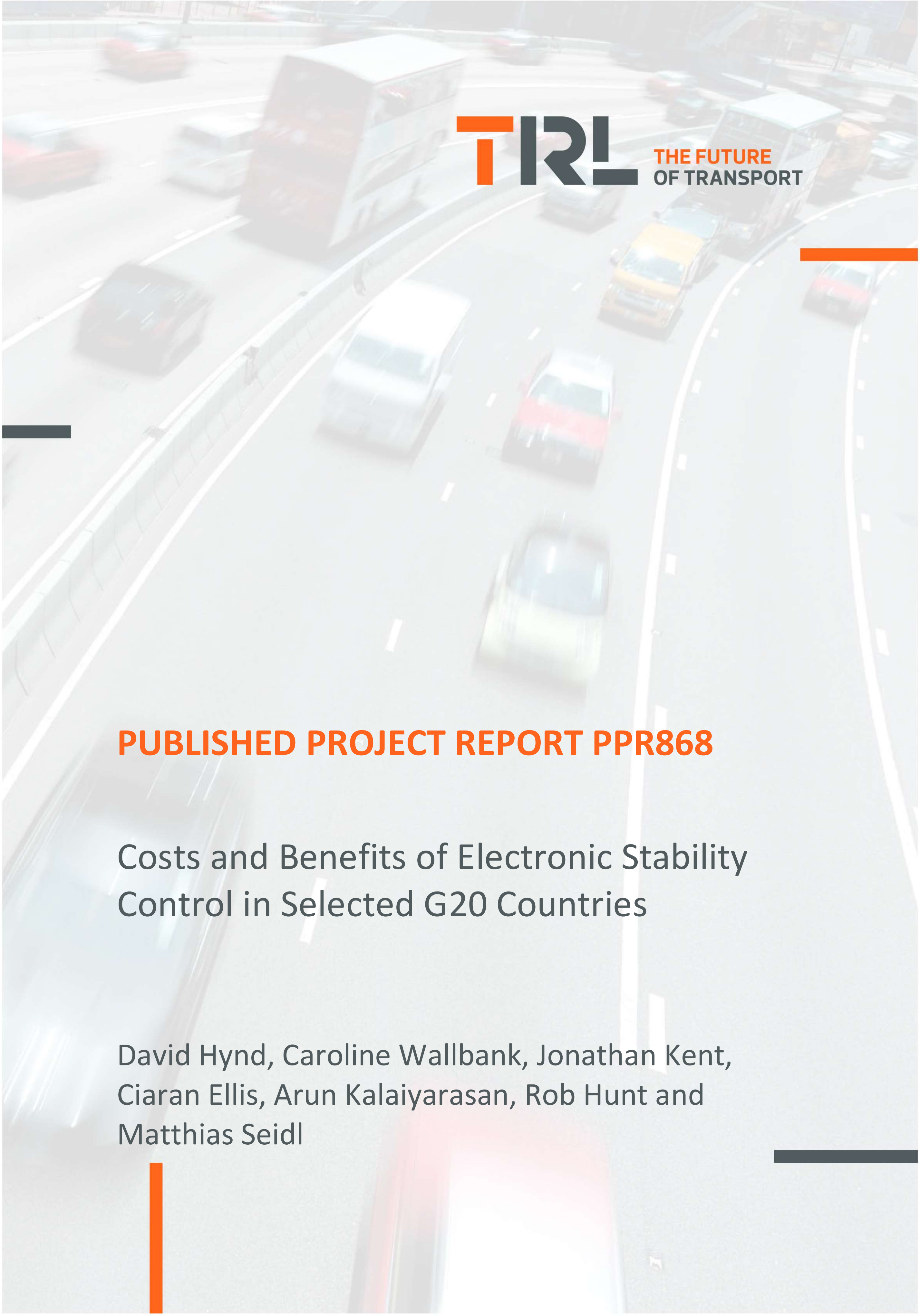

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PUBLISHED PROJECT REPORT PPR868

Costs and Benefits of Electronic Stability Control in Selected G20 Countries

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Report details

Report prepared for:	Bloomberg Philanthropies, Rebecca Bavinger		
Copyright:	© TRL Limited		
Report date:	February 2019		
Report status/version:	Final		
Quality approval:			
Colette Marquez-Estevez (Project Manager)	22 February 2019	Jolyon Carroll (Technical Reviewer)	22 February 2019

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Executive Summary

Electronic Stability Control (ESC) is regarded as the most important vehicle safety regulation for crash avoidance. This technology is designed to prevent skidding and loss of control in cases of over-steering and under-steering. It is estimated that ESC is 38% effective at reducing the number of fatalities in loss of control collisions.

> ESC could eliminate 38 in every 100 fatal collisions involving loss of control

In 2017, the UN General Assembly adopted a series of road safety performance targets, one of which includes the objective to ensure that 100% of vehicles are equipped with ESC in 2030. At the G20 level[1], only 13 countries currently adhere to the UN regulation on ESC. Amongst the list of countries that do not have an ESC regulation is China, which is currently the biggest producer of passenger cars globally. The absence of a uniform ESC regulation means that sub-standard vehicles are currently being produced, sold and exported to other countries, contributing to the substantial number of global road traffic casualties.

> The absence of regulation for ESC is contributing to global casualty figures and resulting in substantial economic burden

Using a range of data sources and statistical modelling, this study estimates the impact of ESC legislation, mandating the technology to be fitted to all new vehicles in G20 countries from 2020. The results show that ESC could save around 42,000 lives between 2020 and 2030 (sensitivity analysis suggests this could be up to 60,000 lives). In monetary terms, this equates to around US$17.5 billion. In addition, it is estimated that a further 47,500 lives could have been saved between 2020 and 2030 if earlier regulatory action had ensured that ESC was fitted throughout the whole vehicle fleet in each country by 2020. A simplified modelling approach suggests that regulation could also prevent up to 150,000 serious injuries, equating to an extra US$4 billion in economic benefit.

> ESC could save up to 42,000 lives if the appropriate regulations were introduced in Argentina, Brazil, China, India, Indonesia, Mexico and South Africa in 2020

Information from the literature and industry sources suggests that ESC is relatively cheap to implement on vehicles which already contain Anti-lock Braking Systems: just US$50 per car. If regulation for ESC were introduced in the countries of interest in 2020, by 2030 almost 420 million cars across these seven countries could have the technology installed.

> ESC costs as little as US$50 to fit to each new passenger car

[1] The G20 countries include: Argentina, Australia, Brazil, Canada, China, EU – Germany, France, Italy, UK (the EU and these four member states are all members), India, Indonesia, Japan, Mexico, Republic of Korea, Russia, Saudi Arabia, Turkey, South Africa and United States of America.

ESC regulations are cost beneficial and thus recommended across the G20

Comparison of the estimated benefits and costs show the benefit-to-cost ratio is greater than 1 (2.27 if only fatalities are considered and 2.80 if both fatalities and serious injuries are accounted for). In addition, the 'in-year' benefit-to-cost ratio for the region is greater than 1 within a year of implementation of the regulation, when both fatalities are serious injuries are considered (and within 3 years when only fatalities are considered). These results indicate that the benefits outweigh the costs, and suggest that ESC regulations should be recommended for implementation across the G20 countries. For example, a benefit-to-cost ratio of 2.8 can be interpreted as follows: "for every dollar spent by consumers in purchasing vehicles with these technologies, there is a \$2.80 return in economic benefit to society".

Based on current trends, it is estimated that the global target for all vehicles to be fitted with ESC by 2030 will not be met

Assuming ESC regulation is implemented in 2020 for Argentina, Brazil, China, India, Indonesia, Mexico and South Africa[2], it is estimated that by 2030 only 85% of the total car fleet in the G20 countries will have ESC fitted. This demonstrates that, unless more is done, the G20 will not meet the global target of 100% fitment by 2030. Therefore it is essential that at the very least these countries immediately adopt ESC regulation to get as close to the global target as possible.

[2] Since the analysis and report were finalised, Argentina and Brazil have announced that they will start applying ESC regulations in 2020, and the Indian government has committed to introducing ESC regulation in 2022. Based on the estimates in this report, these announcements have the potential to save over 9,000 lives and 30,000 serious injuries between 2020 and 2030.

Table of Contents

1 Introduction

According to the World Health Organisation, road traffic injuries are the eighth leading cause of death globally, responsible for around 1.4 million deaths each year. To reduce this burden, the UN General Assembly has declared a decade of Road Safety targets. One among the 12 targets is to meet high-quality safety standards such as the recommended priority UN Regulations, Global Technical Regulations, or equivalent recognized national performance requirements in 100% of new and used vehicles fleet by 2030[3].

Figure 1 shows the countries applying priority UN vehicle standards. The G20 countries are responsible for 98% of the world's passenger car production, but not all of them apply the most important vehicle safety regulations.

Figure 1: Countries applying priority UN vehicle safety standards (WHO, 2015), with G20 countries highlighted

Electronic Stability Control (ESC) is regarded as the most important UN regulation for crash avoidance. The success of ESC has led to it rapidly becoming mandatory in many high income countries. At the G20 level, only 13 countries adhere to the UN regulation on ESC (see Figure 2), of which the majority are high-income countries. Amongst the list of countries that do not have an ESC regulation is China, which is currently the biggest producer of passenger cars globally. The absence of a uniform ESC regulation means that sub-standard vehicles are currently being produced, sold and exported to other countries, contributing to the substantial global road traffic casualty numbers.

[3] www.who.int/violence_injury_prevention/road_traffic/12GlobalRoadSafetyTargets.pdf?ua=1

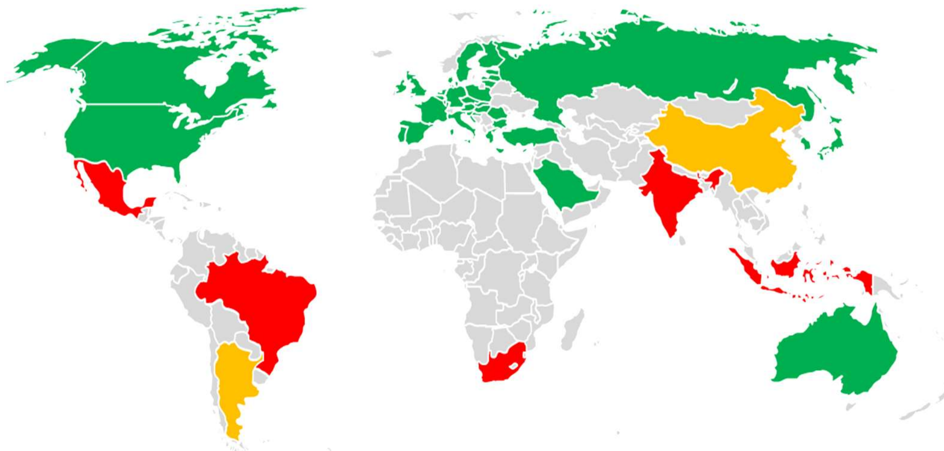

Figure 2: G20 countries by status of ESC regulation

(Green = ESC regulation implemented, Orange = ESC regulation in planning or voluntary agreement in place, Red = no ESC regulation planned, or timescales unconfirmed)

In November 2017, the Members States of the UN General Assembly finalised a comprehensive set of 12 global road safety targets[4]. One target relates specifically to the safety of vehicles:

> **Target 5: By 2030, 100% of new (defined as produced, sold or imported) and used vehicles meet high quality safety standards, such as the recommended priority UN Regulations, Global Technical Regulations, or equivalent recognized national performance requirements**

This target includes implementation of the UN Regulation for ESC. If this target is achieved, it will eliminate production and importation of new and of used vehicles that do not meet ESC (and other[5]) basic minimum safety standards.

1.1 Background

In 2015, TRL carried out a statistical analysis to determine how many lives could be saved in Brazil if minimum car secondary safety regulations and consumer testing programmes were applied to new vehicles (Cuerden *et al.*, 2015). This analysis was then extended by Wallbank *et al.* (2016) to predict how many car user deaths and injuries could be prevented in four Latin American countries (Argentina, Chile, Mexico and, from the previous study, Brazil). The major regulations considered were UN Regulations No. 14, 16 (seatbelts and their anchorages), 94 (occupant protection in frontal collision) and 95 (occupant protection in

[4] More information on the targets is available from: http://www.who.int/violence_injury_prevention/road_traffic/road-safety-targets/en/

[5] The target also includes regulations front and side impact protection (UN Regulations 94 and 95), pedestrian protection (UN Regulation 127 or GTR 9), seatbelts (UN Regulation 16), seatbelt anchorages (UN Regulation 14), child restraints (UN Regulations 44 and 129) and motorcycle braking (UN Regulation 78 or GTR 3).

side or lateral collisions). Primary safety systems (e.g. ESC) were not considered in this analysis.

Electronic Stability Control is a crash avoidance technology. ESC assists the driver from losing control of the vehicle by continuously monitoring the vehicle's direction of travel, steering wheel angle and the speed at which the individual wheels are rotating. If the direction of travel of the vehicle does not match with the intended direction of travel, as indicated by the steering wheel position, ESC will selectively apply the brakes and modulate the engine power to keep the vehicle travelling along the intended path.

ESC aims to prevent skidding and loss of control in cases of over-steering and under-steering. A number of studies throughout the world have demonstrated that ESC is especially effective at preventing single vehicle ('run off road') and rollover collisions; reducing both serious and fatal injuries. For instance, NHTSA estimates that nearly 2000 lives were saved by ESC in the US in 2015 (Webb, 2017), up from nearly 500 in 2007 (NHTSA, 2011) as the proportion of the fleet fitted with ESC has increased due to the implementation in 2009 of legislation to mandate the fitment of ESC. More information on G20 country specific ESC regulations, with dates of implementation of ESC requirements for the 13 G20 countries that have already mandated ESC, can be found in Table 1. Outside of the G20, in 2017 Malaysia became the first South East Asia country to mandate ESC.

Fitment of ESC tends to start with large, executive cars (e.g. Krafft *et al.* (2009)) and over time penetrates to mid-range vehicles. However, fitment tends to stall at this point and small family/city cars are often left out. For example, in France, Italy, Germany, Spain and the UK in 2009, ESC was fitted to 100% of E/F segment cars, about 90% of C/D segment cars and about 25% of A/B segment cars. Mandating fitment of ESC will speed up the fitment rate across the fleet, especially penetration of ESC into the small-car segments.

While ESC has reduced fatal and serious injuries (see e.g. Webb (2017) as quoted above), and may also be expected to reduce e.g. damage-only collisions and reduce congestion costs due to collisions being avoided, ABS and ESC are also the beginning of the technology path leading to Automated Emergency Braking (AEB) (see Section 9.1). This includes AEB to prevent car-to-car collisions, car-to-pedestrian collisions and car-to-cyclist/motorcyclist collisions. AEB is already required for heavy vehicles in Europe and a UN Regulation for car-to-car AEB is being developed and is expected to be available in 2019; adoption of this new UN Regulation by the EU is expected to follow, based on a proposed update to the General Safety Regulation[6]. Regulating ESC now is thus logical for prevention of crashes *and* to anticipate coming regulations on AEB.

[6] COM(2018) 286 final 2018/0145(COD). https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1527002949683&uri=CELEX:52018PC0286

1.2 Objectives

The overall aim of this research study is to support the adoption of minimum vehicle safety regulations, in particular the adoption of Electronic Stability Control (ESC) in the countries which do not currently apply the relevant regulation (see Table 1 in Section 1.3). The project aims to build on the previous research to demonstrate the costs and benefits of applying ESC regulation in these countries between 2020 and 2030.

In addition, a supplementary analysis which considers whether the global road safety target (Target 5) will be met for ESC by 2030 has been carried out and presented in Appendix I.

1.3 ABS and ESC requirements in the G20 countries

The study considers the introduction of mandatory ESC requirements in the G20 countries. Table 1 outlines the current status of ESC regulation in the G20 countries (in more detail than shown in Figure 2), highlighting the countries which do not currently apply mandatory ESC regulations.

The two primary extant international standards for ESC in light passenger vehicles are:

- UN Regulation 140[7] or the equivalent Global Technical Regulation, UN GTR 8[8]
- Federal Motor Vehicle Safety Standard (FMVSS) 126[9]

[7] ESC was introduced in UN Regulation 13-H, Revision 1, Amendment 2 effective from 22 July 2009; this was replaced by UN Regulation No. 140 from 22 January, 2017.

[8] United Nations (2008, as amended). Global Technical Regulation (GTR) No. 8. Electronic Stability Control Systems.

[9] Federal Motor Vehicle Safety Standard No. 126 – Electronic Stability Controls for Light Vehicles. Mandatory for all vehicles sold in the US since 1 September 2012.

Table 1: Status of ESC regulation in the G20 countries, January 2018

Country	Current ESC Regulation	Regulation Standards
Argentina	No	Announced in December 2017 that regulation would be delayed at least 2 years
Australia	Yes Since 2011	Australian Design Rule 31/03 - Brake Systems for Passenger Cars; Applies UN Regulation 140, Equivalent to the technical requirements of GTR-8
Brazil	No	Intend to regulate, but timescale to be confirmed
Canada	Yes Since 2011	CMVSS 126, CMVSS 136
China	No	Voluntary agreement with 12 major Chinese brands to fit from January 2018; Taiwan Province introduced mandatory ESC requirements in January 2018 complying with Regulation 140
EU - Germany/ France/ Italy/ UK‡	Yes Since 2011	UN Regulation 140 (Previously in UN Regulation 13-H)
India	No	None planned
Indonesia	No	None planned
Japan	Yes Since 2012	Japan Safety Regulation for Road Vehicle Article No. 12; Applies UN Regulation 140
Mexico	No	None planned
Republic of Korea	Yes Since 2012	KMVSS Article 90-2, Adopts FMVSS 126, Complies with GTR No. 8 / UN Reg 13-H
Russia	Yes Since 2014	UN Regulation 140
Saudi Arabia	Yes Since 2017	UN Regulation 13-H†
Turkey	Yes Since 2012	UN Regulation 140
South Africa	No	None planned
United States of America	Yes Since 2009	FMVSS 126

‡ NB: The EU and the four member states listed are all G20 countries

† Legislation was adopted when Regulation 13-H *did* require ESC; this has subsequently been moved to Regulation 140, but it is clear that the intent was to mandate ESC in Saudi Arabia

Table 2 shows the status of ABS regulation in the G20 countries as of 1 January 2018. It is necessary to have ABS fitted to a car before ESC can be fitted. Most of the G20 countries already mandate fitment of ABS or will do by 2020, so ABS costs and benefits are not accounted for in this study; for Indonesia and South Africa, legislation to mandate ABS would be required alongside legislation to mandate ESC. Analysis of data from manufacturers' web sites and local NCAP web sites indicates that the ABS is fitted to all new cars in China, that fitment exceeds 50% in Indonesia and 70% in South Africa [10].

Table 2: Status of ABS regulation in the G20 countries, January 2018

Country	Current ABS Regulation
Argentina	Yes
Australia	Yes
Brazil	Yes
Canada	Yes
China	Test methods for ABS are in place, but not clear whether fitment is mandatory – market analysis indicates 100% fitment Taiwan mandated ABS from January 2018
EU - Germany/ France/ Italy/ UK	Yes
India	Yes From 1 April 2018 for new Types and 1 April 2019 for all new vehicles
Indonesia	No
Japan	Yes
Mexico	Yes From November 2019 for new vehicles and November 2020 for all vehicles
Republic of Korea	Yes
Russia	Yes
Saudi Arabia	Yes
Turkey	Yes
South Africa	No
United States of America	Yes

[10] Note that this analysis is based on the top 20 makes and models in each country, and therefore assumes that these models are representative of all new cars sold. The fitment percentages presented here represent the proportion of new cars with ABS fitted as standard; optional fitment is not included.

More information on the status of ABS and ESC legislation in these countries can be found in Appendix A.

1.4 Content of this report

This report documents the research undertaken to determine the potential benefits and costs associated with the implementation of the ESC regulations in the G20 countries.

- Section 2 gives an overview of the analysis method and modelling used to investigate changes to the car occupant casualty population as a result of the introduction of ESC, both on a voluntary basis (which forms the baseline for the analysis) and as a result of mandatory regulation
- Section 3 examines the current level of ESC fitment in the G20 countries being studied and how this is likely to change between now and 2030 due to voluntary fitment
- Section 4 provides an overview of the effectiveness of ESC in preventing casualties (see Appendix C for detailed review)
- Section 5 estimates the number of lives and serious injuries that could be saved in each country from 2020 to 2030 if ESC regulation was introduced in 2020
- Section 6 estimates the monetary benefit that would accrue from the casualties saved
- Section 7 estimates the monetary cost of mandating ESC fitment
- Section 8 presents the benefit-to-cost ratio for each country
- Section 9 discusses the limitations of this research
- Section 11 presents the overall conclusions of the study

2 Method

The method applied for this study considers the effect of implementing ESC standards on car occupant fatalities and serious injuries. Specifically, the modelling calculates the benefit-to-cost ratio for car occupants of regulating the primary safety measure ESC (with system performance conforming to UN Regulation No. 140 or similar legislation).

Note that only the seven countries highlighted in Table 1 which do not currently have an ESC regulation in place, are modelled in this project.

The main steps for the model are outlined in Figure 3. Each of these steps is described in more detail in the following sections.

Figure 3: Modelling steps for the ESC cost-benefit model

Note that the benefits of ESC are not necessarily restricted to car occupants. For example, it is possible that the introduction of ESC will also reduce the number of pedestrian and pedal cyclist fatalities (referred to collectively as Vulnerable Road Users, or VRUs, in this report), since it will reduce the number of drivers which lose control of the vehicle and subsequently collide with a pedestrian or pedal cyclist. However, this effect is very hard to quantify and is considered likely to be small. Indeed, most studies on the effectiveness of ESC assume that the number of VRU affected is small or zero. For example, Kahane (2014) demonstrate that ESC in cars and LTVs does not have a statistically significant effect on fatal collisions with pedestrians, bicyclists, or other non-occupants[11]. As a result, only one model – for car occupants – is developed. The authors acknowledge that this might lead to a slight underestimate of the benefits of ESC.

Note also that the modelling approach applied to serious injuries is a simplification of that applied to the fatality savings and as a result, substantial caution should be applied to the results. The full list of assumptions required for this analysis are documented in Appendix E.

The fatality data used in this paper has been converted to the internationally recognised definition: death within 30 days of the collision and as a result, fatality figures are directly comparable across countries.

2.1 Fleet penetration of ESC

In order to determine the potential impact of the ESC regulation, one of the first required steps was to determine the proportion of the vehicle fleet that currently has ESC fitted. This was estimated using available data from each country.

Once this was agreed upon, the next step was to predict how the level of ESC fitment might change in the future, based on estimated levels of uptake of the technology. This was predicted under two different scenarios:

1. 'Do Nothing' case - No ESC regulation is introduced in any of the seven countries, and therefore any estimate of fitment is based solely on voluntary uptake of the technology, led by the willingness of manufacturers to fit the necessary components to vehicles and the willingness of consumers to pay for them.

2. 'Regulation' case - In 2020, every country adopts the ESC regulation, mandating the fitting of the technology in all new passenger cars. In practice, this means that ESC would be fitted in all new car models from 2020, and in all new cars from 2022, to give manufacturers sufficient time to alter their processes if necessary.

Estimates of the fleet penetration of ESC, both with and without regulation, are derived in Section 3.

[11] In contrast, the meta-analysis conducted by Høye (2011) actually suggests that fatal crashes involving pedestrians, bicycles or animals increased due to ESC. The modelled effect was reported to be a 22% increase for all light vehicles (with a 95% confidence interval of 8% to 38%); however, the corresponding results for passenger cars and LTVs separately were not significant, supporting the finding from Kahane (2014).

2.2 Effectiveness of ESC

The effectiveness of ESC at mitigating collisions, serious and fatal injuries was estimated based on a review of the literature. For many of the G20 countries under review in this study, relatively limited collision data was available – for instance, some only report the total number of car occupant fatalities, with no information on the type of collision (e.g. loss-of-control collisions) or other injury severities. This meant that an estimate of the effectiveness of ESC at reducing car occupant fatalities across *all collision types* was required. However, this metric was not directly available from the literature; the nearest metric was the effectiveness at reducing car occupant fatalities across *ESC-relevant collision types*, such as single vehicle loss of control and rollover. Therefore, an additional analysis was undertaken to estimate the proportion of ESC-relevant fatal collisions out of all fatal collisions, based on police-reported collision data from Great Britain and the United States. It is recognised that the collision types in these two countries are likely differ from those in the seven countries of interest for this study (in particular due to factors including the nature of the roads, the vehicle fleet and the weather); however, the limited information available means this cannot be quantified. As a result, some caution should be applied to the resulting mean estimate, and sensitivity analysis is employed to account for this.

The mean estimate for effectiveness (~35%) was applied in the study, and the upper and lower estimates were used in the sensitivity analysis (see Appendix D). An overview of the effectiveness estimate is given in Section 4, with a more detailed review of the literature in Appendix C.

2.3 Casualties saved by ESC

Once the two previous steps had been completed, it was then possible to estimate the number of lives and serious injuries that could be saved from 2020-2030 if ESC was mandated by legislation in all seven countries in 2020.

Prior to estimating this, it was important to understand how many fatalities there would likely be in each country between now and 2030 in the absence of ESC legislation, which forms a baseline for the benefit estimate. When estimating the number of car occupant fatalities, it is important to account for levels of exposure. For example, the number of fatalities is likely to be influenced by the amount of car travel (more casualties are expected when there is more car travel) and the size of the population (more casualties are expected in countries with a higher population).

The first step to estimate these baseline fatalities was to extrapolate forwards the car occupant fatality rate. There are a number of measures of exposure which could be used for this rate, some of which are likely to be better correlated with casualty numbers than others. A hierarchy of these exposure measures is presented in Table 3.

Table 3: Hierarchy of exposure measures for car occupant casualties

Rank	Measure	Description	Comments
1	Car passenger kilometres	The unit of measurement representing the transport of one passenger by car over one kilometre	The preferred measure of exposure for car occupant risk.
2	Car vehicle kilometres	The unit of measurement representing the travel of one car over one kilometre	This takes no account of the number of passengers in each vehicle and therefore can underestimate occupant risk for vehicles with more occupants.
3	Registered cars	The number of cars registered in each country	This takes no account of how far each car is driven and therefore how much exposure to collision risk the occupants experience.
4	Population	The number of people who live in each country	This takes no account of how many people travel by car, or how far. This is a crude estimate of road safety risk.

For the seven countries modelled in this report, a review of available exposure measures was conducted. Table 4 shows the exposure measures used, where measures with highest rank were prioritised over other measures available.

The car occupant fatality rate[12] for each country was extrapolated forwards assuming an exponential trend. This was considered to be the trend which fitted the data best and produced the most sensible predictions going forwards (e.g. for some countries, assuming a linear trend led to a negative number of predicted fatalities by 2030). Secondly, to understand the size of the potential car fleet for ESC fitment, the number of registered cars was extrapolated forwards, assuming a linear trend[13]. Finally, the predicted level of voluntary uptake of ESC in the 'Do Nothing' scenario, and the subsequent fleet fitment rate, along with the estimated effectiveness of ESC, were accounted for in order to obtain a baseline number of fatalities.

[12] The fatality data was sourced, where possible, from in-country sources or from published summary statistics by the World Health Organisation (WHO) or the International Transport Forum (ITF). For China, Ministry of Health death registration data was used instead of police reported collisions, because there are reported uncertainties in the latter. The casualty figures were all converted to the standard definition (death within 30 days of the collision). See Appendix B.1 for a more detailed explanation of the data used in this analysis.

[13] With the exception of China, where the vehicle fleet has been growing rapidly in recent years, a linear trend is the best fit for the current passenger car fleet trends in each country – see Appendix B.3. Despite the almost exponential growth in China, a linear trend has been applied here as there is some evidence that car sales growth is slowing (Gao *et al.*, 2016).

Table 4: Exposure measures used for the modelling by country

Country	Measure (rank)	Source
Argentina	Registered cars (3)	International Organization of Motor Vehicle Manufacturers (OICA, 2017)
Brazil	Registered cars (3)	International Organization of Motor Vehicle Manufacturers (OICA, 2017)
China	Passenger kilometres[14] (1)	China's Statistical Yearbook, published yearly (National Bureau of Statistics of China, 2016)
India	Passenger kilometres[14] (1)	Road Passenger Transport estimates from the Organisation for Economic Co-operation and Development (OECD, 2018)
Indonesia	Registered cars (3)	International Organization of Motor Vehicle Manufacturers (OICA, 2017)
Mexico	Passenger kilometres[14] (1)	Road Passenger Transport estimates from the Organisation for Economic Co-operation and Development (OECD, 2018)
South Africa	Registered cars (3)	International Organization of Motor Vehicle Manufacturers (OICA, 2017)

To estimate the number of lives saved, the same process was followed again, this time accounting for the increase in fleet fitment of ESC that would be achieved by implementing regulation mandating ESC fitment from 2020.Further details of this modelling are given in Section 5.

To estimate the number of serious injuries saved, a more simplified modelling approach was applied, using data from STATS19 to estimate the ratio of fatal to serious casualties in ESC relevant collisions, and then determining the effectiveness of ESC to prevent serious injuries, as opposed to fatalities. Further details are given in Appendix E.

2.4 Casualty economic benefit

For the purpose of developing a benefit-to-cost ratio for this study, the casualty savings outlined in the previous section have to be expressed in monetary terms. This has been done using the 'valuation of a statistical life' (VSL) method, which is based on the amount that people are willing to pay to avoid injury or death, expressed in terms of GDP per capita.

The VSL method is reviewed in Section 6 and a monetary benefit per fatality and serious injury derived for each of the seven countries. This value is then applied to casualty savings

[14] Note that these figures are labelled 'passenger kilometres' and not 'car passenger kilometres' – we have assumed these figures actually represent the latter and do not include passenger kilometres by other modes (we acknowledge this may not be correct but the magnitude of the exposure measure is not actually of importance for this work, provided the trend over time in this measure is similar for car passenger kilometres).

from Section 5 to give a total economic benefit arising from the introduction of ESC legislation.

2.5 Cost of regulation

The cost of implementing legislation to mandate the fitment of ESC was then estimated based on a review of the literature. Evidence for the cost of fitting ESC was gathered and a representative cost was selected for application in this study. This cost was based on model year 2004 vehicles and was therefore updated to a 2018 cost using two processes:

1. Inflation, to account for inflation rates between 2004 and 2018; and
2. Discounting, to account for cost reductions that typically occur in automotive systems over time due to 'learning effects' (i.e. iterations of system design that reduce fitment costs by reducing part counts, system complexity and streamlining production) and economies of scale (which increase with increased fitment rates and the increased focus on platform sharing over the last decade).

The 2018 costs were then projected forward to attribute a 'present value' to future costs. This reflects the societal norm that benefits and costs in the future are valued less highly than present benefits and costs. Finally, the resulting costs are applied to the predicted vehicle fleet that will be fitted with ESC due to regulation.

The cost analysis is presented in Section 7.

2.6 Cost-benefit model

To assess the value of implementing the ESC regulation, it was necessary to compare the benefits with the costs. The final component of the model therefore brings together both the predicted benefits and costs. A benefit-to-cost ratio was generated, where the benefit value was divided by the cost. In these circumstances:

- A value of < 1 indicates that the cost of the measure exceeds the monetary valuation of benefits
- A value of exactly 1 reflects the breakeven point where benefits to costs are balanced evenly
- A value of > 1 indicates that the benefits outweigh the costs, and it is these measures which become most easily recommended for implementation.

For predictions of future benefits it is important to note that discounting has been applied. This represents the concept that, generally, people prefer to receive goods and services now rather than later (see Section 7.3for more details). The benefits presented represent the economic benefit to society of reducing fatalities or serious injuries. The costs are the consumer costs, i.e. the amount extra that consumers would be expected to pay to equip a new vehicle with the associated technology.

2.7 Sensitivity analysis

A sensitivity analysis has been included in the modelling to investigate whether any of the inputs are overly influential on the outputs (Appendix D). It also supports a quality check as to the confidence level, which is appropriate given the limitations of some of the input data and assumptions.

3 ESC Fitment

This chapter estimates the proportion of the current fleet that is fitted with ESC and predicts how this may change between 2020 and 2030 in two scenarios:

1. 'Do Nothing' case - No ESC regulation is introduced in any of the seven countries, and therefore any estimate of fitment is based solely on voluntary uptake of the technology, led by the willingness of manufacturers to fit the necessary components to vehicles and the willingness of consumers to pay for them.
2. 'Regulation' case - In 2020, every country adopts the ESC regulation, mandating the fitting of the technology in all new passenger cars. In practice, this means that ESC would be fitted in all new car models from 2020, and in all new cars from 2022, to give manufacturers sufficient time to alter their processes if necessary.

3.1 Do Nothing Fitment

A proportion of cars in the G20 countries will already have ESC fitted, and the proportion of cars with ESC fitted would be expected to grow, with or without any mandatory fitment regulations, due to voluntary fitment by manufacturers.

Therefore, to understand how many additional lives could be saved due to mandatory regulations, it is first necessary to estimate the expected penetration of the technology through the fleet if no regulation is enacted.

With no regulation in place, some manufacturers may still decide to fit ESC technology either as a standard fitment or as an optional extra. The expected speed of uptake within a country will depend both on the willingness of manufacturers and customers to pay for these technologies, and therefore would be expected to differ between countries.

Appendix B presents information on the size of the car fleet and new car sales in each country between 2005 and 2015. These data have been used as the basis for the modelling in the following sections.

It can be observed from ESC uptake in Europe (Global NCAP data[15]), that under voluntary conditions ESC is fitted first to the larger more expensive classes of vehicle, for instance the Luxury and Executive segments. There is then propagation to the Large and Medium (compact) segments. Finally, there is uptake within the smallest and cheapest, Small and Mini, segments of the market. It is not always the case that voluntary uptake reaches all vehicles in these segments. Where there is a prevalence for smaller and cheaper cars, then these countries may not reach full fitment under voluntary conditions. To illustrate this, before ESC was mandated in Europe (2008 to 2009) fitment levels reached 60%. Country-by-country, a fitment of 99% was observed in Sweden and 80% in Germany versus a fitment of 41% in France and 53% in the Netherlands. In France, the Small segment occupied almost 50% of all car sales, whereas in Germany this was 34%. However, as noted in Section 9.2, it should be noted that there are several strategies that can be used to influence voluntary uptake rates as well as resorting to mandating ESC.

[15] www.globalncap.org

3.1.1 *Proportion of New Cars Fitted with ESC*

For Western European countries (Seidl *et al.*, 2017), ESC technologies are fully mature and fitment rates have been found to follow an S-shaped curve and to plateau after around 15 years. The period until full voluntary adoption for the countries in this study is estimated to be closer to 20 years, based on fitment data provided by the Global NCAP. Data was available for all countries apart from Mexico and South Africa. This period of 20 years is longer than was observed for Western European countries (Seidl *et al.*, 2017), but may represent different pressures on manufacturer fitment of ESC between the markets and development cycles for the technology.

After deciding on the 20-year adoption period, the maximum voluntary percentage that a country is likely get to after this time was estimated based on the trajectory observed in the Global NCAP data. This was relatively straightforward for countries with at least seven years of sales and production data available. For countries with fewer data points, assumptions were made about the maximum level given similarities in the time when ESC was first adopted and imports/exports.

For Mexico and South Africa, information on standard fitment of ESC was obtained from vehicle manufacturers' (OEM) internet sites. Since limited information was available on the whole of the passenger car fleet, the ESC fitment rate of all new cars in these countries was assumed to match that of the top 20 selling cars in the country. A single estimate was provided from internet sources for either 2017 or 2018 (for Mexico and South Africa, respectively).

Table 5 shows the estimated launch year for voluntary uptake and the proportion of new cars which are expected to be fitted after 20 years, based on data from the sources listed. These figures have been used as the basis for developing the fitment curves in the following sections.

Table 5: Estimated launch year and level of voluntary uptake of ESC in each country

Country	Launch Year	% of cars fitted after 20 years of voluntary fitment	Number of years of data available (data source)
Argentina	2005	60%	2 years (Global NCAP[16]), 1 year (OEM)
Brazil	2010	60%	, 2 years (OEM)
China	2001	46%	7 years (Global NCAP), 1 year (OEM)
India	2008	45%	8 years (Global NCAP)
Indonesia	2010	45%	1 year (Global NCAP), 2 years (OEM)
Mexico	2010	60%	2 years (OEM)
South Africa	2008	60%	2 years (OEM)

[16] www.globalncap.org

3.1.2 *Proportion of All Cars Fitted with ESC*

The number of cars fitted with ESC within a given year (y), depends on the number of cars fitted in the fleet the previous year, the number of cars fitted joining the fleet and any cars with ESC fitted that leave the fleet.

$$CarsFitted(y) = CarsFitted(y-1) + NewCarsFitted(y) - LeavingCarsFitted(y)$$

The number of cars leaving the fleet that are fitted with ESC is relevant for countries with a high turnover or scrap rate of cars. In countries with relatively low motorisation levels, cars generally do not leave the fleet at a high rate, as older cars are sold on rather than scrapped and replaced. The average age of cars was found to be 13 years in Argentina[17], nine years in Brazil[18], 16 years in Mexico[19] and 10 years in South Africa[20]. Given that the period of interest is 10 years (2020-2030) and that there are only low levels of fitment currently, it is reasonable to assume that the number of cars leaving the fleet with ESC fitted will be negligible for these countries. Therefore, the number of cars fitted simplifies to:

$$CarsFitted(y) = CarsFitted(y-1) + NewCarsFitted(y)$$

No information is available on the age of the fleet in China, Indonesia or India; however, the proportion of cars which are new in Indonesia each year is comparable to the four countries listed above (6% in 2015, compared to 5% in Argentina, 6% in Brazil, 3% in Mexico and 6% in South Africa). Hence the simplification is also assumed to apply to this country.

The rate of introduction of new cars into the fleet in China and India has been consistently higher than the other countries over the past decade (16% for China in 2015 and 12% for India) and shows little sign of slowing. This rapid motorisation means that it is likely that the rate of fleet turnover up to 2030 will be much greater, and thus it is important to take into account the vehicles which leave the fleet with ESC fitted for these two countries. Analysis of the current sales data suggests that vehicles in these two fleets are, on average, 10 years old when they are scrapped. This has been incorporated into the model, assuming that the proportion of vehicles leaving the fleet with ESC fitted in a given year matches the proportion entering the fleet 10 years earlier.

[17] US Commercial Service (Third Edition). Automotive Resource Guide - A Reference for US Exporters. Available from www.trade.gov/td/otm/assets/auto/CS_Resource_Guide.pdf

[18] Valour International (2016). Car fleet starts aging again after two decades., viewed January 2018. Available from: www.valor.com.br/international/news/4534673/car-fleet-starts-aging-again-after-two-decades

[19] PwC (2014). Doing Business in Mexico Automotive Industry. PwC Mexico.

[20] Department of Transport, 2004. www.arrivealive.co.za/document/04ageofvehicle.pdf

Figure 4 shows the modelled percentage of new cars fitted with ESC and Figure 5 the corresponding proportion in the whole car fleet for each country. Table 6 presents the estimated fitment level in each country in 2030.

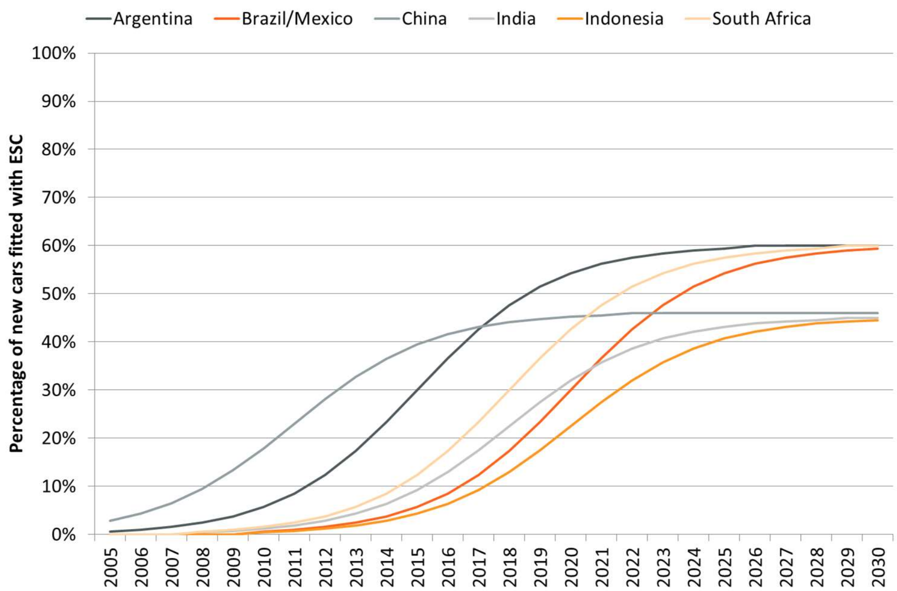

Figure 4: Percentage of newly registered cars equipped with ESC in voluntary uptake scenario

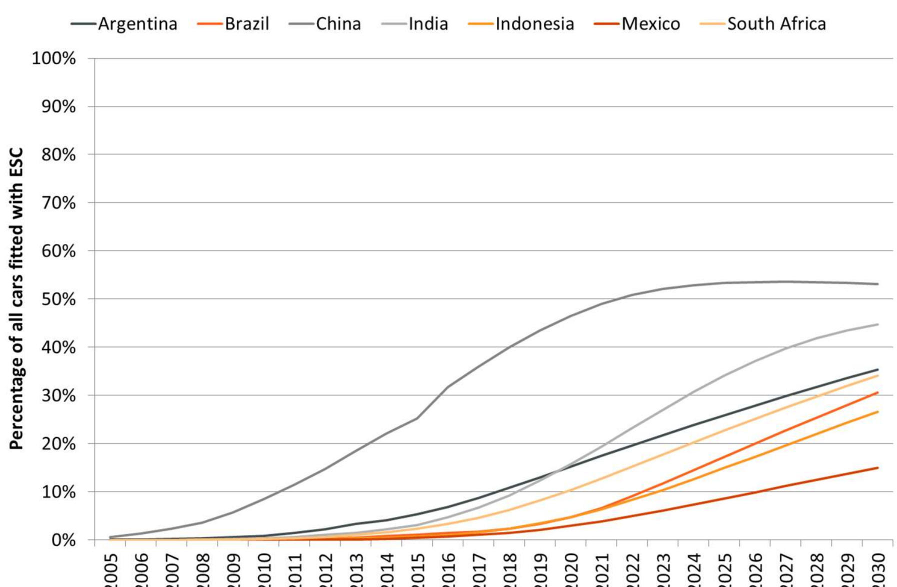

Figure 5: Percentage of all registered cars equipped with ESC in voluntary uptake scenario

Table 6: Estimated level of ESC fitment in each G20 country in 2030 in voluntary uptake scenario

Country	Estimated percentage of new cars fitted with ESC in 2030	Estimated percentage of total fleet fitted with ESC in 2030
Argentina	60%	35%
Brazil	59%	31%
China	46%	53%
India	45%	45%
Indonesia	45%	27%
Mexico	59%	15%
South Africa	60%	34%
Total	**47%**	**44%**

The results show that, based on these assumptions, around 44% of the total car fleet (221 million cars) will be fitted with ESC in 2030 under the voluntary uptake scenario.

3.2 With Regulation Fitment

By 2020, fleet fitment is expected to reach between 23% and 54% for new cars for the countries, and between 3% and 47% for all cars, according to the methodology used above.

Under the regulation scenario, we assume that regulation comes into force, making ESC fitment mandatory in Argentina, Brazil, China, India, Indonesia, Mexico and South Africa. From 2020, all new car models sold in the country would be required to have ESC fitted. We have assumed that, in reality, a two-year transition phase would be allowed, so 100% of new cars would be fitted with ESC by 2022. In 2021, the new car fitment percentage is assumed to follow a linear trend between the predicted value in 2020, and 100%. This is shown most clearly in Figure 6, where the solid lines represent the new car fitment percentage in the voluntary scenario (the ‘current timeline’) and the dashed lines represent the fitment percentage if the regulation is implemented (the ‘revised timeline’).

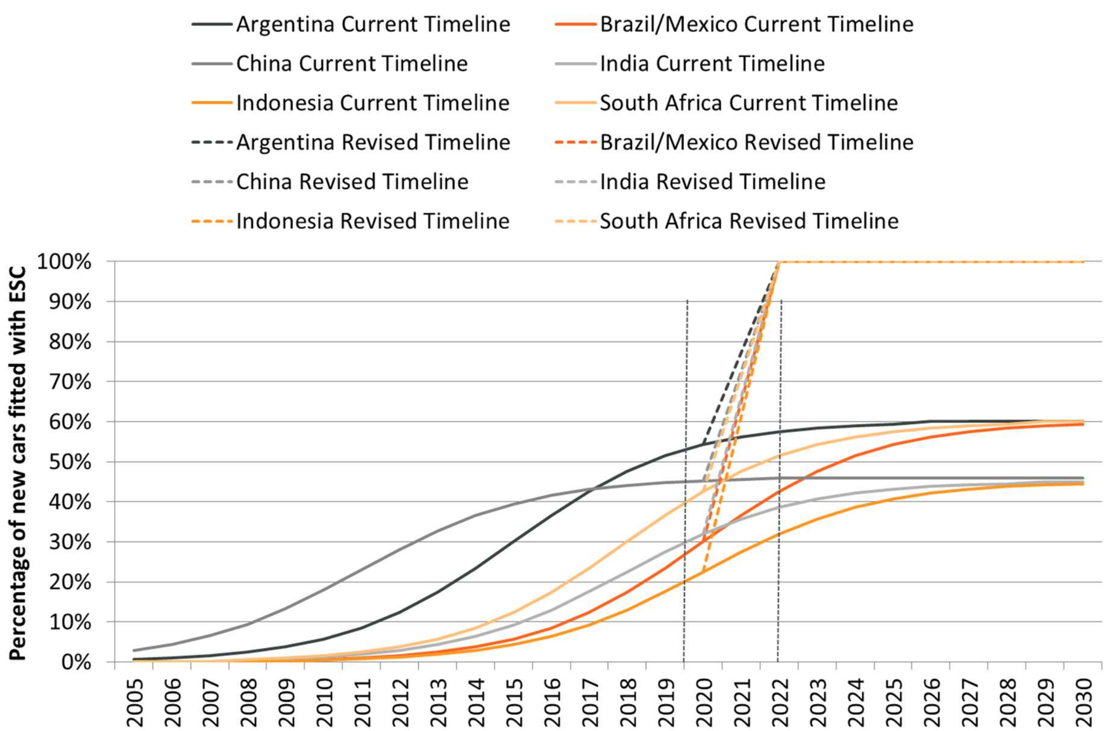

Figure 6: Estimated percentage of newly registered cars fitted with ESC, if the ESC regulation is implemented in 2020 (2005-2030)

Figure 7 shows the change in the ESC fitment percentage of all cars that it is estimated will be seen if the regulation is implemented in 2020. Again, the solid lines refer to the fitment in the voluntary uptake scenario, whereas the dashed lines incorporate the impact of the regulation. Table 7 presents the estimated fitment rates in each country in 2030.

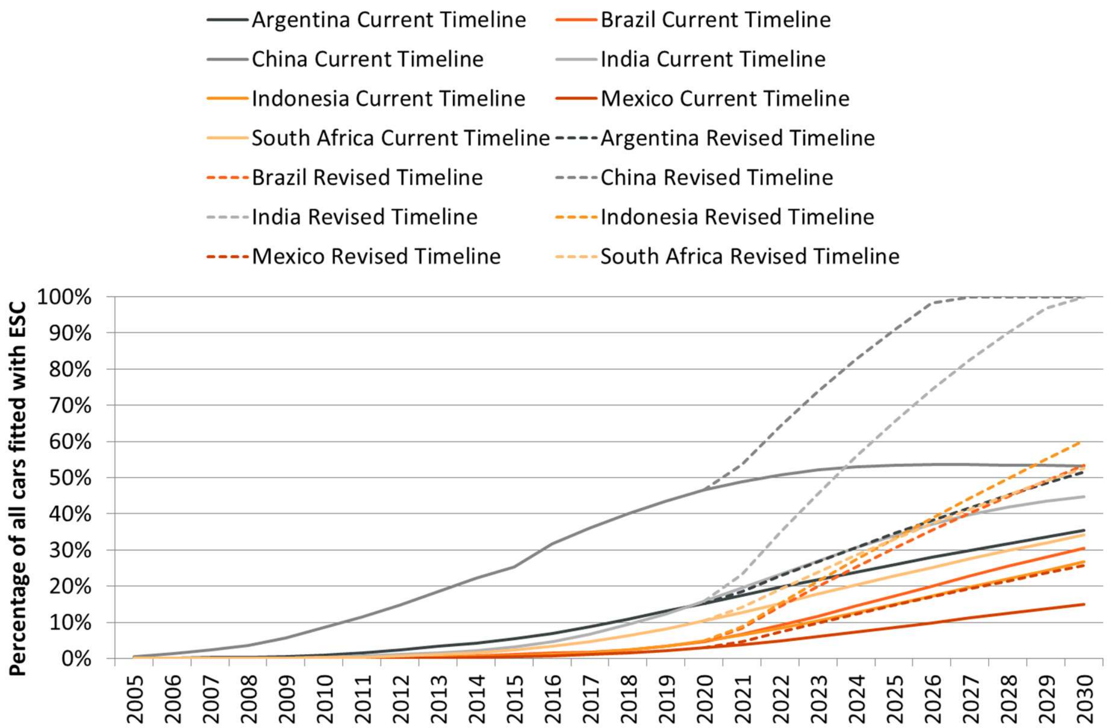

Figure 7: Estimated percentage of all registered cars fitted with ESC, if the ESC regulation is implemented in 2020 (2005-2030)

Table 7: Estimated level of ESC fitment in each G20 country in 2030, if the ESC regulation is implemented in 2020

Country	Estimated percentage of new cars fitted with ESC in 2030	Estimated percentage of total fleet fitted with ESC in 2030
Argentina	100%	52%
Brazil	100%	53%
China	100%	100%
India	100%	100%
Indonesia	100%	60%
Mexico	100%	26%
South Africa	100%	53%
Total	**100%**	**83%**

It can be seen by comparing the results in Table 7 with the voluntary uptake scenario (Table 6), the impact of the regulation on the fitment rate varies between the countries, with an increase of between 11 and 55 percentage points. The largest increase is seen in India, and the smallest in Mexico.

Note that due to the fast fleet turnover in China and India, all of the vehicle fleet is predicted to be fitted with ESC by 2030. In reality this is unlikely to be true (since there will be a small proportion of much older vehicles retained in the fleet) but for the purposes of this analysis this small error (due to the assumptions required around fleet turnover) is unlikely to greatly affect the results.

Overall, around 83% of the total car fleet in these countries (418 million cars) will be fitted with ESC in 2030 under the regulatory uptake scenario, an increase of almost 200 million compared to the voluntary scenario which will result in fitment to 44% of the fleet in 2030 (Table 6).

Note that fitment predictions for the 13 G20 countries which have already implemented ESC regulations are shown in Appendix I.

4 Effectiveness of ESC in Preventing Casualties

4.1 Summary of the Literature Review

The literature review identified 120 potential sources of which 15 met the selection criteria for high-quality studies on the effectiveness of ESC at preventing collisions. An in-depth description of the review criteria and analysis of each study may be found in Appendix C and the findings are summarised in this section.

Arriving at a best-estimate value that is representative of the range of results from these studies is not trivial, because the reported values vary widely due to different focuses regarding:

- Geographic region (mostly USA, Australia, or European countries);
- Vehicle category (e.g. passenger cars (US or EU definition), SUVs, light trucks (LTVs), 4WDs);
- Collision types (e.g. all collisions, single vehicle collisions, rollovers, or multi vehicle collisions); and
- Collision severities (all collisions including property damage only, all injury collisions, serious, KSI (killed or seriously injured), or fatal).

The meta-analysis conducted by Høye (2011), which incorporates most of the relevant individual sources identified, was deemed to be the most appropriate source for a single value estimate because it reconciles the different results and increases the statistical power of estimates for smaller casualty groups. The focus of this project is on casualties in passenger cars (including SUVs as per the European definition of M1 vehicles). However, for many of the countries under study, the number of slight and serious casualties is not known and figures are only available for fatal casualties; therefore effectiveness values for fatal car occupant casualties are required. The most applicable effectiveness estimates by Høye for this focus are quoted in Table 8. It was decided to use the estimates relating to a target population of ESC-crashes[21] (which were compiled from seven different studies), rather than those relating to all fatal crashes, because the latter were based on a single study only, which was subsequently updated with reduced effectiveness estimates (Farmer (2006), updated by Farmer (2010)).

[21] 'ESC crashes' is defined in the meta-analysis as 'crashes that are assumed [by the authors of the underlying studies] to be affected by ESC'. The detailed definitions vary, and it was decided to use 'collisions involving loss of control' as the closest approximation possible to the overall definitions.

Table 8: Relevant ESC effectiveness estimates from the meta-analysis by Høye (2011); bold row denotes the values selected for this cost-benefit study

Crash type	Severity	Vehicle type	Effectiveness	Lower 95% CL	Upper 95% CL	Significant?
ESC-crashes	**Fatal**	**All light vehicles**	**38%**	**15%**	**55%**	**Yes**
ESC-crashes	Fatal	Passenger cars	27%	-4%	49%	No
ESC-crashes	Fatal	LTVs	53%	6%	76%	Yes

The value relating to all light vehicles was deemed most appropriate because the estimate for passenger cars alone was not statistically significant and, furthermore, the vehicle category definition for this project includes SUVs and other passenger carrying vehicles, which fall into the LTV category in the meta-analysis.

In conclusion, the literature review suggests a best estimate of ESC effectiveness for this cost-benefit study of 38% with 95%-confidence limits of 15% and 55%. These values are to be applied to a target population of fatal car occupant collisions involving loss of control of the car.

4.2 Application to the G20 data

As discussed in Section 4.1, review of the literature has concluded that ESC is 38% effective at reducing the number of fatalities in loss of control collisions. In order to apply this level of effectiveness to the baseline fatality numbers, the numbers of fatalities in these collisions need to be estimated.

There is relatively little data readily available on collision types or causation factors in the seven G20 countries under study. Therefore, it was decided to analyse collision data from Great Britain (GB) and the USA, two regions which publish data of a sufficient level of detail to allow analysis of loss of control and which exhibit very different road characteristics, thereby representing sensible boundaries for a range of the prevalence of loss of control to be expected in different road environments.

For GB, analysis of STATS19 police-reported collision data showed that 43.5% of car occupant fatalities occurred in collisions where a car's loss of control was a contributory factor. The equivalent data set in the US is known as FARS (Fatality Analysis Reporting System). Analysis of this data found that 26.3% of car occupant fatalities occurred in vehicles which lost control prior to impact. Both of these estimates are based on a 5-year average covering 2011–2015 and corrected for the fact that approximately 55% and 45% of the GB and US fleet in the samples, respectively, were already fitted with ESC. For the overall benefit-cost calculations, the mean value between these boundaries was used, i.e. 34.9% of car occupant fatalities were considered to be within the target population for ESC. The upper and lower boundaries of 43.5% and 26.3% respectively were used for the sensitivity analysis.

The estimated total effectiveness of ESC for passenger car fatalities is therefore the product of the two values:

- 38% effective at reducing the number of fatalities in loss of control collisions
- 34.9% of car occupant fatalities occur in loss of control collisions

i.e. the estimated effectiveness of ESC to prevent passenger car fatalities for this study is 13.3%.

4.3 Discussion (validity of meta-analysis estimates used)

The meta-analysis by Høye (2011) was chosen as the most reliable source available for a consolidated ESC effectiveness estimate. Nevertheless, there are three aspects that should be considered when discussing the validity of the estimate, all three of which indicate that the value quoted might be somewhat optimistic compared to reality:

- Publication bias;
- Sample selection bias;
- Findings of later publications; and
- Control for confounding factors.

Høye identified some degree of publication bias in the underlying studies, mostly in studies analysing crash types that are assumed to be most affected by ESC. This means that studies showing the expected effect (reduction of collisions) or that were statistically significant were more likely to be published than those showing an effect contrary to expectation. The author stated that this might lead to somewhat overestimated effectiveness values. The extent of this is unknown.

A certain bias in sample selection is also to be expected, in particular in earlier studies. Authors have typically analysed groups of specific vehicle models where there were enough relevant collisions (in the pre-ESC group) to be able to perform a statistically meaningful analysis. This arguably tends to include a bias towards high-powered, rear-wheel drive cars (that may be more susceptible to loss of control leading to run off road collisions) and taller SUVs (which have a higher centre of gravity and therefore are more susceptible to single-vehicle rollover collisions). Some of the studies incorporated in the meta-analysis received updates in later years to reflect the larger datasets available:

- Farmer (2010), an update to the study Farmer (2006): The 2010-results were lower than the 2006-results (effectiveness estimates for all fatal crashes reduced from 43% to 33%)[22].
- Kahane (2014), an update to the study Dang (2007): The 2014-results were similar to the 2007-results.

[22] This study has limitations relating to the variety of vehicle models included, which is why it was not used as a single source. See explanation further on.

- Scully and Newstead (2010), an update to the study Scully and Newstead (2008): The 2010-results were lower than the 2008-results (effectiveness estimates for all driver injury crashes reduced from 9.8% to 8.2%).

The study updates do not call into question the overall validity of the 2011-meta-analysis but might indicate a tendency of early studies to overestimate the effects of ESC.

An important confounding factor that was not sufficiently controlled for in many studies is changes in vehicles' crashworthiness design over time. The period of ESC introduction into the car fleet in study countries overlapped with a period of rapidly increasing secondary safety driven by changes in legislation and consumer testing (see Table 9). When simply comparing collision risks of ESC-equipped and non-equipped vehicles, the effectiveness will be overestimated[23] because later model years are more likely to have both, ESC and improved secondary safety, and because larger vehicle segments were more likely to be equipped with ESC early-on and generally offered better occupant protection than average vehicles.

Table 9: Examples of regulatory and consumer crash tests (secondary safety requirements) introduced in the EU and USA during the period of ESC fleet dispersion

Year	EU	USA
1994	–	FMVSS 214 (dynamic side impact mobile deformable barrier test)
1995	–	IIHS moderate overlap frontal crash test
1996	Euro NCAP offset deformable barrier frontal impact Euro NCAP mobile deformable barrier side impact test	–
1998/2003 (new types/new vehicles)	Directive 96/79/EC (frontal impact protection, later UN Regulation No. 94) Directive 96/27/EC (side impact protection, later UN Regulation No. 95)	–
2001	Euro NCAP pole side impact test	–
2003	–	IIHS side impact test
2010	–	FMVSS 214 (oblique pole side impact test)

[23] It should be noted that application of the induced exposure method is not sufficient as control for this aspect because the control group most frequently chosen for being unaffected by ESC (rear-end crashes) is expected to also be only mildly affected by improved frontal and side impact safety. This means that comparing injury accidents between these groups still measures the effects of both ESC and secondary safety, especially when considering fatal collisions only.

Some, but not all, studies included in the meta-analysis have applied measures to limit the confounding effects of vehicle design changes, such as:

- Comparing only similar car models of a limited range of model years before and after ESC introduction; for instance applied by Lie *et al.* (2006), Dang (2007), and Kahane (2014). This approach can limit the effects of increasing secondary safety over time, but it cannot eliminate it entirely because the introduction of ESC might often be linked to the introduction of a new vehicle model generation. The estimates might therefore tend to overstate the effects of ESC.
- Limiting the selection to otherwise identical vehicles with and without ESC, as applied by Farmer (2006) and Farmer (2010). This approach successfully eliminates the issue of confounding secondary safety, but reduced the selection of available car models almost exclusively to luxury/SUV and sports cars (97% of the car crashes analysed by Farmer (2010) involved such vehicles; i.e., only 3% involved smaller segment cars). The effectiveness values found for these vehicles might not be representative of an average fleet. The high engine power, the high share of rear-wheel drive, and the specific usage patterns, particularly of sports cars, might lead to a higher share of dynamic loss of control amongst single vehicle collisions. Similarly, SUVs have a high centre of gravity and therefore a higher risk of single vehicle rollover collisions. These estimates might therefore again tend to overstate the effects of ESC. Also, where ESC is offered as an option, it may be that owners of cars with ESC have different characteristics or risk-taking profiles to those who choose cars without ESC.
- Defining cohorts to compare the effect between vehicles of identical model years (thereby comparing vehicles which are arguably at a similar stage of secondary safety engineering; albeit being different makes and models), as applied by Scully and Newstead (2010). The authors performed additional logistic regression to identify the likely remaining error in their ESC effectiveness estimates due to confounding variables, and concluded that the likely overestimate related to secondary safety with the chosen cohort method was only marginal (between one to five percent of the results found; *not* percentage points).

The non-existent or insufficient control in many of the studies leads the authors of this review to conclude that the stated effectiveness values for ESC are likely to have an optimistic tendency because the measured effects can partly be attributed to secondary safety improvements.

It is uncertain how big the effect of publication bias, updated findings and confounding factors on the effectiveness value presented by Høye is, but the general tendency towards an overestimate should be reflected in the sensitivity analysis in order to arrive at robust cost-effectiveness estimates.

5 Estimated Casualties Saved

This section presents estimates of the number of lives and serious injuries that could be saved in each country from 2020-2030 if ESC regulation is introduced in 2020. This is done by accounting for the increase in the fleet fitment rate that will occur, on top of any fitment that is due to voluntary uptake of the technology. The calculations relate to vehicle sales in each country; it is hoped that vehicles manufactured in-country and exported to markets that do not have ESC would also benefit, but this is hard to quantify and is not guaranteed by implementation of the regulation.

5.1 Baseline fatality forecasts

The first step in the modelling process is to determine the baseline fatality estimates for each country. As described in Section 2, these estimates take into account the current trend in the fatality rate (to account for general improvements to road safety over time) and the predicted levels of voluntary uptake of ESC.

The available fatality data, passenger kilometre estimates (where available) and trend in the number of registered cars for each country are presented in Appendix B. As outlined in this appendix, there are a number of challenges with these data:

- Limited fatality data are available for some countries (especially Brazil, China and South Africa)
- The definition of a fatality is not consistent across countries (for the purposes of these modelling fatalities in all countries have been converted to those within 30 days of the collision)
- Data from China are particularly uncertain – hospital fatality data has been used in place of police-reported fatalities, due to uncertainties in the accuracy of reporting.

There is some uncertainty in what the ‘passenger kilometres’ figures (available only for China, India and Mexico) represent. We have assumed that the trend for these figures actually represents the trend in ‘car passenger kilometres’.

Figure 8 and Figure 9 take the fatality and exposure data for each county and calculates the trend in car occupant fatalities per million passenger kilometres (for China, India and Mexico) and the trend in car occupant fatalities per million registered cars (for Argentina, Brazil, Indonesia and South Africa). As explained in Section 2.3, the best exposure measure available was selected for each country. For Argentina, Indonesia and South Africa, fatality data was available for 2016, but the number of registered cars was only available up to 2015. Therefore, the 2016 fatality rate has been calculated by extrapolating the number of registered cars forward by one year, assuming a linear trend to give an estimate for 2016 (see Figure 12).

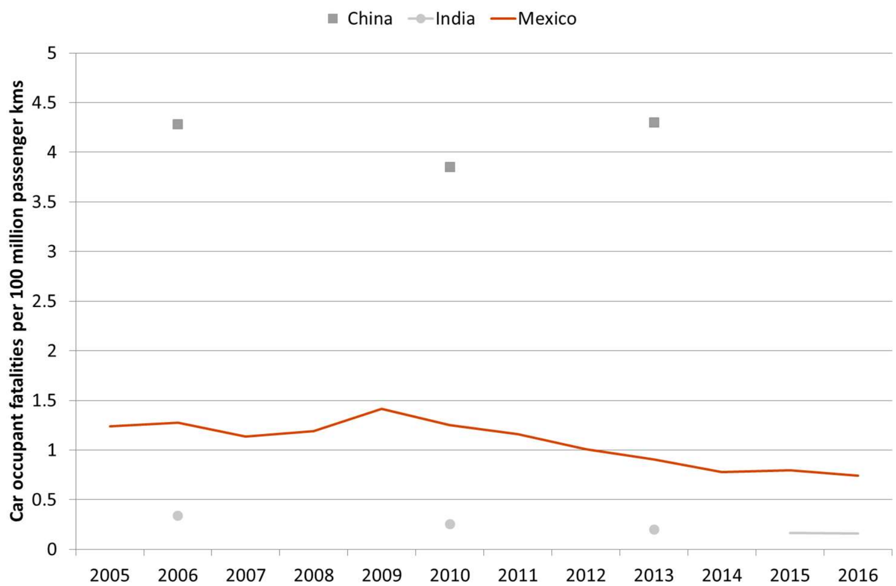

Figure 8: Car occupant fatality rate (per million passenger kms) for China, India and Mexico (2005-2016)

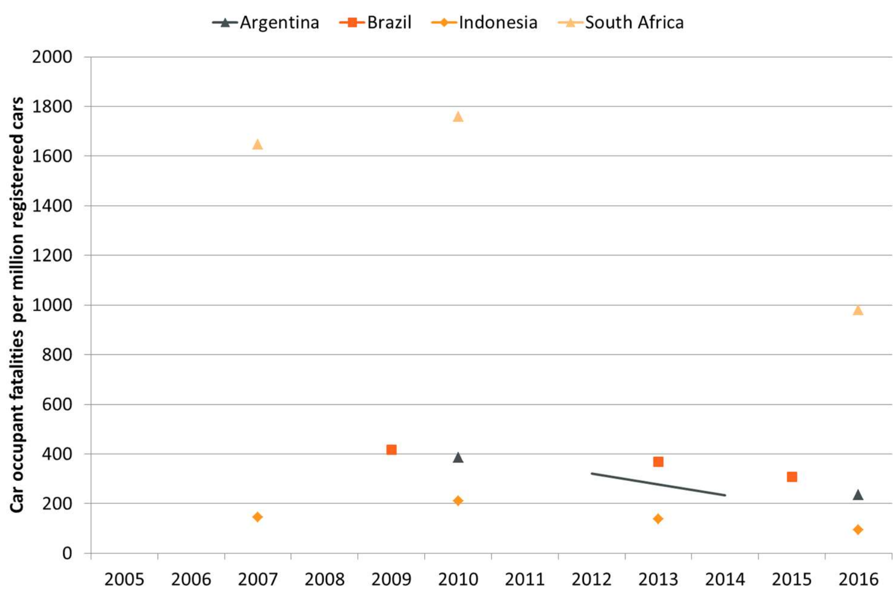

Figure 9: Car occupant fatality rate (per million registered cars) for Argentina, Brazil, Indonesia and South Africa (2005-2016, latest available data shown in each case)

The first step in the baseline fatality forecasts is to extrapolate this rate forwards, following an exponential trend, up to 2030 (Figure 10 and Figure 11). This assumes that the current trend in road safety developments continues into the future; and where external stimuli are required for this to happen, then they are applied.

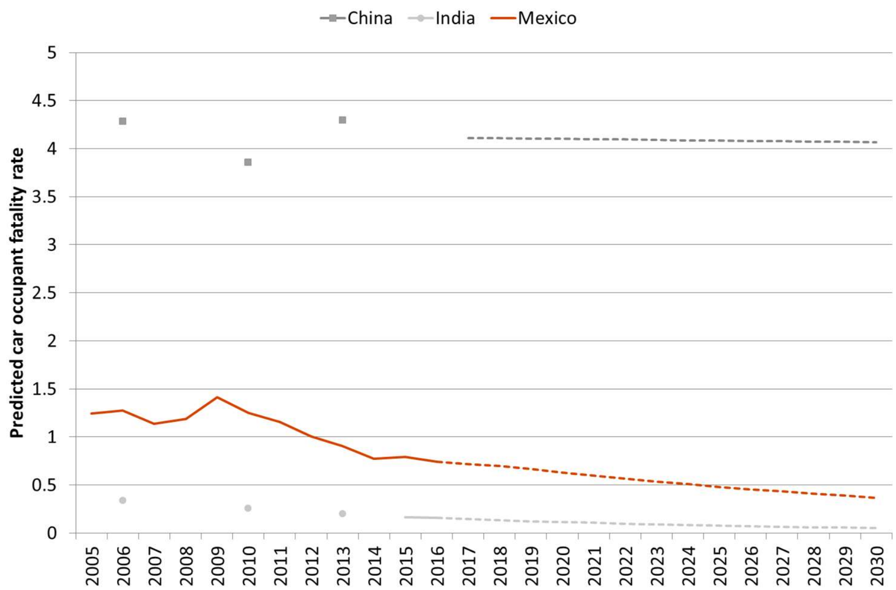

Figure 10: Predicted car occupant fatality rate (per million passenger kms) in China, India and Mexico (2005-2030)

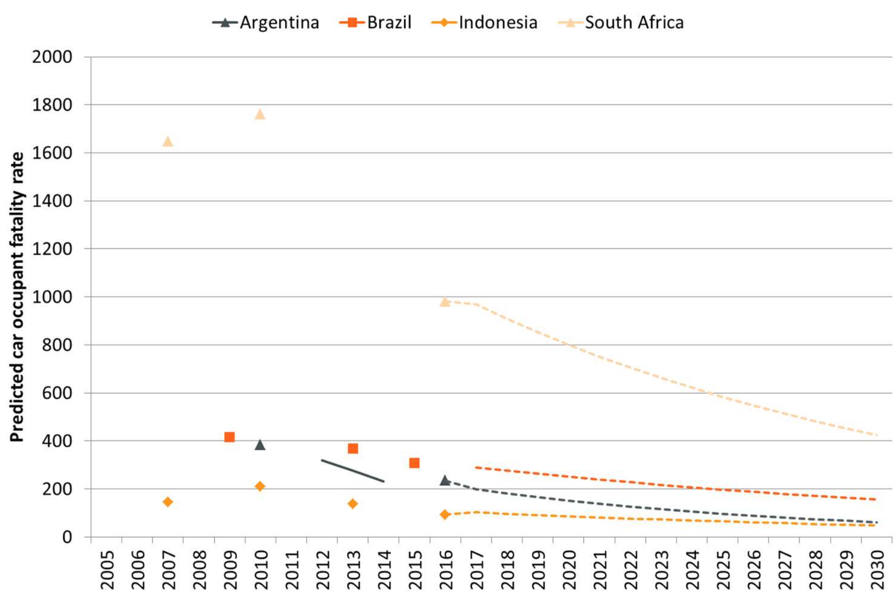

Figure 11: Predicted car occupant fatality rate (per million registered cars) in Argentina, Brazil, Indonesia and South Africa (2005-2030)

Based on these predictions, the car occupant fatality rates will continue to fall in each of the seven countries. However, by 2030, the rate will vary considerably between countries: in Indonesia, there are expected to be 49 car occupant fatalities per million registered cars but in South Africa there are expected to be 425. This variation is primarily due to a combination of uncertainty in the underlying casualty data and variations in the rate of increase of fleet size.

Alongside the predictions of the fatality rate, the number of registered cars is projected forwards, assuming a linear trend (Figure 12).

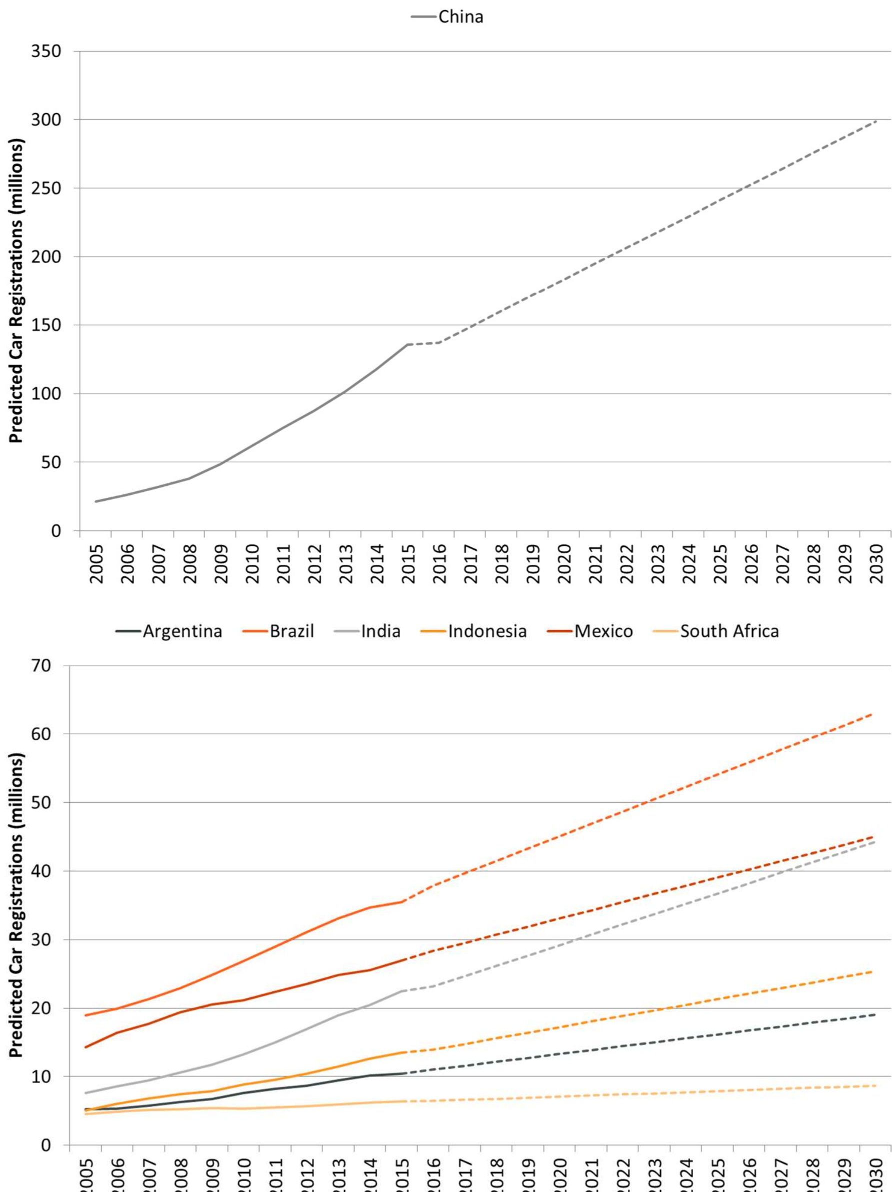

Figure 12: Predicted number of registered cars in each G20 country (2005-2030)

These forecasts predict that by 2030, the total number of registered cars across the seven countries (504 million) will be more than double the number in 2015 (250 million) and over six times more than the number in 2005 (77 million). However, there are variations in the rate of increase in each individual country. For example, in China, there are predicted to be 14 times as many registered cars in 2030 (299 million) as there were in 2005 (21 million) but in South Africa the number of registrations is expected to less than double over the same period (increase from 4.6 million to 8.7 million). This highlights the differences in fleet turnover between the countries, supporting the analysis in Section 3, which shows that ESC will penetrate the fleet in some countries quicker than in others.

The estimates of the car occupant fatality rate and the number of registered cars estimates are then combined to calculate the predicted number of car occupant fatalities (occurring each year) up to 2030 (Figure 13).

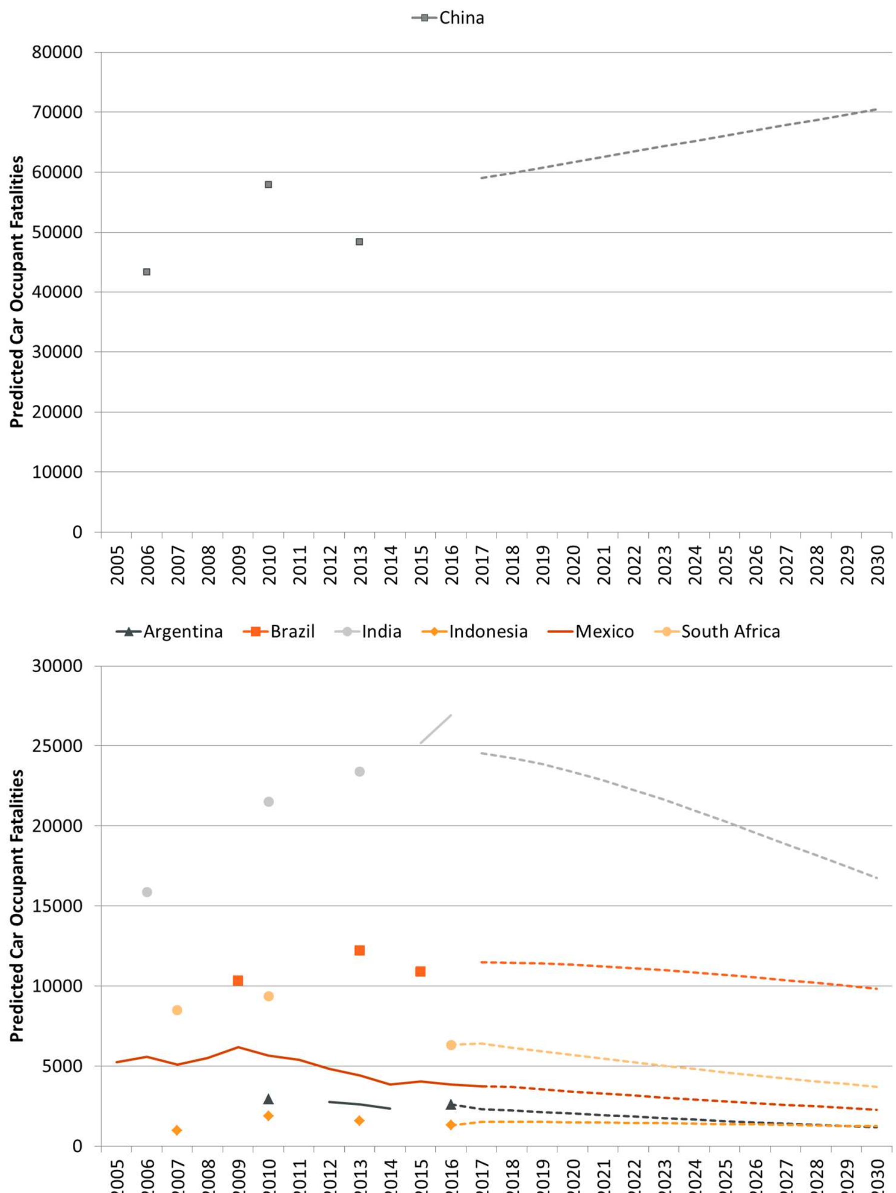

Figure 13: Predicted number of car occupant fatalities in Argentina, Brazil, China, India, Indonesia, Mexico and South Africa, 2005-2030

The number of car occupant fatalities is expected to fall in six of the seven countries between 2016 (or the last year of available data) and 2030. The one exception is China, where the number of fatalities in 2030 (70,434) is expected to be 46% higher than the last recorded number (48,354 in 2013). However, it should be noted that this predicted trend is based on only 3 years of data, the least of any of the countries being analysed. Accounting for voluntary uptake of ESC

Finally, in setting the baseline fatality forecast, adjustments are made to account for the levels of voluntary uptake of ESC that it is estimated will be seen in the vehicle fleet of each country before 2030 – and therefore the impact voluntary fitment will have on the target population for regulatory intervention. The impact of this is modelled by first predicting how many new vehicles enter the fleet with ESC fitted in each year, as described in Section 3.1 and then combining this with the effectiveness estimate of ESC (38%) from the literature and the target population (35%), as described in Section 4.

Figure 14 shows the final estimate of fatalities for each country, assuming no ESC regulations come into force in these countries before 2030. The 'baseline' estimates replicate those shown in Figure 13 (i.e. are based on assuming the current trends in road safety continue). The 'current timeline' figures represent the additional saving due to the voluntary uptake of ESC.

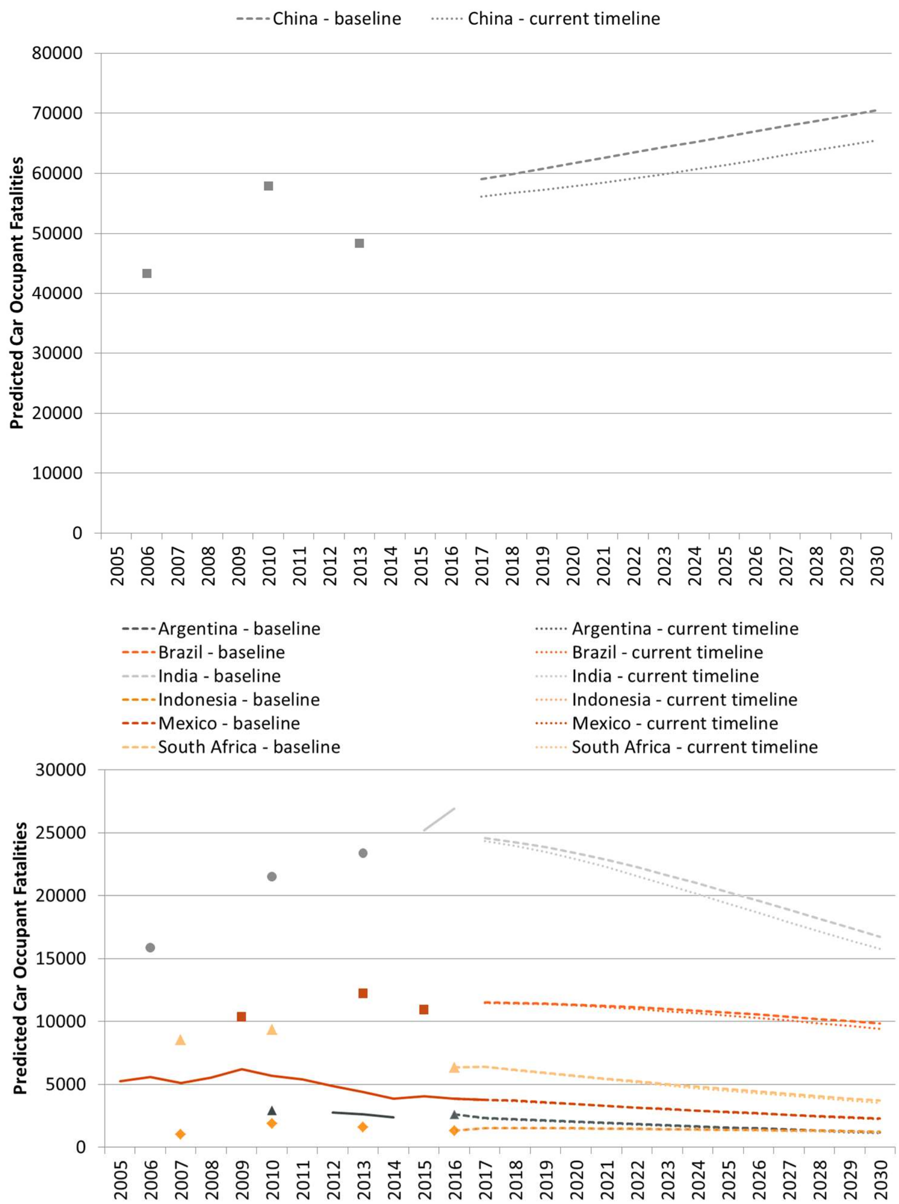

Figure 14: Predicted number of car occupant fatalities in each G20 country adjusted for voluntary uptake of ESC (2005-2030)

There is a relatively large difference in the baseline and current timeline estimates for China and India, suggesting that the voluntary uptake of ESC that is expected to occur in these countries is likely to be beneficial towards reducing car occupant fatalities. However, in the other four countries, there is a relatively small difference in the baseline and current timeline estimates, suggesting that the level of voluntary uptake means that ESC will not penetrate the vehicle fleet quickly enough to create a substantial reduction in car occupant fatalities by 2030. This gives more justification for considering implementation of a regulation in order to speed up the fleet penetration of the technology.

5.2 Accounting for ESC regulation

Now that the number of car occupant fatalities has been predicted under the ‘current timeline’ of ESC fitment – thus forming a baseline for comparison with the introduction of legislation – it is now possible to investigate how many lives could be saved by implementing regulation mandating fitment of ESC to all new car models from 2020, and to all new cars from 2022.

The impact of the regulation is to alter the expected level of ESC fitment in each country from 2021 onwards. The model now assumes that up to and including 2020, the fitment rate will be based on voluntary uptake of the technology, as in the ‘current timeline’ setting, but that from 2022 onwards, 100% of all new cars will have ESC fitted. In 2021, the fitment rate of new cars is assumed to follow a linear trend between the predicted value in 2020 and 100% in 2022.

Figure 15 shows the number of car occupant fatalities which are expected to be saved each year in each country if the ESC regulation is implemented in 2020.

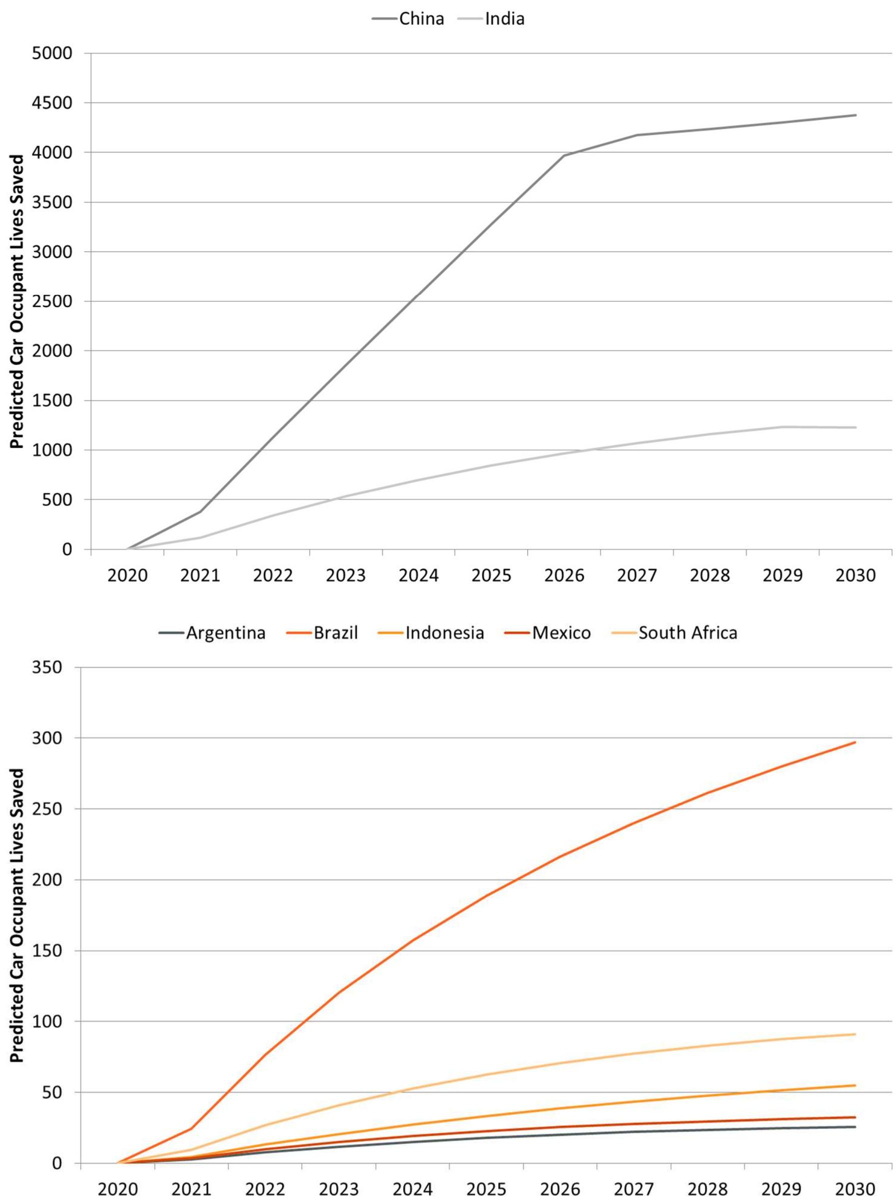

Figure 15: Estimated number of car occupant lives saved each year due to implementation of ESC regulation in 2020 (2020-2030)

This shows that, as the number of vehicles fitted with ESC in the fleet increases, the number of lives saved gradually increases for all countries. There is a slightly different trend in China and India, compared with other countries: from 2027 onwards for China, the rate of increase in number of lives saved slows down, and in 2030 for India, the number of lives is marginally smaller than in 2029. The reason for this change in trend is because those are dates by which it is estimated that the entire fleet will be fitted with ESC. ESC fitment levels off at 100% at this point (Figure 7), and since the effectiveness of ESC is a fixed proportion of fatalities, this means that the number of lives being saved also levels off.

Table 10 presents the total number of car occupant fatalities that are expected to be saved in each country over the whole period from 2020-2030. Upper and lower estimates are also presented from the sensitivity analysis (see Appendix D). Note that these estimates do not account for any other safety interventions that may be implemented over the same period.

Table 10: Total number of car occupant lives saved between 2020 and 2030 due to mandatory fitment of ESC

Country	Number of lives saved (2020-2030)	Number of lives saved (lower estimate from sensitivity analysis)	Number of lives saved (upper estimate from sensitivity analysis)
Argentina	171	68	248
Brazil	1,861	735	2,694
China	30,287	11,955	43,836
India	8,193	3,234	11,858
Indonesia	335	132	485
Mexico	217	86	314
South Africa	602	238	871
Total	**41,666**	**16,447**	**60,306**

The results show that, in total, around 42,000 lives could be saved by the ESC regulation across all seven countries.

However, this figure differs substantially between countries. It is estimated that over 30,000 lives could be saved in China between 2020 and 2030 and over 8,000 in India, but in Argentina this figure is only 171. These variations are mainly explained by differences in the number of baseline fatalities, adjusted for voluntary uptake of ESC (Figure 14) – China and India have substantially more fatalities each year than the other countries, meaning that the potential savings are much greater.

For each country, the upper and lower estimates for the number of lives saved from the sensitivity analysis were based on changing the effectiveness of ESC from the 38% figures used in the best-estimate case to 15% (lower estimate, Scenario 3 in Appendix D) or 55% (upper estimate, Scenario 2 in Appendix D). This suggests that the effectiveness of the system itself at reducing fatalities is likely to have the biggest impact on the casualty results of any of the inputs considered within the sensitivity analysis.

In addition to the fatality savings predicted above, it is estimated that a further 47,500 lives would have been saved between 2020 and 2030 if earlier regulatory action had ensured that ESC was fitted throughout the whole vehicle fleet by 2020. This additional benefit will not be achieved because of the time it will take for the fleet to turnover and for older cars which don't have ESC fitted to be replaced.

5.3 Estimated Serious Injuries Saved

Based on the information in Figure 15 and Table 10, an estimate was made as to the number of serious injuries that could be prevented in each country between 2020 and 2030 by the ESC regulation, applying the methodology described in Appendix E. This information is contained in

Table 11: Total number of car occupant serious injuries saved between 2020 and 2030 due to mandatory fitment of ESC

Country	Number of serious injuries saved (2020-2030)	Number of serious injuries saved (lower estimate from sensitivity analysis)	Number of serious injuries saved (upper estimate from sensitivity analysis)
Argentina	619	244	896
Brazil	6,724	2,654	9,732
China	109,420	43,192	158,372
India	29,600	11,684	42,841
Indonesia	1,212	478	1,754
Mexico	784	309	1,134
South Africa	2,175	858	3,149
Total	**150,533**	**59,421**	**217,876**

The results show that, in total, around 150,000 serious injuries could be saved by the ESC regulation across all seven countries.

It is worth noting that there are likely to be other casualty groups (e.g. pedestrians or pedal cyclists involved in collisions with cars) who would also benefit from the implementation of ESC. In conceivable circumstances, the car may be responsible for the collision after losing control in a way which could be mitigated by ESC. However, quantifying the level of benefit amongst these other groups of casualties is much more difficult than for car occupants[24], and the effect is considered likely to be small (see Section 2), so this has not been included in the scope for this study.

5.4 Total Estimated Casualties Saved

The total number of lives and serious injuries saved is shown in Table 23.

[24] It is often unclear from the collision statistics what happened first in an accident: the loss of control or the VRU becoming a hazard to the vehicle. ESC would likely only be effective in the former case.

Table 12: Lives and serious injuries saved for car occupants due to implementation of ESC regulation in 2020 (2020-2030)

	Cumulative lives saved, 2020-2030	Cumulative serious injuries saved, 2020-2030
Argentina	171	619
Brazil	1,861	6,724
China	30,287	109,420
India	8,193	29,600
Indonesia	335	1,212
Mexico	217	784
South Africa	602	2,175
Total	**41,666**	**150,533**

This demonstrates that by 2030, nearly 42,000 lives and over 150,000 serious injuries could be saved in total due to ESC regulations.

6 Estimated Monetary Benefit

This section outlines the economic benefit associated with the fatality savings presented in Section 5. It uses the Value of Statistical Life methodology (described in Section 6.1) to present a monetary value of the lives saved (Section 6.2).

6.1 Value of a Statistical Life

As outlined in in the previous study (Wallbank *et al.*, 2016), there are two main methods of estimating the economic losses due to road traffic crashes: the valuation of a statistical life (VSL) and cost-of-illness methods.

The VSL method is based on the willingness to pay to avoid injury, and presents estimates of the economic loss due to a road traffic fatality in terms of GDP per capita. The cost-of-illness method combines estimates of labour loss, medical, funeral, property damage, transport delays and administrative (including insurance and police) costs to estimate the cost of a fatality (Bhalla *et al.*, 2013). The VSL method can easily be compared across countries and updated, and hence has been selected for this study.

The VSL method is intended to capture how much individuals are willing to pay to reduce the risk of death. Because risks to life come from a multitude of sources and individuals can undertake many different actions to reduce these risks, it follows that there are multiple ways to estimate the VSL (Bosworth *et al.*, 2017). Upon analysing data from 68 measurements of willingness-to-pay conducted in 13 countries, Miller (2000) proposed the relationship VSL = 137.6*GDP per capita. This value was used as the higher estimate in the sensitivity analysis in this report. In 2009, a study for the International Road Assessment Program (IRAP) (McMahon and Dahdah, 2008), reviewed the willingness-to-pay literature and recommended that VSL = 70*GDP – this is used as the lower estimate in the sensitivity analysis in this report. The mean of these two values (103.8) is used as the central estimate in the best-estimate calculations. In addition, Bhalla et al. (2013) reviewed a number of relevant VSL studies and showed that the economic loss due to a serious non-fatal injury was equivalent to 17 times GDP per capita. Table 13 shows the lower and upper estimates for the valuation of a statistical life in each country, as well as the estimates for the valuation of a serious injury.

Table 13: Economic loss of death and serious injury using VSL method

Country	Forecast GDP per capita (2018) (2018 US$)	Economic loss of one death due to traffic collision (current US$, thousands)	Economic loss of one serious injury due to traffic collision (current US$, thousands)
Argentina	12,924	905 – 1,778	220
Brazil	8,807	616 – 1,212	150
China	9,182	643 – 1,263	156
India	1,913	134 – 263	33
Indonesia	3,865	271 - 532	66
Mexico	8,321	583 – 1,145	141
South Africa	5,237	367 - 721	89

The VSL method is not a perfect measure: one of the criticisms of this method is that the VSL constant could be lower in lower income countries (Viscusi, 2005) – something that has not been considered in this report.

In addition to the estimates from Bhalla *et al.* (2013) (who used the Miller (2000) and McMahon and Dahdah (2008) estimates discussed above), alternative VSL estimates were also identified in the literature (Viscusi and Masterman, 2017). Although these estimates are newer than those presented by Bhalla *et al.*, the former were selected as the most appropriate for this project because the estimates also include the relationship between GDP per capita and serious non-fatal injuries. In addition, Viscusi & Masterman acknowledge that their VSLs exceed the values that policy makers in foreign nations have used in the past. Despite this, the Viscusi and Masterman estimates are tested as part of the sensitivity analysis in Appendix D.

6.2 Benefits

Figure 16 shows the estimated economic benefit that could be achieved each year, broken down by country, between 2020 and 2030 by implementing the ESC regulation in 2020. For the purposes of this analysis, the average of the upper and lower estimates of the cost of a fatality, along with the estimate of the cost of a serious injury, (as presented in Table 13) has been used to estimate the economic benefit of the lives saved by ESC, after which the monetary benefits have been discounted, as explained in Section 7.3.

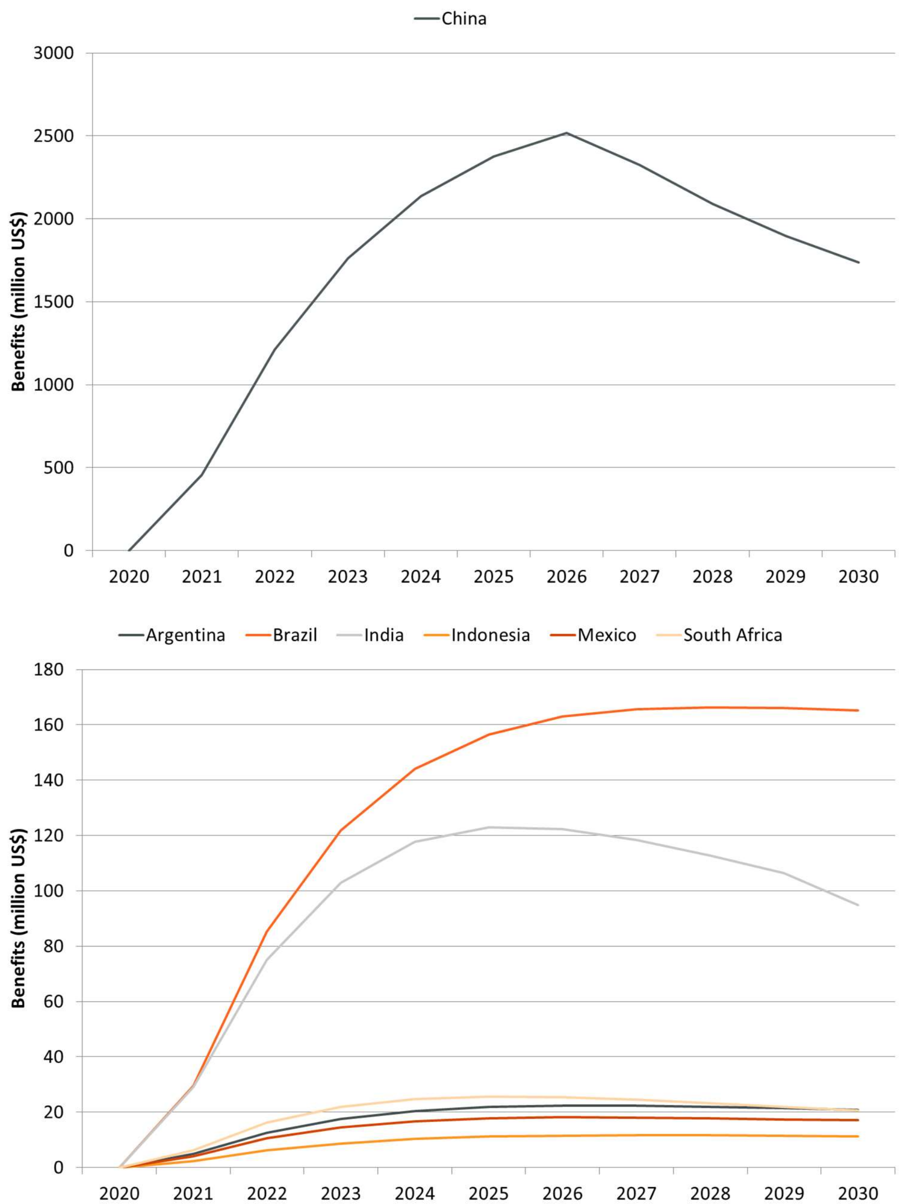

Figure 16: Estimated economic benefit for car occupants due to implementation of ESC regulation in 2020 (2020-2030)

The results show that in general, the level of benefit is increasing over time, with a tailing off and possible slight decrease in benefit as 2030 approaches. The one country which is an exception to this is China, where the level of benefit falls from 2026 to 2030, linked to the fitment rate and fatality trend (as described in Section 5.2).

Table 14 presents the cumulative number of lives and serious injuries saved in each country from 2020-2030, as well as the resulting economic benefit.

Table 14: Estimated economic benefit for car occupants due to implementation of ESC regulation in 2020 (2020-2030)

Country	Cumulative lives saved, 2020-2030	Cumulative serious injuries saved, 2020-2030	Mid estimate of economic loss of one death due to traffic collision (2018 US$, thousands)	Estimate of economic loss of one serious injury due to traffic collision (2018 US$, thousands)	Discounted economic benefit, 2020-2030 (2018 US$, millions)
Argentina	171	619	1,342	220	186.2
Brazil	1,861	6,724	914	150	1,363.5
China	30,287	109,420	953	156	18,504.4
India	8,193	29,600	199	33	1002.2
Indonesia	335	1,212	401	66	96.2
Mexico	217	784	864	141	152.1
South Africa	602	2,175	544	89	210.8
Total	**41,666**	**150,533**			**21,515.5**

Overall, it is estimated that from 2020-2030, US$21.5 billion of economic benefit will be seen across the seven countries if the ESC regulation is implemented in 2020.

7 Estimated Costs

7.1 Sources of ESC cost information

A small literature review was undertaken to identify information about the cost of fitment of ESC. Two primary sources were identified:

1. A 'tear-down' study of 11 2005 model year (MY) light passenger vehicles performed by (Ludtke & Associates, 2006) for NHTSA
2. Cost information provided by the automotive industry to the Standards and International Vehicle Safety Standards Branch of the Australian Department of Infrastructure, Transport Regional Development and Local Government (DITRDLG, 2009) in support of a Regulatory Impact Statement on ESC

It should be noted that the NHTSA tear-down study forms the basis for the cost information in the preamble to GTR-8 (UN, 2008)[25].

Ludtke & Associates (2006) analysed the ESC, ABS and TCS (Traction Control System) components from 11 US market light passenger vehicles (cars, SUVs, vans and light trucks) from ten OEMs from three manufacturing regions (the US, Europe and Asia). OEMs provided a list of parts associated with each system in each model. The parts were then costed assuming a manufacturing volume of 250,000 units per annum. Some OEMs specified the parts for each system assuming that it was installed as a standalone system, so the total cost for all three systems was less than the sum of the costs of the three systems; other OEMs specified the parts for ABS, with the additional parts required for TCS and then ESC specified. Additional costs were included using Detroit (Michigan, USA) area automotive industry manufacturing process practices, direct labour rates, labour overhead rates, material costs, representative company fixed costs and profit, tooling expenses, and capital equipment costs. The costs were therefore considered to represent the costs to the end user (purchaser) of the vehicle. The costs are shown in Table 15 below.

As noted above, the OEMs provided parts breakdowns in different ways. The last column of Table 15 represents the cost of ESC if ABS (and TCS, which had an additional cost as low as $6) is already fitted to the vehicle.

It can be observed that the cost of ESC is markedly different across the three regions of origin, with the mean for Asian vehicles being $131.81, Europe being $89.07 and the US being $54.62. It is not known why, but this may reflect a) a difference in the maturity of the technology between the different regions, or b) the sophistication of the vehicles selected (early adopters tended to be in higher vehicle segments (e.g. luxury and executive) and may have had more sophisticated systems than is necessary to meet regulatory requirements). It

[25] It should be noted that OEMs and Suppliers are often unable to provide cost information directly because it is commercially sensitive information; hence NHTSA have used tear-down studies to estimate the cost of safety systems.

should not be related to the production volume of the vehicles involved, because a production volume of 250,000 units per year was assumed for all vehicles.

Table 15: Total manufacturing end-user costs for ABS, TCS and ESC in 2006 US dollars (Ludtke & Associates, 2006)

Vehicle number	Region	Type	ABS (2006 US$)	TCS (2006 US$)	ESC (2006 US$)	Total (2006 US$)	Roll Sensor	ESC Cost (2006 US$)
1	USA 1	SUV	263.46	169.46	115,85	548.77	Yes	115,85
2	Europe 1	PC	344.64		108.54	453.17	No	108.53
3	Asia 1	PC	294.57		336.69	485.53	No	190.96
4	Asia 2	LT	370.58	373.94	442.01	509.06	No	135.12
5	USA 2	PC	407.10		184.37	480.76	No	73.66
6	Europe 2	SUV	455.50	13.25	69.61	538.35	No	69.61
7	Asia 3	SUV	378.38		408.74	479.29	Yes	100.91
8	USA 3	VAN	472.18	472.18	37.57	509.74	No	37.57
9	USA 4	PC	374.29	5.69	37.06	417.60	No	37.06
10	USA 5	PC	399.99	5.69	70.19	476.43	No	70.19
11	Asia 4	SUV	439.69		436.25	539.92	No	100.23

A regulatory impact assessment for ESC was performed by the Australian Government (DITRDLG, 2009) to establish the costs and benefits of complementing voluntary fitment of ESC with an intervention to mandate fitment for all passenger cars by adopting UN GTR-8. In addition to the NHTSA cost data reported above, the Australian Government also received cost data from the Federal Chamber of Automotive Industries, an industry body representing manufacturers and importers of passenger vehicles. The FCAI provided a cost estimate of AUS$350 for ESC only (assuming ABS already fitted) (US$242 at 1 April 2009 exchange rate). This was a fitment cost only and did not include the cost of R&D, although this was primarily associated only with platforms that did not already have ESC such as some vans.

7.2 Recommended cost of ESC fitment

For the purposes of this study, it would be possible to use the lowest cost from the NHTSA study (2006 US $37.06). This is lower than the value of US$111 used in the preamble to GTR-8, which was based on the mean cost from the NHTSA study. This lower cost could be justified for a number of reasons:

- The lowest cost is considered representative of what is required to fit functional ESC, i.e. the cost necessary to meet regulatory requirements. A manufacturer may elect to fit a more sophisticated (and therefore more expensive) version for some models. For example, a manufacturer may fit a ‘sportier’ variant of a car model with different driving modes (including different steering weight, gearbox response and suspension settings), which may require a more sophisticated ESC implementation. For the purposes of this study, these additional costs are viewed as part of the optional cost to the consumer of the sportier variant, and not part of the basic cost necessary to meet regulation and deliver the intended safety benefit.

- At the time of the NHTSA tear-down study, each car tended to be on a unique platform, possibly shared by a limited number of 'stable-mates' (i.e. similar models across different brands in the same company, all within the same segment). This limited the economy of scale that could be realised for ESC. Today, manufacturers have developed modular vehicle platforms which span many segments in an effort to reduce development costs and increase the economies of scale for components such as ESC (including their attachments to the vehicle). For example, VW group have moved from six platforms for B, C, D, E, SUV and Sports segment vehicles in 2005 to one platform (MQB), covering over 41 vehicle models in these segments across four brands in 2017.
- One of the effects of regulation is to minimise the costs of safety critical components.

However, a higher cost of US$50 for fitment of an ESC system has been used for this cost-benefit study. This allows for some variation in the cost of fitment across different vehicle types and countries, and therefore represents a conservative approach to the cost-benefit estimate. This fitment cost was also agreed with Global NCAP.

This cost value assumes that ABS is already fitted. Further information on ABS fitment is shown in Section 1.3.

7.3 Application of ESC cost in the cost-benefit model

The available cost information was primarily from model year (MY) 2005 vehicles, but the specific cost brought forward to this study was from a MY 2004 passenger car. In order to represent these costs in the 2018 to 2030 timescale, two processes were implemented:

1. Bring MY 2004 costs up-to-date as MY 2018 costs, including the effects of both inflation and discounting (defined below); and
2. Attribute a 'present value' to future costs (NB: the present value calculation is also applied to the benefits).

Inflation: The available cost information is in US$, so an inflation calculator internet site[26] that uses data from the US Labor Department's Bureau of Labor Statistics was used for annual inflation rates.

Discounting: The available cost information for ESC is from relatively early generations of ESC system and it is well established that over time the cost of vehicle safety systems tends to reduce (e.g. Abeles (2004)). This may be due to design changes, increased production volume, a lower mark-up for mandatory safety systems with respect to optional (market-driven) systems, and so forth. Agencies such as NHTSA have applied a 'discounting'

[26] www.usinflationcalculator.com

rate to account for the expected cost reductions over time[27]. Discounting rates may range up to 90% for technologies such as airbags (Abeles, 2004), but a rate of 20% is more typical; a rate of 8% per year building to a maximum of 20% has been assumed for this study.

Present value: In this study a discount rate is applied to both the costs and benefits (presented in today's terms). The application of a discount rate reflects that benefits and costs further into the future are valued less highly than present benefits and costs.

For private sector project evaluation, it is usual to use the return that an investor could get in the open market as a discount rate (the Opportunity Cost of Capital). Projects are then evaluated as more worthwhile if they can offer a better return than would be gained from investing elsewhere. For projects with a social benefit, a lower rate is normally used to reflect the difference in people's expectations of returns on social projects versus private ones.

It should be noted that there are considerable variations in the social discount rates applied in different world regions, with variations between 3% (lower limit in developed countries) and over 12% (upper limit in developing countries, in some cases up to 15%) (Zhuang *et al.*, 2007). Table 16 lists the social discount rates applied in this study. The lower and upper estimates represent recommended ranges for the sensitivity analysis. The rates are expressed in real terms, i.e. not including the effects of inflation. The rates reported are extracted from the most appropriate source identified for each country and all fall within the corridor cited above.

Table 16: Social discount rates applied in this study (real rates, per annum)

Country	Social discount rate	Source
Argentina	4.5%	Lopez (2008)
Brazil	4.5%	Lopez (2008)
China	8.0%	Zhuang *et al.* (2007)
India	8.65%	Shanmugam (2006)
Indonesia	6.1%	Zhuang *et al.* (2007)
Mexico	4.5%	Lopez (2008)
Saudi Arabia	5.0%	Based on the cost-benefit analysis by Ahmad and Ramana (2014)
South Africa	8.0%	DEAT (2004)

While these rates were calculated a number of years ago, in other parts of the world social discount rates have stayed relatively stable over the same period. For example, the social discount rate used by the UK Treasury in 2003 was 3.5% (HM Treasury, 2003), and the same

[27] www.nhtsa.gov/sites/nhtsa.dot.gov/files/fmvss/DEIS_Appx_C.pdf

rate has been used in subsequent updates up to the most recent (HM Treasury, 2013). Similarly the EU rate for poorer regions of Europe has fluctuated only slightly between 2002 and today (in 2002 the recommended social discount rate was 5% (European Commission, 2002), in 2008 it was 5.5% (European Commission, 2008) and it has since reverted to 5% (European Commission, 2014).

7.4 Estimating the total cost of the ESC regulation

Now that a suitable estimate of the fitment cost of ESC has been determined, it is possible to investigate what the total cost of implementing the regulation would be over the period 2020-2030.

7.4.1 Predicting numbers of newly registered cars

The first step in the modelling process is to estimate the number of cars that are going to enter the vehicle fleet in each country, up to 2030. As with the predictions of the total number of registered cars (Figure 12), this has been done by extrapolating the data that is available, assuming a linear trend. The results are illustrated in Figure 17.

The results show that the number of newly registered cars is expected to increase in every country up until 2030, with the exception of South Africa, where the trend is constant. There was a fall in the number of newly registered cars in Brazil from 2012 to 2016, which occurred due to an economic recession in the country from 2012 to 2017. The upwards trend predicted between 2017 and 2030 is based on the assumption that it takes approximately 5 years for new car sales to return to pre-recession levels (based on the trend in GB following the 2007-2010 recession) [28].

[28] In Figure 17, the downwards trend in new car registrations in Brazil is expected to continue until 2017 when the recession in Brazil finished, the trend from 2022-2030 is based on the linear trend of data from 2005 to 2016, and a linear assumption is made between 2017 and 2022. In reality, it is unlikely there will be a step change in registrations in 2022.

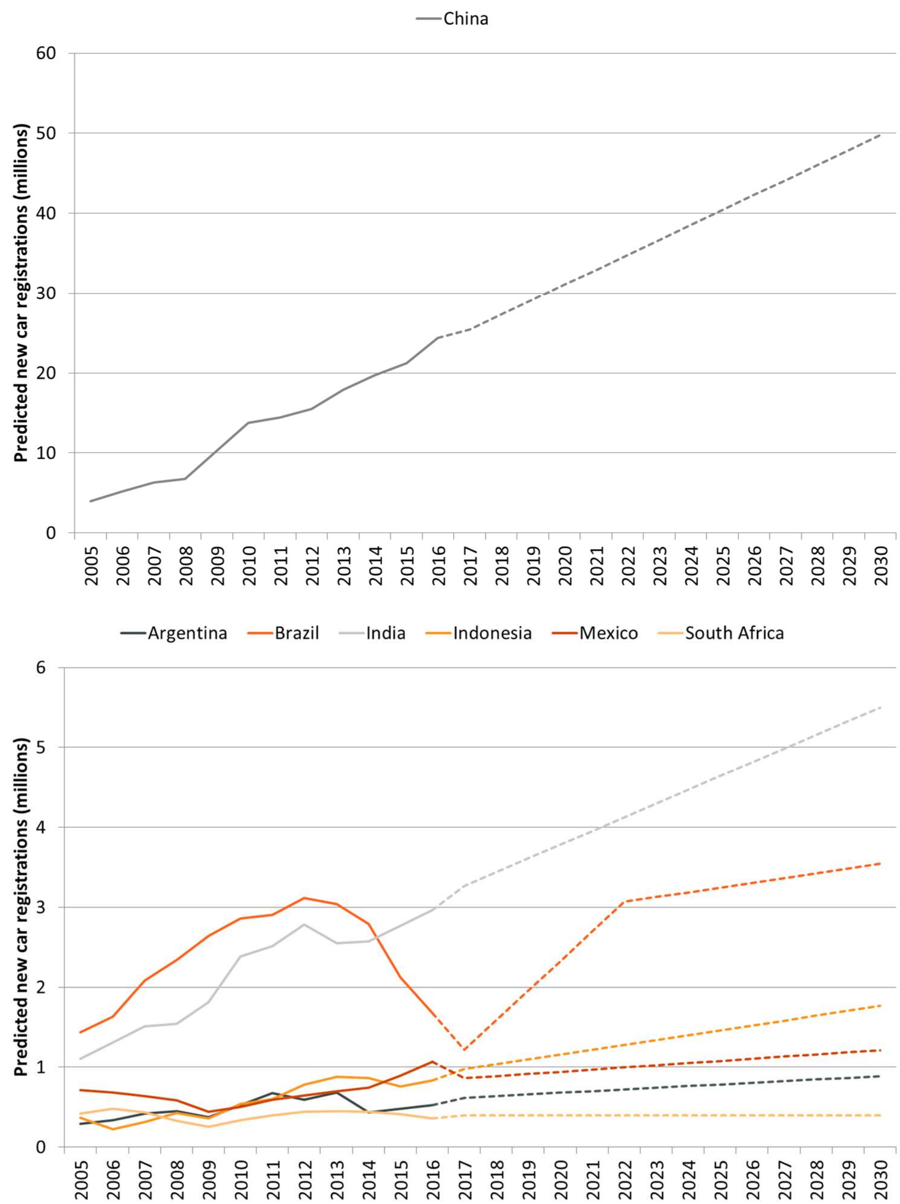

Figure 17: Predicted number of newly registered cars for each G20 country (2005-2030)

7.4.2 Predicting the level of extra ESC fitment

The next step in the modelling process is to use this information to estimate the number of extra cars that would need to be fitted with ESC in each year if the regulation were to be introduced in 2020. As explained in Section 3, this is done by comparing the respective fleet fitment rates of new cars under the voluntary uptake scenario 'current timeline' and under the scenario where the regulation is implemented 'revised timeline' (see Figure 6).

Figure 18 presents the number of extra cars that would need to be fitted with ESC, if the regulation were to be implemented in 2020. Recall that in practice, this means that ESC would be fitted in all new car models from 2020, and in all new cars from 2022, to give manufacturers sufficient time to alter their processes if necessary.

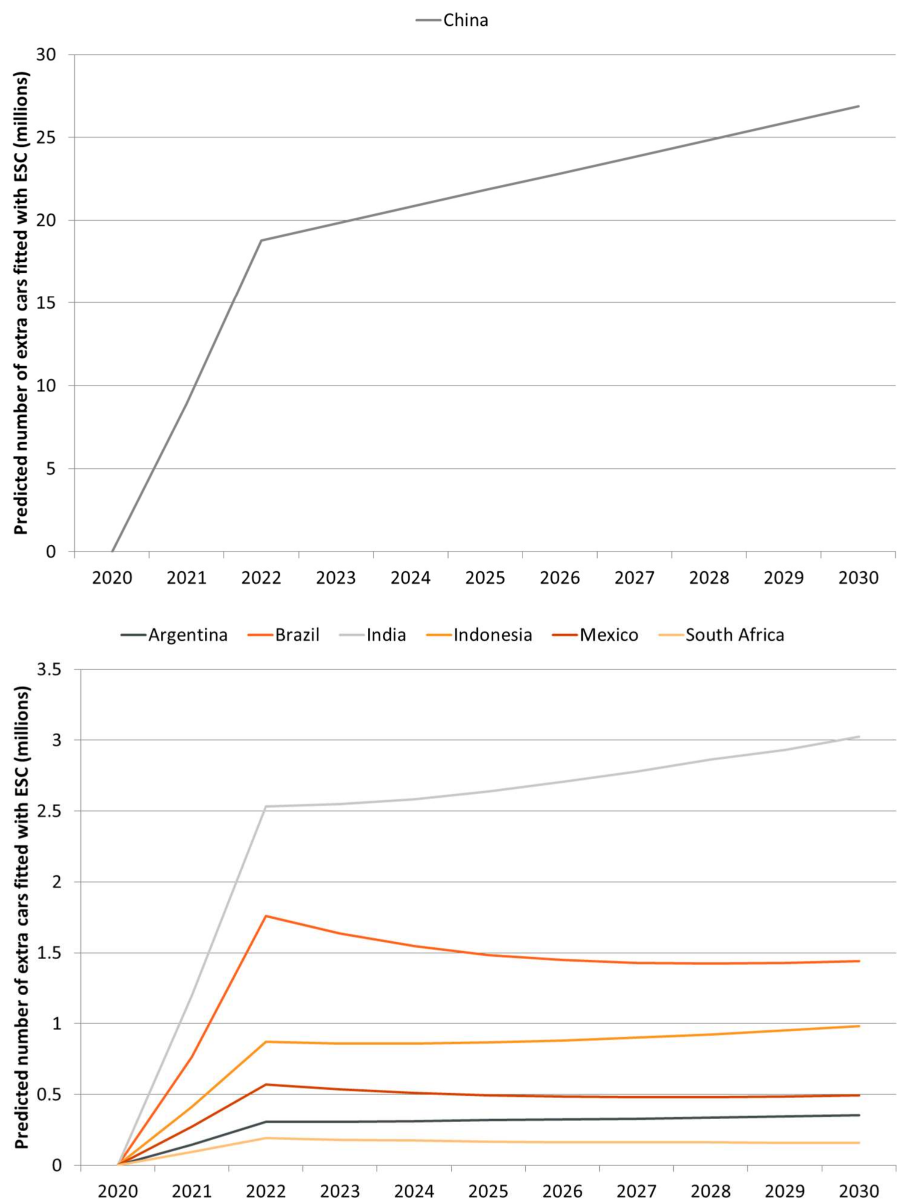

Figure 18: Predicted number of extra cars that would be fitted with ESC, if a regulation were introduced in 2020 (2020-2030)

The results are as would be expected, given the regulation timeline. Between 2020 and 2022, the fitment rate of new cars is increasing from the predicted fitment rate in 2020 to 100%, assuming a linear trend. Therefore, the number of extra cars that need to be fitted with the technology is also increasing approximately linearly. Then, from 2022 onwards, the fitment rate of new cars remains at 100%, so the trend in Figure 18 depends mainly on the trend in numbers of new car registrations (Figure 17), which is significantly upward for China and India and slightly upward for the other countries, with the exception of South Africa, where the trend is constant. These are fairly similar to the trends that are seen here.

7.4.3 Predicting total cost of ESC fitment

The final stage in this part of the modelling process is to combine the predicted extra number of cars that need to be fitted with ESC (Figure 18) with the estimated ESC fitment cost of US$36.46 (2018 US$) to produce estimates of the total cost of implementing the regulation in each country. Figure 19 presents this, by country, in each year from 2020-2030, accounting for discounting.

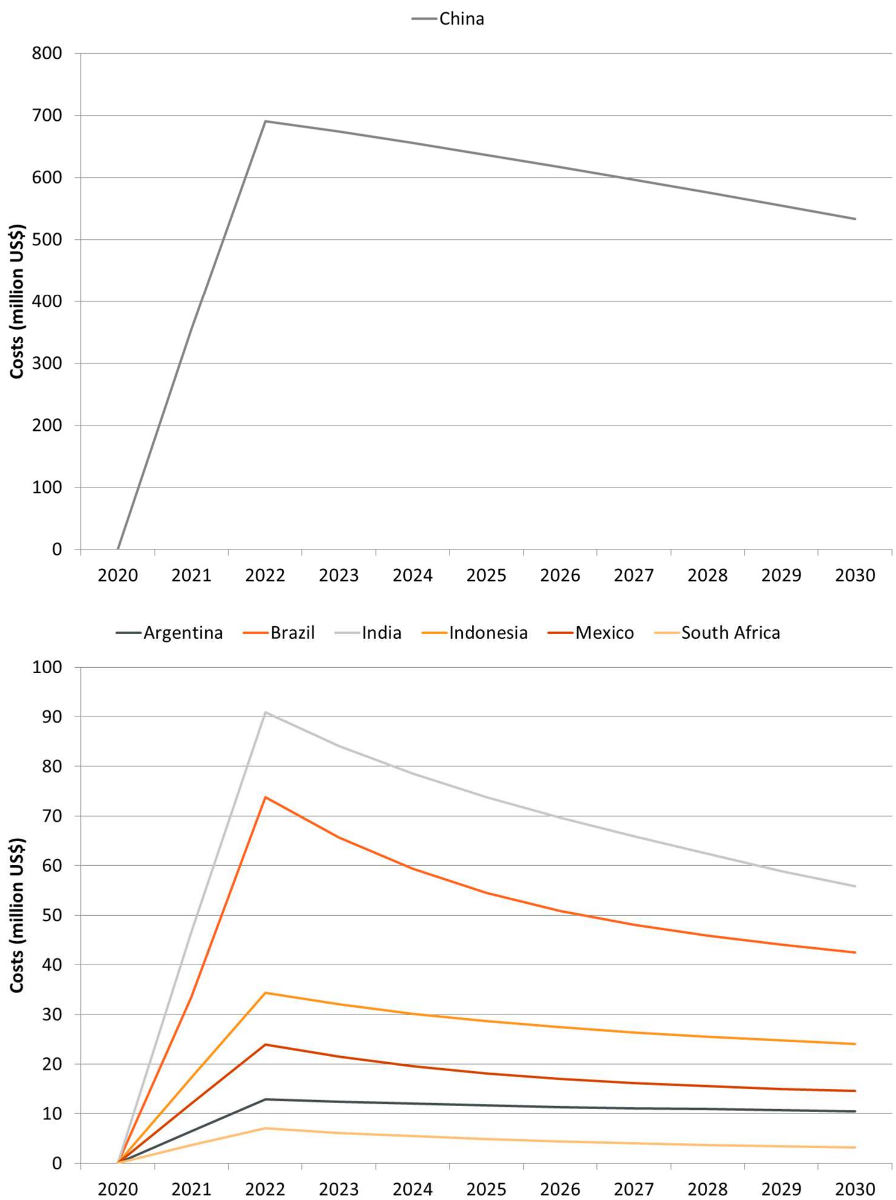

Figure 19: Estimated costs with implementing ESC regulation in 2020 (2020-2030)

Table 17 presents a cumulative estimate of the number of extra cars that would need to be equipped with ESC in each country from 2020-2030, were the regulation to be introduced, and converts this into a total economic cost, accounting for discounting.

Table 17: Estimated costs associated with implementing ESC regulation in 2020 (2020-2030)

Country	Predicted additional vehicles equipped, 2020-2030	Discounted economic cost of fitting ESC, 2020-2030 (2018 US$, thousands)
Argentina	3,085,878	109,863
Brazil	14,362,463	518,213
China	214,353,072	5,886,365
India	25,802,064	686,693
Indonesia	8,504,016	270,566
Mexico	4,811,799	173,440
South Africa	1,611,940	46,058
Total	**272,531,233**	**7,691,198**

The results are that the total cost of implementing the regulation across the seven countries would be approximately US$7.7 billion. However, it is worth noting that the cost of the regulation in China comes to around US$5.9 billion, almost 80% of the total across all seven countries. This is due to the rapid growth in new car registrations in China, which is expected to continue up to 2030 (Figure 17).

8 Benefit-to-cost estimate

This section takes the benefit estimates presented in Section 6 and the cost estimates in Section 7 and calculates the benefit-to-cost ratio (BCR) for each country. These BCRs allow a comparison of the extent to which the benefits exceed (or fall short of) the costs related to implementation of ESC over the period 2020–2030, compared to the baseline scenario (which includes voluntary uptake of the technology). Values greater than 1 indicate that the benefits are greater than the costs incurred.

In addition to the overall results over the period, results for individual years and ranges of uncertainty from the sensitivity analysis are presented. A full description of the method used for the sensitivity analysis is presented in Appendix D.

Table 18 presents the year in which the BCR in each country (and all countries combined) becomes greater than 1. This represents the year in which the benefits of the ESC regulation are greater than the costs. Note that these estimates do not account for any other safety interventions that may be implemented over the same period.

Table 18: Year in which the BCR for implementation of ESC regulation crosses 1 for each country

Country	Year in which BCR increases above 1	Year in which BCR increases above 1 (conservative estimate from sensitivity analysis)	Year in which BCR increases above 1 (optimistic estimate from sensitivity analysis)
Argentina	2023	>2030	2021
Brazil	2022	2025	2021
China	2021	2023	2021
India	2023	>2030	2022
Indonesia	>2030	>2030	>2030
Mexico	2026	>2030	2023
South Africa	2021	2023	2021
Total	**2021**	**2024**	**2021**

Across the G20 countries as a whole, the best-estimate BCR for the region becomes greater than 1 within a year of implementation, indicating that the casualty benefits of ESC regulation would outweigh the costs.

For three of the countries, the best-estimate suggests that the BCR will be larger than 1 within two years of the ESC regulation being implemented (2021 in China and South Africa and 2022 in Brazil) and the conservative and optimistic estimates also suggest that the BCR will be larger than 1 within five years of the implementation date. In these countries, there is no evidence to suggest that ESC regulation would not be worthwhile.

For three of the other countries, the BCR is expected to take slightly longer to become larger than 1, but still within only a few years of the implementation of ESC (2023 in Argentina and

India and 2026 in Mexico). In these countries, there is also evidence to suggest that the regulation would be worthwhile.

In Indonesia, the BCR is not expected to increase above 1 by 2030, suggesting that over the time period 2020 to 2030 the ESC regulation may not be cost-beneficial. However, it should be noted that the results only include the modelled car occupant fatality and serious injury benefits, and do not consider wider benefits to less severe casualties or other road users. Furthermore, the modelling presented here is based on the assumption that current trends continue, but there is limited casualty data on which to base these trends for some countries, including Indonesia, and the level of underreporting is unknown. As a result, if the implied safety improvements in these countries slow, or if the reported fatality figures are subject to a degree of underreporting and an alternative trend emerges, then the benefits of ESC could be much greater. This should be monitored and the implications for ESC economics reconsidered if new evidence becomes available.

For each country, the conservative BCR estimates from the sensitivity analysis were based on changing the effectiveness of ESC from the 38% figures used in the best-estimate case to 15% (Scenario 3 in Appendix D). This suggests that the effectiveness of the system itself at reducing fatalities is likely to have a big impact on the BCR results, with only Brazil, China and South Africa showing a cost-beneficial result under this scenario.

The optimistic estimates are based on Scenario 10, which uses an alternative Value of Statistical Life for each country (Viscusi and Masterman, 2017) to those presented in Table 13. These estimates demonstrate that if the VSL estimate for each country is substantially higher compared to the mid-estimates used in the rest of this report, the regulation is cost-beneficial in six of the seven countries, with Indonesia being the one exception.

Figure 20 shows the trend in the BCR over the period 2020-2030.

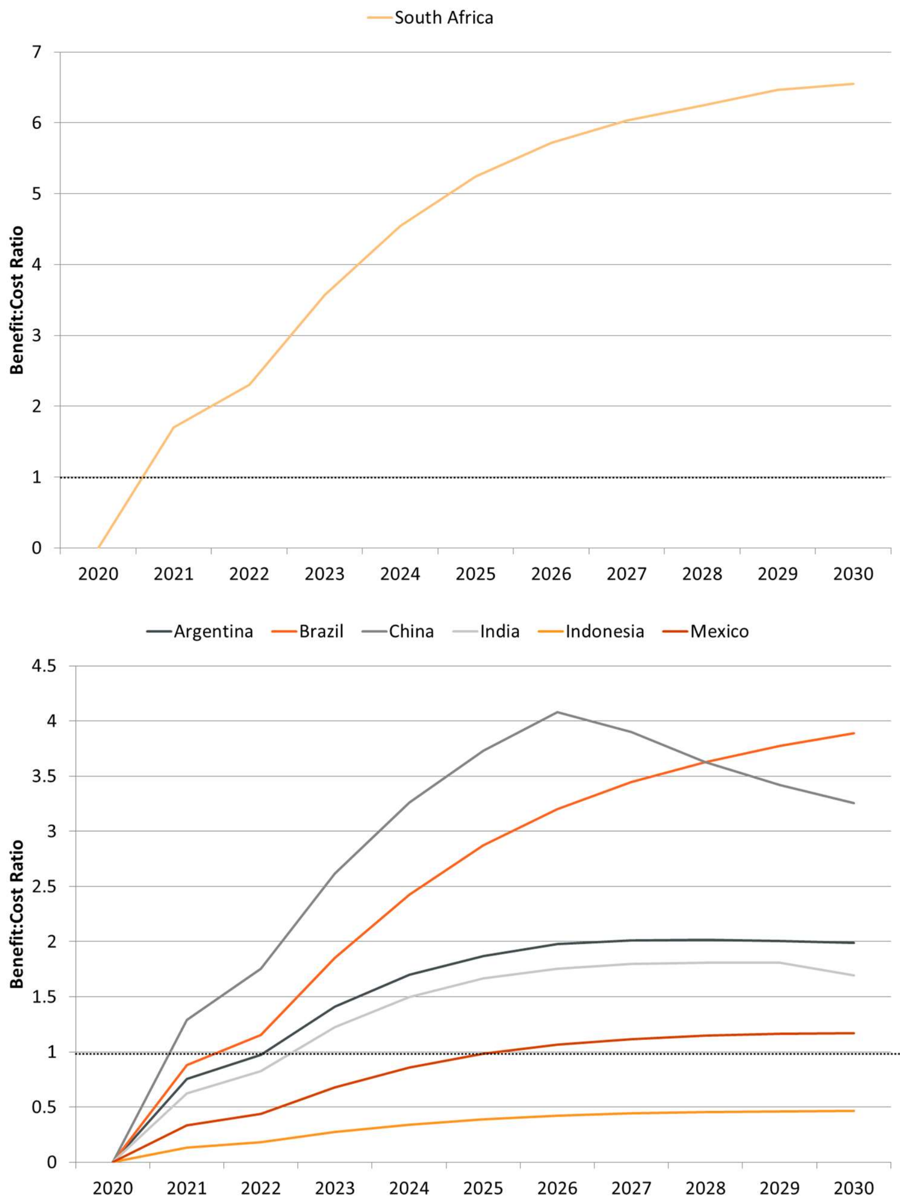

Figure 20: Estimated benefit:cost ratio associated with implementing ESC in 2020 (2020-2030)

For all the countries except Indonesia, the BCR increases as uptake into the fleet increases and the ratio becomes cost-beneficial at some point between 2021 (South Africa) and 2026 (Mexico).

9 Other Considerations

This section of the report presents a short discussion of some of the additional benefits of mandating ESC, actions that can be taken to stimulate the update of ESC pending the introduction of legislation, and the application of ESC to heavy vehicles.

9.1 Additional benefits

Both ESC and ABS are building blocks for Automated Emergency Braking systems (AEB). AEB combines sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid a collision. AEB systems use cameras or radar to scan the road ahead of the vehicle for obstacles and may alert the driver to the presence of an obstacle before braking, or just apply the brakes. Early systems were designed to apply full ABS braking if a collision became unavoidable, so mitigated rather than prevented collisions. Newer generations of AEB system attempt to stop the vehicle prior to a collision occurring and may work over the entire speed range of the vehicle (although collisions may only be avoided at the lower end of the speed range, say up to 80 km/h, depending on the system). Early AEB systems were designed to recognise a potential collision with another car or a larger vehicle, while current systems often also detect and mitigate collisions with pedestrians and cyclists.

As part of a review of the cost-effectiveness of 24 safety measures that could be considered for regulation in the EU, Seidl *et al.* (2017) evaluated the costs and benefits of AEB and AEB with pedestrian/cyclist detection (AEB-PCD) through detailed literature review and stakeholder engagement. It was reported that public acceptance of AEB was very high, with 55% of drivers knowing about AEB and 93% of those wanting AEB on their next car. Seidl *et al.* found that there was strong evidence of the benefits of AEB in reducing fatal, serious and slight casualties, as well as damage-only collisions. They identified the potential for a reduction in car insurance premiums due to a substantial reduction in front-to-rear collisions, which have a marked influence on insurance premiums due to whiplash injury claims and vehicle damage claims. There is also good potential for the harmonisation of technical requirements (e.g. for regulation) across regions.

An example effectiveness for AEB for M1 vehicles (passenger cars, SUVs etc.) of 38-42% of casualties across all injury severities, with a relatively lower effectiveness at higher injury severity levels, was given based on Fildes *et al.* (2015) and Cicchino (2016). Pedestrian AEB is now widely available, but cyclist-specific AEB is less common. Nevertheless, effectiveness of both was reported by Rosén (2013) as:

- M1 Pedestrian detection: 47.8–49.8% (fatal), 41.7–42.4% (serious)
- M1 Cyclist detection: 52–58% (fatal), 32.2–33.4% (serious)

Costs for both systems were estimated at €186-249, although this would be shared across both systems (as well as other systems such as lane keep assist and intelligent speed adaptation if fitted, so potentially as low as €47–62 per system).

No concerns regarding either the benefit or cost estimates were raised by stakeholders and there were no substantial stakeholder objections regarding implementation if the BCA was demonstrated to be greater than one.

Although full benefit-to-cost ratios were not calculated, a benefit-to-cost ratio markedly greater than one might be expected. This is because of the high effectiveness and large target population for AEB, which includes a large number of damage-only and slight injury collisions, and the even higher effectiveness values for serious and fatal vulnerable road user casualties for AEB-PCD. The benefit-to-cost ratio would depend on the specific casualty population in any given country. Nevertheless, mandating ABS and ESC is an important part of delivering the substantial casualty savings from AEB and AEB-PCD.

9.2 Stimulating the uptake of ESC

The majority of this report focuses on the costs and benefits of mandating the fitment of ESC via legislative measures. Legislation can take time even when there is the political will to introduce it and, in some cases, there may not be that political will for many years. Therefore, the report has been supplemented by a short review of approaches that have been taken to accelerate the uptake of ESC in the absence of legislation. The full literature review may be found in Appendix F.

In summary, the two main examples that were identified were Sweden and Australia, which both had successful national efforts to introduce ESC prior to the introduction of legislation.

In summary, both Sweden and Australia had a significant focus on the following areas:

- Government car purchase and leasing policies
- Encouraging other large fleet buyers/leasers to implement ESC policies
- Publicity of the benefits of ESC to consumers

Furthermore, Sweden also influenced the voluntary take-up of ESC through car insurance pricing.

Both countries were very successful, with voluntary fitment rates exceeding 60% despite the absence of legislation. This shows the potential for well co-ordinated national initiatives to encourage a good level of standard ESC fitment; nevertheless, legislation to mandate the fitment of ESC was subsequently implemented. This ensured that the whole fleet met the same performance standard and ensured that consumers did not face a ‘safety lottery’ when making their car purchase decisions and ensured a level playing field for all manufacturers.

NCAPs have also had a strong role in encouraging the fitment of ESC in a number of regions. For instance, Euro NCAP started publishing an ESC fitment rating in 2007[29], which showed the availability of ESC (standard, optional and none) for all the available variants of a vehicle model (i.e. not sales weighted). This garnered lots of press coverage, particularly relating to

[29] www.euroncap.com/en/vehicle-safety/safety-campaigns/2008-esc-fitment-survey

manufacturers with lower than average fitment rates[30]. From 2011 until 2014 (when ESC became mandatory in Europe for all new cars), Euro NCAP also tested the performance of the ESC system in a test similar to that defined in regulations.

9.3 ESC for heavy vehicles

ESC is already mandatory for heavy vehicles in the EU and is being phased-in in the US (see Appendix H). The legislation in both jurisdictions covers a wide range of heavy goods vehicles, buses and coaches. Some vehicle types are exempt from the legislation, for instance in the EU:

- Exempt HGVs include off-road variants, rigid (non-articulated/semi) trucks with more than three axles, tractor units between 3.5 and 7.5 tonnes, and special purpose vehicles are exempt;
- Exempt buses and coaches include those with more than three axles and articulated buses.

The existence of legislation in the EU and US means that requirements and test procedures already exist that could be implemented in other jurisdictions. The inclusions and exclusions may need to be revised for the specific vehicle types in other regions, but the general regulatory principles have been established and manufacturers are mass-producing vehicles with ESC, which establishes the feasibility of the measures.

[30] E.g. www.whatcar.com/news/shamed-car-makers-dont-fit-esc and www.carmagazine.co.uk/car-news/industry-news/euro-ncap-slams-uk-safety-record

10 Limitations

When analysing casualty figures, it is important to account for levels of exposure. For example, the number of car occupant casualties is likely to be influenced by the number of cars (more casualties are expected when there are more cars) and also the level of car traffic in a country (more casualties are expected when there is more car travel and subsequently more car traffic, measured in vehicle-kilometres travelled).

As described in Section 2.3, the number of car occupant fatalities has been estimated for this study by projecting forwards the number of fatalities per passenger kilometre, or per registered car, up to 2030. For each country, the measure of exposure was selected based on available data. Passenger kilometres is considered the preferable measure for car occupants, since this expresses the risk to car occupants based on the amount of movement of these passengers on the road network. However, these data were not available for Argentina, Brazil, Indonesia and South Africa and as a result, registered cars were used for these countries instead. The limitation of this is that the number of cars may not be a good measure of exposure for all countries. For example, since not everyone who owns a car is likely to drive every day, this can mean that the number of cars may not be the most appropriate measure of exposure.

In addition to challenges with the exposure data not being ideal for every country, some concerns have been raised about the casualty data for China: Hu *et al.* (2010) report that there are inconsistencies between the police-reported data and that reported by the death registration data (collected by the Ministry of Health) and that "these inconsistencies strongly suggest that the decreasing trend in road traffic mortality shown by police-reported data may not be genuine". As a result, the Ministry of Health data has been used to model the trend in car occupant fatalities for this country. However, there is still some inherent uncertainty in the results (and those for the other countries), since the model assumes that current trends in fatality rates continue as they have done in recent years. For some countries these trends are well established and based on over 10 years of data, but for many of the countries studied, the analysis is limited to only three data points (provided by the WHO reports).

The South Africa fatality data in particular raises some questions since the disaggregation by road user category only provides data for three road user types: drivers of 4-wheeled cars and light vehicles, passengers of these vehicles and pedestrians. It is unclear why no road user fatalities are reported for pedal cycles, powered 2-wheelers or heavy goods vehicles and as a result, some caution should be applied to the results presented here for this country since the fatality numbers may be an over-representation of the number of car occupant fatalities in the country.

The ESC system cost information used in this study is relatively old; it has been adjusted for inflation and manufacturing efficiencies, but this might not reflect the true cost savings that have been achieved.

The type and severity of collision are important: many studies report ESC effectiveness in terms of a reduction in the number of all collisions, or all ESC-relevant (loss-of-control) collisions. The countries being evaluated in this report do not have sufficiently fine-grained collision statistics for ESC-relevant effectiveness values to be used. Indeed, many report only the number of car occupant fatalities, with no information on the number of serious injuries or the types of collision in which the casualties occur (e.g. front impact, rollover, single vehicle loss-of-control etc.). Therefore, the proportion of car occupant fatalities in loss-of-control collisions for GB and the US has been used as an estimate of the proportions in the countries under study; however, it is likely that the true value will vary from country to country depending on the nature of the roads, the vehicle fleet, the weather and other factors.

Most studies used the induced exposure method – typically comparing collisions where ESC would be expected to have no effect (e.g. front-to-rear shunts) with collisions that relate to the intended function of ESC (such as single-vehicle loss-of-control and rollover collisions). Some additionally controlled for driver characteristics such as age and sex, and some for vehicle characteristics such as the static stability factor (SSF)[31].

Most of the studies reviewed used police-reported collision data, either all police reported collisions or only those involving fatally injured road users. Furthermore, most used data from a time period when crash test regulations were introduced in Europe, or when they were significantly upgraded in the US. For the evaluation of the effect on fatalities this is important, because the risk of being killed in an ESC-relevant collision would have been reduced by the crash safety improvements as well as by the introduction of ESC. However, given that the crash regulations were focused on less severe car-to-car collisions, it is likely that the greater proportion of the benefit is attributable to the fitment of ESC which can avoid the collision altogether.

All the figures used in the modelling are subject to a degree of uncertainty; as a result, sensitivity analysis has been carried out (see Appendix D) to evaluate the impact on the BCR of changing the input values or assumptions. Whilst these figures represent the range of results which might be expected if one of the assumptions is incorrect, they cannot fully account for major disruptions which might occur in these markets in the future. For example, we know there is a relationship between the economy and road safety (Wegman *et al.*, 2017) and as such, severe changes to the economic landscape could affect new vehicle uptake, and subsequently the uptake of ESC into the fleet. Changes to the economy are also known to influence the amount and way in which people drive, which in turn affects their risk of collision. This level of disruption cannot be predicted or captured within the models in this study and hence if changes such as these were to occur the impact of implementing ESC in each country could be substantially different to that presented here.

[31] The static stability factor is half the track width of a vehicle divided by the height of its centre of gravity, and is essentially an estimate of how top-heavy the vehicle is; the lower the SSF the more likely a vehicle is to roll over in a tripped single-vehicle crash (e.g. NHTSA, DOT HS 809 868)

11 Conclusions

The G20 countries are responsible for 98% of the world's passenger car production, but not all of these countries apply the most important vehicle safety regulations. Electronic Stability Control (ESC), which helps prevent the driver from losing control of the vehicle, is regarded as the most important UN regulation for crash avoidance. However, at the G20 level, only 12 countries adhere to the UN regulation on ESC. The absence of a uniform ESC regulation means that sub-standard vehicles are currently being produced, sold and exported to other countries, contributing to the substantial global road traffic casualty numbers.

This research study aimed to demonstrate the costs and benefits of applying ESC regulation in the G20 region between 2020 and 2030, providing a benefit-to-cost ratio (BCR) to assess whether adoption of minimum vehicle safety regulations for ESC is likely to be economically worthwhile. The seven countries included in this study, which do not currently apply this regulation, are Argentina, Brazil, China, India, Indonesia, Mexico and South Africa.

11.1 Fitment of ESC

Before estimating the potential casualty benefits of regulation for ESC, it is important to first estimate the proportion of the fleet which would be fitted with the technology if regulation were introduced in 2020.

Using information on the number of new cars, size of the overall car fleet and predictions for fleet turnover, it is estimated that if regulation were introduced in each of the seven countries in 2020, by 2030 almost 420 million cars could be equipped with ESC. This equates to around 83% of the predicted total car fleet in these seven countries, and represents an increase of almost 200 million vehicles compared to the 'do nothing' scenario, based only on voluntary fitment by manufacturers.

Supplementary analysis of the other thirteen G20 countries which have already implemented ESC (see Appendix I) shows that a similar proportion (87%) of the total fleet are estimated to be equipped by 2030. Therefore, assuming regulation is implemented in 2020 for the seven countries of interest in this study, in total across all G20 countries 85% of the total car fleet will have ESC fitted in 2030, demonstrating that unless more is done the G20 will not meet the global target of 100% fitment by 2030.

11.2 Lives saved by ESC regulation

The method applied for this study considers the effect of implementing ESC standards on car occupant fatalities, and a simplified approach (involving substantial assumptions) is adopted for serious injuries. However, it is noted that the results presented here might still underestimate of the true benefits of regulation, since it is possible that the introduction of ESC will also reduce the number of pedestrian and pedal cyclist fatalities through a reduction in the number of drivers who lose control of the vehicle and subsequently collide with these road users. The modelling has not considered the benefit to these groups, although this benefit is expected to be relatively small. In addition, slight injuries are not included.

Based on a review of the scientific literature, it is estimated that ESC is 38% effective at reducing the number of fatalities in loss of control collisions. Since there is relatively little data readily available on collision types in the seven G20 countries under study, it was not possible to directly measure how many fatal collisions in each country were due to loss of control; analysis of casualty data from GB and the US results in an estimate of 34.9% of car occupant fatalities occurring in loss of control collisions. Combining these two estimates means that the effectiveness of ESC applied to the fatality data in this study is 13.3%.

When this figure is applied to the car occupant fatality data, accounting for the additional fitment of ESC due to regulation, it is estimated that around 42,000 lives could be saved (sensitivity analysis suggests this figure is between 16,000 and 60,000).

The equivalent effectiveness estimate for serious injuries was 21%. The simplified modelling approach suggests that around 150,000 car occupant serious injuries could be prevented if ESC regulations were introduced.

11.3 Economic benefits and costs

The Valuation of Statistical Life (VSL) method estimates the economic loss due to a road traffic fatality or road traffic serious injury in terms of GDP per capita. This method suggests that, in monetary terms, the fatality savings equate to around US$17.5 billion, and the serious injury savings to around US$4 billion.

In addition to the benefits, the cost of implementing the ESC regulation was also estimated, taking into account the fitment cost per vehicle. This cost estimate (US$50, or US$36.46-US$102 in the sensitivity analysis) was obtained from a review of the literature and reviewed by Global NCAP, and then applied to the number of additional vehicles equipped with ESC under the regulation scenario. The total cost to consumers across all seven countries is estimated to be US$7.7 billion.

Comparison of the benefits and costs results in the benefit-to-cost ratio exceeding 1 for five of the seven countries by 2023, and in six countries by 2026. This best-estimate indicates that the casualty benefits of ESC regulation would reasonably quickly outweigh the costs.

When these results are considered on a country-by-country basis (), some countries (namely South Africa, Brazil and China) have a BCR larger than 1 extremely quickly (and both the optimistic and conservative estimates result in the BCR being greater than 1 by 2025). This indicates that there is no evidence to suggest that the ESC regulation would not be worthwhile for these countries. For Indonesia the best-estimate BCR is less than 1 up until 2030, suggesting that the costs may outweigh the casualty benefits over the period 2020-2030.

11.4 Recommendations

Based on the BCR results, **it is recommended that ESC regulations are introduced in these seven countries as soon as practicable[32].** With implementation in 2020, some countries do not achieve cost-beneficial casualty savings until 2026 or later and any delay in implementation would delay the realisation of the casualty savings that ESC has been shown to deliver.

It is necessary to have anti-lock braking systems (ABS) fitted to a car before ESC can be fitted, and the costs presented in this paper assume this is the case. Most of the G20 countries already mandate fitment of ABS or will do by 2020, so ABS costs and benefits are not accounted for in this study. The exceptions to this are Indonesia and South Africa which do not currently legislate for ABS. Despite this, data from manufacturers' and local NCAP websites indicates that standard fitment in new cars already exceeds 50% in Indonesia and 70% in South Africa, so the assumptions made in this paper around ESC costs are likely to be valid for most new cars. In order to ensure regulation for ESC is easy to implement in all G20 countries, **it is recommended that ABS regulations are also implemented** particularly in Indonesia and South Africa, but also in China where market analysis suggests the fitment rate is 100% but it is not clear whether fitment is mandatory.

Note that there are likely to be other benefits to ESC regulation than those presented in this report. For instance, ABS and ESC also provide a platform for the fitment of Advanced Emergency Braking (AEB) systems, which have the potential to eliminate or reduce the severity of a large number of collisions. In particular, car front-to-rear shunts, which are very common and therefore have a high economic cost, can be greatly reduced by the fitment of AEB. Indeed, UN Regulation 131 describes AEB requirements for heavy vehicles (M_2, M_3, N_2 and N_3) and AEB for cars is assessed in Euro NCAP.

[32] Since the analysis and report were finalised, Argentina and Brazil have announced that they will start applying ESC regulations in 2020, and the Indian government has committed to introducing ESC regulation in 2022. Based on the estimates in this report, these announcements have the potential to save over 9,000 lives and 30,000 serious injuries between 2020 and 2030.

Acknowledgements

This report represents combined contributions from two groups within TRL. The authors are grateful to all members of the team who contributed to the project. Notably Agnes Boscoe-Wallace and Rishabh Ramnath contributed substantially to the information presented in this report.

Data from within the seven countries considered for this project was found to be scarce at times. Therefore, the authors also acknowledge the direction and supporting literature provided by Dr Marcilio Alves at the University of Sao Paulo, Brazil, Stephan Brodziak at El Poder del Consumidor, Mexico and Sonia Aguilar Gonzalez and Saul Alveano at the World Resources Institute, Mexico.

The authors would also like to than David Ward and Jessica Truong of Global NCAP for discussion and input throughout the study.

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Appendix A Status of ABS and ESC Regulation in Selected G20 Countries

Argentina

The Government of Argentina mandated ABS for all vehicle models since January 2014 and intended to mandate ESC starting January 2018[33]. Further to this in December 2017, the government updated that the ESC regulation would be delayed by at least 2 years[34].

Brazil

The Brazilian Government introduced regulation in 2011, providing compulsory fitment of ABS[35]. The government also intend to mandate ESC, but the timescale remains to be confirmed[36].

China

In 2008, The People's Republic of China introduced Regulation GB 21670-2008 Technical Requirements and Test Methods for Passenger Car Braking Systems. The regulation includes test requirements for vehicles fitted with ABS. From the high fitment rate observed currently (100% standard fitment for cars sold in Jan 2018 – see Section 3), these requirements appear to be mandatory. There is no current national regulation for ESC in China, but 12 major Chinese car manufacturers voluntarily agreed to fit ESC from January 2018[37].

On the other hand, Taiwan province recently mandated both ABS[38] and ESC[39] for new vehicle types with effect from January 2018 and all vehicle types effective January 2020.

India

The Government of India has mandated ABS for all new models of cars and mini-buses from April 2018 and all new vehicles of existing models from April 2019 onwards. The Automotive Industry Standard AIS-133 defines requirements for M1 (passenger car and SUV) and N1

[33] IRTAD Road Safety Annual report 2017

www.sipotra.it/wp-content/uploads/2017/10/Road-Safety-Annual-Report-2017.pdf

[34] www.carsmagazine.com.ar/se-postergo-la-obligatoriedad-del-esp-en-argentina

[35] Contran Resolution No. 380 of April 28, 2011 - Provides for the Compulsory Use of an Anti-lock Braking System

[36] www.consumersinternational.org/news-resources/blog/posts/20160330-safer-cars-increased-safety-is-paramount/

[37] www.fiafoundation.org/blog/2017/october/chinese-auto-makers-commit-to-stop-the-crash-with-electronic-stability-control

[38] www.mvdis.gov.tw/webMvdisLaw/Download.aspx?type=Law&ID=26961

[39] www.mvdis.gov.tw/webMvdisLaw/Download.aspx?type=Law&ID=23253

(van) category vehicles fitted with ESC, but from the current low fitment rate (see Section 3) it is clear that these requirements are not mandatory.

Indonesia

There are no current regulations for ABS and ESC in Indonesia. The ASEAN Mutual Recognition Arrangement (MRA) initiative is undertaken to adopt testing and inspection of automotive products based on compliance with internationally accepted standards[40]. The ASEAN Member States (AMS) have agreed to harmonise the technical requirements of automotive products based on the UN Regulations. Phase 1 of this initiative involves harmonising 19 UN Regulations, including R13 and R13-H; however, the implementation status is unknown.

Mexico

The Mexican authorities have announced that ABS regulation would be mandated from November 2019 for new vehicles and November 2020 onwards for all vehicles[41]. There is no ESC regulation planned for the near future.

Saudi Arabia

In March 2015, Saudi Standards, Metrology and Quality Organization (SASO) updated the Saudi Technical Regulation (SASO GSO 42:2015[42]) to mandate a number of safety requirements which includes ABS and ESC for models starting from 2017. These regulations are based on UN Regulations; compliance with FMVSS is accepted as an alternative.

South Africa

The Compulsory Specification for Motor Vehicles of Category M1 (VC 8022)[43] published on 5 September 2014 adopts the requirements of UN Regulation 13[44], but specifically excludes the requirements related to ABS. Updates to the safety regulations based on those of UN and Europe are being considered as part of the 'Decade of Action for Road Safety in SA' programme[45].

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[40] Harmonising Standards and Technical Regulations in ASEAN member states.

www.asean.org/storage/images/2015/October/outreach-document/Edited%20Automotive.pdf

www.thaiauto.or.th/2012/Automotive-Summit/doc/ppt/2015/25-6-15/203_PM/10.ASEAN%20MRA%20and%20status%20of%20Implementation%20Rev%201.pdf

[41] hkmb.hktdc.com/en/1X0A6BEP/hktdc-research/Mexico-Sets-New-Requirements-on-Essential-Safety-Components-in-Motor-Vehicles

[42] http://www.puntofocal.gov.ar/notific_otros_miembros/sau849_t.pdf

[43] www.nrcs.org.za/siteimgs/vc/Amended%20VC%208022%20Category%20M1%20vehicles.pdf

[44] Although UN Regulation 13 is referenced in VC 8022, the requirements are related to vehicles of categories M, N and O which implies that the intent must have been also to reference Regulation 13-H

[45] Decade of Action for Road Safety in SA

www.arrivealive.co.za/United-Nations-Decade-of-Action-for-Road-Safety-2011-2020

Appendix B Core Data

This section presents the core data used for the modelling. It summarises the current trends in road collision fatalities (Section B.1) and the vehicle fleet (Section B.2) for each country.

B.1 Fatality data and road safety developments

Across the world there are many different definitions regarding how road collision fatalities are counted. For example, within the seven G20 countries studied in this project the definitions are as follows:

- Argentina: death within 30 days of the collision
- Brazil: death any time after the collision (as a result of the injuries sustained)
- China: death within 7 days of the collision
- India: death within 30 days of the collision
- Indonesia: death within 30 days of the collision
- Mexico: death any time after the collision (as a result of the injuries sustained)
- South Africa: death within 30 days of the collision

The most widely recognised ‘official’ definition is death within 30 days, and 100 countries across the world now adopt this practice (WHO, 2015).

Because of the differences in the definitions, reported fatality data from different countries are not directly comparable without some adjustment. For the purposes of this study, fatality data from Brazil, Chile and Mexico have been adjusted to present fatality numbers at 30 days. The adjustment factors used are 0.97 for Brazil and Mexico and 1.08 for China (Iaych, n.d.). Figure 21 shows the historical adjusted road collision fatality figures for each country for the period 2005-2016.

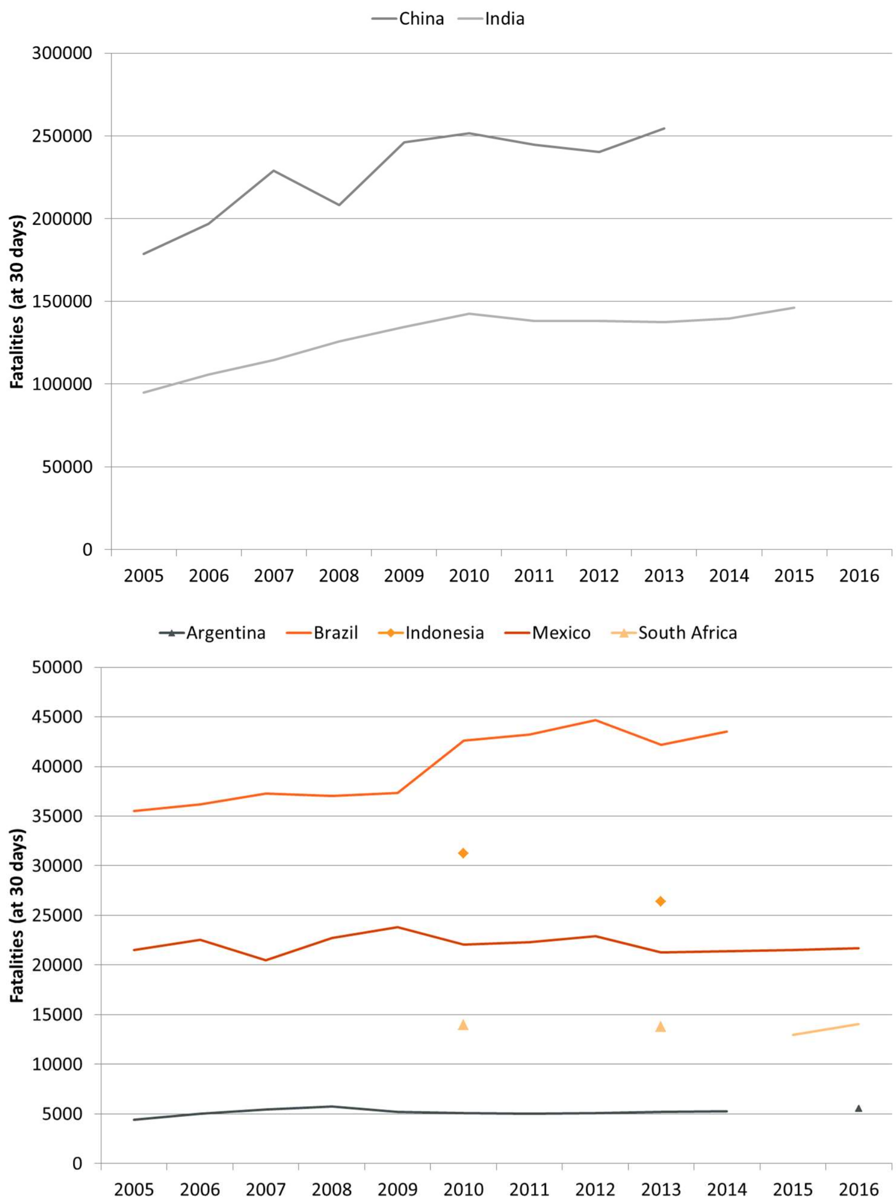


Figure 21: Number of road collision fatalities (at 30 days) in Argentina (ITF, 2017), Brazil (WHO, 2015), China (Huang *et al.*, 2016), India (Government of India, 2017), Indonesia (WHO, 2015), Mexico (INEGI, 2017) and South Africa (WHO, 2015), 2005-2016 (where data available)

This figure demonstrates that the amount of data available for each country varies: there are only two data points for Indonesia, whilst other countries (Mexico) have fatality data for the whole period (2005-2016).

There is also a degree of unreliability with the data presented for China, due to uncertainties in the accuracy of reporting (Hu *et al.*, 2010). This report concludes that “our findings support the hypotheses that rates of death from road traffic collisions based on police reports and on death registration data are different, and that unlike police-reported data, death registration data fail to show any recent decline. These inconsistencies strongly suggest that the decreasing trend in road traffic mortality shown by police-reported data may not be genuine." As a result, this report has used the Ministry of Health death registration data, rather than the figures reported by police, to model the casualty trend for China. However, there is still some inherent uncertainty in these results.

Figure 22 shows the distribution of fatalities by road user type.

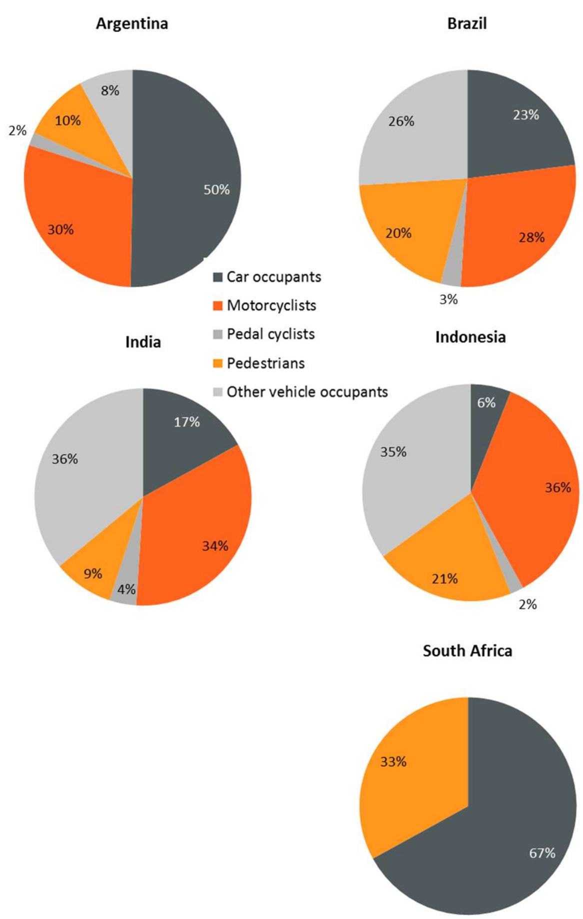


Figure 22: Distribution of road collision fatalities by road user type in Argentina (ITF, 2017), Brazil (WHO, 2015), China (Huang *et al.*, 2016), India (Government of India, 2017), Indonesia (WHO, 2015), Mexico (INEGI, 2017) and South Africa (WHO, 2015)

The distribution of fatalities differs substantially by country, although car occupant fatalities are relatively common in six of the seven. Indonesia is the one exception, where car occupants only accounted for 6% of reported fatalities. It also had the highest proportion of motorcyclist fatalities, suggesting that the comparative levels of car and motorcycle riding are different from other countries. South Africa had the highest proportion of recorded fatalities which were car occupants (67%). However, this figure may be higher than the actual proportion, as only car occupant and pedestrian fatalities have been recorded.

For this study, we combine the fatality estimates and percentage of car drivers to predict number of car occupant fatalities. These are presented in Figure 23.

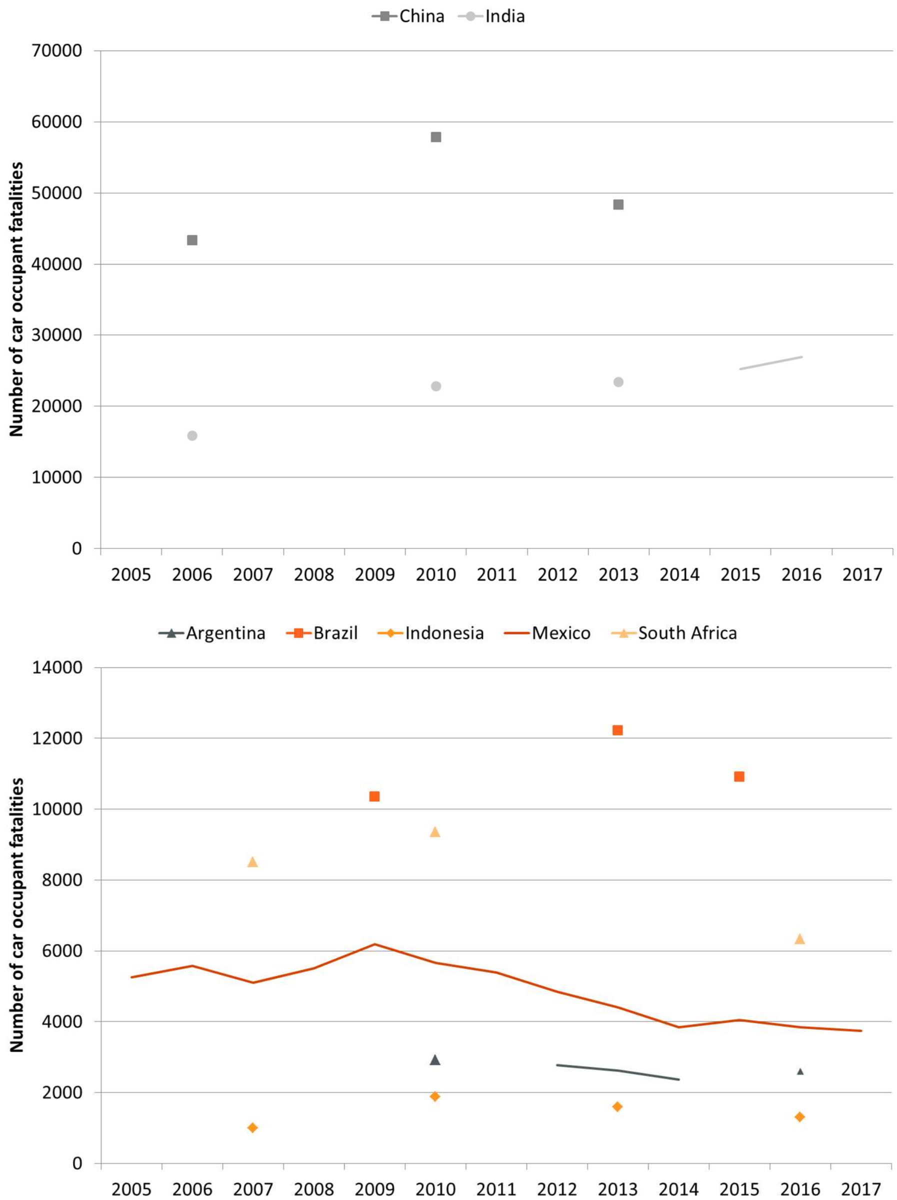


Figure 23: Number of car occupant fatalities in Argentina (ITF, 2017), Brazil (WHO, 2015), China (WHO, 2015), India (Government of India, 2017), Indonesia (WHO, 2015), Mexico (INEGI, 2017) and South Africa (WHO, 2015), 2005-2016 (where data available)

It is clear that, with the exception of Mexico, there is a limited amount of data available on the number of car occupant fatalities in each country. This reduces the reliability in the predictions of these fatality numbers forward to 2030 (presented in Figure 11 in Section 5.1). This presents a substantial limitation when predicting the number of lives that could be saved by introducing the ESC regulation (Section 5), and therefore affects the reliability in the level of benefit (Section 6) and final benefit-to-cost ratio (Section 8).

B.2 Passenger kilometres

As explained in Section 2.3, there is a hierarchy of exposure measures for road casualty data and passenger kilometres is the unit of measurement which is most likely to be highly correlated with casualty figures. However, these data were only available for three countries in this study: China, India and Mexico (Figure 24).

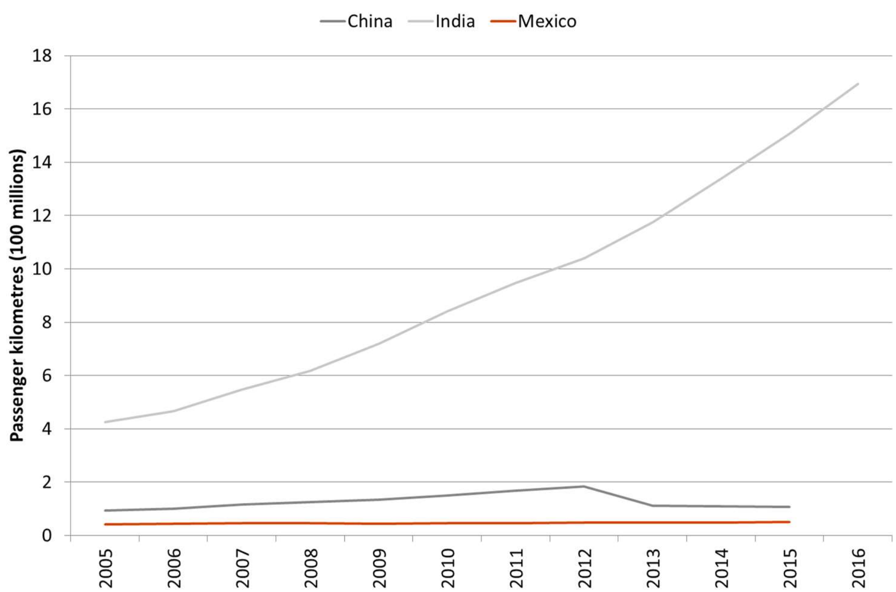


Figure 24: Passenger kilometres[46] in China (National Bureau of Statistics of China, 2016), India and Mexico (OECD, 2018), 2005-2016

The trend in passenger kilometres has increased in all three countries, with the most substantial growth evident in India.

[46] Note that these figures are labelled 'passenger kilometres' and not 'car passenger kilometres' – we have assumed these figures actually represent the latter and do not include passenger kilometres by other modes (we acknowledge this may not be correct but the magnitude of the exposure measure is not actually of importance for this work, provided the trend over time in this measure is similar for car passenger kilometres).

B.3 Vehicle fleet

Figure 25 shows the total number of registered cars in each of the seven countries between 2005 and 2015.

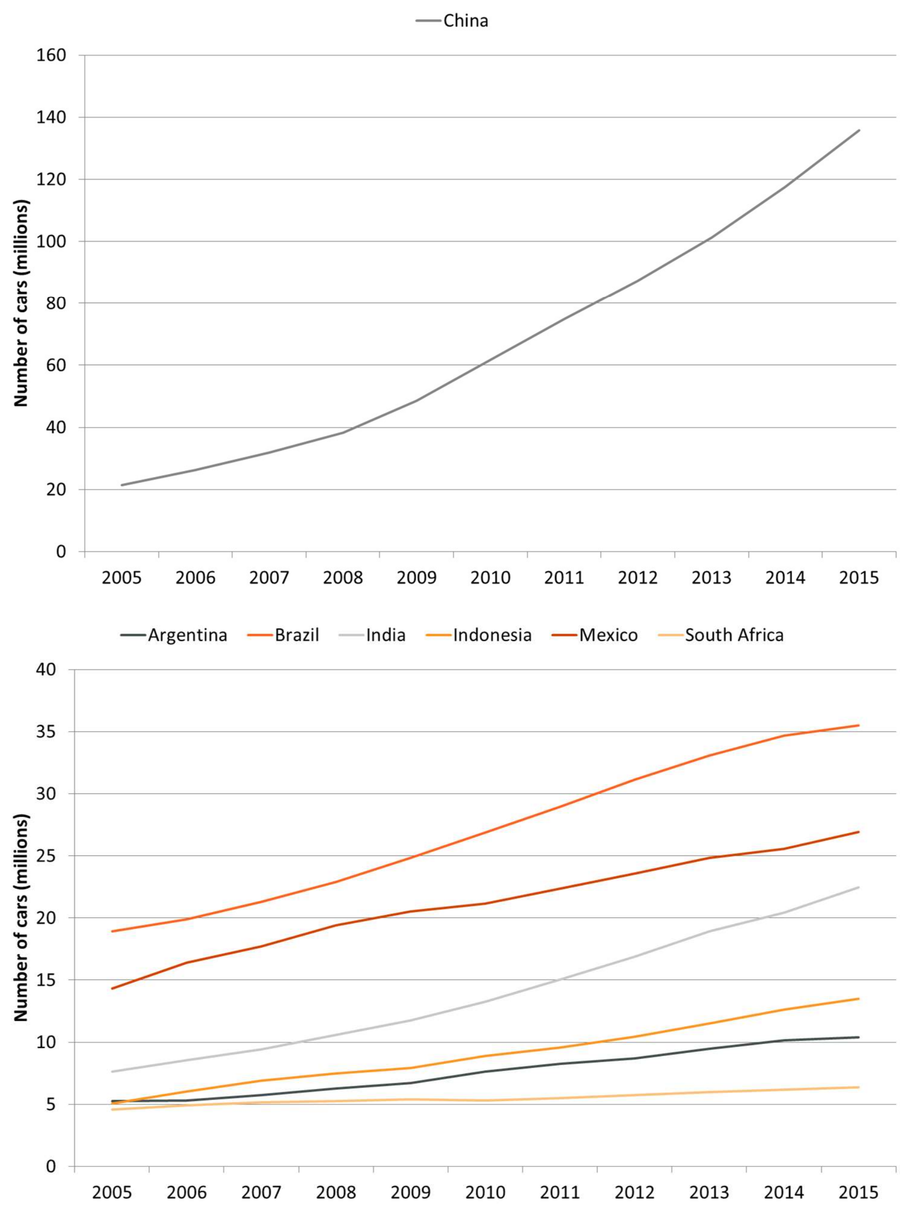


Figure 25: Total number of registered cars in Argentina, Brazil, China, India, Indonesia, Mexico and South Africa, 2005-2015 (OICA, 2017)

The trend shows that the number of cars has increased in every country in recent years and in most cases markedly so. The highest rate of growth has occurred in China, which has seen car registrations increase more than six-fold (from 21 to 136 million); this is substantially more than the 16% increase in passenger kilometres observed in this country over the same time period (see Figure 24). This supports the justification for using passenger kilometres as the measure of exposure for this country since it is evident from this graph, and from contextual information found in the literature, that car ownership in China has been seen as a rite of passage or a symbol or wealth rather than considered for practical reasons (FIA Foundation, 2015). Car owners in cities can only reach very limited speeds and this has led to mandatory restrictions on car use in particularly congested areas (Deng, 2017) and as a result, the increase in passenger kilometres travelled hasn't kept up with the increase in car registrations.

In addition to examining the trend for registered cars, it is important to understand how new cars infiltrate the fleet in order to understand the fleet turnover. Figure 26 shows the number of new cars sold in each country between 2005 and 2016.

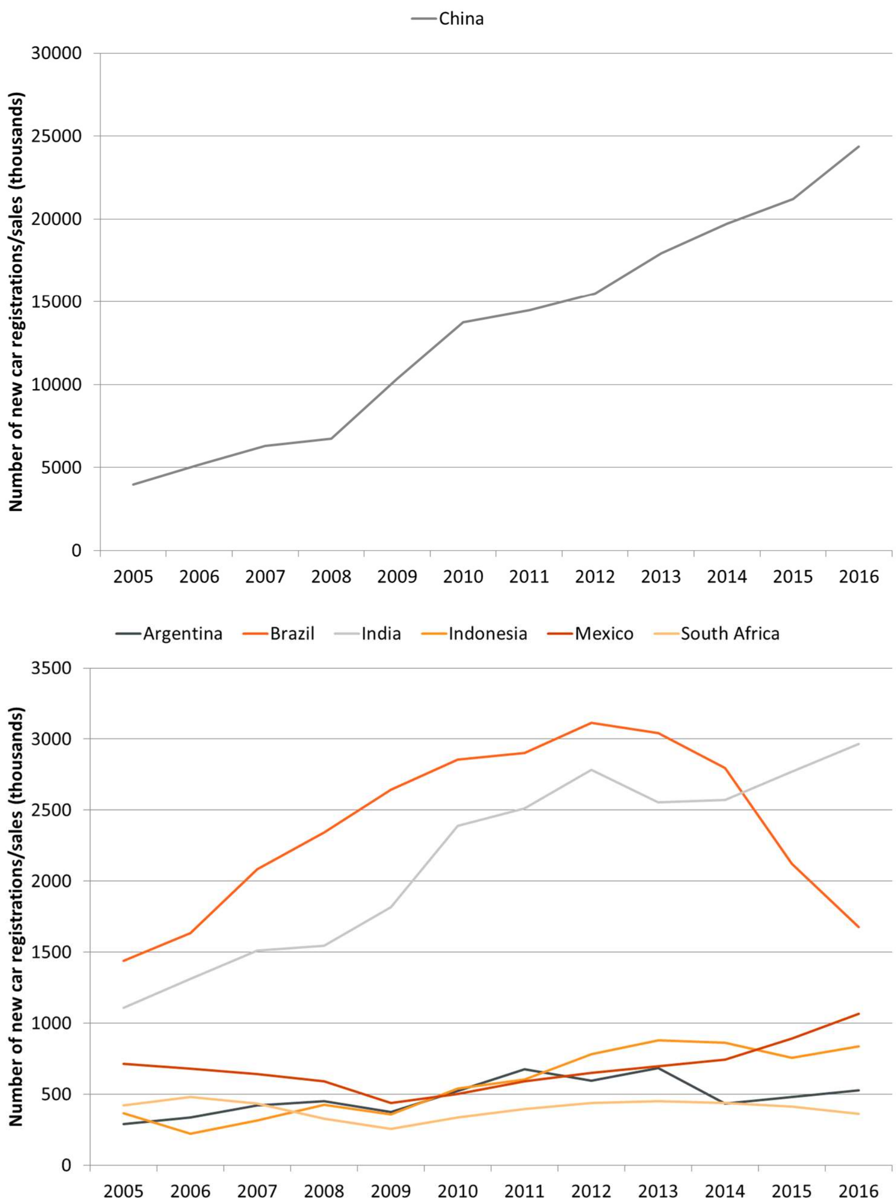


Figure 26: New car sales in Argentina, Brazil, China, India, Indonesia, Mexico and South Africa, 2005-2016 (OICA, 2017)

In this case, the trend is different between countries. Whilst China, India and Indonesia experienced an upward trend throughout the period, other countries experienced periods of both growth and decline in new car sales. The most obvious example is Brazil, where there was a large reduction in vehicle sales from 2014-2016 due to the economic decline; however, despite this, Brazil remains in the top five passenger vehicle markets worldwide (Posada and Façanha, 2015).

It is important to note that these data present the number of new cars that are registered in each country, which is not the same as the number that are produced in the country. On the one hand, a new car that is produced in a country may then be exported elsewhere, and on the other hand, a new car may be imported into a country, having been produced elsewhere. For the purposes of this analysis, it has been assumed that all new registered cars have been produced to meet the safety regulations of the country in which they are registered. It is worth noting that in reality, this may not always be the case (e.g. a car produced in Europe and registered in Brazil may have extra technologies fitted which are not required by law in Brazil).

Appendix C Literature review – ESC Effectiveness

C.1 Introduction

This project systematically identified, interpreted and appraised all research relevant to establishing the effectiveness of Electronic Stability Control (ESC). Effectiveness, in the context of this project, refers to how well a particular technology or design feature works. This could be gauged by the number of lives that have been saved since its adoption, a reduction in injury severity for a key target population, or number of collisions prevented.

A standardised framework was utilised to identify and assess the quality of pertinent information sources in order to extract relevant data in an unbiased and replicable manner.

This section describes the processes of source selection, critical appraisal and data analysis employed to extract relevant data from the selected articles. It will further describe the conclusions of this systematic review to identify the effectiveness for each safety measure.

C.2 Methods

This systematic literature review was conducted following the core principles and methods described by Seidl *et al.* (2017). Following these predefined processes, this literature review was completed in the four key steps outlined below Figure 27.

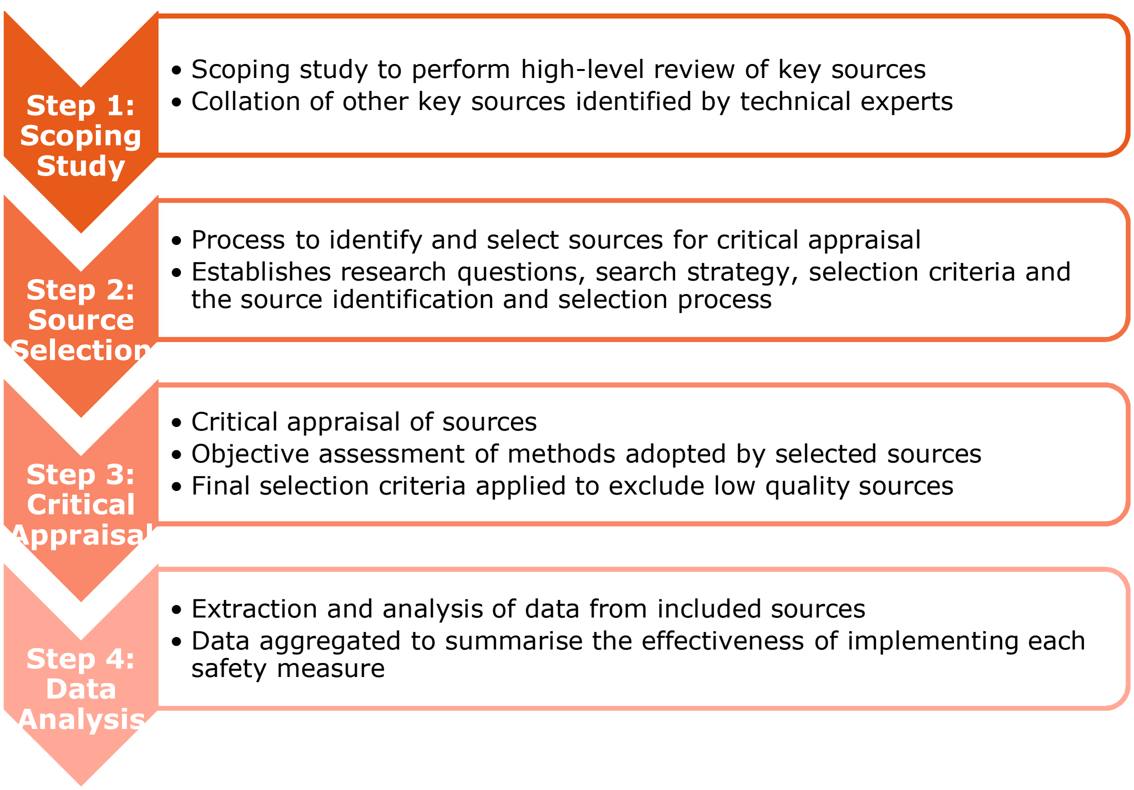


Figure 27: Top-level overview of systematic literature review process

C.3 Scoping study

This scoping study identified studies that were collated during previous research and that were deemed relevant to the scope of this project. These sources were further supplemented by several other key sources that were identified by technical experts. Sources were selected for critical appraisal if they met one of the following inclusion criteria:

- The source contained quantitative primary data on the impacts of ESC implementation (e.g. casualty benefits, etc.)
- The source contained evidence that could be used to indirectly calculate the impacts of ESC implementation
- The sources contained evidence that could be used to assess the potential maximum effectiveness relevant to each safety measure

In addition to being selected for critical appraisal, the bibliographies of these sources were queried to identify any further studies cited by these sources that were deemed relevant to the safety measures investigated in the scope of this project. Finally, all sources identified during this scoping study were used to establish the inputs for the source selection process.

C.4 Source selection

The source selection process adopted a standardised approach for systematically searching for, and selecting, the sources relevant to the investigated safety measures. This approach required the development of four key research questions to establish a search strategy for several literature databases. This search strategy was implemented, in combination with predefined selection criteria, to identify and select sources for critical appraisal. The following sections summarise the approaches taken for each of these steps.

C.4.1 Research questions

For each safety measure investigated by this project, a number of research questions were designed to query literature databases for the purposes of locating and identifying relevant research. These questions used the TIO (Target group [T], Intervention [I] and Outcome [O]) approach to structure and formulate each research question:

- Does the fitment of Electronic Stability Control (I) to a car (T) reduce the frequency (O) of road traffic collisions?
- Does the fitment of Electronic Stability Control to a car (T) reduce the Severity (O) of road traffic collisions?
- Does the fitment of Electronic Stability Control (I) to a car (T) reduce the frequency (O) of road traffic collision related fatalities?
- Does the fitment of Electronic Stability Control to a car (T) reduce the frequency (O) of road traffic collision related injuries?

C.4.2 Search strategy

A list of appropriate keywords, focused around the requirements of the research questions, was then generated for each TIO search term. These keywords are shown below in Table 19.

Once a full list of keywords for the Target Group, Interventions and Outcome were finalised, these were transferred into a query with the following logical structure:

(“A” or “B” or “C” or…) AND (“D” or “E” or “F” or…) AND (“G” or “H” or “I” or…)

Where A, B, C are the Target Group keywords; D, E, F are the Interventions keywords, and G, H, I are the Outcome keywords. Boolean logic operators (OR/AND) were also used to limit the scope of the search.

Table 19: Literature review search strategy

Target Group (T)	Intervention/action (I)	Outcome (O)
Car OR M1 [category] OR Automobile OR Occupant* OR Passenger*	“Electronic Stability*” OR ESC OR “Electronic Stability Control*” OR ESP OR “Electronic Stability Programme” OR VDC OR “Vehicle Dynamic Control” OR DSC OR “Dynamic Stability Control” OR VSA OR “Vehicle Stability Assist” OR ASC OR “Active Stability Control” OR DSTC OR “Dynamic Stability and Traction Control”	Frequen* OR Sever* OR Collision OR Effect* OR Incident OR Accident OR Rate OR Incidence Prevalence OR Trauma OR Injury OR Casualty OR Hospital OR Mortality OR Morbid* OR Fatal* OR Killed OR KSI OR Slight* OR Serious* OR Abbreviated Injury Scale OR AIS OR Incapacity OR Disability or RTA OR RTC OR “Road Traffic Accident*” OR “Road Traffic Collision*”

C.4.3 Literature databases

All online databases available to TRL, which provide an archiving and records management service for TRL, were searched for relevant sources. The databases searched on behalf of this literature review are outlined below.

TRID (Transport Research International Documentation): TRID is a database that combines ITRD (OECD’s International Transport Research Documentation database) and the US-based database TRIS (Transport Research Information Service). Together they form one of the most comprehensive transport research databases available today.

http://trid.trb.org/

ScienceDirect: ScienceDirect is a leading full-text scientific database offering journal articles and book chapters from more than 2,500 peer-reviewed journals and over 11,000 books.

http://www.sciencedirect.com/

ITRP Transport Research Portal: ITRP is portal for accessing information from databases of past and ongoing research projects worldwide. This portal is an international collaborative project funded by the European Commission FP7 programme. Its aim is to foster closer and more effective communication between researchers working in the field of transport technologies, both in the EU and internationally. It seeks to do this by facilitating exchange of information and developing a framework for long term collaboration.

http://www.intransport.eu/search/index.php

ARRB Knowledge Base: The ARRB knowledge base a free full text searchable resource of ARRB publications from 1962 to present, including conference papers, reports and bulletins. There are over 5,000 items in the resource with more being added as they are scanned.

http://arrbknowledge.com

PubMed: PubMed Is a public version of MEDLINE, arguably the world's largest medical database. Its records contain many levels of medical research from meta-analyses and systematic reviews to case studies. It includes accident studies, safety, human factors, psychology etc.

http://www.ncbi.nlm.nih.gov/pubmed/

TRIP (formerly the Transport Research Knowledge Centre): TRIP gives you an overview of in-progress and completed transport research activities at European and national levels, based around the EU research framework funding programme.

http://www.transport-research.info/web/index.cfm

Google Scholar: Google Scholar is a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines. Released in beta in November 2004, the Google Scholar index includes most peer-reviewed online journals of Europe and America's largest scholarly publishers, plus scholarly books and other non-peer reviewed journals.

http://scholar.google.co.uk/

C.4.4 Source selection criteria

All duplicate sources, conference abstracts, editorial letters, review articles and statements of expert opinion were excluded. Source titles and abstracts were then screened for relevance based upon the criteria previously specified in C.3, with identified sources included for the detailed review of the full manuscript. Some studies had been updated a number of times since its first literation. If this was the case, only the latest version was reviewed. Finally, the bibliographies of all the sources that were selected for full text review were recursively searched for further relevant sources.

C.5 Critical appraisal

To ensure only high quality sources were selected for inclusion, a simplified version of the source assessment process developed by Seidl *et al.* (2017) was adopted by this study. This allowed for an objective assessment of the relevance and methodological quality of each source. Each source was appraised against standardised criteria such as geographical scope, dataset, age range of data, and inclusion of relevant factors (e.g. does it factor in changes in other regulations occurring at the same time).

Reviewers were trained in applying the process and the consistency of reviews was assured via a system of spot checks and individual feedback.

C.6 Included Sources

The flow of sources through the source selection process can be seen in the flow diagram in Figure 28. A total of 120 sources were returned from the source selection process, of which 85 were excluded based on the criteria. Of the 35 articles selected for the source assessment, a total of 15 met the selection criteria and were included for full evaluation.

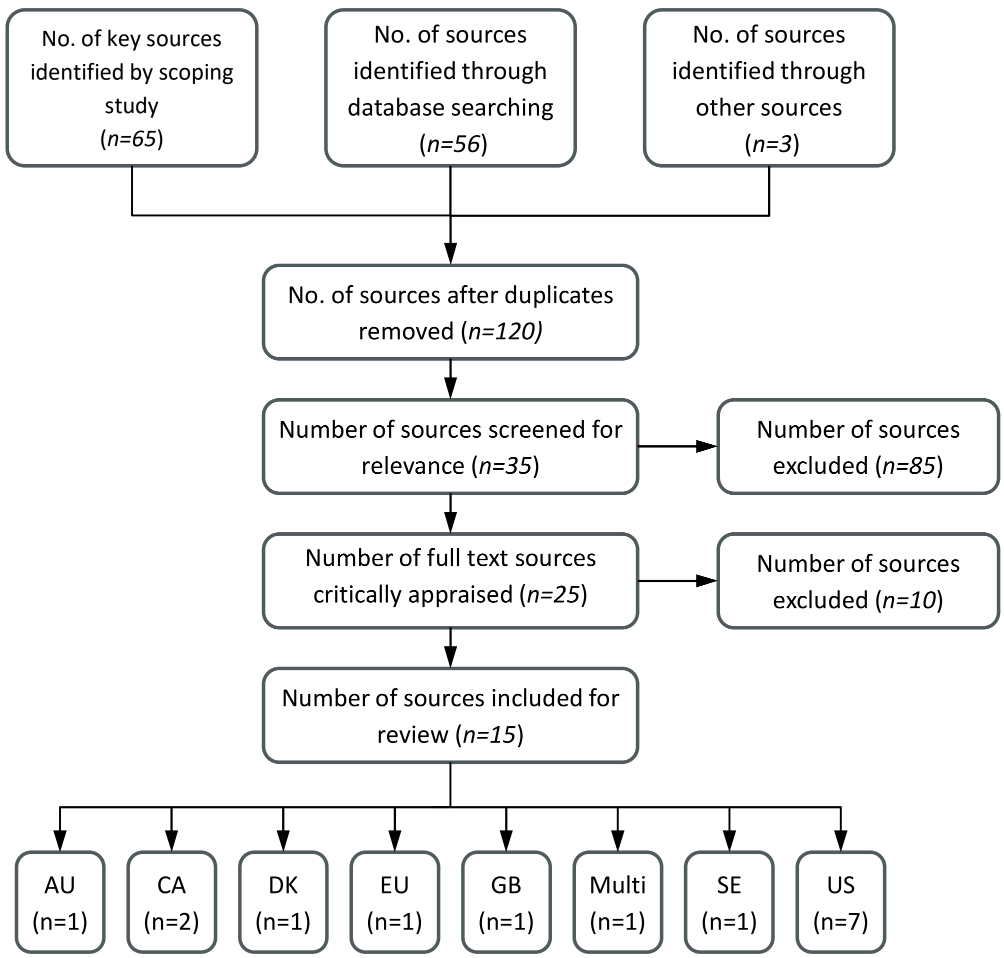


Figure 28: Source selection process flow diagram

Of the 15 included sources, 7 (47%) sources contained relevant information from the United States, 2 (13%) reported effectiveness ranges from Canada and 1 (7%) reported information for each of the following countries; Australia, Denmark, Sweden, the UK and Europe as a whole. It was vital to use a range of national datasets as certain countries often favour certain types of vehicles e.g. large SUVs and rear wheel drive vehicles in the US. Reliance on one dataset could result in higher effectiveness values than expected. Certain databases also go in to more detail such as weather and road condition.

C.7 Data analysis

The following sections shall provide a descriptive overview of the data aggregated from all sources included within the data analysis section.

C.7.1 *The effects of Electronic Stability Control (ESC) on crashes — An update* (Høye, 2011)

This investigation develops upon an earlier meta-analysis conducted by Erke (2008). Erke used 38 effect estimates from eight studies conducted between 2003 and 2006. Due to the fleet penetration of ESC at the time of the investigation, the study was limited as the majority of reports featured a low number of primarily large, rear wheel drive luxury vehicles which were not representative of day to day cars. The meta-analysis by Høye (2011) is based on 207 effect estimates from twelve studies (five from Erke study, three updates from the Erke study and four new studies) and includes a larger number and variety of vehicles including Sports Utility Vehicles (SUVs).

ESC was found to be more effective in preventing fatal crashes than non-fatal. The study determined ESC could prevent up to 40% of all fatal crashes involving loss of control. This can be broken down in to more specific collision types; approximately a 70% reduction in fatal collisions where a roll over was the first harmful event (50% for all injury severities), a 40% reduction for road run-off and loss of control collisions and a 25% decrease for Single Vehicle Collisions. Multi-vehicle collision involvement remained largely the same. ESC proved to be more effective in SUVs compared to passenger vehicles due to their higher centre of gravity and differences in driver types.

The results are likely to be overestimated, especially for non-fatal collisions because of publication bias. The study also acknowledged ESC may lead to changes in driving style. However, it is unlikely that this would have a major negative impact on the safety benefits. A more depth look at this study can be found in Section 4.

C.7.2 Real-World Assessment of Relative Crash Involvement Rates of Cars Equipped With Electronic Stability Control (Thomas and Frampton, 2007)

The aim of this study was to evaluate the reduction in collision involvement of cars equipped with ESC systems for all collisions, road varieties and loss of control conditions (Thomas and Frampton, 2007). In addition, the study also included potential cost benefits and fleet penetration. The Great Britain police-reported collision data from STATS19 for 2002-2005 were matched to vehicle licensing information to obtain the car make, model and year of manufacture. Collisions involving pedestrian, motor cycle or bicycle were excluded from the study because the injury severity of these vulnerable road users (VRU) tends to dominate the injury severity of the collision. The study used the induced exposure method[47] to determine the change in collisions, and rear-impact collisions were used as the control group. There were 10,475 case vehicles and 41,656 control vehicles in the dataset.

The results show that ESC effectiveness was 7% in collisions of all severity. Serious collisions were 11% lower compared to non-ESC cars and fatalities 25% lower. The potential savings in collision costs for a 100% take up of ESC amounted to £790 million pounds annually by preventing 9,919 collisions. ESC appeared to offer additional benefit in adverse road conditions. Overall effectiveness was estimated as 20% for icy conditions and 9% for wet conditions, compared to 5% for dry roads. The effectiveness of ESC in reducing fatal collisions on wet road surfaces was 38% compared to 17% on dry road surfaces. In terms of serious collisions, the effectiveness was 22% for wet roads compared to 3% for dry. The study suggested a high ESC effectiveness on skidding (23%) and overturning collisions (36%). The corresponding values for serious collisions were 33% and 59% respectively. Effectiveness in serious side collisions was found to be much higher (22%) compared to that in serious frontal collisions (2%). Single vehicle collisions were also those where ESC is often supposed to have a significant effect: compared to non-ESC cars, 27% fewer ESC-equipped vehicles were involved in all single vehicle collisions compared to 7% for multi and single vehicle collisions taken together.

Thomas and Frampton considered certain limitations to this analysis since there may be other significant differences in handling characteristics between case and control vehicles in addition to ESC systems. Additionally, the chances of collision involvement would also be dependent on driving behaviour; if the case vehicle is a model preferred by drivers with lower risk acceptance the vehicles will not be exposed to comparable driving situations and again the effectiveness of ESC would tend to be over-estimated. Another important limitation to this study is the influence of improved secondary safety on injury reduction. There may have been further improvements in the vehicles secondary safety introduced at the same time as ESC systems, which would likely to influence the collision outcome. With these limitations, the effectiveness estimated in this study might be an overestimate, in particular for fatal and serious collisions.

Study Type: Induced Exposure
Data Source: STATS19 (GB)
Data Years:

- Collisions 2002-2005
- Vehicle MY 2002-2005

Vehicle Type:
Cars

Collision Type:

- Single vehicle, Multiple vehicle
- Skidding
- Overturning

Control Group: Rear-end collisions
Effectiveness Estimates:
Effectiveness for the above collision types ✓
Effectiveness for all collision types ✓

[47] The induced exposure method compares changes in casualty rate for collision types for which the fitment of ESC would be expected to reduce the collision risk (e.g. single-vehicle loss of control collisions and single-vehicle rollover collisions) with collision types that ESC would not be expected to affect (e.g. front-to-rear collisions, also known as rear-end shunts).

C.7.3 *Potential Effectiveness of Electronic Stability Programs (ESP) - What European Field Studies Tell Us (Sferco et al., 2001)*

In a predictive study, Sferco *et al.* (2001) evaluated the potential effectiveness of ESC when installed more widely. The study was based on the European Accident Causation Survey (EACS) which contained information about 1,674 collisions (involving in vehicles that were not equipped with ESC) in five European countries from 1995 to 2000. All types of collisions involving injuries with at least one passenger car involved were taken into consideration. The study was performed in three stages by experts who judged what the outcome may have been if ESC had been fitted:

- A first stage identified the proportion of collisions in which the proposed countermeasure could influence the outcome;
- In the second stage, the effectiveness of the available technology in influencing the outcome was established
- Finally, in the third stage, the effect on driver behaviour of having the countermeasure fitted was determined.

The initial analysis of all collisions from the EACS database suggested that ESC could have a probable or definite influence in about 34% of fatal collisions and 18% of injury collisions. When only loss of control collisions was considered, the predicted values were 67% for fatal and 42% for injury collisions. A more detailed analysis revealed that collisions involving loss of control had specific patterns. These types of collisions were more likely to occur on roads with only one lane in each direction, in the rain, when the shoulder is grass, on curves and on straight lines. And it was estimated that in these loss of control fatal collisions, ESC would have a probable or definite influence in about 86% of collision on roads with one lane in each direction, 91% of collisions in the rain, 36% of collisions on grass shoulder, 50% on curves and 39% on straight lines. Some cautions about potential effectiveness estimates produced in this way were raised in the study. In particular, data consistency in different countries and lack of national or international representativeness in the EACS sample were identified as particular concerns.

Study Type: Predictive
Data Source: EACS-European Accident Causation Survey (FI, FR, DE, IT, ES)
Data Years:
- Collisions 1995-2000
- Vehicle MY 1995-2000

Vehicle Type:
Cars

Collision Type:
- All collisions
- Only loss of control collisions

Control Group: NA
Effectiveness Estimates:
Effectiveness for the above collision types ✓
Effectiveness for all collision types ✓

C.7.4 *Follow Up Evaluation of Electronic Stability Control Effectiveness in Australia (Scully and Newstead, 2010)*

The study by Scully and Newstead (2010) evaluated the effectiveness of ESC systems in reducing collision risk in Australia and New Zealand. It was an update from a previous study with increased quantity of data to assess how the effectiveness of ESC differs with different driving situations, collision types, vehicle types and injury severities. The study was based on police-reported collision data from Monash University Accident Research Centre's (MUARC's) used car safety rating project. It included collision data for the period between 2001-2008 covering records of 1,323,025 vehicles. Vehicles without a valid Vehicle Identification Number (VIN) were excluded from the study as VINs were used to determine ESC fitment status. Vehicles with more than five seats ("people movers") were also excluded from the study, as this group of vehicles had low fitment rates and including vehicle groups in which there were almost no vehicles in the database would potentially bias estimates. The study included:

- 4WDs (compact, medium and large);
- Passenger cars (light, small, medium and large); and
- Commercial vehicles (utilities and vans).

To ensure the group of vehicles fitted with and without ESC were of similar age, the samples were also restricted to vehicles manufactured more recently, leaving 515,559 vehicles remaining in the dataset, of which 27,252 vehicles were fitted with ESC and 439,543 vehicles were without ESC.

This study used the induced exposure method, in this case using front-to-rear collisions (also known as rear-end shunts) as a baseline collision type that would be unlikely to be affected by ESC fitment. To control for the confounding effects of driver characteristics, vehicles fitted with ESC were compared with non-fitted vehicles by matching driver (age, sex) and vehicle characteristics (secondary safety). Estimates of effectiveness derived using both driver and vehicle characteristics were compared with estimates derived when only vehicle characteristics were used to match vehicles. From this the confounding influence of driver characteristics on the estimates of effectiveness were quantified.

To control for the confounding effects of secondary safety, the study limited the sample vehicles to those manufactured from 1998 onwards. The groups of ESC fitted vehicles were matched with non-fitted vehicle groups according to the year of manufacture and market group. Also, the study states that using rear impacts to induce exposure limited the biasing effect of differences in secondary safety between the two groups of vehicles. Logistic regression models were used to measure the difference between the secondary safety provided by ESC-fitted vehicles compared with non-fitted vehicles in rear end collisions and then in all other types of collisions. The parameters of these models were then used to estimate the extent to which the estimates of effectiveness in terms of collision risk reduction are a result of ESC vehicles having better secondary safety.

The effectiveness estimated under each vehicle category was broadly classified into three types based on injury severity: *All severities, Driver injury* and *Driver serious injury*. The overall effectiveness estimates for all types of collisions showed that ESC was associated with a significantly reduced risk of driver injury collisions by 8.2%, with a 95% confidence limit ranging from 0.9% to 14.9%. The effectiveness estimates for collisions of all severities and driver serious injury collisions were both insignificant.

The results from the study also showed that ESC would reduce the risk of involvement in single vehicle collision of all severities by 27.3% for all vehicles, 18.6% for cars, 10.43% for commercial vehicles and 56.21% for 4WDs. In rollover collisions, ESC would reduce the risk of all severities by 55.6% for all vehicles, 33.69% for cars, 53.85% for commercial vehicles and 81.64% for 4WDs. In head on collisions, ESC would reduce the risk of all severities by 4.74% for all vehicles, 70.41% for commercial vehicles, 41.91% for 4WDS and the estimates were insignificant for cars.

Also, the study found no significant reductions in estimated collision risks on wet or icy roads, with the exception of results for 4WDs (14.6% reduction all severities). The effectiveness values on dry roads were similar to the overall effectiveness results.

Study Type: Induced Exposure
Data Source: Monash University (MUARC's) – Police reported (AU)
Data Years:

- Collisions 2001-2008
- Vehicle MY 2001-2008

Vehicle Type:
Cars, Commercial vehicles, 4WDs

Collision Type:

- Single vehicle, Multiple vehicle
- Rollover
- Head on
- Side impact

Control Group: Rear end collisions
Effectiveness Estimates:
Effectiveness for the above collision types ✓
Effectiveness for all collision types ✓

C.7.5 SUV Rollover in Single Vehicle Crashes and the Influence of ESC and SSF (Kallan and Jermakian, 2008)

The aim of this study was to evaluate the changes in rollover rates for single vehicle collisions in SUVs (Kallan and Jermakian, 2008). The impact of ESC on those collisions, along with changes in Static Stability Factor (SSF – a measure of the geometric resistance of a vehicle to rollover, calculated as half the track width divided by the height of the centre of gravity of the vehicle) and other vehicle and driver characteristics were also estimated. The study was based on the National Highway Traffic Safety Administration (NHTSA) National Automotive Sampling System General Estimates System (NASS-GES). The dataset for the study was limited to police-reported single vehicle collisions that occurred during the period 2001-2006 involving SUVs. The study results showed that rollover was less likely (adjusted OR=0.33, 95% CI=0.20-0.55) to occur in SUVs with ESC as to those without ESC. Similarly, SUVs with higher Static Stability Factor (≥1.20) were less likely to roll over compared to those with lower SSF (adjusted OR=0.31, 95% CI=0.20-0.48). Vehicle size, driver age and driver alcohol use were considered as additional factors that related to and increased likelihood of rollover. The study shows that even after controlling for these factors, SUVs with ESC were two-thirds less likely to roll over than their counterparts known not to have the technology. Also, SUVs with SSF ≥1.20 were found to be 69% less likely to rollover in those same single vehicle collisions. The overall ESC effectiveness for all rollover collisions involving SUVs was found to be between 67-82%.

Study Type: Other
Data Source: NASS-GES (US)
Data Years:

- Collisions 2001-2006
- Vehicle MY 2001-2006

Vehicle Type:
Cars, SUVs

Collision Type:

- Single vehicle - rollover

Control Group: Vehicle size, driver age, alcohol use, etc.
Effectiveness Estimates:
Effectiveness for the above collision types ✓
Effectiveness for all collision types ✗

C.7.6 *Could ESC (Electronic Stability Control) Change the Way We Drive? (Rudin-Brown et al., 2009)*

Rudin-Brown *et al.* (2009) evaluated possible behavioural adaption of drivers to ESC upon its widespread introduction into the Canadian vehicle fleet. The study was performed in the form of two separate telephone surveys, involving public opinion and ESC owner/driver opinion. The first survey was conducted as a random-digit-dialled telephone survey across Canada, with participants aged 16 years and older who own and drive passenger vehicles. Of the 1405 contacted participants only 500 completed the survey, giving an overall response rate of 35.6%. The second survey was conducted with 1017 participants from the province of Quebec and British Columbia, who own and drive 2006-2008 model ESC-equipped (as standard) vehicles.

The results from the 2008 public opinion survey (first survey) revealed an overall low ESC awareness, only 39% of the respondents having heard of ESC. In contrast, the results of the second survey revealed that 63% of the drivers were aware of ESC technology and its fitment in their vehicles. 23% of the drivers reported noticing changes in their driving behaviour since they started driving a vehicle equipped with ESC. The most commonly reported behavioural changes were; felt more confident (24%), felt safer (18%), drove more carefully (18%), drove slowly (13%), better able to control/handle (11%), can drive faster (9%) and able to drive in adverse conditions (8%).

89% of the drivers reported positively that ESC made driving safer, which included improved driver confidence, increased vehicle stability, improved safety and avoidance of skidding. 2% reported negatively that it made driving dangerous, which included the driver becoming too dependent on ESC, driving faster/ aggressively and having a false sense of security. The study concluded that behavioural adaption to ESC is likely in certain drivers; however, its proven effectiveness in reducing the likelihood of involving in a collision outweighs any potential increase in unsafe driving.

There are certain limitations associated with this study. The foremost would be whether an individual's actual behaviour matched their self-reported behaviour. Telephone surveys have their own limitations as well, one of which is a selection bias, because only respondents who were willing to complete the survey and had time to do so would have responded. Also, the study failed to assess the type of vehicles to which the recorded behaviour was associated. Other studies such as Farmer (2010) and Kahane (2014) show that there are variations in the ESC performance with vehicle types.

Study Type: Telephone survey
Data Source: Randomly selected Drivers/owners of passenger vehicles with and without ESC. (CA)
Data Years:
- Vehicle MY 1997-2005

Vehicle Type:
Passenger vehicles

Collision Type: NA
Control Group: NA
Effectiveness Estimates: NA

C.7.7 Field Performance Study of Electronic Stability Control System Effectiveness in US Fatal Crashes (Padmanaban, 2007)

The aim of this study was to evaluate the effectiveness of Electronic Stability Control systems in reducing fatal single and multiple vehicle collisions in the US (Padmanaban, 2007). The study was based on FARS data collected between 1993 and 2005 and identifying ESC equipped vehicles between the model years 1994-2005. Models with ESC systems were compared with the same models three years prior to introduction of ESC as standard equipment for the same models. Many of the vehicles in the study database were luxury vehicles since ESC was introduced in 1997 in the US and only few luxury models were optionally fitted with ESC by 2005.

The study then grouped the collision types into two broad categories as control group (collisions ESC would not prevent) and response group (collisions ESC would be expected to affect). Collision involvements in which a vehicle was stopped, parked, backing up, or entering/ leaving a parking space, travelled at a speed less than 10 mph, was struck in the rear by another vehicle, or was a non-culpable participant in a multi-vehicle collision on a dry road were included in the control group.

The results from the study showed that ESC was highly effective for all single-vehicle first harmful rollovers (69% for cars and 70% for light trucks). However, the effectiveness estimates were not significant for either passenger car or light truck multiple-vehicle rollover collisions. Also, ESC effectiveness was not statistically significantly for single-vehicle rollovers where the first harmful events included collision with a tree, pole, guardrail, culvert, ditch or embankment. These types of rollover collisions were primarily off-road rollover collisions.

Study Type: Induced Exposure
Data Source: FARS (US)
Data Years:
- Collisions 1993-2005
- Vehicle MY 1994-2005

Vehicle Type:
Cars, Light trucks

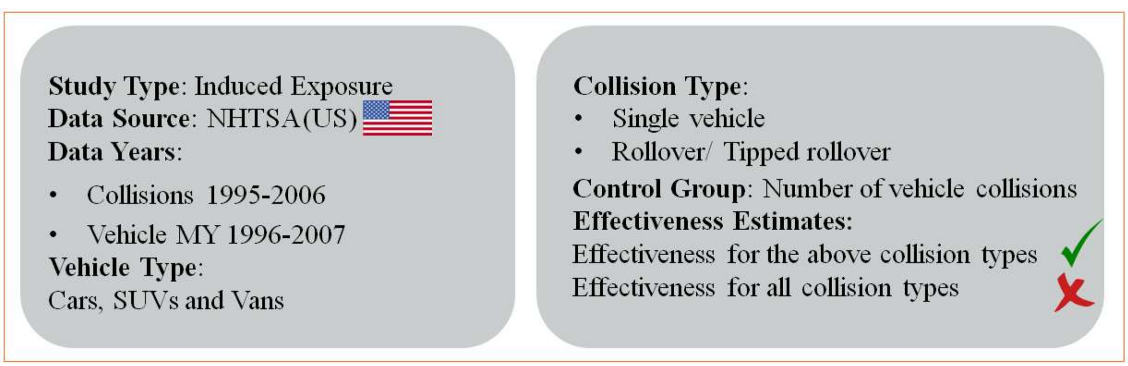
Collision Type:
- Single vehicle, Multiple vehicle
- Rollover
- Side impact

Control Group: Rear-end collisions
Effectiveness Estimates:
Effectiveness for the above collision types ✓
Effectiveness for all collision types ✓

C.7.8 *Vehicle rollover risk and electronic stability control systems (MacLennan et al., 2008)*

In 2008, MacLennan *et al.* (2008) published a study examining the relationship between vehicle rollover and presence of ESC. The study was performed on data obtained from the US NHTSA's National Automotive Sampling System (NASS) General Estimates System (GES). Only 1996-2007 model year vehicles involved in a police-reported multiple vehicle collision were included in the study. The vehicle type included passenger cars, SUVs and vans (standard and mini vans). Vehicles were then grouped based on models with ESC (standard and optional separate) and without ESC. The primary outcome of interest from the study was rollover occurrence, including tripped type rollovers (when the vehicle initially slides sideways and roll occurs when the wheels contact an obstruction). Other variables considered in the study were vehicle body type (passenger car, SUV/van), collision type (single-vehicle or multi-vehicle), driver characteristics (sex and age), alcohol, speeding, failure to yield right-of-way and the Static Stability Factor (SSF) of each vehicle. A total of 321,065 vehicles were included, out of which 92.4% were categorised as having ESC unavailable, 5.1% as ESC optional and 2.5% as ESC standard. Optional ESC vehicles were those in which the purchaser had to pay extra for ESC to be installed on a vehicle that did not normally have it. Vehicles with no clear information on fitment were classified as unknown and were not included in the study.

The results from the study showed that vehicles in the ESC-standard group were 38% less likely to have a rollover and 41% less likely to have a tripped rollover compared with the ESC-unavailable group. SUVs/vans with standard ESC had a 53% decreased risk of rollover, and passenger cars with standard ESC had a 32% decreased risk. Similarly, in single-vehicle collisions, ESC-standard vehicles had a 39% decreased rollover risk. ESC was more protective for SUVs/vans (RR 0.40, 95% CI 0.26 to 0.61, $p \leq 0.001$) than for passenger cars (RR 0.77, 95% CI 0.53 to 1.12, $p=0.171$). Tripped rollovers were significantly reduced among SUVs/vans (RR 0.36, 95% CI 0.22 to 0.59, $p<0.001$) and reduced among passenger cars (RR 0.68, 95% CI 0.45 to 1.02, $p=0.064$). Also, ESC was more protective for vehicles with low Static Stability Factor (SSF) values (i.e. less stable vehicles). Vehicles in the high-SSF group were 37% less likely to have a rollover when ESC was fitted to it. However, in the low-SSF group ESC fitted vehicles were 51% less likely to have a rollover. The limitation of this study is that all vehicles were included without matching on model type, with no control of the confounding factors.



C.7.9 *Effectiveness of Electronic Stability Control on Single-Vehicle Accidents (Lyckegaard et al., 2015)*

Lyckegaard *et al.* (2015) evaluated the effectiveness of ESC for single-vehicle collisions while controlling for a number of influencing confounding factors. The study was performed using police-reported injury collisions from 2004 to 2011 in Denmark involving passenger cars manufactured between 1998 and 2011. The presence of ESC was categorised into no, optional and yes. The no and optional category were combined together for the study as it was difficult to know whether the particular vehicle owner chose to install ESC. This could clearly affect the results, but the authors considered this a conservative approach for an effectiveness estimate.

Only cars from injury collisions where one or more cars were involved were included in the data set, excluding collisions exclusively with trucks, bicycles, etc. A total of 13,389 observations were selected and divided into two groups based on collision type (induced exposure method): cars involved in single-vehicle collisions as the case group; and cars in other types of collisions as the control group. Splitting the data into single-vehicle collisions and other types of collisions was based on the assumption that ESC has an effect on single-vehicle collisions and no or only very limited effect on other types of collisions. Two statistical data analysis methods were used: a crude method and logistic regression. With the crude method, the severity categories ranged between crude odds ratio (OR) of 0.39 and 0.42, and 0.40 for all cars in injury collisions. The differences in odds ratio for the various severity categories were insignificant. The crude odds ratio was defined as the odds of an ESC-equipped car getting in a single-vehicle collision compared to any other type of collision (a/b) to the odds of a car without ESC getting in a single-vehicle collision to any other type of collision (c/d).

The crude method does not take characteristics of the driver, the car (other than presence of ESC), the road, or the surroundings into consideration but is a crude estimate of the effectiveness given all of these characteristics. To correct for as many of these characteristics as the input data allowed for, a logistic regression was used to estimate the effectiveness. The following confounding factors were significant. For the driver: age, sex, driving experience, valid driving license, and seat-belt use. For the vehicle: year of registration, weight, and ESC. For the accident surroundings: visibility, light, and location. Finally, for the road: speed limit, surface, and section characteristics.

This study concluded that ESC reduces the risk for single-vehicle injury collisions by 31% when controlling for various confounding factors related to the driver, the car, and the accident surroundings. Furthermore, it is important to control for human factors (as a minimum age and gender) in analyses where evaluations of this type are performed.

Study Type: Induced Exposure
Data Source: Police reported (DK)
Data Years:

- Collisions 2004-2011
- Vehicle MY 1998-2011

Vehicle Type:
Cars

Collision Type:

- Single vehicle

Control Group: Other than single vehicle collisions
Effectiveness Estimates:
Effectiveness for the above collision types
Effectiveness for all collision types

C.7.10 *The effectiveness of Electronic Stability Control System in reducing real life crashes and injuries (Lie et al., 2006)*

Lie *et al.* (2006) published a study identifying the effectiveness of ESC in reducing real-life collisions in Sweden. This study used a carefully selected control fleet to minimise the problem that other vehicle or driver factors may influence the results. Police-reported collisions in Sweden with at least one injured occupant collected between 1998 and 2004 for the vehicle model years 1998 to 2005 were used in the study. The induced exposure method was used to estimate the exposure to collisions for cars equipped and not equipped with ESC. The study considered front-to-rear (rear-end shunt) collisions as a control group, since this was the only collision type that contained enough cases to be used as a control. In all, 1,942 collisions with ESC-equipped cars were found. The control group contained 8,242 collisions. For every collision the road condition, dry, wet or snowy/icy was used together with the collision type. Front, side and rear impact collisions were also considered in the study for all collisions, as well as single vehicle collisions.

The results from the study show that ESC was effective in reducing 16.7% of all collisions and 21.6% of serious/fatal collisions excluding rear-end collisions. ESC was also found to be effective in single, oncoming and overtaking serious/fatal collisions (40.6% reduction). The estimates on ESC-related collisions for different road surfaces show that effectiveness on a dry surface was not significant, while the reduction for serious and fatal collisions on wet (56.2%) and surface covered by ice or snow (49.2%) was large and significant. Treated together, the estimate for all surfaces except dry is 53 ± 18%, demonstrating a minimum of 35% reduction in serious and fatal collisions. Overall the study concluded that ESC was effective to reduce collisions with personal injury, particularly serious and fatal injuries.

Study Type: Induced Exposure
Data Source: Police reported (SE)
Data Years:

- Collisions 1998-2004
- Vehicle MY 1998-2005

Vehicle Type:
Cars

Collision Type:

- Single vehicle
- Oncoming
- Overtaking

Control Group: Rear-end collisions
Effectiveness Estimates:
Effectiveness for the above collision types
Effectiveness for all collision types

C.7.11 Updated Estimates of Fatality Reduction by Electronic Stability Control (Kahane, 2014)

In a similar study using the induced exposure method, Kahane (2014) estimated the percentage of fatal collision reduction by ESC based on FARS data from 1997 through 2011. The analysis was based on the selected list of make-models that switched from not having ESC to being equipped with ESC. Model year from 1998 through 2011 was included in the study, which included 59 make-models of passenger cars and 54 make-models of LTVs. In order to minimise the difference between vehicles of the same make-model with and without ESC, the range of model year was limited to six (the last three before and first three after the introduction of ESC). Even with limited model year it is still possible to have changes in stability factor and other vehicle features. To account for those changes, the study tailored the range of model year to balance the database to contain in each make-model, approximately twice as many FARS cases without ESC as cases with ESC. For the analysis of rollovers, one of the 59 car models and 19 of the 54 LTV models were removed from the study as they received ESC simultaneously with rollover curtains. The control group for the study consisted of non-culpable involvements in multi-vehicle collisions on dry roads. The three primary groups of collisions of interest were first event rollovers; single vehicle collisions that are not first event rollovers and not collision with pedestrians, bicyclists, or other non-occupants; and culpable involvements in multi-vehicle collisions.

The study was entirely based on FARS data and the results relate to *fatal collisions*. The results showed a 59.5% drop in first-event rollovers in cars relative to the control group. ESC was found to be more effective in preventing first-event rollovers in LTVs (74.0%) than cars (59.5%). Also, there was a 37.8% reduction in all single-vehicle collisions in passenger cars that do not involve pedestrians, cyclists or other non-occupants. In LTVs, the effect was a likewise significant 55.9% reduction. Of the other single vehicle collisions that do not involve pedestrians, cyclists or other non-occupants, there was 45.5% reduction in LTVs and 31.3% reduction in cars. The effect of ESC in reducing culpable involvement in multi-vehicle collisions was 16.1% for both passenger cars and LTVs.

Study Type: Induced Exposure
Data Source: FARS (US)
Data Years:
- Collisions 1997-2011
- Vehicle MY 1998-2011

Vehicle Type:
Cars, LTVs (commercial vehicles)

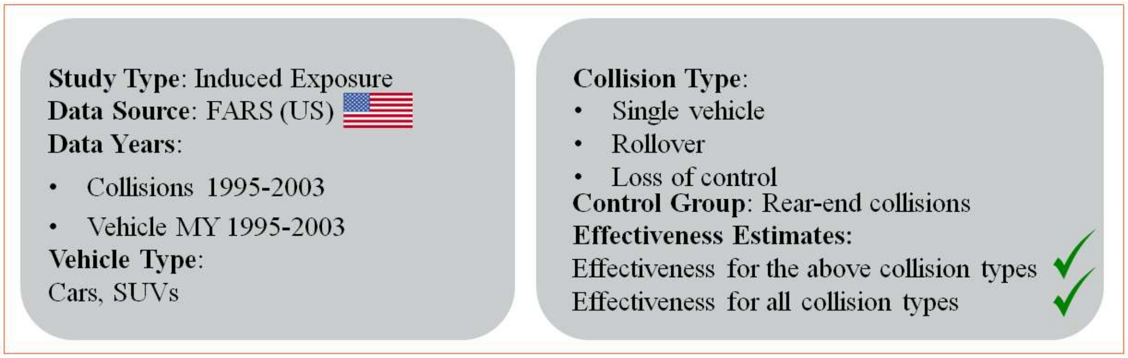
Collision Type:
- Single vehicle
- Multiple vehicle
- Rollover

Control Group: Non-culpable involvements in Multiple vehicle collisions
Effectiveness Estimates:
Effectiveness for the above collision types ✓
Effectiveness for all collision types ✓

C.7.12 The Effectiveness of Electronic Stability Control on Motor Vehicle Crash Prevention (Green and Woodrooffe, 2006)

A similar study on ESC based on FARS data (1995-2003) by Green and Woodrooffe (2006) investigated the effectiveness of ESC by using single-vehicle collisions as the case group and multiple-vehicle collisions as the control group. The results from the study showed a 30.5%

reduction in the odds of single-vehicle collisions for passenger cars equipped with ESC and a 49.5% reduction for SUVs. In relation to running off the road events, the study showed a 34.8% reduction for passenger cars fitted with ESC and a 56.4% reduction for SUVs. The effect of ESC in reducing the likelihood of rollovers was also investigated in the study, showing a 39.7% reduction for passenger cars and a 72.9% reduction for SUVs.



C.7.13 Reductions in crash injury and fatalities due to Vehicle Stability Control technology (Bahouth 2006)

In 2006, Bahouth investigated the impact ESC had on reducing collision involvement rates for six US passenger car and SUV models (Bahouth 2006). This was achieved by comparing the collision rate figures pre and post fitment of ESC. The selected vehicles comprised two passenger car models: Lexus LS430/400 and GS430/400/300 (1997 without and 1998 with) as well as four types of SUV: Toyota Land Cruiser, Lexus LX470 (1999 without and 2000 with) Toyota 4Runner and Lexus RX300 (2000 without and 2001 with). These vehicles were chosen because all variants, of the listed vehicles, sold during the 'ESC standard' years were equipped with ESC and received no additional major design changes. This meant their overall level of safety, in terms of vehicle structure and inclusion of other safety technologies, remained the same. The study did not include vehicles where ESC was previously optional then made standard following a mid-year change within the same model year.

The study used data from the US State data files and the FARS database, between the years 1998 to 2003, from the following States; Florida, Illinois, Kansas, Kentucky, Maryland, Missouri, North Carolina, Pennsylvania, Texas and Utah. US State data files included information on occupants, vehicles and environmental conditions collected in Police Accident Reports (PAR) at the time of the collision. Information provided from PAR could vary significantly due to different reporting requirements per State, time at scene and officer best practice. FARS data includes motor vehicle traffic collision cases where there has been at least one fatality (vehicle occupant or non-motorist) within 30 days of the collision.

The induced exposure method was used to determine the change in collisions. Rear-impact collisions were selected as the control group for the state files and vehicle registration counts for the reviewed fatal collisions.

The study found that there was a 34% (95% CI: 26%, 40%) overall reduction in fatal collision involvement for the reviewed subset of vehicles and a 56% (95% CI: 47%, 64%) reduction in single-vehicle collisions. There was also a 53% (95% CI: 18%, 73%) reduction in KSI (K+A injuries as reported using the KABCO injury scale) and a 26% (95% CI: 15%, 35%) reduction in moderate and slight (B+C) injuries.

Study Type: Induced Exposure
Data Source: FARS (US)
Data Years:

- Collisions 1998-2003
- Vehicle MY 1998-2003

Vehicle Type:
Cars, SUVs

Collision Type:

- Single vehicle

Control Group: Rear-end collisions
Effectiveness Estimates:
Effectiveness for the above collision types ✓
Effectiveness for all collision types ✓

C.7.14 A study of the effectiveness of Electronic Stability Control in Canada (Chouinard and Lécuyer, 2011)

The aim of this investigation was to assess the effectiveness of ESC in Canada in terms of its environmental conditions (e.g. ice, snow and slush) and its national collision landscape (Chouinard and Lécuyer, 2011). The collision data used in this project was taken from the National Collision Database (NCDB) from the years 2000 to 2005. The data set comprised all police-reported injury and 'property damage only' collisions with damage over US$1000. Within the chosen time period, only models from 1997 onwards, whose ESC fitment status was known and that were involved in ESC sensitive collision types were included. In collisions involving more than one vehicle, only one was selected. After this filtering process, this left a total of 1,144,173 vehicles, 17,968 of which had ESC fitted. These vehicles were then split in to four categories:

- Group 1: Vehicles which had ESC fitted on some trim levels of a vehicle;
- Group 2: ESC fitted on all trim levels of a vehicle;
- Group 3: All vehicle models of a certain make had ESC fitted; and
- Group 4: Vehicles that were not fitted with ESC.

The majority of the vehicles included in this study fell in to the premium medium-sized passenger car (e.g. Volvo V50), premium large passenger car (e.g. BMW 7 Series), full-size SUV (e.g. Cadillac Escalade) or sports car category. This may lead to higher effectiveness values than expected as there is a large bias towards powerful rear wheel drive, and four wheel, drive vehicles with a high centre of gravity.

An 'ESC sensitive' collision included all single-vehicle collisions and multiple-vehicle collisions due to a loss of control with intervention of the vehicle dynamics (the driver attempted to avoid the collision). 21% of injury collisions or 24% of all collisions in this study were considered to be ESC-sensitive collisions.

The induced exposure method was used to determine the change in collisions. Chouinard and Lécuyer (2011) adopted collision year and vehicle age to control for the differences in vehicle design and safety pre and post ESC fitment (as proposed by Page and Cuny (2006)), driver age and sex was used to control for driver effect and group for differences between group number (Group 1-3).

The study found for all ESC-sensitive injury collisions, the fitment of ESC was 54.8% (95% C.I. 47.7%, 60.9%) effective and 41.1% (95% C.I. 38.1%, 43.9%) for all ESC-sensitive collisions.

This can be broken down in to the following collision types and environmental conditions:

- 28.4% effective in multi-vehicle ESC-sensitive injury collisions (23.2% in all multi-vehicle ESC-sensitive collisions)
- 18.6% effectiveness for ESC-sensitive single-vehicle collisions of all severities (49.3% effectiveness for ESC-sensitive injury collisions)
- 51.9% effectiveness for ESC-sensitive collisions of all severities involving a Light Transport Vehicle (LTV) (69.6% effectiveness for ESC-sensitive injury collisions)
- 51.1% effective for all ESC-sensitive collisions related to roads covered with ice, snow or slush (71.1% for ESC-sensitive injury collisions)
- 36.3% effectiveness for ESC-sensitive collisions of all severities occurring on dry roads (46.6% effectiveness for ESC-sensitive injury collisions)

35.8% effectiveness for ESC-sensitive collisions of all severities on wet roads (49.5% effectiveness for ESC-sensitive injury collisions).

Study Type: Induced Exposure
Data Source: NCDB–National Collision Database (CA)
Data Years:
- Collisions 2000-2005
- Vehicle MY 1997-2005

Vehicle Type:
Cars, LTVs

Collision Type:
- Single vehicle
- Multiple vehicle
- All ESC sensitive

Control Group: Multiple vehicle/ ESC insensitive
Effectiveness Estimates:
Effectiveness for the above collision types ✓
Effectiveness for all collision types ✓

C.7.15 Effects of Electronic Stability Control on Fatal Crash Risk (Farmer, 2010)

The aim of this project was to determine whether the effectiveness of ESC in the US varies depending on the type of vehicle, style, or manufacturer (Farmer, 2010). The fatal collision involvement rates for a range of ESC-equipped vehicles were compared to otherwise identical vehicle models without the system installed. Data from the years 1999 to 2008 was taken from the Fatality Analysis Reporting System (FARS). FARS collects data from all 50 US states.

Vehicle models were included in the study if ESC was not available then made standard the following model year without any other major design changes; as a result models with ESC were newer, at time of collision, than those without. Model years were limited to the last four years without ESC and the first four years with ESC, meaning that up to 8 years of data could have been used. The study compared collisions across model years but within the same calendar year. The study acknowledged that over this period there were a number of other regulatory and consumer rating-based vehicle design changes, particularly to structural crashworthiness. Effectiveness estimates were adjusted to account for this.

Whilst interpreting the effectiveness values from this study it is important to point out that almost all vehicles in this study fitted in to either the sports, SUV or luxury car category. There is therefore a bias towards powerful vehicles with rear-wheel or all-wheel drive vehicles with a high centre of gravity, both of which would be expected to be associated with an increased risk of loss of control collisions.

The study found in general the fitment of ESC could be associated with an overall reduction in fatal collisions of 33%. This equates to a 20% reduction in multiple-vehicle fatal collisions and a 49% reduction in the case of single-vehicle events. This can be broken down further in to the following vehicle types; a 21% and 16% reduction in multi-vehicle fatal collision involvement for SUVs and cars respectively and a 53% and 46% reduction for single vehicle collisions. The results showed ESC contributed to a 57% reduction in multiple-vehicle rollover fatal collision involvement and a 73% reduction for single-vehicle fatal roll over events. As well as a 50% reduction in multiple-vehicle fatal collisions on wet or slippery roads and a 59% reduction in an equivalent single vehicle event.

The study goes on to say if all 2003–2009 model passenger vehicles had been equipped with ESC, approximately 3,700 fatal collisions could have been prevented in calendar year 2008 and 15,600 fatal collisions if all new passenger vehicles had been fitted with ESC between calendar years 2002-2008.

The study looked at the difference between newer and older ESC systems and the variation between different manufacturers to determine whether there is a difference in performance. A slight variation was found in both cases but deemed statistically insignificant. From this sub-investigation it was found that ESC fitment to the Toyota/Lexus models led to a 41% reduction in fatal collision risk and a 16% reduction in fatal collision risk for Honda/Acura models. This is noteworthy as the Toyota/Lexus models comprised mainly of tall 4WD SUVs (e.g. Land Cruiser and 4Runner), whereas the Honda/Acura models consisted of small to medium sized family cars such as the Accord and Civic. The value for Honda, though lower, may be more representative of an average car.

Table 20 Summary of ESC effectivness studies

Study	Country (ISO Code)	Method	Data Source	Dataset Age	Severity	Type	Effectiveness	Lower (95% CL)	Upper (95% CL)
Thomas and Frampton (2007)	GB	Induced exposure	STATS19	2002-2005	Fatal	All collisions	25%	-5%	46%
Sferco *et al.* (2001)	FI, FR, DE, IT, ES	Case by case assessment	EACS	1995-2000	Fatal	All collisions	34%	ND	ND
Scully and Newstead (2010)	AU	Induced exposure (rear end crashes)	Monash University (MUARC's) - Police reported	2001-2005	All severities	All Single Veh collisions	27.33%	22.93%	31.48%
						All veh - Rollovers	55.60%	47.43%	62.50%
Padmanaban (2007)	US	Induced exposure	FARS	1993-2005	Fatal - rollover	Cars - All rollovers	52.50%	14.60%	73.60%
					Fatal - rollover	Light trucks - All rollovers	55.60%	23.40%	74.20%
					Other fatal / non rollover	Cars - All single veh relevant	44.70%	12.80%	64.90%
MacLennan *et al.* (2008)	US	Induced exposure (no. of vehicle crashes)	NHTSA's National Automotive Sampling System	1996-2007	All	Rollover collisions	38.00%	23.00%	50.00%
Lie *et al.* (2006)	SE	Induced exposure	Police reported crashes	1998-2004	All	Excluding rear end	16.70%	7.40%	26.00%
Bahouth (2006)	US	Induced Exposure	FHWA HSIS	1998-2003	Fatal	All	34.00%	26.00%	40.00%
						Single Veh Collision	56.00%	47.00%	64.00%
Chouinard and Lécuyer (2011)	CA	Induced Exposure	NCDB	2000-2005	All	All collisions (Including non-ESC sensitive)	9.70%	ND	ND
Farmer (2010)	US	Induced Exposure	FARS	1999-2008	Fatal	Overall collision involvement	33.00%	ND	ND

Appendix D Sensitivity analysis

The best-estimate benefit-to-cost ratios presented in Section 8 represent the most likely outcome if road safety trends continue as they have done in recent years. However, there is inherent uncertainty in many of the predictions made and thus sensitivity analysis is required to determine what impact changes to the assumed input values could have on the resulting ratios.

Specifically, the effect of changing the following inputs/assumptions was investigated:

- Vehicle registration extrapolation
- ESC effectiveness estimate
- Target population for ESC
- Maximum level of voluntary uptake
- Value of statistical life
- ESC fitment cost

For each analysis, one of these was varied, whilst the other input values/assumptions remained the same. Table 21 outlines the scenarios tested. Blank cells show where the best-estimate value (see column 2) is used in the model.

Table 21: Varied input parameter values for the scenario analysis for car occupants

Input/assumption	Best-estimate	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Vehicle registration extrapolation	Linear trend for both all cars and new cars	Logarithmic trend						
ESC effectiveness estimate	38%		Higher estimate (55%)	Lower estimate (15%)				
Target population for ESC	Loss of control - assumed to be 34.9% based on GB and US data				Higher estimate (43.5%)	Lower estimate (26.3%)		
Uptake of ESC	Uptake takes 20 years, voluntary uptake reaches 45% to 60%						Uptake takes 20 years, voluntary uptake reaches 45%	Uptake takes 20 years, voluntary uptake reaches 60%

Input/assumption	Best-estimate	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
VSL for benefits estimation	Mid estimate for each country	Low estimate for each country	High estimate for each country	Alternative estimates from Viscusi & Masterman (2017)		
Costs	ESC = $50				Lower estimate ($36.46)	Higher estimate ($102)

Appendix E Serious injury benefits

In addition to the fatality benefits estimated in Section 5 of this report, ESC regulation is also likely to have an impact on the number of serious injuries. This appendix presents the results of analysis to estimate the serious injury savings, and resulting BCRs, which could be obtained on top of the fatality estimates presented in the main body of the report.

It should be noted that this methodology is a simplification of that applied to the fatality savings and as a result, substantial caution should be applied to the results since additional assumptions are required. These are documented below.

E.1 Methodology and assumptions

There is limited information available on the number of serious injuries in each country, and so some assumptions are required to estimate the baseline number of these casualties. For the purposes of this analysis, we have assumed that a simple factoring process can be applied, using data from STATS19 to estimate the ratio of fatal to serious casualties in ESC-relevant collisions.

For car occupants in ESC collisions (i.e. those involving loss of control), we estimate that in GB there are approximately 6.5 serious injuries for every fatality. This factoring assumes that the ratio of fatal to serious casualties is the same in each of the countries included in this study as observed in Great Britain: a substantial assumption given the likely differences in collision types and severity definitions.

In addition to factoring the baseline casualties, the effectiveness estimates for ESC is likely to be different for serious injuries than fatalities. A review of the literature (Appendix C) shows that ESC is 21% effective at reducing car occupant serious injuries in loss of control collisions.

Using these factors, the number of serious injuries prevented by regulation can be estimated and a VSL estimate then applied to estimate the economic benefit. Bhalla *et al.* (2013) reviewed a number of relevant VSL studies and showed that the economic loss due to a serious non-fatal injury was equivalent to 17 times GDP per capita (Table 22).

Table 22: Economic loss of serious injury using VSL method

Country	Forecast GDP per capita (2018) (US$2018)	Economic loss of one serious injury due to traffic collision (US$2018, thousands)
Argentina	12,924	220
Brazil	8,807	150
China	9,182	156
India	1,913	33
Indonesia	3,865	66
Mexico	8,321	141
South Africa	5,237	89

Finally, this economic benefit can be combined with the economic benefit for fatalities prevented (from Section 6) to estimate the total benefit of the casualty savings. This is then compared to costs (from Section 7) to generate new BCRs accounting for both fatalities and serious injuries combined. Appendix E.2 presents the casualty savings.

E.2 Casualty savings

Figure 29 presents the estimated number of car occupant serious injuries saved each year through the implementation of the regulation for ESC.

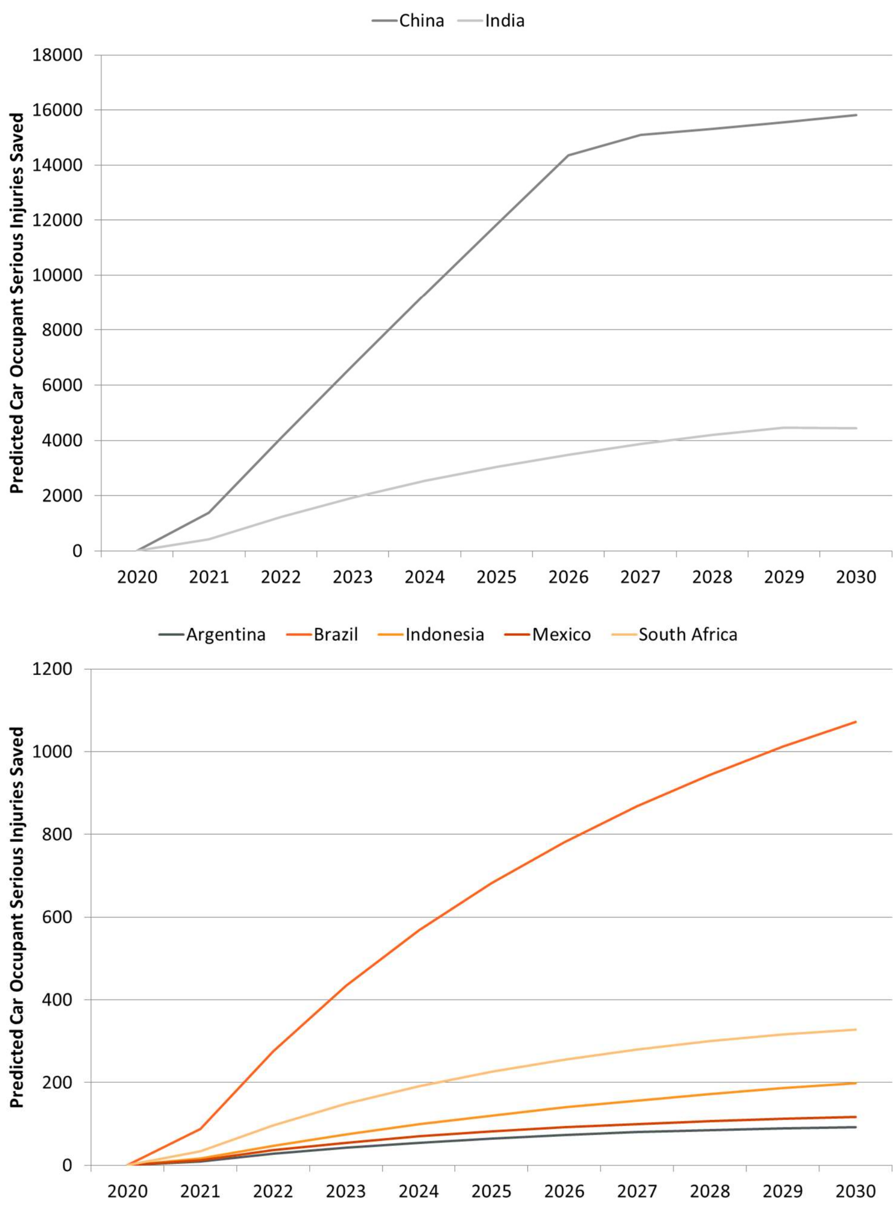


Figure 29: Estimated number of car occupant serious injuries saved due to implementation of ESC regulations in 2020 (2020-2030)

The cumulative results are presented in Table 23.

Table 23: Serious injuries saved for car occupants due to implementation of ESC regulation in 2020 (2020-2030)

	Cumulative serious injuries saved, 2020-2030
Argentina	619
Brazil	6,724
China	109,420
India	29,600
Indonesia	1,212
Mexico	784
South Africa	2,175
Total	**150,533**

This demonstrates that by 2030, over 150,000 serious injuries could be saved in total due to ESC regulations. This is the equivalent to a monetary saving of around US$4 billion, resulting in a total benefit of around US$21.5 billion when fatalities are also added.

Appendix F Fatality benefit-to-cost ratios

This section presents the results of the cost-benefit analysis when just the impact of the safety measures on fatalities is considered. Figure 30 presents the year-by-year benefit-to-cost ratio of implementing ESC in each of the four countries from 2020-2030, just focusing on car occupant fatalities. Table 24 presents the year in which the benefit-to-cost ratio increases above 1 in each country, and Table 25 presents the cumulative benefit-to-cost ratios over the full period.

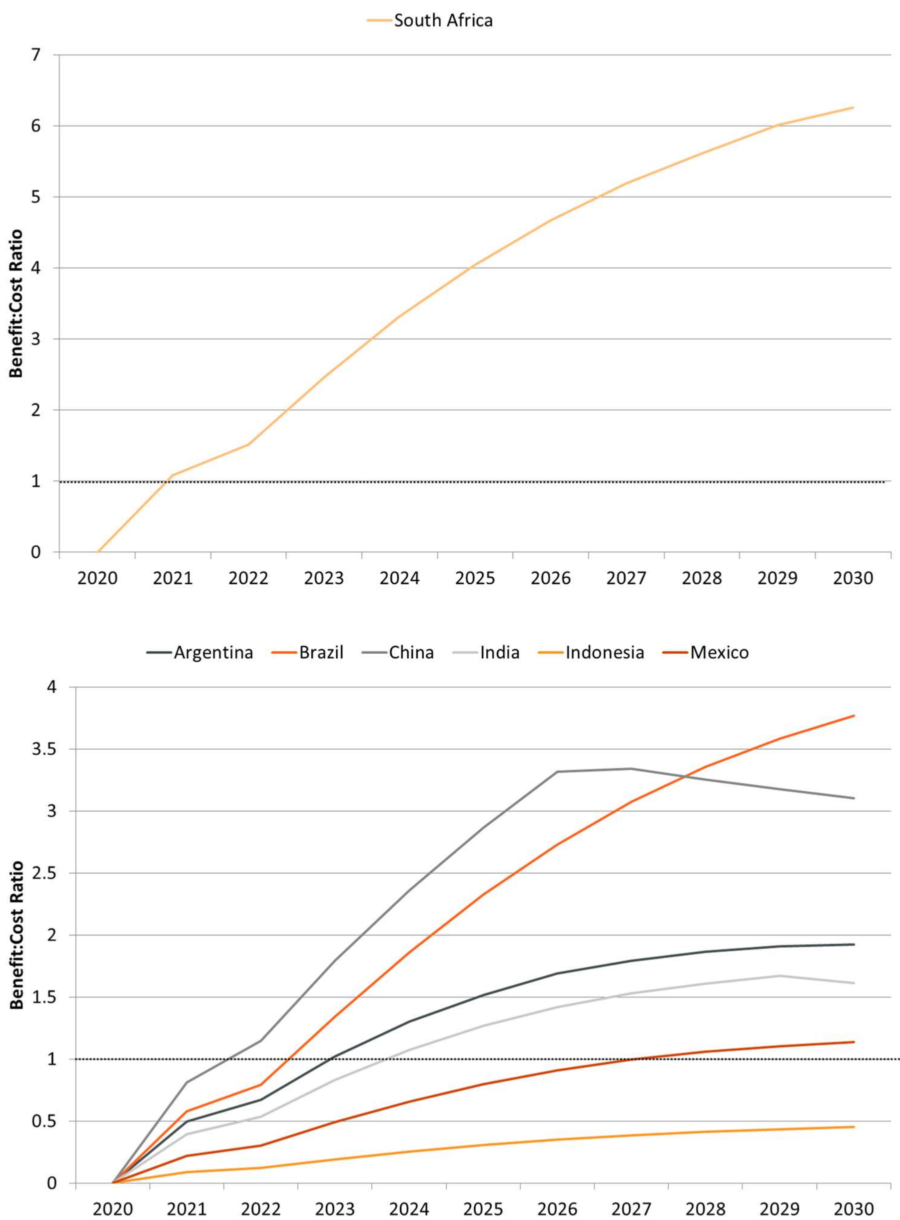


Figure 30: Estimated benefit:cost ratio associated with implementing ESC regulation in 2020, just considering impact on fatalities (2020-2030)

Table 24: Year in which the BCR for implementation of ESC regulation crosses 1 for each country, just considering the impact on fatalities

Country	Year in which BCR increases above 1	Year in which BCR increases above 1 (conservative estimate from sensitivity analysis)	Year in which BCR increases above 1 (optimistic estimate from sensitivity analysis)
Argentina	2023	>2030	2022
Brazil	2023	2026	2022
China	2022	2025	2021
India	2024	>2030	2023
Indonesia	>2030	>2030	>2030
Mexico	2027	>2030	2024
South Africa	2021	2024	2021
Total	**2023**	**2025**	**2021**

Table 25: Cumulative BCR for implementation of ESC regulation for each country, just considering impact on fatalities (2020-2030)

Country	BCR (2020-2030)	BCR (conservative estimate from sensitivity analysis)	BCR (optimistic estimate from sensitivity analysis)
Argentina	1.44	0.57	2.39
Brazil	2.24	0.88	3.60
China	2.54	1.00	3.97
India	1.17	0.46	1.83
Indonesia	0.30	0.12	0.45
Mexico	0.74	0.29	1.27
South Africa	3.70	1.46	6.33
Total	**2.27**	**0.90**	**3.56**

The results show evidence to suggest that even when just the impact on fatalities is considered, ignoring any potential benefit relating to serious injuries, the ESC regulation is expected to be worth implementing. Across the region, the benefit-to-cost ratio increases above 1 within 3 years of implementation, and does so for six of the seven countries by 2027, with Indonesia again being the one exception.

In addition, the cumulative benefit-to-cost ratio for the region from 2020-2030 (2.27) indicates that the fatality benefits of ESC will be more than double the costs of implementation. There are however variations between different countries, with the cumulative benefit-to-cost ratio being below 1 for Indonesia and Mexico.

Appendix G Encouragement of ESC in the absence of legislation

A literature review was undertaken to identify approaches that have been taken to accelerate the uptake of ESC in the absence of legislation. In many cases, legislation was subsequently implemented in order to ensure that the whole fleet met the same performance standard.

G.1 Sweden

Actions taken in Sweden to improve penetration of ESC were summarised in Krafft *et al.* (2009). After an event in Sweden involving a journalist tipping over a car in a manoeuvre test, the car was recalled and ESC was fitted to improve handling. Following this, ESC was progressively implemented on executive mid-size and large cars reaching a 15% new car sales penetration in mid-2003. An initial study of the real-life success of ESC was presented in March 2003 by the Swedish Road Administration (SRA) and Folksam Insurance Company in cooperation with the Swedish magazine “Auto, Motor och Sport”.

A recommendation was communicated at the same time stating that “all car buyers are recommended to choose a car with ESC”. The outcome and the recommendations attracted major media interest. At the same time, vehicle purchase and rental car policies for SRA and Folksam operations were changed so that all new cars purchased from the date of the presentation must have ESC and so that in the near future all short-term or long-term rental cars used by staff of Folksam and SRA must have SRA. The recommendation was made to influence the rental car market, which had a fair market share of new cars. Car rentals overseen by the Swedish Insurance Industry accounted for 50% of all car rentals; the change in policy was also meant to impact other fleet buyers to change their strategy.

An initial screening of how car manufacturers and importers of cars had responded and to what scale ESC fitment was increasing was conducted by the SRA later in 2003. SRA approached some manufacturers and importers to discuss their intentions for ESC fitment, mainly those who were to launch new models. The aim was to get in touch with the marketing departments to show interest in ESC and perhaps impact their decision to make ESC standard fitment. It was possible that several manufacturers and importers modified their intended decision following those contacts. The crucial message from SRA was that ESC should be standard equipment for as many models as possible. With more scientific evidence (Dang, 2004; Farmer, 2004) indicating that ESC was very effective in late 2004, the Director General of SRA sent a letter to all manufacturers and importers requesting them to as quickly as possible stop selling cars without ESC. Even though the letter had no legislative or legal basis it was a plea based on scientific results.

The Swedish Occupational and Health Safety (OHS) Administration in 2004 and 2005 introduced ESC in their checkpoints when employers were queried about a systematic improvement of OHS, which revealed the importance of ESC to many organisations. Around the same time several fleet purchasers had picked up ESC in their purchasing and rental car policies and about 70% of new car sales had ESC by that time.

As a new member of Euro NCAP in 2004, the SRA suggested that ESC should be promoted through Euro NCAP and this was implemented in 2005 as a “strong recommendation to consumers". This was subsequently followed by participation in ChooseESC, the main campaign from e-safety, FIA, the European Commission and many others.

A special commission on crashes in wintertime was formed in Sweden with members comprising many stakeholders such as the tyre industry. Based on results from a scientific study of the benefits of ESC given by SRA and Folksam in 2005 (Lie *et al.*, 2006) revealing more long-term effects and detailed benefit estimates a proposal was made. The commission made a proposal on ESC, with all stakeholders making a commitment to only buy and use cars with ESC. The results of the scientific study and that of the commission's recommendations were brought to the attention of the media.

Furthermore, Folksam Insurance Group modified their premiums in 2007 according to the fitment of ESC and when the government made a purchasing contract with all interested car importers, ESC was an obligatory requirement.

In summary, what had been crucial in the implementation of ESC were the following:

- The scientific evidence, since without this there would have been no action from all stakeholders involved.
- Media involvement. The media had been involved from inception even in presenting the initial scientific results and followed this up by mentioning ESC in most car tests and questioning car manufacturers and importers when new cars were launched.
- The purchasing behaviour from stakeholders involved. SRA and Folksam only used cars with ESC, which conveyed the message that the issue was high-priority and generated a demand from the market place.
- Continuous communication with manufacturers and importers about their intents, indicating the importance to both the government and insurers.
- Continual monitoring of the execution process and benchmarking to other countries.

In a study (Lie *et al.*, 2006), the fitment rate of ESC on new cars in Sweden had reportedly grown to 69% in December 2004, despite the absence of legislation. This was stated to be one of the highest in the world as the other Nordic countries had fitment rates ranging from 30% to 40%, while Europe as a whole had fitment rates as low as 10%.

G.2 Australia

A discussion paper by (Cockfield, 2011) set out to describe the role of the Transport Accident Commission (TAC) in road safety in Victoria, Australia by detailing some of the programmes it developed to both reduce incidence and cost of trauma on the roads. In recognition of the work carried out by Lie *et al.* (2006) in accelerating the fitment rate of ESC in new cars in Sweden, TAC Victoria outlined some key initiatives aimed at accelerating the uptake of current new safety technologies. These initiatives included (Cockfield, 2011):

1. Research and development: The TAC favoured the provision of crash performance information through investing in the Australasian New Car Assessment Programme (ANCAP), as well as the annual development of Used Car Safety Ratings (UCSR) by MUARC (Monash University Accident Research Centre). The results produced by these two projects formed the basis for providing consumers with reliable, accurate

and timely information on the safety performance of both new and used cars. The TAC together with the Department of Innovation, Industry and Regional Development (DIIRD) and Bosch Australia supported an upgrade to the facilities at the Australian Automotive Research Centre to enable ESC testing to be conducted in a timely and convenient manner for Australian, and potentially overseas customers, rather than in Europe and the USA. The availability of the facility enabled the launch of new vehicles onto the Australian market with customised ESC to be brought forward and for consumers to derive the safety benefits earlier.

2. Marketing and promotions: The TAC with partners VicRoads and the Royal Automobile Club of Victoria (RACV) sought to build consumer demand for safer vehicles through the following avenues:
    a. Promotion of car safety ratings and targeted advertising were utilised to educate the consumer about ANCAP star ratings of vehicle crashworthiness and to direct consumers to a specially customised website (www.howsafeisyourcar.com.au). In order to ensure greater demand for vehicle safety, the website was not branded by the TAC so that other States interested in promoting vehicle safety could use it. At the time of publication of the report by Cockfield, three other jurisdictions had adopted it.
    b. Highlighting new in-vehicle safety technologies with proven safety benefits: In February 2007, TAC launched a new public education campaign that specifically highlighted the life-saving potential of ESC and side curtain airbags. The campaign comprised television, radio and supporting outdoor placements and involved both emotive and instructive elements. As an addition to the advertising program, the RACV, VicRoads and the TAC organised a number of publicity events with the precise aim of educating consumers with regard to the availability and effectiveness of ESC systems. With the assistance of Bosch Australia and the State Coroner, a major event was organised at a Melbourne shopping centre in which the Bosch ESC simulator was made available for testing by the public and the Coroner drew a strong link between a number of tragic crashes and the role that ESC could have played in either avoiding it altogether or mitigating the severity of the crash outcome. Further public demonstrations were (and continued to be) staged at additional events including the Melbourne International Motor Show and at the Formula 1 Grand Prix in Melbourne. In summary, the level of activity directly aimed at increasing general community knowledge and pressure on vehicle manufacturers to incorporate safety technology in vehicles, has undergone significant growth in Victoria. Besides targeting the broader community, a target audience of special interest has been senior management and fleet managers within a workplace setting.
3. Corporate behaviour: Australasian jurisdictions had recognised for some years the major role that corporate behaviour can play not only in helping to modify driver behaviour to safer forms, but also to help fast-track the introduction of safer vehicles into the workplace and then, as second-hand vehicles, into the broader vehicle fleet. The main motivators for progress in this area are Occupational Health and Safety

(OH&S); good corporate citizenship; maintenance and insurance costs; and a reduction in staff downtime due to road crash-related injury. In Victoria, a number of developments gave motivation to this pathway for speeding up the introduction of safer vehicles into the vehicle population. They include:

a. Development of in-house vehicle lease/purchase policies by a number of government departments;

b. Production and promotion by VicRoads and the TAC of a Safe Driving Kit in partnership with local government;

c. Collaboration between the TAC and WorkSafe Victoria in order to develop a guidance note and subsequent workplace inspector training to encourage companies to upgrade their fleet for the purpose of improved OH&S.

While developments have been promising in this area, the "uncollected dividends" remain substantial with cost-based decision making by fleet managers still likely to be prevalent.

As a result of these initiatives, the uptake of ESC (as standard) in new cars sold in Victoria grew from 1.5% in 2001 to 71% in 2010. The effect on the rest of Australia was also strong, with voluntary fitment exceeding 60% by 2010.

In summary, both Sweden and Australia had a significant focus on the following areas:

- Government car purchase and leasing policies
- Encouraging other large fleet buyers/leasers to implement ESC policies
- Publicity of the benefits of ESC to consumers

Furthermore, Sweden also influenced the voluntary take-up of ESC through car insurance pricing. Both were very successful, with voluntary fitment rates exceeding 60% despite the absence of legislation. Nevertheless, legislation to mandate the fitment of ESC has ensured that these strong foundations have been built upon to ensure safer vehicles for all.

Appendix H ESC for heavy vehicles

ESC requirements have already been applied to many heavy vehicles in the European and US fleets because they are considered to reduce the likelihood of un-tripped rollovers (a collision type linked primarily to top-heavy vehicles, rather than an object serving as a tripping mechanism) and severe understeer or oversteer conditions that lead to loss of control (NHTSA, 2015). This means that there are already test procedures and performance requirements in place in several jurisdictions that could be applied elsewhere with minimal development effort.

The following sections outline the requirements and the vehicle types to which they apply.

H.1 EU Heavy Vehicle ESC Legislation

In 2009, the EU General Safety Regulation EC[48] introduced a mandatory status for a number of key safety technologies for HGVs including Daylight Running Lights (DRL), Lane Departure Warning Systems (LDWS), Automated Emergency Braking Systems (AEBS) and ESC. ESC was made mandatory in new N_2[49] and N_3[50] category vehicle type approvals from 1 November 2011 and will become mandatory to all newly registered HGVs from 1 November 2018 (European Commission, 2009; Weatherly, 2014). Not all HGV configurations are legally required to have ESC:

- Off-road (G) variants (e.g. N_3G)
- N_2 and N_3 vehicles with more than three axles (e.g. traditional 8x4 rigid tipper or tridem)
- Tractor units (for semi-trailers) which have a gross vehicle mass between 3.5 and 7.5 tonnes, and
- Special purpose vehicles (a vehicle intended to perform a function which requires special body arrangements and/or equipment e.g. Mobile crane) set out in points 5.7 and 5.8 found in Section A of Annex II to Directive 2007/46/EC[51]: Establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles are exempt.

[48] Regulation 661/2009: concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor

[49] Vehicles designed and constructed for the carriage of goods which have a maximum mass exceeding 3.5 tonnes but not exceeding 12 tonnes

[50] Vehicles designed and constructed for the carriage of goods which have a maximum mass exceeding 12 tonnes

[51] Directive 2007/46/EC: establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles

In addition to tractor units and rigid motor vehicles, O_3 (trailers with a maximum mass exceeding 3.5 tonnes but not exceeding 10 tonnes) and O_4 category vehicles (trailers with a maximum mass exceeding 10 tonnes) trailers and semi-trailers (articulated combinations) equipped with air suspension are also legally required to be fitted with ESC, with the same dates as N category vehicles. ESC-exempt trailers include those with more than three axles, for exceptional load transport and those with areas for standing passengers.

Other large vehicles covered with the ESC section of the General Safety Regulation include:

- M_2 (vehicles designed and constructed for the carriage of passengers, comprising of more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tonnes); and
- M_3 (vehicles designed and constructed for the carriage of passengers, comprising of more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes) category buses/coaches.

Buses and coaches which do not require ESC include those with more than three axles, articulated combinations and Class I (and A) buses as defined in UNECE Regulation 107[52].

Rigid HGVs with more than three axles are currently exempt from ESC regulation as they are typically used in off-road applications. In this working environment ESC is not as effective at braking because the system can mistake the tyres losing traction on low grip surfaces, e.g. mud, for the vehicle sliding (RSA, 2015). The larger tyre-to-ground contact area, due to having more axles, also improves vehicle stability. In the future, this exemption may have to be modified due to the growing popularity of the tridem configuration (SMMT, 2016). A Tridem configured HGV has a single axle at the front and three at the rear. This configuration is being adopted for on-road (e.g. box bodies) and off-road applications (replacing traditional tippers due to increased manoeuvrability).

Vehicles below 7.5 tonnes are categorised as Light Goods Vehicles (LGV) and as a result do not fall in to the fitment requirements.

Special purpose vehicles are often built in such low volumes that the fitment of ESC may not be cost-beneficial. Furthermore, in certain specialised vehicles have low maximum speed constraints, e.g. UK Special Types (General) Order (STGO) Cat 2 (vehicles with a GCW between 46 - 50 tonnes) or Cat 3 (not exceeding 150 tonnes) heavy haulage combinations their top speeds are limited to 40 mph and as a result do not require ESC.

The introduction of AEBS in to the European HGV industry was split into two phases; Level 1 and 2 systems (Norwell, 2015). Level 1 AEBS can reduce the speed of a vehicle from 80 kph to at least 30 kph before an impact without any driver input. This minimum performance standard was implemented on 1 November 2013 in new type approvals (with the exception of systems that already met the Level 2 requirement and vehicles not equipped with

[52] UNECE Regulation 107: Uniform provisions concerning the approval of category M2 or M3 vehicles with regard to their general construction. Geneva: United Nations Economic Commission for Europe.

pneumatic rear axle suspension) and to all newly registered vehicles from 1 November 2015. A Level 2 AEBS can reduce the speed of a vehicle from 80 kph to at least 10 kph before an impact without any driver input. The revised performance standard was implemented on 1 November 2016 for new type approvals and will apply to all newly registered vehicles from 1 November 2018. Neither Level 1 nor 2 AEBS can guarantee that the vehicle will come to a complete stop before an impact.

H.2 US Heavy Vehicle ESC Legislation

The United States has recently introducing Federal Motor Vehicle Safety Standard No. 136 – Electronic Stability Control for Heavy Vehicles (FMVSS 136) (NHTSA, 2015). FMVSS 136 requires the mandatory fitment of ESC to (Andersky, 2016):

- Class 7 vehicles – designed and constructed for the carriage of goods which have a maximum mass exceeding 26,000 pounds but not exceeding 33,000 pounds;
- Class 8 vehicles – designed and constructed for the carriage of goods which have a maximum mass exceeding 33 000 pounds;
- Tractor units; and
- Certain buses.

The regulation is split in to three phases; Phase 1, 2 and 3:

- Phase 1 applies to all new Class 7 and Class 8 air-braked 6x4 tractors and came in to effect on 1 August, 2017;
- Phase 2 comes in to effect on the 24 June 2018 and mandates ESC on Class 8 buses; and
- Phase 3 will come in to effect on the 1st August 2019 and will apply to the majority of the remaining Class 7 and 8 air-braked tractors (4x2 and 6x2 tractors), along with Class 7 and 8 air and hydraulically braked buses.

Exemptions to this regulation include rigid HGVs, Class 3-6 vehicles (Gross Vehicle Mass (GVM) of 14 000 pounds – 26 000 pounds) vehicles, heavy-duty severe service tractors (gross axle rating of 29,000 lbs or more), as well as specialty vehicles. Exempt bus types include school buses, those with perimeter seating and transit buses.

Appendix I Progress towards UN Target 5 for ESC in the G20 countries

As outlined in Section 1, the UN General Assembly has adopted a series of road safety performance targets which includes a specific target for vehicle safety:

> Target 5: By 2030, 100% of new (defined as produced, sold or imported) and used vehicles meet high quality safety standards, such as the recommended priority UN Regulations, Global Technical Regulations, or equivalent recognized national performance requirements.

This appendix considers whether the countries in the G20 will likely meet the ESC target by 2030, or by how much they are likely to fall short without specific interventions to speed up the process of fleet fitment.

I.1 Countries with no current ESC regulation

As outlined in the main body of this report, seven of the G20 countries have not yet adopted ESC regulation: Argentina, Brazil, China, India, Indonesia, Mexico and South Africa. The analysis presented in Section 3.2 assumes that from 2020, all seven countries adopt the ESC regulation, mandating the fitting of the technology in all new passenger cars. In practice, this means that ESC is fitted in all new car models from 2020, and in all new cars from 2022, to give manufacturers a sufficient transition period to alter their processes if necessary.

Table 26 presents the estimated fitment percentage of cars in each country in 2030, taking into account the current levels of voluntary fitment, the regulation dates outlined above and the rate of turnover in each fleet.

Table 26: Estimated level of ESC fitment in each G20 country in 2030, if the ESC regulation is implemented in 2020 (reproduced from Table 7)

Country	Estimated percentage of total fleet fitted with ESC in 2030
Argentina	52%
Brazil	53%
China	100%
India	100%
Indonesia	60%
Mexico	26%
South Africa	53%
Total	**83%**

Overall, around 83% of the total car fleet (418 million cars) will be fitted with ESC in 2030 under the regulatory scenario; however, this falls short of the 100% fitment specified in the target. In particular, Mexico is predicted to only have 26% of its total car fleet fitted with ESC, driven by the slow rate of fleet turnover in this country.

I.2 Countries which have already implemented the ESC regulation

Thirteen countries of the G20 countries have already adopted ESC regulation: Australia, Canada, the EU, Germany, France, Italy, UK, Japan, Republic of Korea, Russia, Saudi Arabia, Turkey and the United States of America. Many of these countries adopted the regulation as early as 2009-2011 (see Table 1).

This section presents the results of a similar analysis to that presented in Section 3, which estimates the proportion of new and all cars which will be fitted with ESC in 2030 in each country. In these calculations, the number of cars leaving the fleet that are fitted with ESC is incorporated into the estimates through the equation:

$$CarsFitted(y) = CarsFitted(y-1) + NewCarsFitted(y) - LeavingCarsFitted(y)$$

The first step in the modelling process is to estimate the number of cars that are going to enter the vehicle fleet in each country, up to 2030. This has been done by extrapolating the data that is available, assuming a linear trend. The results for Italy are based on an extrapolation of the figures for 2005-2008 only, since the financial crisis which occurred between 2009 and 2014 appears to have had a large impact on the number of new cars in this country. Hence, the trend over the whole period would predict a large decline in new car sales, which seems unrealistic if the economy stabilises. There is some uncertainty in the figures for Russia, since these oscillate considerably over the period of interest. The results are illustrated in Figure 31.

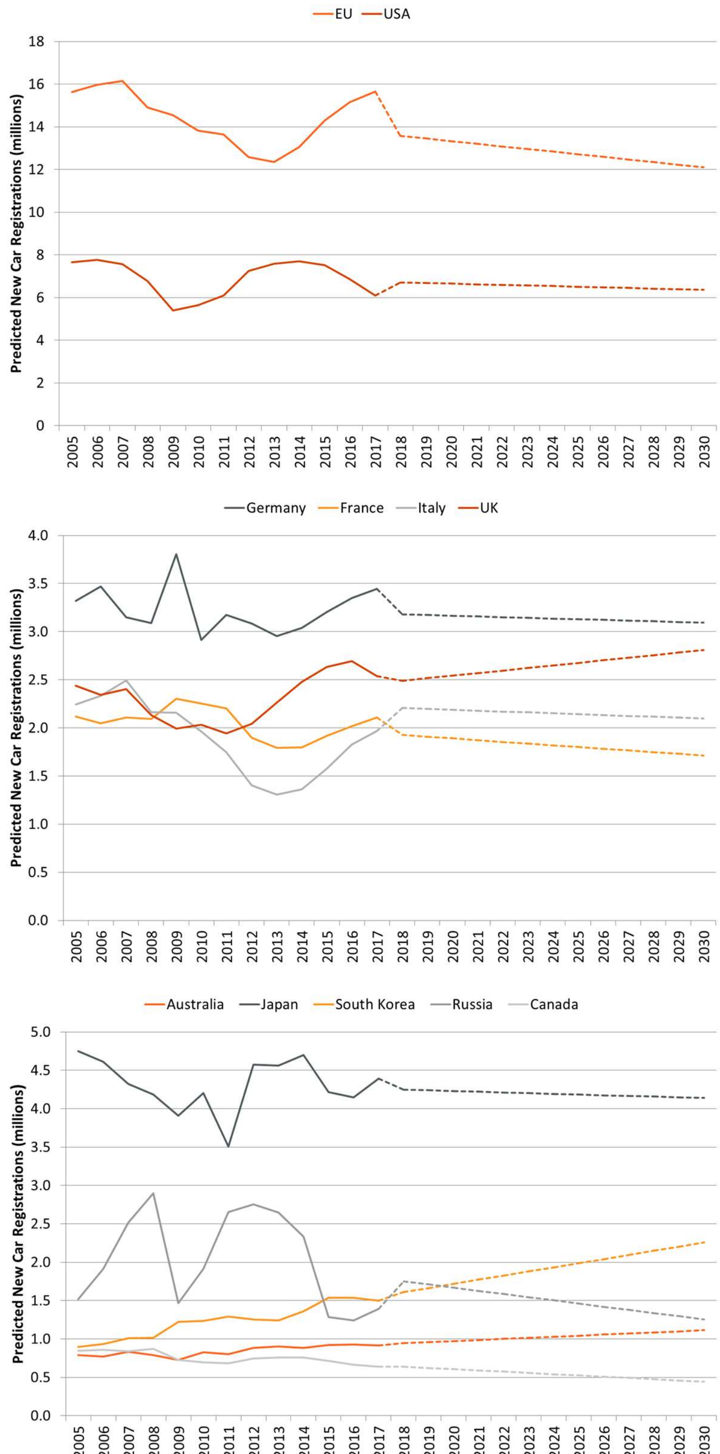


Figure 31: Predicted number of newly registered cars for each country (2005-2030)

The total number of registered cars over the same period is projected forwards using a similar linear assumption for all countries (Figure 32). As with newly registered vehicles, there is some uncertainty in the Russia figures: the current trend is upwards, but this may not be sustainable in the long term.

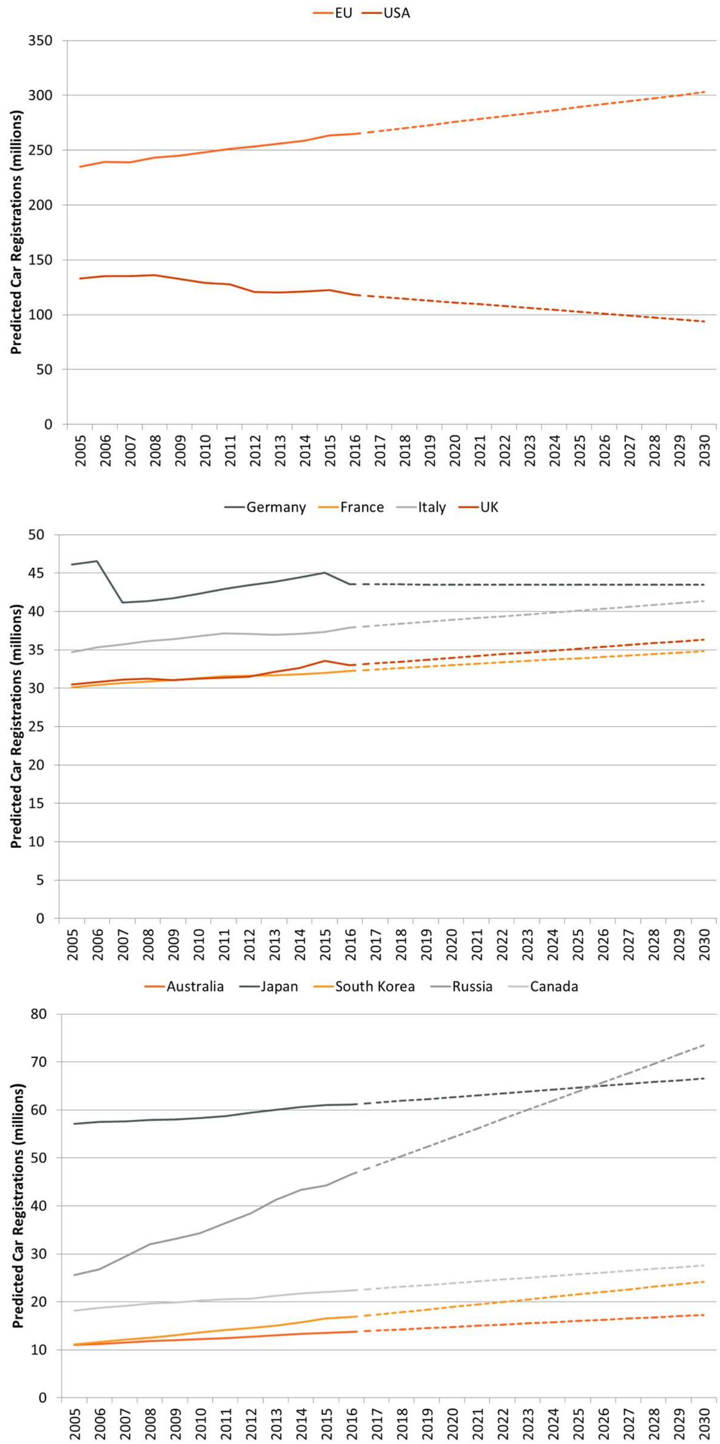


Figure 32: Predicted number of registered cars for each country (2005-2030)

Analysis of trends in the registration data for the 13 countries suggests that vehicles vary in age when they leave the fleet (see the final column of Table 27). These age estimates have been incorporated into the model, assuming that the proportion of vehicles leaving the fleet with ESC fitted in a given year matches the proportion entering the fleet Y years earlier. Note that the figures for Canada and Russia are unusually high compared to the other countries; this is driven by the downwards trend in new cars for these countries, but an upwards trend in all cars, which could be driven by imports of used cars from other countries.

This analysis also considers the launch year of voluntary uptake of ESC, the level of voluntary fitment achieved (based on data provided by Global NCAP or sourced from OEM websites), the date of regulation and the trends in new and all cars. Based on the data available, the S-shaped curves are fitted using different assumptions for each country. These are documented in Table 27.

Table 27: Assumptions for modelling

Country	Launch Year	Length of time taken to achieve maximum voluntary uptake (XX years)	% of cars fitted after XX years of voluntary fitment	Regulation year for new models	Regulation year for all new cars	Estimated average age of vehicles when they leave the fleet (Y Years)[53]
Australia	2001	12	80%	2012	2014	17.5
Canada	1995	15	60%	2009	2012	35.5
EU	1996	15	60%	2012	2015	19.6
Germany	1994	15	80%	2012	2015	14.9
France	1994	15	45%	2012	2015	16.0
Italy	1998	15	60%	2012	2015	21.5
UK	1998	12	60%	2012	2015	15.2
Japan	2000	20	60%	2013	2015	14.4
South Korea	2001	15	60%	2012	2015	15.3
Russia	2003	20	60%	2014	2020	31.5
USA	1995	15	60%	2009	2012	17.1

[53] Based on data from 2005-2015

Figure 33 shows the estimated percentage of new cars fitted with ESC in each country.

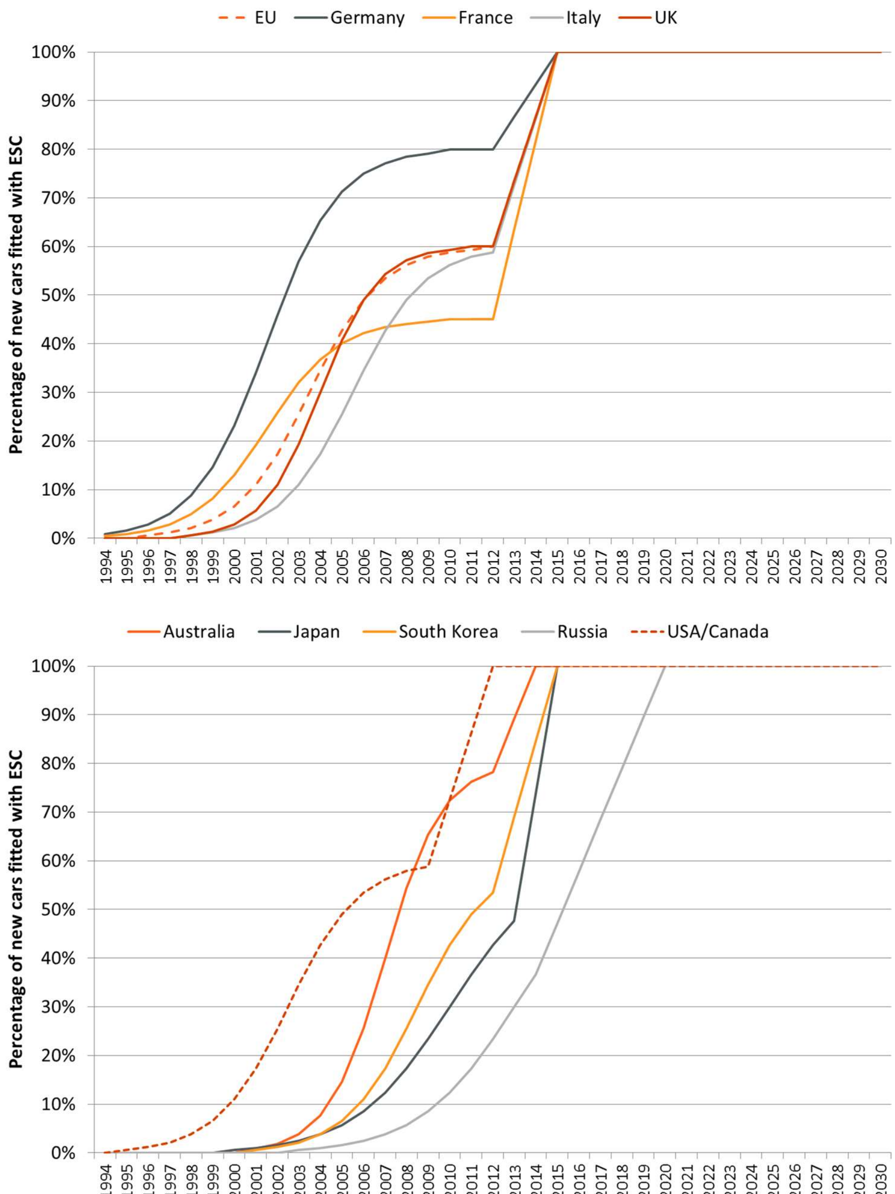


Figure 33: Estimated percentage of newly registered cars fitted with ESC based on the regulation timeline for each country (1994-2030)

Figure 34 presents the equivalent figures for all cars in each country's fleet.

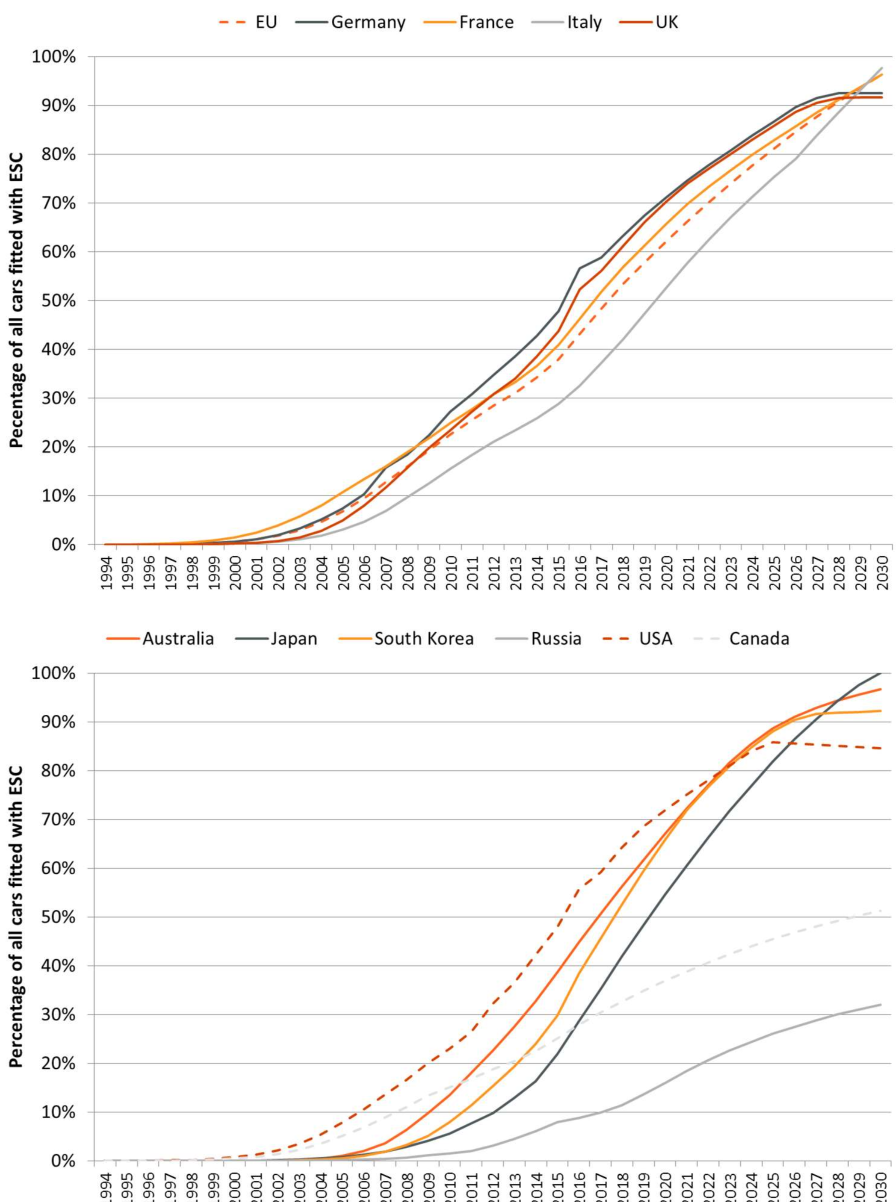


Figure 34: Estimated percentage of all registered cars fitted with ESC based on the regulation timeline for each country (1994-2030)

Finally, Table 28 presents the estimated fitment rates in each country in 2030.

Table 28: Estimated level of ESC fitment in 2030 in G20 countries which already have an ESC regulation

Country	Estimated percentage of total fleet fitted with ESC in 2030
Australia	97%
Canada	51%
EU	96%
Germany	92%
France	96%
Italy	98%
UK	92%
Japan	100%
South Korea	92%
Russia	32%
USA	85%[54]
Total	**87%**

In total in these 13 countries, it is estimated that 87% of cars (660 million cars) will be equipped with ESC in 2030. The figures for most countries are at, or close to, 100%; however, for Canada and Russia these are much lower (51% and 32% respectively). This is because the current trend for new cars in these countries is negative (i.e. there were fewer new cars being brought in 2017 compared to 2005) and as a result, the rate at which ESC infiltrates the fleet is much slower.

[54] This is a similar prediction to that made by the Highway Loss Data Institute in their 2016 bulletin 'Predicted availability of safety features on registered vehicles — a 2016 update' which suggests that ESC will be fitted to 95% of registered vehicles by 2033.

I.3 Progress across the whole G20

Combining the results from Table 26 and Table 28, it is estimated that in 2030 just over 1 billion cars will be fitted with ESC in the G20 countries. **This equates to 85% of the total G20 car fleet, demonstrating that unless more is done to promote the adoption of ESC these countries will not meet the Global Target of 100% fitment by 2030.** The promotion of ESC could be through a combination of regulation (as in the case of the seven countries in Appendix I.1), and scrappage schemes, which encourage a faster turnover of the fleet.

Table 29: Estimates level of ESC fitment in each G20 country in 2030[55]

Country	Estimated percentage of total fleet fitted with ESC in 2030
Argentina	52%
Australia	97%
Brazil	53%
Canada	51%
China	100%
EU	96%
France	96%
Germany	92%
India	100%
Indonesia	60%
Italy	98%
Japan	100%
Mexico	26%
Russia	32%
South Africa	53%
South Korea	92%
UK	92%
USA	85%
Total	**85%**

[55] For the 18 countries for which sufficient data was available

Costs and Benefits of Electronic Stability Control in Selected G20 Countries

The World Health Organization estimates that the number of road traffic deaths has reached 1.4 million per year, with the highest road traffic fatality rates in low-income countries. In 2017, the UN General Assembly adopted a series of road safety performance targets, one of which includes the objective to ensure that 100% of vehicles are equipped with ESC in 2030. The G20 countries are responsible for 98% of the world's passenger car production, but not all of them apply the most important vehicle safety regulations.

The overall aim of this research is to support the introduction of Electronic Stability Control (ESC) in the seven G20 countries that have not yet introduced legislation to mandate ESC. The report estimates the lives and serious injuries that could be saved by 2030 if Argentina, Brazil, China, India, Indonesia, Mexico and South Africa introduced ESC legislation in 2020, as well as the benefit-to-cost ratio for implementing ESC in these countries. The expected progress against the 2030 UN road safety performance target is also estimated.

Other titles from this subject area

PPR766 The potential for vehicle safety standards to prevent road deaths and injuries in Brazil. Cuerden, Lloyd, Wallbank & Seidl. 2015

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ISSN 2514-9652

ISBN 978-1-912433-54-4

PPR868