University of Toronto
Department of Economics

Working Paper 564

Are Automated Vehicles Coming at the Right Speed?

By Donald N. Dewees

August 05, 2016

Are Automated Vehicles Coming at the Right Speed?

Donald N. Dewees
Department of Economics
University of Toronto

Working Paper
5 August 2016

Abstract

Recent press reports have celebrated the development of automated or 'self-driving' cars and the benefits they would bring, yet actual benefits may fall far short of this potential. Drivers are exposed to only a fraction of the costs of accidents that they cause, they may underestimate the risks of accidents, and automated features may work in only a fraction of all driving situations. Studies have found that some drivers respond to safety devices by driving more 'intensely,' and some drivers refuse to accept even proven occupant protection devices such as seat belts. More drivers will resist the purchase and utilization of automated vehicle features that change their driving behaviour, especially if this reduces the speed or enjoyment of their driving. This paper analyzes the likely response of drivers to automated safety features. It suggests that benefits will be much less than forecast and will mostly occur a decade or two in the future because of driver behaviour and our likely reluctance to force drivers to submit to automated control in most driving situations. The shortfall in benefits will depend in part on the details of motor vehicle insurance policies and on public policies adopted by state, provincial and federal governments. There is an economic argument for policy encouragement of cost-effective accident-avoidance features but not for features that save time for the driver.

JEL classifications: K13, R41

Keywords: autonomous vehicles, automobile accident avoidance, driving intensity, insurance risk-rating, moral hazard

Introduction

Recent press reports have celebrated the development of self-driving cars and the benefits, risks and policy challenges they would bring. While the term 'autonomous vehicles' has been used, we will refer to 'automated vehicles' (AV) since there are many degrees of automation leading up to full autonomous operation where the driver can punch in the destination and crawl into the back seat for a nap during the trip. There have been calls for governments to ensure that the legal, regulatory and infrastructure environment is ready for the appearance of AV on our roads so we can secure valuable benefits.[1] A US study finds that private benefits of AV to drivers exceed costs even if full automation technology costs $10,000 per vehicle. (Fagnant and Kockelman, 2015, 175.) A Canadian study of AV also suggests that the benefits of are enormous, swamping the modest increased cost for the on-vehicle systems that make a vehicle autonomous.[2] The majority of the benefits arise from reduced death and injury from collisions avoided by AV technology, while additional benefits arise from freeing drivers to perform non-driving tasks and from reduced highway congestion.

Several factors may cause actual benefits to fall far short of this potential and to occur far in the future. To date, major improvements in vehicle safety have reduced injuries to occupants and pedestrians in the event of a collision, yet studies find that drivers take some of the benefits of safety devices in the form of driving more 'intensely,' achieving more speed or enjoyment but offsetting some of the safety benefits. (Peltzman, 1975; Keeler, 1994; Mannering and Winston, 1995.) Other studies show that some drivers refuse to accept even the most elementary and proven occupant protection devices, such as seat belts. Most safety-related AV features will reduce the risk of collisions occurring by changing driving behaviour – preventing unsafe maneuvers. We should expect more drivers to resist the purchase and utilization of devices that change their driving behaviour than reject occupant protection, especially if the result is to reduce the speed or enjoyment of their driving. This paper will explore the implications of this behaviour on the actual implementation and benefits of AV features using a combination of US and Canadian data.

I assume that most, but not all, drivers will purchase and use features for which the benefits to the driver and occupants exceed the costs. (Mannering and Winston, 1995.) I say 'not all' because the major motivation for regulations that require the installation and use of cost-effective safety technology on new cars is that the public cannot be counted on to buy and use these features voluntarily.[3] Where some of the benefits are conferred on others the driver's incentive to purchase and use them is less than if the driver enjoys all the benefits. This paper assesses the benefits of AV adoption to see which are private and which are public, concluding that the private incentive to purchase some accident-avoidance AV features, is insufficient - less than would be socially optimal. Moreover if drivers choose their driving style by balancing risk against speed and enjoyment, accident-avoidance features will reduce accidents less than would

[1] The Canadian Automated Vehicles Centre of Excellence white paper (CANCOE, 2015) has 30 recommendations to governments at all levels, industry and the public urging funding and infrastructure support for AV to ensure the fastest possible implementation of this technology across Canada. See also Mowat (2016) and Villasenor (2014).
[2] Gill et al. (2015) assume that full AV features would add about 10% to the price of a vehicle (p. 51) or $400/household/year (p. 50), less than 10% of the estimated annual benefits of $65 billion (pp. 29, 30).
[3] NHTSA reports argue that an extensive set of required safety equipment is highly cost-effective, saving lives at a cost well below economists' estimates of the 'value of life.' (Kahane, 2004b.)

be predicted by a model that ignores this 'offset.' In addition, careless drivers, who take risks that on casual observation seem unreasonable, are less likely to purchase or to utilize accident-avoidance features that interfere with their driving, so that real-world benefits will be less than are estimated by assuming universal purchase and utilization. This argues for policies that compel the purchase and use of such AV features, although such compulsion raises difficult issues of personal freedom. These factors will cause the sale of AV features to lag the availability of that technology and their utilization to lag still further. Replacement of the existing vehicle fleet will take time, so full benefits are probably decades away. In short, benefits will be smaller and later than are currently predicted and they will depend on policies that will have to balance safety with personal freedom. There is an important role for public policy with regard to AVs, but that role is nuanced, not just enabling or promotional.

Introduction to AVs.

Autonomous vehicles are not a single thing; they represent a continuum of driver assistance. The US National Highway Traffic Safety Administration (NHTSA, 2013) has a typology for five levels of AV.[4] At the low end we have existing warning systems like forward collision warning, blind-spot warning, lane-departure warning, etc., sometimes referred to as 'driver assistance'. Partial automation involves active accident avoidance systems such as currently available automatic emergency braking, lane-keeping assist as well as adaptive cruise control in which the system goes beyond warnings to take some action, with the driver otherwise in control. Forward collision warning and automatic emergency braking together are expected to reduce rear-end crashes by 40%. (IIHS, 2016a.) Conditional automation has the AV system controlling the vehicle but the driver is always attentive to take over if needed or requested by the system. This Level 2 automation seems to encompass much of the collision-avoidance features of AV. Limited self-driving is a system capable of driving the vehicle even if the driver is not available to intervene, while full self-driving (Level 4) does not require a driver to be available or even present. See Table 1. Each level of automation may function in only a subset of driving situations, such as expressway only or expressway and highway, or it may function in most or even all driving situations including congested city driving and winter blizzards. Levels

Table 1: NHTSA Levels of Driving Automation

NHTSA Level	Name	Definition
0	Driver Assistance	Warning without action: forward collision warning, blind-spot warning, lane departure warning, etc.
1	Partial Automation	Active accident avoidance: automatic emergency braking, lane-keeping assist, adaptive cruise control, etc. All features independent of each other. Driver in control.
2	Conditional Automation	AV system controls the vehicle in some, but not all, situations and driver is ready to take over at any instant if needed.
3	Limited self-driving	AV system controls the vehicle in some situations with the driver available after a transition time.
4	Full self-driving	AV system controls the vehicle even if the driver is not available or not present.
Source: NHTSA (2013, pp. 4, 5)		

[4] A similar typology is presented by Society of Automotive Engineers International (2014, p. 2)

2, 3 and 4 may function with each vehicle operating independently or they could involve vehicles communicating with each other and coordinating their actions. Vehicle-to-vehicle coordination in Level 4 and maybe Level 3 could enable a platoon of vehicles on a highway to follow each other at very close distances, counting on the coordination to brake all vehicles simultaneously if the lead vehicle brakes. Such coordination could nearly double the capacity of a highway, in vehicles per hour, without sacrificing safety. (Shladover, Su and Lu, 2012.)

Every year more driver assistance features appear and the capability of active accident-avoidance systems increases. Some manufacturers are testing prototypes of limited and full self-driving systems and promising that they will be ready for market in the next few years. It seems likely that the technology for full self-driving vehicles (Level 4) could be ready for market in the next five or at most ten years if the market is ready for it.[5]

Magnitude of costs and benefits

A 2015 study by the Conference Board of Canada (Gill et al., 2015) quantifies possible benefits in Canada from the universal adoption of full AV (Level 4).[6] This study relies, in turn, on US estimates for some of its base data, adjusted to Canadian conditions and prices. Gill et al. assume that 80% of collisions could be avoided by AV features, based on NHTSA's estimate that 93% of collisions involve human error[7] and most of these can be avoided by automation. Based on this, they calculate the cost savings of eliminating 80% of the 2000 Canadian fatalities and 160,000 injuries each year. They calculate separately the value of avoided congestion from eliminating these collisions on heavily travelled roads[8] and estimate the value to the driver of not having to attend to driving duties with full self-driving. They also note that full automation would save fuel by reducing congestion and reducing the amount of driving around looking for parking, since the car could drop off the driver and park itself or the car could be shared and not have to park at the end of the driver's trip. Gill et al. emphasise that they have used conservative assumptions[9] so that the estimates, while highly uncertain, are more likely to be low than high. They recognize that improved safety and reduced congestion may lead to more driving (Gill et al., 2015, pp. 52, 53), but they ignore the risk that drivers may respond to collision-avoidance features by driving more 'intensely'. Costs are assumed to equal a 10% increase in the purchase price of vehicles, or about $400/year/household,[10] a small fraction of the benefits and a small fraction of today's costs. Despite this uncertainty, these data provide a basis for at least a rough analysis of the incentives for individuals to adopt features of AV. See Table 2.

---

[5] See Mowat (2016, p. 2) for a discussion of the current state of technology.

[6] Fagnant and Kockelman (2015, p. 175) estimate costs and benfits for the US using different methodology and assumptions but finding similar relative magnitudes: collision avoidance benefits dominate but congestion savings and travel time savings for full automation are also substantial.

[7] Gill et al., 2015, p. 16, fn. 5 citing NHTSA.

[8] Gill et al., 2015, p. 29. They assume that AV could eliminate half of the estimated $10b/year in congestion costs in Canada, 'due mostly to eliminating most non-recurrent congestion alone'.

[9] For example they ignore property damage (damage to the vehicles) arising from collisions.

[10] The 10% assumption is on p. 51. Vehicle purchase costs average $3,875/household (p. 50) per year, averaging across all years. For 9.4 million Canadian households this adds up to about $4 billion/year.

Table 2 shows that avoiding collisions generates \$37.4 + 5 = \$42.4 billion of annual benefits, over 60% of the total benefits. Looking back to Table 1, the primary reduction in the risk of collisions seems to occur in Levels 1 and 2, culminating with the AV system controlling the vehicle under some conditions and thus eliminating human error and distraction- sleep-, alcohol- or drug-reduced performance. Levels 1 and 2 may reduce collisions but they do not allow the driver to do other things except perhaps texting or talking in Level 2, something that many drivers actually do today, unsafely. I will assume that driver time is **not** freed up in Level 2; instead safety is increased. Level 3 allows the driver to engage in significant non-driving tasks, such as reading, writing or perhaps napping at the wheel, thus providing some 'time saving' to the driver, the second largest benefit. It seems unlikely that Level 3 reduces accident risks much compared to Level 2. Only in level 4 with full automation is the driver not needed in the driver's seat or in the vehicle at all, which can save driver time and facilitate vehicle sharing. It seems unlikely that collisions are reduced significantly in moving from Level 3 to Level 4. Aggregate benefits to society from 100% installation and utilization of Level 2 and Level 4 AV features are summarized in columns 2 and 5 of Table 4 below.

Table 2: Annual Benefits and Costs from Full AV Deployment, Canada
(2011 \$ CDN in billions)

Benefit Category	\$ billion/ year	Comment
Collision Damage Avoidance	37.4	\$31.5b from 2000 fatalities, \$15.2 b from160,000 injuries. 80% assumed from driver error. Ignores property damage. Congestion delays from accidents counted separately below.
Collision Congestion Avoidance	5.0	Reduced time lost, fuel consumed and pollution emitted due mostly to non-recurrent congestion caused by collisions.
Time Saving	20.0	Driver time freed for work or entertainment.
Fuel Cost	2.6	Less looking for parking, less road congestion.
Total Benefits	**65.65***	
Costs	~4.0	Assuming a 10% vehicle cost increase (p. 51)

Source: Gill et al. (2015, pp 29-30, 51).
*Total reported in Gill et al. (2015); slightly greater than sum of the parts (65.0).

Owner/Driver Behaviour May Reduce Benefits

The benefits shown in Table 2 are based on eliminating 80% of collisions which is most of the collisions involving human error. This assumes that collision avoidance features are installed and functioning effectively on most vehicles and in most locations. It also assumes that drivers do not respond to AV features in a way that substantially increases accident risks. We can look to experience and theory to explore the extent to which these assumptions are realistic. For simplicity I will treat the driver and all passengers in his/her car as one decision-making entity, called the driver. This is probably a good approximation to the well-functioning household. In addition, I will assume that some drivers are 'careless' in that they underestimate the risk that they will be involved in collisions; underestimate the risk and extent of injury and loss that might attend a collision, or just object to being told what to do.

a. Choosing and Using Occupant Protection

The extent to which drivers have bought and used **occupant protection** technology in the past provides some guidance as to the extent to which they may buy and use accident **avoidance technology** in the future. Cohen and Einav (2003) found that in states without mandatory use of seatbelts only 31% of drivers used them. Enforcement raised this to 48% almost immediately and to 65% by 1998.[11] By 2014, when most states required seat belt use, 13% of front seat occupants were still not wearing seat belts. See Table 3. While usage increased over time, a substantial fraction of the driving population will not use seat belts despite clear evidence that they greatly reduce the risk of fatality for the driver and occupants. Furthermore 45% of fatally injured vehicle occupants are known to be unrestrained, virtually the same percentage as those known to be restrained (47%).[12] See Table 3. Drivers who do not wear seat belts may be involved in more accidents than those who do; occupants of vehicles that crash who do not wear seat belts may be much more likely to be killed than those who wear them, or both. The latter is certainly true; the former seems likely. One can only conclude that some members of the public

Table 3 2014 US Motor Vehicle Crash Data

Event	Number	%	Sub-%
Police-reported crashes (million)	6.1		
Persons injured (million)	2.3		
Fatal crashes	29,989		
Fatalities	32,675	100%	
Car occupants		38%	
SUV occupants		25%	
Pedestrians		15%	
On motorcycle		13%	
Single-vehicle accident fatalities		56%	
Multi-vehicle accident fatalities		44%	
% of fatalities where alcohol was a cause		31%	
Where alcohol was a cause, % with known blood alcohol content (BAC) >0.08			44% of 31%
% of front seat occupants who wear seat belts, daytime*		87%	
% of fatally injured occupants known unrestrained		45%	
% of fatally injured occupants know restrained		47%	
% of fatally injured occupants restraint unknown		8%	

Source: NHTSA, 2015.
* IIHS, Fatality Facts, General Statistics by State, 2014. http://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/state-by-state-overview .

are very reluctant to use basic personal safety protection that is standard equipment and does not reduce their driving speed or behaviour. This suggests that some drivers will not voluntarily purchase accident-avoiding AV technology, limiting the benefits of such technology.

[11] Table 1, p. 835. Interestingly, Cohen and Einav found that states that effectively enforced seat belt usage did not experience an increase in non-occupant fatalities or the total number of accidents, suggesting that increased seat-belt usage arising from this enforcement did not lead to offsetting increases in driving intensity.
[12] The use of seat belts by 8% of occupants was not determined.

b. Incentives to Choose and Use Accident Avoidance Features

Driver utilization of collision-avoidance features differs from occupant protection features in that the former benefits others as much as it benefits the driver and occupants. Predicting the use of accident-avoidance features can be informed by examining driver incentives to use those features. To the extent that drivers are motivated by self-interest, we would expect less utilization of collision-avoidance features relative to the social optimum than of occupant-protection features which benefit only the driver and other occupants.

Economists generally assume that a well-informed consumer in a competitive market is in the best position to choose goods and features of those goods to maximize individual welfare, which will maximize general welfare in the absence of externalities. While this is a useful abstraction and starting point, the real world is filled with consumer ignorance, imperfect competition and externalities any of which may lead consumers to decisions that fail to maximize individual or collective welfare. Surveys have shown consumers to be surprisingly ignorant of the safety features on recently purchased vehicles.[13] This is far from a perfect market. Current regulations require dozens of auto safety features because experience has shown that not all consumers will choose even highly cost-effective safety features.[14]

In single-vehicle collisions, accounting for over half of all collision fatalities, the driver and his/her insurer would bear most costs of the accident including damage to the vehicle, damage to other property, medical costs, lost income and pain and suffering. With perfect information the driver would have incentives to choose the optimal mix of accident-avoidance features. We will treat single-vehicle and multiple-vehicle collisions together since a driver does not know in advance which type of accident might occur. In multiple-vehicle collisions the cost to the driver depends on how liability is assigned to the drivers by the insurance and legal systems. One driver's share of the cost could vary from nil to complete. If there is no insurance, the apportionment of liability is proportional to fault, and the driver has substantial wealth,[15] the incentive to choose optimal features might be preserved.[16]

Insurance, however, is deeply involved in the costs of collisions. Most motorists in North America carry liability insurance and many carry collision insurance to protect against bearing the cost of losses from major accidents. While many insurance premiums vary by age, gender and location, and while premiums may increase after an accident, the driver involved in a serious accident ultimately pays only a fraction of the costs of that accident; this is the very purpose of insurance. All Canadians and some Americans are protected from most medical costs by health insurance. This combination of auto insurance and health insurance means that the driver who is involved in an accident generally bears only a small fraction of the cost of losses from the collision. This will attenuate the incentive to invest in and utilize features that reduce collisions.[17]

---

[13] A survey of 630 owners of cars with Automatic Emergency Braking found that 35% did not know that their car had this important safety feature. (Consumer Reports, 2016a, p. 27.)

[14] Kahane (2004a) studies a list of 19 technologies required by US Federal regulations and some that are not.

[15] Sufficient wealth that s/he can compensate victims of an accident for the full value of all losses.

[16] See Shavell (1979), Ben-Shahar and Logue (2012).

[17] Cohen and Dehejia (2004) find that compulsory auto insurance increases traffic fatalities by reducing the proportion of uninsured motorists on the roads, reducing the number of motorists who face full accident costs.

The extent to which insurance insulates drivers from the consequence of their carelessness and mistakes depends on the details of the insurance arrangement. If premiums are not risk-rated so everyone pays the same premium the driver bears little cost of his/her accidents other than the deductible and uncompensated pain and suffering. The monetary incentive to take care is minimal. If premiums depend in part on safety features of the vehicle this restores some incentive to purchase cost-justified safety features. If premiums depend on accident experience, there is some incentive to enable those features and to drive carefully.[18] If premiums are based on actual driving behaviour, which is increasingly possible with sensors installed in vehicles,[19] the incentive increases further. Today, however, most drivers pay premiums that respond only modestly to accident experience and not at all to risky driving behaviour that does not lead to accidents or traffic tickets with 'points'. They face only a fraction of the costs caused by accidents in which they are involved, particularly major accidents that account for the majority of accident costs. In the absence of hard data I will assume that fraction is 25% of the marginal cost of their accidents. This means that the incentive to buy and utilize safety systems for collision avoidance falls far short of optimal.

Utilization is an issue because currently some warning and avoidance systems can be disabled by the driver.[20] Safety systems sometimes give off false alarms[21] so drivers may switch them off in situations likely to produce false alarms and may leave them off. We have all seen careless driving: driving too fast, following too closely, changing lanes into a space too small to allow safe stopping distances, changing lanes without signalling and weaving through traffic. Many of these maneuvers would not be allowed by Level 2 AV and none of them would be taken by Levels 3 or 4 AV. Are these drivers likely to submit to the placid ride of an AV control, or do they value the fun or time-saving of aggressive motoring much more than their perception of the personal and collective accident risk? If drivers are free to disable most AV safety features, some drivers, perhaps those who most need those features, will disable them, reducing benefits. With only 25% of accident costs imposed on the driver and with the clear evidence of 'careless' behaviour, only a fraction of the potential benefits in Table 2 will be realized.

c. Safer Cars and Aggressive Driving

The issues that may lead drivers not to buy or activate accident-avoidance technology, discussed in subsection b above, may also lead drivers to take more risks, relying on collision-avoidance features to protect them. The FARS data in Table 3 indicates that 31% of total

[18] See Shavell (1979) for an early theoretical analysis of insurance and the incentive to take care with a proof that an insurer with perfect information about the insured's care can provide a perfect incentive to take care. Ben-Shahar and Logue (2012) discuss in principle how the terms of insurance contracts can induce care, with particuar application to motor vehicles (p. 220). See also Schwartz (1999) on auto insurance and driver care.

[19] Some insurance companies offer discounts to drivers who install a recording device in the car. For example Desjardins Insurance in Canada has the Adjusto program that measures four criteria: 'driving smoothness (fast acceleration, hard braking and hard cornering), speed, time of day travelled and distance travelled.' A good score leads to discounts on the insurance rate. See: https://www.desjardins.com/ca/personal/insurance/car-insurance/ajusto/# . In the US, Progressive has offered use-based insurance since the late 1990s. For a history see Desyllas and Sako (2012, section 5.1, 5.2); for some analysis see Paefgen, Staake and Fleish (2014).

[20] For example, on certain models the electronic stability control, distance warning function, collision prevention assist, attention assist, blind spot assist and lane keeping assist can all be deactivated by the driver. See, *e.g.* Mercedes-Benz B-Class Operator's Manual, Edition A, 2014, pp. 200-201.

[21] One survey found many reports of forward collision warning or automatic emergency braking activating when it was not warranted. (Consumer Reports, 2016a, p. 30.)

fatalities are associated with alcohol-impaired driving. It is implausible that 31% of drivers are impaired, so impaired drivers must be disproportionately involved in fatal accidents. Moreover, of drivers killed whose blood alcohol level is known, 44% had a BAC >0.08. Impaired driving is a major cause of motor vehicle fatalities despite the risks of impaired driving being widely publicised. Some drivers are willing to risk serious accidents by driving under the influence.

Peltzman (1975) argued, and Keeler (1994) confirmed, that the occupant-protection features required by 1968 US legislation led to increased ‘driving intensity’ that increased risks to non-occupants and failed to reduce the overall highway fatality rate. Those studies looked at occupant protection features that obviously protected the driver and passengers in the event of a collision. More relevant is the Winston, Maheshri and Mannering (2006) study of the effect of air bags (occupant protection) and anti-lock brakes (ABS) (accident-avoidance) in the1990’s. They found that safety-conscious drivers were more likely to purchase these two features than other drivers but that their increased prevalence did not significantly reduce collisions or injuries. This reinforces the ‘offset hypothesis’ that some drivers will take some of the benefit of collision avoidance and occupant protection in the form of increased ‘driving intensity’ to satisfy their desire for speed and/or enjoyment. O’Neill and Williams (1998) argue that the ‘risk homeostasis’ hypothesis has been completely rebutted, citing several empirical studies. Yet one need not believe that the driving intensity completely offsets the benefits of safety equipment to believe that there is some offset. Indeed long-term accident statistics prove that drivers do not fully offset safety technology. In 1966 there were 5.5 fatalities per 100 million vehicle-mile travelled (VMT) but by 2014 the corresponding figure was 1.07, a reduction of 80%. The injury rate dropped from 189 per 100 million VMT in 1988 to 77 in 2014, a 59% reduction.[22] This suggests that technology has a large beneficial effect but it does not prove that there is not substantial offsetting behaviour. We should expect that increased driving intensity will reduce the benefits of accident-avoidance technology below, perhaps far below, what would be predicted when assuming unchanged driver behaviour. Again, estimated benefits must be discounted.

Apportionment of costs and benefits

To assess the incentives for drivers to take precautions it is useful to review the major benefit categories quantified by the Conference Board of Canada to assess the proportion of the benefits that accrue to the ‘driver’. The proportions should be similar in the US.

Collision Damage Avoidance: $37.5 billion/year

The preceding section identified a number of reasons why the ‘driver’ faces only a fraction, perhaps 25%, of the economic costs of decisions that increase the risk of accidents. This is very uncertain and it depends importantly on insurance policy provisions that in turn depend on technology that is changing rapidly, on insurer behaviour and on public policy. Most of the collision avoidance benefits are achieved at Level 2 and it seems unlikely that the fraction of the accident costs borne by the driver would change between Level 2 and Level 4.

% of benefits accruing to driver ~ 25%.

[22] NHTSA, 2015, P. 1 and NHTSA 1995, Table 2.

Collision Congestion Avoidance: $5 billion/year

Gill et al. (2015) say that AV will reduce congestion by promoting ride-sharing, reducing spacing between vehicles and anticipating traffic patterns. However their estimate of $5 billion/ year in benefits is based mostly on the reduction in congestion arising from reducing traffic accidents during times of heavy traffic. (Gill et al., 2015, p. 29.) They admit that their benefit estimate is highly uncertain. But when one driver avoids causing an accident it benefits all motorists on the road. The driver's share of those benefits is roughly equal to the inverse of the number of drivers delayed by the accident. On a heavily travelled road, this fraction is very small. In economic terms congestion is a public good so the time savings from AV features that reduce congestion are a public good. The driver's incentive to buy an AV to reduce congestion is an insignificant fraction of the public benefit and clearly inadequate.

Not included in the Gill table are the benefits from coordinated vehicle operation in Levels 3 and 4 whereby vehicles can join a platoon and move together at very close spacing on expressways or highways. This could almost double highway capacity, reducing congestion and saving valuable time for motorists or reducing investment in highway capacity or both. We have no estimate of the value of this benefit.[23] In any event this congestion, too, is a public good so an individual driver's benefit from joining such a platoon is insignificant.

% of benefits accruing to driver: ~0.0

Time Saving: $20 billion/year

Gill et al. (2015, pp. 24-26) says that time savings from converting driving time to free time (while the car drives itself) is worth $20 billion/year, based on a calculation of total time saved and an estimate of the value of each hour saved. This saving accrues entirely to the driver that uses Levels 3 and 4 in Table 1 so that the driver can be completely inattentive much of the time. Taking the 'driver' as the decision-maker, there is no externality here. The incentive to buy features providing limited or full self-driving is optimal which means that we should be able to rely on the market to provide AV features that yield time savings.

With Level 2 automation the driver must be ready to take over at any time but the vehicle will drive itself in some conditions. I assume that this allows the driver to talk, text, read or write during some of the automated time. In fact many drivers do this today. I assume that Level 2 automation does not increase the driver's inattention compared to current attention and therefore saves no time. Instead Level 2 automation increases safety. An alternative assumption would be that drivers become more inattentive which would reduce the benefits of Level 2.

% of benefits accruing to driver: ~100%

Fuel cost: $2.6 billion/year

Gill et al. (2015, p. 26) says that fuel savings arise from reduced time looking for a parking space and reduced congestion. This arises only at levels 3 and 4. The fuel saving from not having to look for parking spaces accrues to the driver. However the fuel saving arising from reduced congestion, estimated at $2.6b/year in aggregate, arises from every driver buying an AV. One individual buying an AV reaps only that insignificant fraction of the reduced congestion fuel consumption. Therefore the private incentive to buy an AV to save fuel is only a fraction of the

[23] While Gill et al. offer no estimate of this benefit, Fagnant and Kockelman (2015) include it in their simulations.

social benefit. It is a public good. In the absence of any data, I will assume that the parking search fuel saving represents 20% of the total fuel saving.

% of benefits accruing to driver: ~20%

Summary

If we multiply the percentage of avoided loss (benefit) borne by the driver, derived above, by the aggregate estimated loss in each category, from Table 2, we get columns 4 and 6 in Table 4. In the case of Level 2 AV features which I have assumed achieve most of the safety benefits, column 3 summarizes the social benefits available if universally installed and utilized. The driver's share of the social benefits for each benefit category, shown in column 2, is the same for any level of AV feature, so we can applying the same percentages to column 3, resulting in the aggregate driver benefits for implementing Level 2 shown in column 4. Level 2 is assumed to achieve no savings of the driver's time, since the driver needs to be ready to take over on an instant's notice, with the automation instead increasing the safety of today's distracted driving. The driver's incentive to purchase the safety features up through Level 2 are 22% (9.35/42.4) of the social benefits, clearly inadequate for efficient adoption. Policy encouragement for purchase and use of the safety features through Level 2 may be warranted.

In the case of Level 4, the same calculations, multiplying column 2 by column 5, suggest that drivers face about 45% (29.9/65.65) of the costs that can be avoided by full AV operation, meaning that drivers reap only 45% of the benefits of full AV operation. Each driver, when deciding whether to purchase full AV features and whether to utilize full AV operation when it is available, faces the full costs of purchase and utilization but less than half the benefits. Setting aside issues of imperfect information and 'careless' drivers, we would therefore expect many buyers not to purchase AV features even if the social benefits exceeded the social costs.

Table 4: Driver's Share of Social Benefits

Benefit Category	**Driver Share (%)**	**Level 2 benefit ($bn/year)**	**Driver $ ($bn/yr)**	**Level 4 benefit ($bn/yr)**	**Driver $ ($bn/yr)**
Column	**2**	**3**	**4**	**5**	**6**
Collision Damage Avoidance	25	37.4	9.35	37.4	9.35
Collision Congestion Avoidance	0	5.0	0	5.0	0
Time Saving	100	0	0	20.0	20
Fuel Cost	20	0	0	2.6	0.52
Total Benefits		**42.4 Social**	**9.35 Driver**	**65.65 Social**	**29.9 Driver**
Driver Share			**22%**		**45%**

Based on Gill et al. (2015, pp. 21-31), data from Table 1 and author's calculations.

Implementation Policy Issues

Even if some set of AV features is available in all new vehicles, the analysis above suggests that not all purchasers will spend the money for it unless it is required equipment. Furthermore, if we mandate the installation of some AV features the analysis suggests that some of the drivers whom we most want to submit to at least Level 2 AV will not do it voluntarily. They will not buy optional Level 2 AV features and if those features are standard equipment they will disable them if possible. To this extent, benefit estimates based on universal deployment and usage overestimate the benefits.

For example, in 2016, adaptive cruise control allows the driver to set any speed, regardless of the legal limit, but it slows the vehicle to keep a safe distance from any vehicle ahead. If most vehicles have Level 3 or 4 AV, will we allow those features to be combined with speeds well above the speed limit or will the AV controls limit speeds to the speed limit or some calculated safe speed considering driving conditions? One often finds expressway traffic flowing at a speed well above the posted speed with some vehicles trying to drive even faster than the flow. With full AV and car-to-car communication, can the lead driver in a platoon choose speeds well above the limit or will regulations confine AV platoon speeds to the speed limit or to some calculated safe speed? If the latter, how many drivers will opt out of full AV operation in order to drive faster? The time saving benefits of driving faster accrue to the driver, the costs (accident risks) are shared with other motorists. Opt-out drivers reduce the collision-reduction benefits of AV especially if they are 'careless' drivers. Without compulsion, benefits will be less, maybe much less, than forecast in Tables 2 and 4. Mowat (2016) and Villasenor (2014) discuss public policy issues that AV may raise regarding liability, compulsory purchase and utilization of features, investment in public infrastructure and much more. Government policy will have to balance a conflict between improved safety and personal freedom, a difficult balance when it involves Americans and their cars.

So, we have three factors that will reduce benefits below those calculated assuming an 80% reduction in driver-caused accidents: drivers who do not purchase available AV collision-avoidance features; drivers who do not activate or who de-activate those features some or all of the time; and drivers who increase their driving intensity to take advantage of the reduced risks. In addition, considerable public investment may be required for widespread effectiveness of some AV features and some features may not be effective in complex urban situations or bad weather for decades.[24] Existing data are not sufficient to allow us to predict with any confidence the extent to which these factors will reduce the benefits from vehicle automation. However recognizing that, unlike past occupant protection technology, accident-avoidance features must slow and calm driving behaviour to be effective, the reduction in benefits attributable to those who opt out could be very large. To test sensitivity, I will assume that these factors might reduce the benefits by as little as 1/3 or as much as 2/3. These assumptions reduce benefits of Level 2 automation from $42.4 billion/year in Canada, to between $14 billion and $28.4 billion/year. Since Level 4 automation provides benefits that accrue mainly to the driver, we might assume that a higher proportion of those incremental benefits are achieved, say 80% or 100%. But Level 4 automation can only be enjoyed by drivers who have fully implemented Level 2 collision

[24] Mowat Centre (2016, p. 16) discusses the need for public investment. Chris Urmson, Google's self-driving car project director said in March, 2016 that while self-driving cars might work in good weather and easy roads in a few years, it may be thirty years before they work in challenging conditions. (Gomes, 2016.) See also Gomes, 2014.

avoidance which will be a subset of all drivers. I assume that the net effect of these two factors is to achieve 33% and 67% utilization of Level 4. So the social benefits of Level 4 automation would be, at the low side, $21.7 billion/year and at the high side $44 billion/year. See Table 5.

These considerations raise some regulatory issues that will have to be confronted as AV features spread. We can take advantage of automation to force a reduction in careless driving but only at the price of reducing individual freedom. The benefits discussed above will reduced, perhaps greatly, if we do not restrict individual freedom by compelling the purchase and use of those features. A partial resolution to this dilemma would be to require that on some limited access highways where alternative routes are available access is denied except for vehicles that embody a specified level of AV that is fully enabled. Using the same logic, one could restrict access to existing or future High Occupancy Vehicle (HOV) or High Occupancy Toll (HOT) lanes to vehicles that have fully enabled a specified level of AV. To the extent that these roads and lanes are less congested than the alternatives, such rules will encourage the purchase and utilization of the collision-avoidance features that the market will likely under-value.

Table 5: Equilibrium Benefits to Society of AV Levels
Adjusted for Driving Intensity, Reduced Purchase % and Utilization
($ billion/year)

Benefit Category	**Level 2 benefits**	**33%**	**67%**	**Level 4 benefits**	**33%**	**67%**
Collision Damage Avoidance	37.4	12.3	25.1	37.4	12.3	25.1
Collision Congestion Avoidance	5	1.7	3.4	5	1.7	3.4
Time Saving	0	0	0.0	20	6.6	13.4
Fuel Cost	0	0	0.0	2.6	0.9	1.7
Total Benefits	**42.4**	**14.0**	**28.4**	**65.65**	**21.7**	**44.0**

Based on Gill et al. (2015, pp 21-31), data from Table 2 above and author's analysis.

A second method of encouraging the purchase and utilization of collision-avoidance AV features is improved risk-rating of insurance premiums. The more closely insurance premiums are based on the utilization of proven collision-avoidance features the greater the driver's incentive to purchase and use these features. If premiums are based on driving intensity, the intensity offset will be reduced. Here the development of technology that can record in real time the driver's utilization of accident-avoidance features and the driver's 'intensity' of driving can create financial incentives to utilize them fully. Agencies that regulate auto insurance will have to decide whether they should encourage aggressive risk-rating to encourage the purchase and utilization of accident-avoidance features.

Time Path to Full Benefits

The CBC benefit estimates assume that collision-avoidance features are installed and functioning on most vehicles and in most locations which means that their use is not confined to expressway driving, which constitutes only 25% of all driving in the USA.[25] But AV features will be added to new vehicles incrementally and some AV features will work in certain situations, such as expressways or highways in clear weather, and not in others such as congested city streets or rural lanes and in snow and slush.[26] It takes years for a feature that has been proven effective to become standard on all new vehicles[27] and some accident-avoidance features essential to full AV are not yet even options now so we may not see the full set of collision-avoidance features available in all vehicles until 2025. The median age at scrapping of vehicles in the US was about 13 years more than a decade ago;[28] today it is higher. This means that a feature that is standard in all cars in a given year will not be in most vehicles on the road for more than a decade. The benefits shown in Table 5 represent an end state that cannot be achieved for at least two decades. In the interim those benefits will grow slowly.

One study of the rollout of safety technologies found that emergency stability control (ESC), introduced in 1995, was not installed on 50% of new vehicles until 2006, was standard in 50% of new vehicles in 2007 and was installed in 90% of new vehicles only in 2011. In 2006 ESC was installed in only 12% of all registered vehicles and it had barely exceeded 40% of the fleet by 2013. (HLDI, 2014, p. 4.) Installation in 50% of the fleet was predicted to require 20 years from first introduction. The same study forecast that automatic emergency braking would not be installed on half the fleet until 2027. (HLDI, 2014, p. 6.) This study did not take into account the fact that newer cars are driven more extensively than older cars, so a new feature will represent a higher fraction of vehicle-miles travelled (VMT) than of total registrations. We can correct this deficiency in analyzing the time path to achieving the benefits of Table 5 with model incorporating both vehicle vintage and mileage. NHTSA has published a study of vehicle survivability as a function of age and VMT for each year after a vintage has been sold.[29] For simplicity, we assume a linear rollout of the availability of a full suite of collision-avoidance

[25] Vehicle Miles Travelled (VMT) on interstate highways (urban plus rural) in 2015 total 781 trillion which is 25% of the 3,130 trillion total VMT in that year. U.S. Department of Transportation, Federal Highway Administration, 2016, "Traffic Volume Trends: January 2016, " Table 2, p. 3.

[26] Gomes, 2014; Gomes, 2016. A Consumer Reports survey of owners of cars with forward collision warning or automatic emergency braking found that 'many owners said their FCW system activated when it wasn't warranted. Those with AEB had similar experiences when the brakes clamped for no apparent reason.' (Consumer Reports, 2016a, p. 30.) On my car (a 2014 model) the back-up camera operates poorly after driving on wet or slushy roads; the blind spot detection is sometimes impaired in slushy conditions, the lane-keeping warning can be disabled by snow or by poorly painted lane lines. The owner's manual description of driving safety systems is replete with warnings that the systems will not handle certain situations. For example: "Adaptive Brake Assist cannot always clearly identify objects and complex traffic situations. In these cases, Adaptive Brake Assist may not intervene. There is a risk of an accident. . . . Adaptive Brake Assist does not react: to people or animals, to oncoming vehicles, to crossing traffic, to stationary obstacles, when cornering." Mercedes-Benz B-Class Operator's Manual, Edition A, 2014, p. 66.

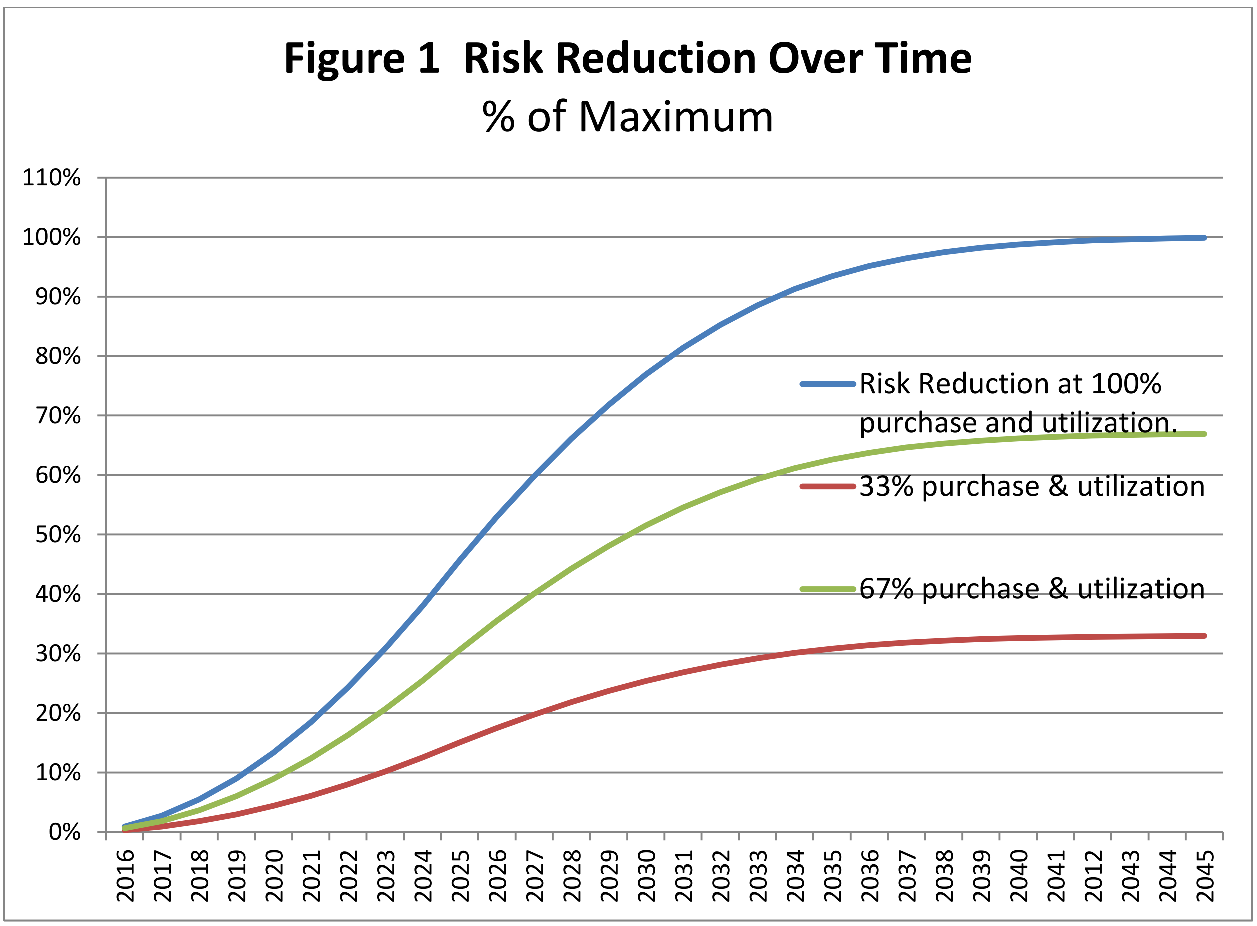
[27] In March, 2016, the U.S. Department of Transportation and the Insurance Institute for Highway Safety announced that 20 automakers had agreed to make automatic emergency braking standard on all new light-duty vehicles by September 1, 2022 - 6½ years later. (IIHS, 2016b.) This feature had been an option for several years and is said to reduce the risk of rear-end crashes by 40%. (IIHS, 2016a, p. 1.) Trucks 8,500 to 10,000 lbs will have AEB standard by September, 2025.

[28] NHTSA, 2006, 'Vehicle Survivability and Travel Mileage Schedules', DOT HS 809 952, Table 7, p. 22.

[29] NHTSA, 2006, 'Vehicle Survivability and Travel Mileage Schedules', DOT HS 809 952.

features in new vehicles at the rate of 10% in 2016, 20% in 2017 with a 10% increase each year until all new cars have those features standard or optional in 2025. For simplicity we further assume that the rate of new vehicle sales is constant and that the miles driven and survivability as a function of age do not change over time. Multiplying the number of vehicles sold in each year by the percentage with full features and multiplying by weighted VMT for each vintage in that year gives a figure that is proportional to available benefits from the full suite of features. This is the top line in Figure 1. Taking our best case (67%) and worse case (33%) assumptions produces the other two lines.

Figure 1 shows that if we ignore the limiting factors of the past section, 50% of the benefits will not be achieved until 2025 and 90% will not be achieved until around 2034, two decades hence. This is slightly faster than the HLDI predictions that ignored VMT as a function of vintage but still slow. Our high case, with optimistic assumptions about purchase, utilization and offset, would not achieve 50% of the theoretical maximum benefits until 2029, while the low case, with more pessimistic assumptions never reaches 50%. While one might argue about the exact parameters of our model, Table 5 shows that we will never achieve the benefits forecast by Gill et al. (2015) and Figure 1 reinforces previous analyses of safety equipment showing that the majority of the benefits are more than a decade away. Even these calculations are highly optimistic. While technology may be advancing rapidly the benefits are moving slowly.



Conclusion: The Market Is Too Slow for Safety

While the numbers discussed in this analysis are subject to considerable uncertainty, some conclusions seem clear. Using the Conference Board of Canada data as a starting point and allocating benefits to the driver and to others, less than a quarter of the social benefits of Level 2 AV features accrue to the driver. The fraction is small because most of the benefits arise from collision avoidance and a driver reaps only a fraction of the benefits from his/her avoiding accidents. Most of the remaining benefits arise from reduced accident-caused congestion which is a public good so a driver's share of those benefits is approximately zero. Drivers capturing less than a quarter of social benefits have a seriously inadequate incentive to invest in the collision-avoidance features of AV systems: most of the features up through Level 2.

Many of the benefits of AV require driver implementation of AV features. Yet the careless driver and the driver in a hurry are no more likely to utilize collision-avoidance features that interfere with their other driving goals than they are to obey the existing traffic rules. A substantial fraction of the collision-avoidance benefits of AV operation would require its utilization by drivers who are unlikely to utilize it. Even if we mandate the installation of collision avoidance systems on new cars, unless we require all vehicles on all roads or on most roads to utilize those features on those roads, we will reap only a fraction of the touted benefits. If we contemplate mandating the installation of accident-avoidance AV features we need to encourage or require their utilization if we are actually to achieve the calculated benefits. The resulting conflict between improved safety and personal freedom is a difficult issue particularly when it involves Americans and their cars.

Studies of both occupant-protection and accident-avoidance technologies have shown that drivers in aggregate will offset some of the benefits of these technologies by increasing driving intensity. If we mandate installation and utilization of accident-avoidance AV features we need to consider policies to ensure that drivers cannot offset the increased safety with increased driving intensity. In the absence of such policies, any assessment of the costs and benefits must discount benefits to recognize this offset behaviour.

Moving on to full Level 3 or 4 AV features, this analysis suggests that only 45% of the total annual benefits, accrue to the driver under today's legal, insurance and regulatory framework. On the other hand, the driver captures 88% of the incremental benefits that Level 4 AV adds to benefits achieved in Level 2. There is minimal externality here and we should expect the market to work well in providing Levels 3 and 4 features on vehicles and in encouraging drivers to utilize those features. There is little justification for government encouragement for full automation other than providing necessary infrastructure as demand warrants.

Missing from this quantitative analysis is Level 4 and maybe Level 3 AV with vehicle-to-vehicle communication that can enable closely-spaced platoons of vehicles to operate on certain types of roads, perhaps doubling road capacity. The increased road capacity benefits of this platooning are a public good for which the individual driver captures an insignificant fraction of the benefits. This is an argument for possible government encouragement of the platooning aspect of Levels 4 and 3 AV operation in situations where it appears cost-effective recognizing real-world limitations on implementation.

Some evidence suggests that a significant fraction of motor vehicle purchasers and drivers are not well informed about the balance of costs and benefits of safety features and may choose not to purchase AV features for which the private benefits outweigh the costs. This offers another justification to consider mandating collision avoidance features of Levels 1 and 2 on all new vehicles, but only if they appear cost-effective when we realistically account for utilization and offsetting behaviour. The time-saving of Levels 3 and 4 AV, which enables the ‘driver’ to ignore driving duties for some or all of the trip are intuitively obvious and not subject to the imperfect information argument for government encouragement.

There is a middle ground in the safety/personal freedom tradeoff. We could reserve certain lanes or highways for vehicles with a specified set of accident-avoidance technology installed and enabled. This could encourage drivers to buy and enable the technology so they could enjoy the benefits of safer and perhaps less congested driving, protected from the risks presented by other drivers. No one would be compelled to submit to AV operation.

Accident insurance is an important element in the shortfall of private incentives to purchase and utilize some AV collision-avoidance features. Not all motor vehicle insurance policies adjust rates based on the safety rating of the vehicle, only a fraction involve monitoring of driving behaviour and many policies do not adjust rates adequately to reflect accident experience and risks. Insurance companies have an incentive to make these changes but the insurance market itself is imperfect and regulators may limit rate differentials. We need to consider whether the regulation of the auto insurance market, already heavily regulated in most jurisdictions, should encourage or require rating systems that reflect as accurately as possible the potential benefits of buying and utilizing collision-avoiding AV features.

Estimates of the benefits of AV tend to focus on the aggregate annual benefits arising from universal installation and utilization of some level of AV features. But those features are not all on the market today and they will not all be installed in all new cars when first introduced. Some features may not work well in many driving situations such as snow and slush-covered roads, congested city streets with dense interactions between motor vehicles, pedestrians, bicycles and other objects. Even when all new cars embody all features it will take more than a decade of new cars replacing old cars before full features are present in most vehicles on the road. Maximum benefits are probably two or three decades away and they may never achieve the estimated levels if AV operation cannot economically become universal. We should look critically at claims of massive benefits from AV in the near future.

The market is providing an increasing array of driver warning and driver assistance technology moving gradually toward full AV operation. Public policy can encourage or retard the adoption and utilization of these features. This analysis suggests that we should lean toward encouraging the adoption and utilization of collision-avoidance features, but only if they appear cost-effective when we realistically adjust for the many barriers to real-world implementation and for offsetting driving behaviour. We should let the market decide the rate at which full autonomous operation is implemented. Difficult policy decisions lie ahead.

References

Ben-Shahar, Omri and Kyle D. Logue, 2012, "Outsourcing Regulation: How Insurance Reduces Moral Hazard," 111 *Michigan L. Rev.*, 197.

Canadian Automated Vehicles Centre of Excellence, 2015, "Preparing for Autonomous Vehicles in Canada: A white Paper Prepared for the Government of Canada," 16 December, 2015. http://www.cavcoe.com/Downloads/CAVCOE_AV_White_Paper.pdf .

Cohen, Alma and Rajeev Dehejia, 2004, "The Effect of Automobile Insurance and Accident Liability Laws on Traffic Fatalities," *J. Law and Econ.*, 47:2, October, 2004, pp. 357-393.

Cohen, Alma, and Liran Einav, 2003, 'The Effects of mandatory seat belt laws on driving behaviour and traffic fatalities,' *R.E.Stat*. 85:4, March 2003, pp. 828-843. http://www.mitpressjournals.org/doi/abs/10.1162/003465303772815754.

Gill, Vijay, Barrie Kirk, Paul Godsmark, and Brian Flemming, 2015, *Automated Vehicles: The Coming of the Next Disruptive Technology*. Ottawa: The Conference Board of Canada, 2015.

Consumer Reports, 2016a, "Safety at Any Price", *Consumer Reports*, April 2016, pp. 24-31.

Consumer Reports, 2016b, "The State of the Self-Driving Car", *Consumer Reports*, May, 2016, pp. 44-49.

Desyllas, Panos and Mari Sako, 2012, "Profiting from business model innovation: Evidence from Pay-As-You-Drive auto insurance," *Research Policy*, 42:1, February 2013, pp. 101-116.

Fagnant, Daniel J. and Kara Kockelman, 2015, 'Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations.' *Transportation Research Part A, Policy and Practice*, vol. 77, July 2015, pp. 167-181.

Gomes, Lee, 2014. "Driving in Circles," Slate, 21 October 2014. http://www.slate.com/articles/technology/technology/2014/10/google_self_driving_car_it_may_never_actually_happen.html .

Gomes, Lee, 2016, "Google Self-Driving Car Will Be Ready Soon for Some, in Decades for Others", *IEEE Spectrum*, 18 March 2016. http://spectrum.ieee.org/cars-that-think/transportation/self-driving/google-selfdriving-car-will-be-ready-soon-for-some-in-decades-for-others .

Highway Loss Data Institute, 2014, "Predicted availability of safety features on registered vehicles – an update," Highway Loss Data Institute Bulletin vol. 31, No. 15, Sept. 2014. http://www.iihs.org/iihs/topics/t/crash-avoidance-technologies/hldi-research .

Insurance Institute for Highway Safety, 2016a, "CRASHES AVOIDED: Front crash prevention slashes police-reported rear-end crashes," IIHS Status Report, 51:1, Jan 28, 2016. http://www.iihs.org/iihs/sr/statusreport/article/51/1/1 .

Insurance Institute for Highway Safety, 2016b, "U.S. DOT and IIHS announce historic commitment of 20 automakers to make automatic emergency braking standard on new vehicles", IIHS News, March 17, 2016, http://www.iihs.org/iihs/news/desktopnews/u-s-dot-and-iihs-announce-historic-commitment-of-20-automakers-to-make-automatic-emergency-braking-standard-on-new-vehicles .

Kahane, Charles J., 2004a, 'Lives Saved by the Federal Motor Vehicle Safety Standards and Other Vehicle Safety Technologies, 1960-2002,' NHTSA DOT HS 809 833, Oct. http://www.nhtsa.gov/cars/rules/regrev/evaluate/809833.html .

Kahane, Charles J., 2004b, 'Cost Per life Saved by the Federal Motor Vehicle Safety Standards,' NHTSA DOT HS 809 835, Dec. http://www.nhtsa.gov/cars/rules/regrev/evaluate/809835.html .

Keeler, Theodore E. 1994. "Highway Safety, Economic Behavior, and Driving Environment". *The American Economic Review* 84 (3), 684–93.

Mannering, Fred, and Clifford Winston. 1995. "Automobile Air Bags in the 1990s: Market Failure or Market Efficiency?" *The Journal of Law & Economics* 38 (2), 265–79.

Mowat Centre, 2016, "Robot, take the wheel: Public policy for automated vehicles" Feb. 2016, Mowat Research #118.

National Highway Traffic Safety Administration, (NHTSA) 2013, "Preliminary Statement of Policy Concerning Automated Vehicles", 30 May, 2013, 14 pgs. http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development .

NHTSA, 1995, 'Traffic Safety Facts 1994', NHTSA, DOT HS 808 292, August. http://www-nrd.nhtsa.dot.gov/Pubs/FARS94.pdf .

NHTSA, 2006, 'Vehicle Survivability and Travel Mileage Schedules', DOT HS 809 952.

NHTSA, 2015. '2014 Crash Data Key Findings,' Traffic Safety Facts Crash*Stats. Report No. DOT HS 812 219, Washington, DC: NHTSA.

O'Neill, Brian and Allan Williams, 1998, "Risk Homeostasis Hypothesis: A Rebuttal," *Injury Prevention* 4, pp. 92–93.

Paefgen, Johannes, Thorsen Staake, Elgar Fleish, 2014, "Multivariate exposure modelling of accident risk: Insights from Pay-as-you-drive insurance data," *Transportation Research Part A: Policy and Practice*, Vol. 61, March 2014, pp. 27-40.

Peltzman, Sam, 1975, 'The Effects of Automobile Safety Regulation', *J. Political Economy* 83:4, Aug, pp. 677-726.

Schladover, Steven E., Dongyan Su and Xiao-Yun Lu, 2012, "Impacts of Cooperative Adaptive Cruise Control on Freeway Traffic Flow," *Transportation Research Record*, 2324(-1), January, 2012.

Schwartz, Gary T., 1999, 'Auto No-Fault and First-Party Insurance: Advantages and Problems,' 73 *S. Cal. L. Rev*. 611.

Shavell, Steven, 1979, 'On Moral Hazard and Insurance,' *Quarterly J. of Economics*, pp. 541-562.

SAE International "Automated Driving," 2014, Standard J3016. http://www.sae.org/misc/pdfs/automated_driving.pdf .

U.S. Department of Transportation, Federal Highway Administration, 2016, "Traffic Volume Trends: January 2016, https://www.fhwa.dot.gov/policyinformation/travel_monitoring/16jantvt/16jantvt.pdf

Villasenor, John, 2014, 'Products Liability and Driverless Cars: Issues and Guiding Principles for Legislation,' Brookings Institution, Center for Technology Innovation, April.

Winston, Clifford, Vikram Maheshri, Fred Mannering, 2006, "An Exploration of the offset hypothesis using disaggregated data: the case of Antilock brakes," *J. of Risk and Uncertainty*, vol. 32 pp. 83-99. http://link.springer.com/article/10.1007/s11166-006-8288-7.