The Impact of Connected Automated Vehicles on the Insurance Sector: A comprehensive Analysis of Legal and Risk Factors

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DECLARATION

I herewith declare that this thesis has not been submitted to any other University or higher education institution, or for any other academic award. Any contribution made by other authors is explicitly acknowledged in the thesis. I also declare that I have obtained copyright permission for the published work and that the proper citations to the journals are provided.

17/11/2019

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ACKNOWLEDGEMENTS

The PhD was a journey that I am glad to have begun, but that I am all the happier that it is coming to an end now. At the end of this journey, I look back at times of frustration and doubt but even more at moments of joy and deep appreciation, which became all the more pleasant because I could share them with the following people.

First, I would like to sincerely thank my principal supervisor, Dr. Finbarr Murphy, who has accompanied me as a patient mentor over the last three years and whose guidance was vital for my personal and academic growth.

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I would particularly like to thank my wife, my family, and my friends for their exceptional support and willingness to back me up, which has given me the freedom to successfully persevere this voyage of academic discovery.

With deep gratitude,

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Projects and Funding

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This project targets to contribute to improved road safety by development and deployment of Advanced Driving Assistance Systems (ADAS). The research objectives are

- To take a significant step forward in ADAS and therefore makes advances towards autonomous driving;
- To obtain a more comprehensive analysis of a drivers’ situational context using a data fusion module;
- To support drivers in accident avoidance and to mitigate the consequences of collisions;
- To design and develop intuitive and personalisable HMI to warn and assist the driver in anticipating potentially critical events.

Cloud-LSVA (Grant no.: 688099; URL: https://cloud-lsva.eu/)
The objective of this project is to support the integration of large-scale big data, video annotation and cloud-based solutions for improved ADAS development and Digital Mapping.
ABSTRACT
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Fabian Pütz
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November 2019

The introduction of connected automated vehicles (CAV) offers significant societal benefits and economic opportunities while similarly posing major challenges to society, businesses, research, and regulatory bodies. In addition to directly affected markets, such as the automobile manufacturing and transportation sectors, insurance is one of the core downstream sectors acutely sensitive to the adoption of this emerging technology. In fact, the adoption of CAV technology has the potential to profoundly affect existing business models of insurers with key triggers arising from changes to liability frameworks, a changing risk landscape and changes of customer interfaces and market structure induced by a shift of societal mobility approaches.

Due to the facilitating role of insurers for the introduction of new technology, the strategic implications for this stakeholder have to be understood holistically and proactively to ensure a seamless introduction. Given that insurance as a subject of academic research is interdisciplinary by character and since the strategic implications emerging with CAV technology originate from both legal and risk factors, this thesis provides a multidimensional research approach linking different research disciplines and research methods.

Using the current German liability and insurance framework as a case study, this thesis confirms that the methodology to allocate liability based on the strict liability of the vehicle owner is generally compatible with peculiarities of automated driving. However, adjustments to the existing framework are necessary to maintain an adequate level of claimant protection for accidents caused by automated vehicles. In addition, this thesis highlights that an adequate ultimate allocation of liability costs is potentially inhibited because of several barriers that hinder the shift of liability costs to the manufacturer side. This is particularly because the ability and motivation of motor insurers to conduct subrogation claims is negatively affected by a lack of required technical and engineering know-how and because market-wide conduction of subrogation claims would erode the business volume of motor insurance.

In addition to legal challenges arising from existing liability and insurance frameworks, this thesis analyses data-driven use cases to present the access to in-vehicle data as another core CAV-related legal question from an insurance-perspective. Finding a status quo where OEMs begin to leverage their superior access to in-vehicle data for the expansion of their own business models, the analysis underlines that the increasing interconnection of modern automobile vehicles will have a significant strategic impact on insurance-related service offerings. However, by analysing this status quo from a business ecosystem perspective, it becomes apparent that taking the role of a physical dominator to extract maximum short-term value might be an obvious but not necessarily successful approach for OEMs on long-term. This is because the shift from a goods-dominant supply-chain perspective to a service-dominant perspective will also need a profound redefinition of OEMs´ supply-chain relationships. This finding supports the resolution of contrasting positions of OEMs and third-party providers and enables an unbiased and
farsighted approach of regulatory bodies to prevent that inadequate advantages of single actors result in market failure to the detriment of customers.

For analysing the potential impacts of CAV technology on insurance-relevant risk-factors, this thesis provides qualitative and semi-quantitative analyses of relevant drivers for motor insurance and automotive product recall risk. Referring to CAV technology’s impact on motor insurance risk exposure, the research concludes that automated driving vehicles indeed have the potential to significantly decrease the number of road accidents caused by human-error. However, as there is insufficient data available about the reliability of highly automated driving systems in real-world applications, reliable quantification of future accident risk exposure is inhibited. Therefore, assumptions of a sharply decreasing accident risk exposure are by no means straightforward nor statistically proven, especially as the provided analysis reveals risk-relevant peculiarities of every single level of automation. In addition, new risks such as the risk of automotive cyber-attacks are likely to emerge with the penetration of CAV technology which, in turn, introduce potential sources of yet unknown catastrophe-alike risk exposures to MTPL insurance.

For the analysis of automotive product recall risk, this thesis couples the qualitative assessment of CAV-induced risk drivers from legal and technology-related sources with an analysis of historical product recall data from different product recall databases. With this approach, this thesis finds an increasing risk of product recalls induced by CAV technology, which is triggered by the increasing complexity of vehicle hardware and software and by an increasing legal and reputational risk in the case that CAV technology fails.

With the provided multidimensional research approach, this thesis contributes to an improved understanding of legal frameworks regulating CAV technology’s introduction and enables regulatory bodies for a proactive and farsighted adaption of existing legislation. Particularly referring to the improved understanding of liability frameworks, the contribution to existing literature results from the fact that the provided in-depth analysis not only extends on liability law on a detached basis but considers important interdependencies resulting from motor insurance law and from motor insurers’ central role within the liability settlement process.

In addition to the contribution to an improved understanding of legal factors, the analysis of CAV technology’s impacts on motor insurance risk characteristics contributes to an improved understanding of CAV technology’s inherent risk-factors. This is particularly useful as existing research and public expectations often seem to be biased and not sufficiently granular in the analysis of idiosyncrasies of single levels of automation. Furthermore, the presented research on CAV technology’s implications to product recall risk contributes to a comprehensive academic discussion of relevant risk-factors and serves as a cornerstone for academic research on a largely unaddressed aspect.

From a business perspective, the findings of this thesis not only provide an holistic assessment of the impacts of CAV technology on the insurance sector enabling insurance entities to take proactive strategic measures for adapting existing business models to a probably changing business environment but also support stakeholders on the CAV technology supply side in implementing adequate risk management frameworks to cope with emerging risks exposures such as product liability and product recall.
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ABS</td>
<td>Anti-lock Braking System</td>
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<tr>
<td>ACC</td>
<td>Automated Cruise Control</td>
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<tr>
<td>ADAS</td>
<td>Advanced Driving Assistance System</td>
</tr>
<tr>
<td>ADS</td>
<td>Automated Driving System</td>
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<tr>
<td>AEB</td>
<td>Automated Emergency Braking</td>
</tr>
<tr>
<td>Art.</td>
<td>Article</td>
</tr>
<tr>
<td>AV</td>
<td>Automated Vehicle</td>
</tr>
<tr>
<td>B2B</td>
<td>business to business</td>
</tr>
<tr>
<td>B2C</td>
<td>business to customer</td>
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<tr>
<td>BaFin</td>
<td>Bundesanstalt für Finanzdienstleistungsaufsicht (German Federal Financial Supervisory Authority)</td>
</tr>
<tr>
<td>BGB</td>
<td>Bürgerliches Gesetzbuch (German Civil Code)</td>
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<tr>
<td>BN</td>
<td>Billion</td>
</tr>
<tr>
<td>CAGR</td>
<td>Compound Annual Growth Rate</td>
</tr>
<tr>
<td>CAV</td>
<td>Connected Automated Vehicle</td>
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<tr>
<td>C-ITS</td>
<td>Cooperative Intelligent Transport Systems</td>
</tr>
<tr>
<td>DDT</td>
<td>Dynamic Driving Task</td>
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<tr>
<td>ECU</td>
<td>Electronic Control Unit</td>
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<tr>
<td>e.g.</td>
<td>for example</td>
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<tr>
<td>EPS</td>
<td>Electronic Power Steering</td>
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<td>ESC</td>
<td>Electronic Stability Control</td>
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<tr>
<td>etc.</td>
<td>et cetera</td>
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<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>f.</td>
<td>following</td>
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<tr>
<td>FCW</td>
<td>Forward Collision Warning</td>
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GDV Gesamtverband der Deutschen Versicherungswirtschaft (German Insurance Association)

GPS Global Positioning System

i.e. in especially

IoT Internet of Things

KBA Kraftfahrtbundesamt (Federal Motor Transport Authority)

KfzPflVV Verordnung über den Versicherungsschutz in der Kraftfahrzeug-Haftpflichtversicherung (Regulation on insurance cover in motor vehicle liability insurance)

LKA Lane Keeping Assistant

Mio. Million

MTPL Motor third-party liability

NatCat Natural catastrophe

No. Number

NHTSA National Highway Traffic Safety Administration

OBD On-Board-Diagnose

OEDR Object and Event Detection and Response

OEM Original Equipment Manufacturer

p. /pp. Page/Pages

PflVVG Pflichtversicherungsgesetz (Law on compulsory insurance for owners of motor vehicles)

ProdHG Produkthaftungsgesetz (Product Liability Act)

RAPEX Rapid Exchange of Information System

RORAC Return on risk-adjusted capital

SAE Society of Automotive Engineers

S-D logic Service-dominant logic

StVG Straßenverkehrsgesetz (German Road Traffic Act)

USD US-Dollar
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>VDA</td>
<td>Verband der Automobilindustrie e. V. (German Association of the Automotive Industry)</td>
</tr>
<tr>
<td>VVG</td>
<td>Versicherungsvertragsgesetz (German Insurance contract law)</td>
</tr>
<tr>
<td>WiFi</td>
<td>Wireless Fidelity</td>
</tr>
<tr>
<td>%</td>
<td>Percentage</td>
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<tr>
<td>§</td>
<td>Paragraph</td>
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<tr>
<td>€</td>
<td>Euro</td>
</tr>
<tr>
<td>$r$</td>
<td>correlation coefficient</td>
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Chapter 1: Introduction

1.1 Introduction

Technological progress has shaped human mobility for centuries. In fact, the exploitation of air and maritime space has not only enabled humans to outstrip the natural borders of endogenous human locomotion but has also revolutionised land mobility in terms of range, speed and personal availability of travel options. The first technological revolution of land mobility was heralded early in the nineteenth century, by the substitution of muscle-powered mobility with the mechanised locomotion of public railway transportation systems. This was followed by the 1886 introduction of Carl Benz’ automobile combustion engines. This innovation extended the scope of mechanical mobility from public transportation to individual movement, while Henry Ford’s 1908 development of assembly-line processes rationalised the manufacture and massification of an affordable individually-owned vehicle.

However, following this second wave of the land mobility revolution, the technological capability of automobile vehicles has advanced through evolutionary rather than revolutionary progress. That said, contemporary automobile and transportation sectors are on the cusp of profound changes arising from a number of factors which include increasing connectivity, automation, shared use, and the electrification of automobiles (McKinsey&Company 2019). While the specific time horizon of this development remains indeterminate, such driving forces have the potential to affect not only the technical infrastructure of the automobile vehicle itself but also the comprehensive traffic infrastructure and the future application of multi-modal mobility approaches (Bagloee et al. 2016) (Bunghez 2015).

The phenomenon of automated vehicles on the roads is hardly a new sight. Indeed, horse-drawn carriages share many characteristics with their automated vehicle counterparts, since horses are capable of performing certain driving decisions independent from human steering commands. Despite General Motors’ first conceptualisation of automated highway driving in the late 1950s (Rillings 1997), in which magnetised vehicles followed a steel cable embedded in test tracks, applications of automated driving vehicles to date,

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1 These driving forces are also summarised by the acronym “CASE” or “ACES” representing the respective sub-trends of Connectivity, Automation, Shared-Mobility and Electrification.
have remained limited to research projects and were largely perceived as the unfeasible and unreplicative realm of science-fiction.

However, recent technological progress in the field of computer, communication, and sensor technology is expected to foster a new era of automation and interconnection of physical smart devices (Internet of Things). Reflecting this overall development to the automobile sector, it is anticipated that advances in the field of Advanced Driving Assistance Systems (ADAS) and automated vehicle (AV) technology will make automated driving vehicles a reality within the coming years or decades. Together with an increasing interconnection of these vehicles, this has a direct bearing on the automobile and transportation sectors, and the potential to change individual and societal mobility approach at a fundamental level. It is further held that the reality of automated vehicles on the roads will impact societal mobility demands by inducing a shift from possession-based to service-based satisfaction. Finally, it is expected that this technology will inter alia enhance overall travel safety and comfort (Bunghez 2015), and will increase mobility options for the elderly or disabled (Harper et al. 2016a) (Fagnant and Kockelman 2015).

1.2 Definition of levels of automation

To provide a consistent nomenclature and to facilitate the comprehension of the later argumentation of this thesis, it is first necessary to define and differentiate between different levels of automated driving capability of road vehicles. For this, it is referred to the general definition of the Society of Automotive Engineers (SAE), which defines six levels of automated driving capability (SAE International 2016).

By contrast, the German Federal Highway Research Institute (BASt) uses a similar definition approach by classifying five levels of automation (Federal Highway Research Institute Germany 2012). Indeed, this approach was published earlier and was used as a basis reference in SAE’s definition approach. Despite a high degree of similarities, SAE’s definition approach can be viewed as a more granular derivative, especially as it anticipates the level of “full automation” (SAE level 5) for vehicles, which do not require a (physical or remote) human driver at all. As this more granular assessment provides a better fit for the evaluation of driving responsibility and as it is commonly used in the international literature, this nomenclature will be used unless explicitly stated (e.g. see chapter 2).
SAE defines the six levels (level 0 to 5) of automation based on the specific role the human driver and the driving automation system\(^2\) take considering

- the lateral (steering) and longitudinal (acceleration/deceleration) control,
- the monitoring of the driving environment and
- the performance of the fallback function in case that the automated driving system\(^3\) fails to properly fulfil the dynamic driving task.

The dynamic driving task comprises the fulfilment of lateral and longitudinal motion control, the tactical maneuver planning and display of action (e.g. signalling) as well as the subtask of monitoring and responding to objects and events in the driving environment (object and event detection and response, OEDR). The resulting six different levels of automation are shown in Figure 1.

![Figure 1: Six levels of automation of road vehicles. The table shows the six different levels of vehicle automation defined by SAE. Source: “Taxonomy and Definitions for Dynamic Driving Task”](image)

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\(^2\) This term includes all „hardware and software that are collectively capable of performing **part or all** of the dynamic driving task on a sustained basis; this term is used generically to describe any system capable of level 1-5 driving automation."

\(^3\) This term includes all „hardware and software that are collectively capable of performing **the entire** dynamic driving task on a sustained basis; [...] this term is used specifically to describe a level 3, 4, or 5 driving automation system."
Generally, the six levels of automation can be classified into levels, in which the human driver still is in the position to always perform at least parts of the dynamic driving task (level 0 to 2) and into levels in which the automated driving system is capable to perform the entire dynamic driving task at least for limited use cases (level 3-5).

In vehicles with “no driving automation” (level 0), the human driver performs the entire dynamic driving task and is not assisted by any driving automation systems. However, the human driver can be supported by driver assistance systems which either warn the driver (e.g. lane departure warning) or assist the driver without direct intervention to the vehicle's longitudinal and/or lateral control. These systems regularly only increase the manoeuvrability of the vehicle (e.g. anti-lock braking system (ABS), electronic stability control (ESC) or electronic power steering (EPS)) and interfere with the stabilisation level of the vehicle.

Vehicles equipped with “driver assistance” (level 1) are capable of performing either the longitudinal or lateral motion control at least in a limited scope of use cases. The driver is responsible to perform the complementary motion control and has to constantly monitor the driving environment. An example of this level of automation is the implementation of adaptive cruise control (ACC), which not only considers the speed of the own vehicle but also adjusts speed based on the distance to a vehicle ahead, or automatic emergency braking (AEB).

On the next level, vehicles with “partial driving automation” (level 2) are capable to perform the longitudinal and lateral motion control within limited use cases. As the system itself is not able to proactively recognize own limits of capability, the driver has to constantly monitor the driving scene to be ready to take over driving action if needed. Examples for partial driving automation applications are ACC systems coupled with lane keeping assistance (ACC+LKA), which couples the automated longitudinal motion control of ACC with the lateral motion control of the lane keeping assistance system, parking assistance systems, which not only fulfil the longitudinal but also lateral motion control, or traffic jam assistance, which performs the motion control of the vehicle in the limited use case of a traffic jam.

Vehicles equipped with “conditional driving automation” (level 3) capability are able to perform the entire dynamic driving task within a limited scope of use cases, including monitoring of the driving environment. The human driver acting as the system’s fallback
has to be vigilant to intervene and take over the dynamic driving task in a timely manner if the automated driving system recognizes own limits of capability and requests human driver’s intervention. Hence, the human driver does technically not have to constantly supervise a vehicle in automated driving mode but has to keep up a minimum level of situational awareness. For instance, the application of the highway traffic pilot is classified as conditional driving automation, as the vehicle is capable of fulfilling the entire dynamic driving task in the use case of highway driving, but the driver still has to return to driving performance, if the system requests so.

In contrast to this, vehicles with “high driving automation” (level 4) are also capable to perform longitudinal and lateral motion control within limited use cases but recognise own limits of capability and fulfil a minimum risk maneuver (e.g. parking the vehicle safely) in case that the human driver does not take over the dynamic driving task in a timely manner. The driver does not have to serve as the fallback of the automated system and does not have to monitor the driving scene during the automated driving mode.

Vehicles equipped with “full driving automation” (level 5) capability are capable to perform the entire dynamic driving tasks within all use cases. Hence, a manually or remotely steering human is not required anymore. All vehicle occupants are passive passengers and only take the decision of strategic route planning.

1.3 Relevance of the Research

In addition to the automobile and transportation sectors per se, a number of downstream businesses will also be profoundly affected by the advances in connected automated vehicle (CAV) technology. Indeed, the insurance sector is one of the core downstream sectors and is acutely sensitive to the adoption of this emerging technology since it assumes both the individual and societal risks resulting from the use and production of motor vehicles. Since the insurance sector serves to protect individuals and businesses from the financial losses inherent in CAVs, it is a crucial requirement and facilitator of the introduction of new technology. Given this central role, relevant implications to this sector require comprehensive analysis to assess the capability and motivation of this stakeholder to support the introduction of CAV technology. In addition, as insurance also functions as a tool to indicate the financial value of inherent risks to businesses and society it also assumes a pivotal incentive and steering function.
Motor insurance is valued at € 137.5 bn (2017) and accounts for about 39 % of the total annual premium volume of European non-life insurance business (Insurance Europe 2019). Measured by premium volume, it is the most important line of (non-life) insurance business. Therefore, any changes in the technical capability of automobile vehicles which influence inherent (accident) risk exposure and/or societal mobility behaviour and legal approaches to allocating liability, may fundamentally impact the motor insurance sector. As such, the strategic implications of CAV technology inter alia extend to the following aspects:

- **Allocation of liability:** Does a shift of legal allocation of liability for accidents caused by automated vehicles lead to a significant shift of liability costs to vehicle manufacturers and consequently to a material decline of premium volume in motor insurance?

- **Future risk landscape:** Does the expected increase in overall road safety lead to a sharp reduction of residual (financial) insurance risk?

- **Change of customer interfaces and market structure:** Does a shift of societal mobility behaviour to a service-based mobility approach lead to a shift of customer interfaces in the (motor) insurance market?

In addition to strategic questions for motor insurance, an holistic assessment of CAV technology impact incorporates aspects of product liability and automotive product recall risk. These are essential both as a means to achieve a comprehensive understanding of the potential impacts of CAV technology for the insurance sector, and to enable vehicle manufacturers and their suppliers to proactively implement adequate risk management approaches to cope with a changing risk landscape.

Despite the central role of the insurance industry to the successful introduction of CAV technology and the extensive research needs of this stakeholder, the existing academic and practice-related literature on CAV technology from the insurance perspective is largely underserved. Nonetheless, the range of CAV academic research is constantly growing but currently obtains to the the following areas:

- Aspects of ethics, dilemma-situations, and liability
- societal and macroeconomic implications
- impact on (intermodal) transportation systems and transportation policies
- forecasts of societal acceptance and adoption of CAV technology
• accident research on the effectiveness of ADAS functionalities
• engineering (e.g. vehicle-infrastructure, sensor) and software programming

Not only is literature with a specific research focus on research needs of insurance entities conspicuously scarce but also is the existing academic research on CAV technology largely separated by the underlying research discipline. Since the impacts of CAV technology on insurance stem from triggers rooted in a diversity of underlying research disciplines, this obstructs a coherent evaluation of insurance-relevant implications.

As the strategic aspects of CAV technology and insurance which are distinctly framed by separate academic research disciplines remain coherent from an insurance perspective, this thesis breaches the divide in the current literature by applying a multidimensional research approach that combines a variety of underlying research disciplines and methodologies. Traditionally, insurance-affiliated academic research disciplines are legal and actuarial sciences. While these continue to be relevant, supplementary analyses from such disciplines as accident research and production research can facilitate a more proactive assessment of CAV impacts on insurance risk. As underlying shifts in risk exposure and legal approaches directly affect the business model of (motor) insurance, the findings of these disciplines must then be assessed from a business economics and marketing perspective in order to devise suitable approaches for innovation and strategy.

That said, an holistic and transparent picture of CAV technology implications for the insurance sector can only be construed from a proper synthesis of cross-doctoral research. In spite of this, the academic study of CAV technology remains fragmented to the specific underlying disciplines and has not been compiled from an insurance perspective so far, which is where this thesis contributes to the academic discussion with an holistic research approach.

Much research on CAV technology´s impact on risk-factors such as accident risk has already been undertaken. This research is drawn up from accident research assessing the effectiveness of single ADAS functionalities which but mainly focusses on overall accident activity only (e.g. see (Avery and Weekes 2019) (Kusano and Gabler 2012) (Jermakian 2011) (Harper et al. 2016b) (Cicchino 2017) (Yue et al. 2018) (Blower 2014) (Grover et al. 2015) (Highway Loss Data Institute 2017)). Even when the perspectives of accident research and insurance overlap, divergent research needs arise from differing focus and risk metrics to evaluate CAV technology´s net risk impact. For instance, loss
scenarios contributing to major parts of insurance loss expenditures are not necessarily relevant to accident research focusing on road safety from the perspective of societal cost (i.e. the number of road traffic fatalities). This missing link between accident research and insurance-related analysis limits the exchange of research findings from accident research into insurance-related insights. This is especially problematic since (motor) insurers are the central stakeholders assuming financial risks resulting from CAV technology. A further limitation in the existing literature is linked to the fact that academic research on the effectiveness of CAV technology in reducing the number of accidents is generally limited to single ADAS functionalities with lower automation levels (i.e. Automated Emergency Braking and Lane Keeping Assistant). As such, extant research only presents findings for CAV technology already penetrated into the market but is not useful to reduce ambiguity in assessing the risk-factors of automated vehicles with higher levels of automation capability (Pütz et al. 2019). In this case, the existing literature to date remains at a very initial stage, using flat as unproven, and arguably biased assumptions of CAV risk-factors.

Existing practice-related literature focusing on CAV risk-factors from an insurance perspective is dominated by publications from two author groups. On the one hand, consultancy firms introduced forecasts on the impact of CAV technology on motor insurance market premiums with a prediction of sharply decreasing premium volumes due to a significant expected decline in the number of road accidents (KPMG 2016) (Morgan Stanley and Boston Consulting Group 2016). On the other hand, insurance-affiliated institutions, such as the German Insurance Association (2017) offered a more moderate projection which underlined the persistent importance and economic legitimacy of the motor insurance business model. However, as the used input-variables of the presented forecasts are flat and the calibrations of used models are not transparent for most of the existing practice-related publications, it is evident that such opposing projections are, at least partially, biased by the business interests of the publishing parties. Finally, while the existing discourse largely examines the probable impacts of CAV technology on the risk-factors of accident risk, it faults to address the possible implications for secondary risks. In particular, the possible impacts on the risk of automotive product recalls are not yet introduced to the academic discourse. This gap is especially problematic since product recalls present significant financial risk to automotive manufacturers and their suppliers (Murphy et al. 2019). Thus, the resulting intransparency of inherent risk exposure inhibits the implementation of adequate risk
management frameworks which, in turn, hampers the smooth introduction of CAV technology.

In fact, the discourse on questions of liability for accidents caused by automated driving vehicles is a research field in which academic and practice-related literature is already firmly established, both internationally and with a specific focus on the German liability framework. However, the existing literature in this field is mainly limited to evaluations of existing liability frameworks on a conceptual level by analysing general challenges of the different existing liability concepts such as fault-based and strict liability schemes (Duffy 2013) (Lohmann 2016) (Schellekens 2015) (Bertolini et al. 2016) (Rapaczynski 2016) (Schroll 2015). Thus, existing literature tends to evaluate liability frameworks on a detached basis and forego adequate consideration of the practical role of motor insurance. This is especially problematic as obligatory motor insurance is a central component within the claim settlement process of motor liability claims. Thus, it must be understood as an integral part when analysing the suitability of liability frameworks. Therefore, it is essential that liability frameworks are not only analysed on a conceptual level but also holistically analysed by considering aspects arising from the practical implementation via motor insurance. As such, the granular assessment of the German liability and insurance framework provided in this thesis addresses a significant gap in existing literature, advances a more sophisticated legal understanding of liability and insurance frameworks for CAV technology and contributes to adequate risk governance in this field.

In contrast to the existing discourse on liability aspects of CAV technology, discussion of the access to in-vehicle data has not yet been introduced as a relevant field of academic research and can also not be found for other fields of application arising with data-driven services in an IoT-based business environment. The research that exists in this field mainly focusses on implications of individual freedom of choice, information overload and surveillance (Dotson 2012; Brey 2017) (Rickard et al. 2017) (Martínez-Béjar and Brändle 2018) but largely misses academic discourse on how effective regulatory frameworks determining the access to data from smart devices have to be designed to achieve regulatory objectives such as a fair and undistorted competition. So far, the strategic relevance of an adequate access to in-vehicle data from an insurance perspective has only been addressed by practice-related literature and achieved a degree of transparency through discussions on the C-ITS platform in which various (business) stakeholders debate the technical and legal frameworks necessary for access to in-vehicle
data. Such discussions merely underscore the competing economic interests of the involved stakeholders which inhibit a joint market solution (European Commission 2016) (European Commission 2017) (Barbero et al. 2018) (German Association of the Automotive Industry (VDA) 2016) (Insurance Europe 2016). The dearth of academic engagement creates the potential for regulatory bodies to base legislative action on incomplete and/or biased information. Thus, the introduction of this key regulatory question into the academic discussion is essential to tackle another important gap in the existing literature and further contributes to a more comprehensive understanding of the regulatory frameworks for CAV technology.

1.4 Research Objectives and Research Questions

Even at this early stage of its technical maturity, the wide-ranging societal, legal, and business impacts of CAV necessitate an assessment of the potential implications to ensure that the various stakeholders may confront the challenges and benefit from the opportunities afforded by technology. In response to the gaps identified in existing academic and practice-related literature, this research addresses the central role of insurance companies for the introduction and facilitation of CAV technology and presents an holistic analysis of the inherent strategic implications. Due to the central role of insurers in assuming risks on a societal level and robust interrelation of insurance with the underlying legal allocation of liability, this thesis is also of interest to supervisory bodies and safety experts. To this end, the present research contributes to a rigorous risk assessment and risk regulation framework of CAV technology to facilitate a smooth and efficient introduction. With this overarching contribution, this thesis specifically contributes to

- a farsighted and proactive customisation of liability and insurance frameworks for accidents caused by CAV technology which considers an adequate level of protection for accident victims and a reasonable allocation of liability costs;
- a farsighted and proactive design of legal frameworks which determine the access to in-vehicle data so as to ensure an undistorted and fair competition of parties involved;
- a transparent and comprehensive assessment of CAV technology’s probable risk impacts to enable both insurance industry and regulatory bodies to base decisions on a firm and unbiased ground;

- an holistic assessment of CAV implications for the insurance sector in order to support insurance entities to take proactive strategic measures to adapt business models to a changing competitive environment.

Given this contribution to the proactive strategic planning of insurance entities, certain strategic pathways may not be uniformly valid across the entire insurance sector. On the contrary, it is necessary to consider that various insurance entities have different characteristics (e.g. regarding know-how, risk-bearing capacity, customer groups, …). This implies that a differentiated assessment of the potential impacts to the specific market participants has to be conducted as the different characteristics induce divergent strategic positions, adaptivity, and courses of action to cope with chances and risks resulting from CAV technology.

As required by the various underlying research disciplines, each chapter of this thesis applies a relevant methodology to elucidate the aforementioned research objectives. In so doing, this thesis contributes to the academic and practice-related discussion of CAV from a liability and insurance perspective by engaging with and answering the following research questions:

**Research Questions regarding legal aspects of CAV (aspects of liability):**

- *How is liability for road accidents of automated vehicles allocated based on the current legal provisions? To which extent do liability costs shift to the automotive supply chain?*

- *To what extent does the resulting allocation of liability costs lead to an adequate incentive function for stakeholders (preventive function of liability law)?*

- *Does the current liability and insurance framework ensure an adequate level of claimant protection (compensation function of liability law)?*

- *What changes to the current liability framework are necessary with CAV penetrating the market?*

Answers to these research questions derived from an in-depth analysis of the current German liability and insurance framework are presented in Chapter 2.
Research questions regarding legal aspects of CAV (access to in-vehicle data):

- How is access to in-vehicle data legally regulated today?
- How are in-vehicle data already used and monetarised in the automotive and insurance market? Which use-cases for in-vehicle data exist and/or will evolve with the penetration of CAV technology?
- What changes to the regulation determining the access to in-vehicle data are necessary to protect legitimate interests from the perspective of consumer-protection and competition?

These research questions are answered in Chapter 3 of this thesis, providing an analysis of the current European regulatory framework, which also integrates an assessment of existing use-cases and data-driven business models in insurance-related mobility services.

Research questions regarding insurance-related aspects of CAV (motor insurance):

- How will changes to future risk exposure impact the business volume of motor insurance?
- How will the risk characteristics of a motor insurance portfolio change in terms of frequency, severity, and volatility of losses?
- How will a possible change in societal mobility behaviour induce a shift of customer-interfaces in the motor insurance market?
- How will the progressing penetration of CAV impact the competition of the motor insurance market? How are the single market-players strategically positioned?

Chapter 4 of this thesis provides guidance on these specific research questions by coupling analysis of the risk-relevant peculiarities of the single levels of automation to accident risk with an analysis of probable implications to motor insurance risk characteristics.

Research questions regarding insurance-related aspects of CAV (product recall insurance):

- How will CAV impact the risk of automotive product recalls in the future?
• What risk characteristics do automotive product recall events show regarding frequency, severity, and volatility of losses?

• How can product recall risks be efficiently mitigated between the involved parties of the insured entities and insurance companies in a holistic risk management framework?

These research questions are answered by the research delineated in Chapter 5. This combines a qualitative analysis with that of historical product recall statistics to identify triggers of product recall risk emerging with CAV technology. This overall analysis is used as a basis to provide guidance on effective risk-mitigation avenues on both a production and financial level.

Given the research objectives and questions outlined above, this elaboration is especially beneficial to the early stage strategic business planning process undertaken by insurance companies. Furthermore, the extensive and farsighted analysis of legal aspects, such as liability for CAV technology and the access to relevant in-vehicle data, supports the evaluation of this issue from the perspective of legislative bodies on a national and international level. Finally, the assessment of the potentially changing risk exposure is also beneficial to the implementation of proactive corporate risk management measures for companies within the automobile and mobility sector.
1.5 Thesis Structure

This thesis consists of four discrete academic research papers exploring the impact of CAV technology from different perspectives and contributing to the single research objectives as outlined in the previous section. Each article has been published in a peer-reviewed academic journal in the fields of legal studies and risk regulation, production research or journals dedicated to the interdisciplinary discourse of the impact of technological change on society. The collective thesis contributes to the academic discussion of legal and risk governance of CAV technology while providing strong links to the insurance industry as a key stakeholder. For this, the first part of the thesis (chapter 2 and 3) focusses on legal aspects such as liability for automated vehicles and the access to in-vehicle data. The second part of the thesis (chapters 4 and 5) focusses on risk-related aspects and provides analyses of CAV inherent motor insurance and product recall risk.

The sequencing of the chapters is designed to support the robust interrelations between aspects of liability and regulation of CAV technology on the one hand and aspects of CAV insurance risk on the other. Since the inherent liability risk exposure to insurance companies basically depends on the design of the underlying liability and insurance schemes, aspects of liability regulation are analysed first to form a basis for the deduction of relevant risk implications in subsequent chapters. Chapter 2 analyses the current German liability and insurance framework for (automated) vehicles resulting from different sources of law, namely the German Road Traffic Act, German Civil Code, Product Liability Act, and relevant motor insurance law. This chapter is based on the paper “Reasonable, Adequate and Efficient Allocation of Liability Costs for Automated Vehicles: A Case Study of the German Liability and Insurance Framework” published in the European Journal of Risk Regulation (EJRR). Based on an in-depth analysis, this article delineates societal and insurance business-related implications and addresses the shortcomings of the current framework. In particular, the research considers not only the central role of motor insurers for processing of motor liability claims but also the interdependencies between current liability and motor insurance law.

The central objectives of a functioning liability and insurance framework are on the one hand to ensure that damaged third parties are sufficiently compensated for losses they suffer from malicious action of the responsible party (indemnity function). On the other hand, the imposition of liability also assumes an important preventive function since the risk of being obliged to compensate for losses should incentivise an adequate level of
caution. Thus, the imposition of liability is an instrument to achieve a balance between the level of independent and free individual action and the level of reasonable caution when exposing risks to society (Shavell 2007) (Faure et al. 2016). The analysis provided in this chapter uses both functions as guiding principles to evaluate the current framework’s suitability for automated driving vehicles.

In referring to the inherent level of claimant protection, the research concludes that the building blocks of strict liability of vehicle owners and obligatory motor insurance coverage are largely capable of covering peculiarities of CAV technology. However, a potential reduction of claimant protection compared to today’s level results from the fact that strict liability of the vehicle owner is only limited and also arises from inconsistencies between this liability limit and obligatory minimum sums to be insured. Referring to the framework’s ability to reasonably allocate liability costs, the research deduces several barriers that hinder the efficient shift of liability costs from the owner of the vehicle to the manufacturer’s side. This is mainly due to motor insurers’ central role within the claim settlement process and the fact that the ability and the motivation to conduct subrogation claims could be negatively affected by a lack of technical and engineering know-how and because market-wide conduction of subrogation claims would erode the business volume of motor insurance.

Given the focus of existing literature on higher level conceptual aspects of liability frameworks for CAV technology, the provided in-depth analysis integrating both conceptual liability and processual insurance aspects offers important insights to the academic discourse. This is especially because this research approach takes the motivational aspects of motor insurers as key stakeholders into consideration. The conclusions of this analysis demonstrate that prevailing opinions which maintain that liability costs would be fairly balanced between the owner and manufacturer of the vehicle by the way of subrogation claims may be overly optimistic. In addition, this analysis invalidates prior research positions which neglect the relevance of questions about the ultimate allocation of liability costs, as liability costs would flow back to the owner of the vehicle anyway, either by paying the insurance premium or an additional price component when purchasing the vehicle. Here, the analysis shows that the adequate allocation of cost-inflation risk is tied to ensuring an adequate incentive function of the liability scheme. Through these findings, this thesis contributes to an enhanced legal understanding of liability and insurance frameworks for CAV technology and to adequate risk governance in this field. Even if the provided analysis is based on the German liability
and insurance framework, it is also contributing to improved risk governance in the international context. Existing frameworks can generally be separated into schemes that impose strict liability to the driver/owner of the vehicle (e.g. Germany or France) and into schemes which allocate liability based on fault of the (human) driver (e.g. the UK). Stating this, especially liability frameworks (only) based on human driver’s fault are exposed to shortcomings when applying them to accidents caused by automated driving vehicles as fault would not be attributable to the human driver anymore. With an unaltered preservation of this approach, third-party claimant protection would potentially be eroded as no party would be obliged to compensate losses. In consideration of this weakness, the UK legislator has introduced the “Automated and Electric Vehicles Act” including liability of manufacturers into the scope of regular motor insurance (UK Parliament 2018). Even when using a different nomenclature and methodology compared to the German legislator, the result of this approach implies the same rationale of providing a one-stop shop and clear path of compensation with the motor insurer as the central institution within this compensation process. Thus, the provided analysis in this thesis aids the definition of a blue-print framework which could also be used in other jurisdictions. This is especially important due to the need for an amalgamation of law in the international context as this is required to ensure a consistent level of claimant protection in cross-border traffic situations and to increase the transparency of legal risk for manufacturers distributing products in several jurisdictions.

In addition to liability aspects, the access to in-vehicle data is an equally essential legal question arising with CAV technology penetrating the market and which potentially impacts the business model of motor insurance. Therefore, Chapter 3 analyses the legal and technical status quo which determines access to in-vehicle data and describes current approaches and legal conditions for market participants to establish digital business ecosystems for offering mobility- and telematics-based (insurance) services. The chapter is based on the paper “Connected Automated Vehicles and Insurance: Analysing Future Market Structure from a Business Ecosystem Perspective” as published in the journal Technology in Society. Insurance-related use cases are utilised to illustrate the technical and legal asymmetry of data access for OEMs and third-party providers and to indicate the strategic implications for both sides as well as the consequences for the regulatory objectives of an adequate level of competition and sufficient variety of service-offerings. This research finds that motor insurers’ ability to integrate themselves in business ecosystem platforms built around CAV is currently disadvantaged due to a lack of
adequate access to the in-vehicle data required for telematics-based services. However, the research also indicates that the shift of the vehicle to an interconnected smart device makes it necessary that automotive manufacturers (OEMs) open their business ecosystem platforms for third parties to maximise own value propositions. As this awareness does not yet appear to be reflected in adequate proactive action of OEMs, the regulatory objective of fair and undistorted competition is probably not achieved by market self-regulation.

With these findings, this chapter enriches the scope of existing academic literature on the legal factors of CAV technology as this mainly focuses on questions of liability only. This is a substantial contribution as the research indicates significant spillover effects on customer interfaces and the competitive environment of motor insurance. Utilising insurance-related use cases in the field of mobility services, the research also serves as a cornerstone of a broader discussion about access to data from connected smart-devices in an era where IoT-driven business models are significantly gaining importance. With the finding that a proactive opening of data access enables OEMs also to increase own value-propositions on long-term this research supports the resolution of contrasting positions of key stakeholders of CAV technology. Moreover, such a finding enables unbiased and farsighted legislation of regulatory bodies in this field which is required to prevent that inadequate advantages of single actors result in market failure to the detriment of customers. Finally, this chapter also shows strong links to liability aspects delineated in the previous chapter as the analysis shows that the current legal approach of allocating the obligation to maintain motor third party liability insurance with the vehicle owner could potentially have significant spill-over effects on customer interfaces if the status of the vehicle owner would shift from many individuals to few commercial fleet providers.

Based on the analysed allocation of liability in an era of automated driving vehicles, it is equally important to assess the future risk exposure resulting from CAV technology. As the insurance sector not only covers financial risks from the use of motor vehicles through motor insurance but also those from the production through product liability and product recall insurance, a comprehensive analysis of the future risk exposure has to consider both.

With regard to motor insurance risk-factors, Chapter 4 comprises an analysis of the potential shifts of the volume and inherent characteristics of motor insurance risk induced by a progressive interconnection and automation of motor vehicles. This chapter is based
on the paper “Driving to a Future without Accidents? Connected Automated Vehicles’ Impact on Accident Frequency and Motor Insurance Risk” published in the Environment Systems and Decisions journal. Most apparently, an expected increase in road safety induced by CAV has a direct impact on the overall number of road accidents. If effective, the decreasing number of road accidents, ceteris paribus, decreases the overall loss expenses and, given the strong competition, would also reduce the overall premium volume of the motor insurance business. However, this development is by no means straightforward or statistically proven, and the analysis provided in this thesis emphasises the risk-relevant particularities of every level of automation.

With the provided research approach, this thesis contributes to a more accurate discussion of CAV risk-implications which is not always conducted in a sufficiently granular and objective manner. In addition, the holistic assessment of the net alteration of the inherent risk exposure also needs to consider emerging risks such as the risk of remote cyber-attacks or software/hardware failure of the vehicle system. Especially due to these emerging risks, the risk profile of the motor insurance industry could be reshaped particularly if cyber-attacks introduce a source of catastrophe-alike accumulation risk to motor third-party liability insurance. This finding broadens the scope of existing literature of CAV impacts on motor insurance risk from a one-dimensional forecast of overall premium volume with an additional perspective on possible shifts of risk characteristics of (residual) risk exposures. In addition, this article delineates important analyses of the impact of a changing societal mobility approach from a possession-based to service-based mobility on risk-factors and customer interfaces of the motor insurance market. Here, the research concludes that this shift would have a profound impact on customer-interfaces and the market structure as it would shift the demand-side from a business-to-customer polypoly (retail mass-market) to a business-to-business oligopoly market. This would particularly impinge on insurers focusing on private retail motor insurance, leading to significant strategic risks of their business model. With these findings, the research contributes to a proactive and farsighted strategic adoption of motor insurance business models and supports a more rational academic and public discussion of the potential benefits of CAV technology, thereby enabling an informed and evidence-based decision-making approach by regulatory bodies and business entities.

However, to aid a comprehensive risk-governance in the field of CAV technology, the analysis of motor insurance risk only represents part of the relevant risk exposure. Even if motor insurance is the most important line of (non-life) insurance business also other
business lines are potentially affected by shifts in the underlying risk landscape. This is especially important as adequate mitigation of (liability) risks resulting from the production process is acutely relevant to foster innovativeness of the automotive supply side. As the analysis of liability and insurance framework (chapter 2) in this thesis already presents strong links to this risk assessment by providing a legal analysis of inherent product liability risk, the following, Chapter 5 complements risk analysis by offering an analysis of CAV technology’s impact on the risk-factors of automotive product recall events. This chapter is based on the paper “The Impact of Autonomous Vehicle Technologies on Product Recall Risk” published in the International Journal of Production Research (IJPR). Considering relevant drivers from legal and technology-related aspects, the research identifies a potentially increasing risk of product recalls induced by CAV technology due to the increasing complexity of vehicle hardware and software and an increasing legal and reputational risk if CAV technology fails. With this finding, the research introduces an important aspect of CAV’s inherent risk exposure into academic discourse, which contributes to a comprehensive academic discussion of relevant risk-factors. In addition to the relevance of this perspective for a transparent risk assessment of insurance entities, this finding also supports the proactive implementation of risk management frameworks for manufacturers of CAV technology. This finding is crucial, as the analysis of inherent risk characteristics reveals high financial and temporal tail-risks of product recall events. As the manifestation of extensive product recall events could also hamper innovation on the supply-side, the research contributes to a seamless introduction of CAV technology by providing risk-mitigation avenues to set-up efficient risk management frameworks with insurance as a core element.
1.6 Description of Research Methodology

As a discipline of academic research, insurance can be divided into several sub-disciplines which traditionally *inter alia* include:

- mathematics and actuarial studies (e.g. for the purpose of insurance premium pricing)
- legal studies (e.g. for the assessment of liability or the definition of insurance contract wordings)
- business economics and marketing (e.g. for strategy and innovation or for structuring organisation and processes)
- macroeconomics (e.g. for asset management decisions)

However, when analysing the impact of CAV technology on the insurance sector, also additional disciplines such as accident research and production research are to be included in the relevant sub-disciplines of insurance-related academic research to enable a more transparent and holistic analysis of emerging risk exposures. To derive in-depth and comprehensive propositions for the implications of CAV technology to the insurance sector and, in particular, to the single affected lines of business, this thesis presents an interdisciplinary and cross-sectional analysis by combining relevant academic disciplines and research approaches.

Due to the emerging character and complexity of CAV technology, a significant level of uncertainty and ambiguity obtains to the various technical, societal and legal aspects involved. Indeed, the extent of ambiguity in forecasting the impacts to the insurance sector is even amplified since the implications for the insurance sector rest on the interdependencies of different underlying triggers on a technical and societal level and as reliable quantitative data for the (risk) evaluation of CAV technology is scarce. Due to the given level of uncertainty in this field, this thesis is based on an inductive research approach, wherein single observations are used to generate hypotheses on the future impacts of CAV technology to the insurance sector. To this end, the relevant observations are deduced from qualitative and semi-quantitative research methods.

In *Chapter 2*, current German legislation is used as a case study to ringfence any potential inadequacies regarding the inherent level of claimant protection (indemnity function). This analysis is based on a teleological interpretation of law, which describes the method to interpret legislative provisions in the light of their purpose and their implicit or explicit
socio-economic goals. With regard to the ultimate allocation of liability (preventive function) resulting from the current framework, the chapter uses a normative economic analysis of law to showcase the central role of motor insurers and a potential lack of their ability and motivation to forward liability costs to vehicle manufacturers.

The same qualitative research approach of using a case study is also applied to analyse the legal and technical status quo determining access to in-vehicle data from connected (automated) vehicles provided in Chapter 3. By utilising insurance-related use cases the strategic relevance of the access to in-vehicle data and the current asymmetry of data access is illustrated. The concept of business ecosystem platforms is applied to conceptualise current approaches of vehicle manufacturers to broaden the scope of their traditional business model by also integrating (insurance-related) digital mobility services. Based on the findings from this analysis, a normative economic analysis of law is applied to evaluate the status quo from a societal and business perspective, with a specific focus on competition law targeting an environment of fair and undistorted competition.

For the evaluation of CAV risk exposure, reliable historical data from real-world applications of CAV are not widely available for the determination of the potential impact of these vehicles (e.g. regarding accident risk or cyber vulnerability). Moreover, the high degree of ambiguity when forecasting the technical and social implications of CAV technology does not allow for precise quantification of inherent risk exposure. Therefore, the analysis of common-sense opinions, field testing or use of analogies from similar technological developments of the past, can generally be used to reduce the uncertainty around future projections. However, such approaches cannot be effectively applied to the forecast of CAV technologies risk implications as:

- existing opinions on CAV risk-factors often appear to be biased, contradictory and imprecise in defining the level of automation at scope
- each level of automation demonstrates idiosyncrasies of risk so that previously penetrated advanced driving assistance systems cannot necessarily be used as risk measures for higher levels of automation
- existing field testing of higher automated vehicles regularly rely on human safety-drivers assuming driving-responsibility in case of critical incidents and intransparency of risk-relevant data does not allow independent or objective assessment of risk-factors
• other automated systems are regularly used in delimited areas (e.g. manufacturing facilities) or show a significantly lower level of complexity than road traffic environments (e.g. rail or air traffic systems)

Due to the extent of ambiguity tied to these shortcomings, this thesis does not aim to precisely quantify potential implications on CAV risk, but rather to provide overall guidance of CAV technologies´ net risk balance. As such, a qualitative and semi-quantitative research approach is equally suitable to increase transparency about CAV’s overall future risk balance, enabling business and regulatory bodies to make farsighted decisions on a better-informed basis. For the analysis of CAV’s impact to the motor insurance risk exposure in Chapter 4, statistical data available from the German Insurance Association (GDV) and the German Federal Financial Supervisory Authority (BaFin) is used to assess the inherent current insurance risk characteristics of the covered risks by means of frequency and severity. Data on the German market is also of use to examine other motor insurance markets as the scope of the single risks covered under German motor insurance policies is similar to that of insurance policies in other countries and as road traffic risk, with the limitation of minor peculiarities (e.g. from diverging liability law), is largely comparable to equally developed countries. On this basis, a qualitative assessment of the accident risk of single levels of automation is based on a literature review and by analysing the limited available risk-indicators for human-driven and automated driving vehicles accident risk. This assessment also includes an analysis of indirect risk triggers such as a shift in societal mobility approach from possession-based to service-based mobility. To deduce a comprehensive understanding of risk implications, potentially emerging risks are also qualitatively analysed in terms of inherent insurance risk exposures.

For the assessment of CAV’s potential impact on the risk of automotive product recalls in Chapter 5, an in-depth qualitative analysis of relevant risk drivers is conducted and supported by evidence from an analysis of historical product recall patterns. In this case, automotive product recalls due to sensors, software and electronic control units are used as a proxy to indicate the increasing relevance of these components for overall product recall activity in an era of automated driving vehicles.
1.7 Concluding remarks

The insurance industry is a central stakeholder of CAV technology and (a lack of) this industry’s contribution could either facilitate or hamper its seamless introduction. The introduction part of this thesis has described the manifold strategic levels on which CAV technology potentially affects insurance business models which is why an holistic analysis of relevant implications requires an interdisciplinary research approach. At the same time, it has been delineated that these implications are not only relevant for insurers from a business perspective, but also have significant intersections with academic research so that both perspectives are mutually stimulating each other. Despite the extensive research needs in the field, the existing discourse is still limited and fragmented to the single underlying academic research disciplines but not merged and transferred to be useful from an insurance perspective. To bridge this gap, this thesis offers a multidimensional research approach that combines insights from different research disciplines and research methodologies. Thus, each of following chapters represents a vital element for achieving the research objectives described above.
References Chapter 1


Department for Mobility and Transport.


Insurance Europe (2016) *Access to in-vehicle data can maximise the benefits consumers gain from motor insurance* [press release], 14.06.2016, available: [accessed](http://dx.doi.org/https://doi.org/10.1016/j.aap.2016.06.017).


KPMG (2016) 'Does Motor Insurance Have a Future'.


Chapter 2: Reasonable, Adequate and Efficient Allocation of Liability Costs for Automated Vehicles: A Case Study of the German Liability and Insurance Framework


Publication status: Published

Authors’ contribution

Fabian Pütz carried out the main part of legal analysis and writing of the case study. Dr. Finbarr Murphy and Dr. Martin Mullins contributed to the structure and concept of the paper and carried out major revision work. Prof. Dr. Karl Maier and Prof. Raymond Friel contributed as experts with their deep legal knowledge as advisors for discussions of research findings. Prof. Dr. Torsten Rohlfs contributed with ideas from an insurance perspective and revision.
Reasonable, adequate and efficient allocation of liability costs for automated vehicles: A case study of the German liability and insurance framework

Abstract

In general, a functioning liability and insurance framework should ensure an adequate level of third-party claimant protection and a reasonable and adequate final allocation of liability costs for the involved parties. This research examines whether the liability and insurance framework resulting from the amendment to German Road Traffic Act meets these two central objectives. The article shows that a reasonable and adequate allocation of liability costs is inhibited because of several barriers that hinder the shift of liability costs from the owner of the vehicle to the manufacturer. In particular, it is highly dependent on the practical application of subrogation claims. The ability and the motivation of motor insurers to conduct subrogation claims could be negatively affected because of a lack of required technical and engineering know-how and because a market-wide conduction of subrogation claims would erode the business of motor insurance. This article proposes changes to the current framework particularly by removing specific exclusions of product liability and by easing the burden of proof of a product defect.

1. Introduction

The progressive technical development in the field of advanced driving assistance systems (ADAS) and automated driving makes it feasible that motor vehicles with a high level of automation will be ready for market within the next decade. The vision of automated vehicles on public roads not only depends on technical progress but also requires an adequate liability framework to ensure legal certainty for the relevant stakeholders on both the demand and supply side.

Several national legislators have recognised the need for adjustments and are currently discussing amendments to existing liability laws (e.g. see draft law amendment in the UK (Butcher et al. 2017)). The German legislative body has already implemented an amendment to the existing Road Traffic Act (Straßenverkehrsgesetz (StVG)). This amendment sets legal requirements for the operation of highly and fully automated
vehicles\textsuperscript{4} and mainly preserves the existing liability and insurance framework, characterised by a combination of strict liability of the vehicle owner\textsuperscript{5} and fault-based liability of the (human) driver. This liability framework is coupled with obligatory insurance to be maintained by the owner covering liability costs of himself, the driver and the titleholder of the respective vehicle. Original Equipment Manufacturers (OEMs) are not directly included into the legal framework and the legislator expects that motor insurance companies examine and conduct subrogation claims under existing product liability law in the case that a defect of the automated driving system causes an accident.

In general, a functioning liability and insurance framework should meet two central objectives. In the external relationship to the damaged third-party, the design of the framework has to ensure an adequate level of claimant protection. In the internal relationship between the liable parties, a reasonable and adequate ultimate allocation of liability costs fulfils an important incentive function for the involved parties. On a more abstract level, the retrospective allocation of liability costs also has a preventive function, aiming to achieve a balance between the level of independent and free individual action and the level of reasonable caution and care when exposing risks to the society (Shavell 2007) (Faure et al. 2016).

Because the progressive automation of motor vehicles will successively reduce the relevance of the owner and human driver for the occurrence of road accidents, we use the liability and insurance framework resulting from the amendment to the StVG in Germany as a case study to analyse whether this framework adequately ensures these two central objectives.

This issue has already been subject to existing academic research. With regard to the inherent level of claimant protection, the prevailing opinion recognises the adequacy of the existing framework and consequently seeks to preserve the current approach (Schubert 2015). Referring to the adequate allocation of liability costs, Lohmann recognises the importance of the incentive function of liability cost allocation and concludes that liability costs would be fairly balanced between the owner and manufacturer of the vehicle by the way of subrogation claims (Lohmann 2016). That this

\textsuperscript{4} The German legislative body does not follow the classification wording of SAE but uses the terminology of the German Federal Highway Research Institute. The equivalent levels of automation referring to SAE nomenclature would be conditional automation (level 3) and high automation (level 4).

\textsuperscript{5} We use the term “owner” for the German legal term “Fahrzeughalter” and the term titleholder for the German legal term “Fahrzeugbesitzer”. German law distinguishes between the right of property title and the right of disposal. The owner of a vehicle is the person, who owns the right of disposal and has the duty to maintain the vehicle in safe condition. The titleholder is the person or institution formally owning the property title of the vehicle.
assumption could be too optimistic and not hold true in the application of current product liability law is only slightly touched by Vellinga (2017). By contrast, Armbrüster states that the question about the allocation of liability costs practically would only be of minor relevance. This is because liability costs would flow back to the owner of the vehicle anyway, either by paying the insurance premium or an additional price component when purchasing the vehicle (Armbrüster 2017).

With regard to these positions, we suggest a more granular analysis of the existing liability and insurance framework. This is necessary to show that a reasonable and adequate ultimate allocation of liability costs indeed is also of practical importance, as it determines whether insurance premiums could shift from motor insurance to product liability insurance. Based on this assumption, an in-depth analysis of single provisions and the interrelations of the different sources of law is applied, as only this makes it possible to deduce whether the existing framework actually leads to a reasonable allocation of liability costs.

With this approach, we also find that the existing liability and insurance framework broadly matches the predominant goal of an adequate protection of injured claimants. However, we show that the high level of claimant protection could be interrupted in large scale accident events.

Assessing the framework’s ability to reasonably allocate liability costs, we find that there are specific exclusions and limitations of liability in the Product Liability Act as well as shortfalls in terms of the ability of motor insurers to conduct subrogation claims against a manufacturer. In addition, we also find a lacking interest of motor insurers to conduct subrogation claims as this successively erodes the own business model. Ultimately, this could impede a reasonable and adequate ultimate allocation of liability costs, which potentially inhibits the crucial incentive function of liability.

II. Current law regarding legal liability for automated vehicles

Due to the progressing automated driving capability of motor vehicles, the German legislative body has recognised the need for adjustments to the StVG. Therefore, an amendment was elaborated which came into force in June 2017. The aim of this amendment is to ensure a clear allocation of liability for highly and fully automated vehicles.
vehicles (SAE level 3 and 4). Autonomous vehicles are not within the scope of this amendment.

In general, the StVG distinguishes between two parties, which can be addressed when a third-party suffers damage due to the operation of a motor vehicle. While the StVG imposes strict liability on the owner of a vehicle (§ 7 StVG), the human driver is only liable based on fault (§ 18 StVG). This legal approach is coupled with the obligation for the owner to take out and maintain motor third-party liability (MTPL) insurance coverage protecting himself, the titleholder and the driver of the vehicle against liability claims from third parties caused by the use of the vehicle (§ 1 Law on compulsory insurance for owners of motor vehicles (PflVG)). In this respect, the damaged third-party has the possibility to directly claim against the respective MTPL insurer (§ 115 Insurance contract law (VVG)).

1. Liability of the owner of the motor vehicle

The strict liability approach of the German liability system is based on the legal logic that the usage of a motor vehicle opens an (abstract) source of risk to society. This introduction of risk is legally accepted but the individual who benefits from the usage of the risky object has to bear strict liability if the (abstract) risk becomes manifest. As well as for owners of motor vehicles, the concept of strict liability is inter alia applied to owners of aircraft, animals and operators of railways and power plants.

The owner does not necessarily need to be the titleholder of the vehicle, as German law separates the right of property title determining the titleholder (§ 903 German Civil Code (BGB)) and the right of possession determining the owner (§ 854 BGB). The main characteristics of the owner are that he is the person who uses the vehicle for his own account and has the power of disposition. The owner regularly bears the operating costs and benefits from the use of the respective motor vehicle (Euler 2011).

The owner is obliged to compensate for claims with strict liability (§ 7 (1) StVG). To ensure the ability to meet these financial obligations, the owner has to maintain obligatory MTPL insurance coverage (§ 1 PflVG). The strict liability of the owner for losses due to

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6 We use the term “autonomous” vehicle for vehicles which technically have the capability to self-reliantly fulfill the driving task in a comprehensive manner and do not require a (human) driver at all (SAE level 5).

7 For example, in case of a credit-financed car the bank typically is the titleholder of the car as long as the debtor has not paid back the credit. However, the debtor still has the factual right of daily disposition and the duty to adequately maintain the vehicle as the owner of the vehicle.
the same event is generally limited to €5 million for personal injury and death of a third-party and to €1 million for property losses (§ 12 (1) StVG). However, these maximum liability limits are doubled if the damages result from the use of a highly or fully automated driving function (§ 12 (1) StVG).

The obligation of the owner to bear strict liability is only excluded where the accident is caused by force majeure (§ 7 (2) StVG) or if the driver used the vehicle without the knowledge and will of the owner, unless the use of the vehicle has been made possible by fault of the owner (§ 7 (3) StVG). The obligation to compensate a damaged party is excluded, if the injured party was actively engaged in the operation of the motor vehicle (§ 8 no. 2 StVG). With this exclusion, the liability of the owner for damages to the driver is regularly exempted. Assessing this exclusion against the background of automated driving vehicles, it is questionable, whether the (human) driver can still be classified as actively engaged in the operation of the motor vehicle. Because of the legal approach to ascribing the human (driver) the attribute of being the driver even while using automated driving functions in the scope of the intended use, it could be assumed that this exclusion will still be applicable to automated vehicles. This is because the driver is still in a position of latent engagement due to the obligation of an adequate level of awareness and supervision even if he does not actually fulfil the active steering task during automated mode (von Bodungen and Hoffmann 2016). However, with autonomous vehicles this exclusion should logically be void if no passenger in the vehicle can be considered to be (actively) engaged in the operation of the vehicle.

2. Liability of the driver of the motor vehicle

According to the StVG, the driver of a vehicle is liable up to equal compensation limits as the owner, if the damage to a third-party is due to his fault. For this, the fault of the driver is presumed (§ 18 StVG) but can be refuted by providing evidence.

In the amendment of the StVG, the definition of the “vehicle driver” is not extended to the automated system but designates the human driver as the driver of the vehicle even for the time he does not technically control the vehicle by an active steering action (§ 1a (4) StVG). Within the scope of the intended use of the automated driving function, the driver of the vehicle is generally allowed to turn away from the traffic scene and vehicle control (§ 1b (1) StVG), but has to keep situational awareness to always fulfil his obligation to immediately (without undue delay) take over vehicle control.
• if the highly or fully automated system so requests or (§ 1b (2) no. 1 StVG)
• if he recognises or should recognise on the basis of obvious circumstances that
  the conditions for the intended use of the highly or fully automated driving
  functions no longer exist (§ 1b (2) no 2 StVG).

Even if the amendment to the StVG does not explicitly differentiate between highly and
fully automated vehicles, the legal requirements of the driver of the vehicle implicitly
lead to a certain distinction. This is because not only the scope of the intended use but
also the duration and extent of (legally accepted) turning away from the driving scene
should increase with progressing automation.

In addition, the driver is also liable under the general provisions of the German Civil
Code, if he intentionally or negligently and unlawfully injures the life, body, health,
freedom, property or another right of another person (§ 823 (1) BGB). The conditions of
an intentional injury are that the damaging party acts consciously and willingly with
regard to the occurrence of the damaging event. A person’s act is classified as being
negligent if the person fails to exercise reasonable care (§ 276 (2) BGB).

In contrast to the provisions of the StVG, the liability resulting from the BGB is not
limited to a maximum amount. However, the damaged third-party bears the burden of
proof that the preconditions of liability (intentional or negligent, unlawful action) and the
causality between the action and the damage are met.

3. Product liability

The vehicle producer is not explicitly included in the liability framework of the StVG.
However, even if the car manufacturer is not explicitly mentioned as a liable person, the
explanatory memorandum clarifies that the respective motor insurance company has the
possibility to subrogate claims under applicable product liability laws.

As the provisions regarding product liability resulting from Directive 85/374/EEC are
largely harmonised in the European Union, the following analysis focuses on the specific
German implementation of these provisions in the Product Liability Act (ProdHG),
acknowledging that producer liability can also result from either a contractual relationship
or tortious claims under the German Civil Code.

The provisions of product liability hold a producer liable for claims of a damaged third-
party if a defective product causes a person's death, bodily injury, damage to his health or
damage to an item of property (§ 1 (1) ProdHG). The liability resulting from ProdHG is strict.

The scope of the ProdHG only covers property damage if this damage was caused to an item of property other than the defective product (ibid). Following from this, the scope of the ProdHG does not cover spreading defects which are defects to a functionally separable component part that lead to damage to the whole product. Hence, subrogation claims for damages to property items are only possible for MTPL insurance losses and not for insured losses to the own vehicle.

Furthermore, the producer has only to compensate for damages if the item of property is of a type which is ordinarily intended for private use or consumption and mainly used accordingly by the damaged person (ibid). This exclusion is especially relevant for third-party damages to commercially or publicly used property/infrastructure, such as commercial vehicles (buses, commercial trucks), buildings or traffic infrastructure, which are not covered by the literal interpretation of this provision. Assessing the wording of this legislation in the case of a car-to-car-accident event, vehicles mainly used for a commercial purpose would generally not be covered by the scope of the ProdHG. Today, the prevailing possession-based mobility approach highly reduces the relevance of this exclusion. Assuming that the progressive automation will promote a shift towards the usage of commercial shared-mobility services, the relevance of this exclusion could potentially grow in the future. Assuming this, it is questionable whether this exclusion is reasonable, because the commercial usage of shared passenger vehicles, except for the frequency of usage, does usually not materially differ from the characteristics of private usage. In addition, most companies that use vehicles for a commercial purpose generally do not have specific technical and engineering know-how before purchasing (automated) vehicles and therefore depend on the reliability of vehicles in the same way as private users do.

The ProdHG defines a product as defective when it does not provide the safety that the consumer, with consideration of all circumstances, is entitled to expect. Relevant circumstances which have to be considered are the presentation of the product, the kind of use that has reasonably to be expected and the time the product was put into circulation (§ 3 ProdHG). For the legal interpretation of the existence of a defect, the objective safety expectations of a reasonable average user or consumer are used as a reference. The damaged party bears the burden to prove the defect, the damage and the causal
relationship between the defect and damage (§ 1 (4) ProdHG). As an easing of the burden of proof, the damaged party only has to prove that the defect existed at the time of the loss occurrence but not the temporal and local origin of the defect (Komescher 2011). If the damaged party can provide this evidence, the manufacturer has to prove that exclusions of liability are applicable.

In contrast to the provisions of the StVG, the ProdHG does generally not limit the maximum liability amount for damages caused to an item of property. However, the maximum liability amount for personal injury damages caused by identical products with the same defect is limited to €85 million (§ 10 ProdHG). The application of this maximum liability amount is not harmonised within the European Union but if a member state decides to implement a different liability limit, the minimum threshold of €70 million has to be applied (Council of the European Union 1985). Even if we assume that this limit is high enough to cover losses arising from single accident events, this limitation of liability could especially gain in relevance, because the interconnection of vehicles and the correlation of risk behavior of a vehicle fleet based on the same algorithm potentially induces accumulation risk, where multiple accidents could cause personal injury damages in excess of the implemented threshold. In this case, it would be unreasonable if exceeding loss amounts were to shift back to either the insured owner or the damaged third-party.

Furthermore, the obligation to compensate for property damage under the ProdHG only applies if the respective damage exceeds a threshold of €500 (§ 11 ProdHG). Hence, motor insurers could not subrogate property losses that do not exceed this threshold. Under current regulations, this is understandable as legal and procedural costs induced by conducting of subrogation claims could easily exceed this threshold and lead to economic inefficiencies. We expect that this threshold should not lead to a material inadequate allocation of liability costs from a macro-level view on the overall insured portfolio, as MTPL losses below this threshold account for only 0.43 % (2015)\(^8\) of all insured MTPL loss expenditure. However, from the perspective of the individual insured person, not being able to conduct a subrogation claim because of the minimum threshold can have adverse consequences because of the impact to the individual insurance premium, which is commonly based on a no-claims bonus system in the German market.

\(^8\) Share of loss expenditures for MTPL-losses, which do not exceed the threshold of €500, from total loss expenditures for MTPL-insurance in the year 2015. Source: German Insurance Association.
In addition to the limitation of maximum liability amounts for personal damages and the deductible for property damages, the liability of the manufacturer *inter alia* is generally excluded if, under consideration of all circumstances, it is probable that the defect which caused the damage did not exist at the time when the producer put the product into circulation (Article 1 (2) no. 2 ProdHG).

This exclusion is relevant as the capability of automated vehicles will likely not be static but could be altered by (over-the-air) software updates so that the inherent accident risk exposure fluctuates over time. However, the provisions of the ProdHG generally do not oblige the producer to monitor the circulated product after sale. Therefore, it should be discussed whether the temporal attachment point of putting the product into circulation has to be renewed with every (material) change to the product functionality. On a technical side, this discussion has also to be supported by vehicle approval authorities with setting guidelines defining material changes to system functionality, which require a repeat process of type approval test. If the temporal attachment point of product circulation would not be renewed with every (material) change, residual technological development risk would fall back to the owner of the vehicle, who is liable with strict liability.

In addition, the legal provision that claims based on the ProdHG expire ten years from the time when the producer put into circulation the product which caused the damage (Article 13 ProdHG) could also lead to a shift of residual technological risk to the owner of the vehicle. This exclusion will not be relevant in the first years with automated vehicles on the road but in case that an automated vehicle which is older than ten years causes an accident.

Finally, the liability of the manufacturer is excluded if the state of scientific and technical knowledge at the time when the producer put the product into circulation was not such as to enable the detection of the defect (Article 1 (2) no. 5 ProdHG). To apply this exclusion of liability it has to be objectively referenced against the scientific and technical knowledge which was generally accepted and available at this time. This exclusion is potentially important with the progressing automation of modern vehicles because general standards and sufficient case law decisions for programming driving algorithms and testing autonomous vehicles do not yet exist.
III. Adequacy of the existing liability and insurance framework for autonomous vehicles

Based on the description of the different sources of liability of the owner and driver of a motor vehicle on the one hand and the producer on the other, the resulting liability and insurance framework is depicted in Figure 2.

Even if a claim of a damaged third-party against the producer is legally possible, the dashed line reflects the associated higher financial and organisational effort required. Hence, the damaged third-party will rather not use this path if the claim is sufficiently compensated by a direct claim against the motor insurer due to the strict liability of the owner.

![Figure 2: German liability and insurance framework for losses caused by (highly and fully automated) motor vehicles. The figure depicts an overview of the several sources of liability of the involved parties in case of losses due to road accidents.](image)

Today, above 90% of all road accidents are caused by human error. Therefore, an investigation of the product liability claims is very low in the (German) motor insurance market. However, with the progressive automation of motor vehicles and a shifting responsibility for the causation of accidents to OEMs and their suppliers, the interdependencies of the current liability and insurance framework and regulations regarding product liability have to be assessed and aligned to create a consistent and adequate framework for automated vehicles.
In the following, we analyse the adequacy of the existing liability and insurance framework for automated and autonomous vehicles based on the following criteria of assessment:

- **Protection of the claimant**: Does the current framework adequately ensure the protection of the damaged (third-party) claimant?
- **Responsibility-based allocation of costs**: Does the current framework adequately allocate liability costs to the responsible party?
- **Cost-efficiency of the claims process**: Does the current framework ensure a cost-efficient allocation of liability costs?

Within this analysis, we make suggestions for adjustments to the liability and insurance framework that would ensure higher adequacy for the categories analysed.

1. **Protection of the claimant**

The central idea of the existing (strict) liability and insurance framework is to ensure an as high as practicably possible level of protection for the damaged third-party claimant. Claimant protection must be evaluated as a two-stage process considering the maximum extent of (financial) protection and the required processual effort to achieve this compensation. Hence, the following analysis assesses the easiness of the claims process (e.g. regarding the speed of the process, clarity of relevant institutions to contact and the burden of proof) and the material (maximum) compensation to the claimant.

The central idea of claimant protection from a processual point of view is anchored with the strict liability of the vehicle owner, obligatory MTPL insurance and the possibility to direct claim against the respective motor insurer. The strict liability of the owner and the possibility to claim directly against the motor insurance company is a generally proven process that ensures a clear path for compensation from the motor insurer as the central institution, which comprehensively compensates justified liability claims for all probably liable parties. In fact, this strict liability approach is also practicable with automated vehicles, so that it can serve as a blueprint for other countries’ legal approaches, which are based on the fault of the human driver (Duffy 2013). That said, the strict liability approach has to be embedded into a well-functioning and robust insurance market to effectively protect third-party claimants.
The preservation of the current process for automated vehicles in large part will assure claimant-friendly processing of liability claims with respect to the speed of the process and clarity about the relevant institutions. This is supported by legislation, which generally limits the period for processing claims to three months (§ 3a PflVG). Therefore, speedy processing of third-party claims is supported by the legal environment. However, the adequacy of the current framework for autonomous vehicles will only guarantee a high level of claimant protection if the maximum material compensation covered by this process is also adequately determined.

On the one hand, it could be argued that the current framework generally does not reduce the compensation of a claimant damaged by an automated vehicle. This is because the doubling of the maximum liability limits for owner’s strict liability increases the maximum achievable compensation that can be claimed without providing evidence of fault. The legislator inter alia rationalises the need for an increase, because the fault-based unlimited liability of the (human) driver may not apply where the accident is caused by a technical failure of the automated driving function.

That said, it is questionable whether the increase of maximum liability amounts will adequately replace the unlimited fault-based liability of the (human) driver and adequately ensure the protection of the claimant for severe loss scenarios. This is because the current approach of applying the liability of the owner and (human) driver, which are covered by motor insurance, on a first level and the possibility to subrogate claims under product liability law only on a second level procedurally separates the damaged third-party from claims against the manufacturer. This separation could turn out to be disadvantageous if the claimant is only compensated up to the lower limitations of strict liability of the owner, even if the manufacturer is held liable during the subrogation claim process of the motor insurer.

With a limited financial tail-risk of single insured MTPL losses on a portfolio basis, we expect that the great majority of accidents will be sufficiently covered by the increased maximum liability amounts. However, single accident occurrences have already shown that possible maximum losses for MTPL insurance can greatly exceed the applicable threshold. For instance, this can be illustrated by the highest recorded MTPL insurance loss, where due to the fault of the driver, a vehicle crashed with a train, which derailed and crashed into another train. Ten people died and about 80 were injured leading to an insured loss of about € 30 million.
If this accident had been caused by an automated vehicle, the claimant would (additionally) have to claim against the manufacturer under applicable product liability laws for losses, which exceed the maximum compensation amounts of the StVG. This would expose the claimant to higher legal costs and effort. In turn, this potentially hinders claimants from claiming for compensation that exceeds the maximum liability limits of the StVG, even if those claims would be legally justified. In doing so, the current framework could contravene the principle of a one-stop-shop approach and hence reduce the level of claimant protection with regard to the required processual effort to claim for adequate material indemnification.

Therefore, policy sets may be improved by a further increase of maximum liability amounts for owner’s strict-liability. This approach is also imperative from a societal point of view because the limitation of maximum liability amounts would otherwise potentially result in disproportionate residual legal risk and uncertainty of compensation to damaged third parties. From an insurance market point of view, this should not be problematic, as commonly sums insured in the German market greatly exceed the liability limits of the StVG\(^9\) anyway.

2. **Responsibility-based allocation of liability costs**

With automated vehicles on the road, the responsibility for the causation of road accidents will successively shift from the human driver to the automated system itself. Therefore, only accidents that are caused by inadequate maintenance (e.g. missed software-updates) of the automated vehicle can be attributed to the owner’s sphere of responsibility (Bertolini et al. 2016). With autonomous vehicles, which do not need a human driver anymore, the fault of the human driver will not longer be a relevant contributing factor to accident occurrences. The owner of the vehicle will only be left with the possibility to influence the risk of the vehicle through a reasonable effort to maintain the physical components of the vehicle and update the autonomous system’s software. Hence, it is expected that the share of accidents which potentially fall under the applicability of product liability will increase (German Ethics Committee 2017).

That said, the preservation of the strict liability approach for automated vehicles is systemically consistent with the legal logic that the owner of the vehicle, from whose use

\[^9\] Commonly sums insured in the German motor insurance market are limited to € 100 million.
the owner benefits, opens a source of risk to society. Hence, the owner of the vehicle will ultimately bear the residual risk of liability, which legally cannot be attributed to the manufacturer or other potentially liable parties. However, the owner’s only limited possibility to influence the risk exposure of the vehicle makes it necessary to reconsider the balance of liability cost allocation between the owner and manufacturer of the vehicle in favor of the owner.

From a macro-level view, which does not consider the allocation of liability costs after a specific insured loss event, it could be argued that the owner of the vehicle will ultimately carry liability costs anyway, either directly by paying insurance premiums or indirectly through an additional price component when purchasing a vehicle. This price component then accounts for the product liability risk of the manufacturer (Armbrüster 2017). However, this argument only ensures that liability costs are adequately attributed to a superordinate entire portfolio (e.g. homogenous portfolio of insured or portfolio of buyers of certain vehicles) but not that liability costs are also adequately allocated on an individual basis (e.g. impact on no-claims discount on individual insurance contract).

Furthermore, this perspective does not consider the allocation of expense inflation risk to the owner or manufacturer. In case that the owner pays an additional premium when purchasing the vehicle, the risk that the premiums are not sufficient to meet liability claims is shifted to the OEM. By contrast, if the owner of the vehicle is still obliged to pay obligatory motor insurance premiums, the risk of expense inflation indirectly remains with the owner of the vehicle, as it iteratively flows back via insurance premium adjustments. In addition, allocating liability costs to the producer, who adds these costs as an additional premium to the vehicle price, would ceteris paribus mean that less reliable vehicles are in turn more expensive, which in turn reduces the marketability of unreliable vehicles. In this way, the allocation of liability costs to the producer would support a more prudent testing approach of manufacturers before placing their vehicles on the market (Marchant 2012).

It could further be argued that a responsibility-based allocation of liability costs for a specific accident event is generally applied by the current framework because the motor insurer covering owner’s strict-liability in the external relationship to the damaged third-party can regress claims from the producer under applicable product liability laws. Where this subrogation claim is successful, the liability costs are ultimately born by the producer. In doing so, the design of the liability and insurance framework has to ensure that the
residual risk of owner’s liability is not inadequately increased by the design and conditions of the subrogation claim process. For this, the extent of reasonable and adequate allocation of liability costs depends on the willingness and the ability of the motor insurer to conduct subrogation claims under the current product liability laws.

The current scope of MTPL insurance is only limited to the satisfaction of justified claims and the rejection of unjustified claims (“passive legal protection”, see § 2 (1) Regulation on insurance cover in motor vehicle liability insurance (KfzPfLVV)). In contrast, MTPL insurance does not cover the owner’s interest in law enforcement against other parties (“active legal protection”). If a motor insurer settles a justified MTPL claim and the insured is entitled to reclaim damages from another third-party, the claim of the insured is assigned to the motor insurer to the extent that the motor insurer already compensated the third-party claimant (“cession of right”, see § 86 VVG). Hence, the insured currently has neither a legal nor contractual right within the applicable law (§ 2 (1) KfzPfLVV) and standard motor insurance wording that would oblige the insurer to conduct a subrogation claim against the vehicle producer or automotive supplier. This is not problematic for manually driven vehicles because subrogation claims to third parties do not play a significant role and do not affect the overall achievable premium volume of the motor insurance market. Thus, conducting subrogation claims against third parties is in the best (economic) interest of both the insured and motor insurer, as this prevents adverse impacts to the individual insurance contract of the insured and also lowers claims expenses and, in turn, improves underwriting results of the insurer.

This alignment of interest could decrease because the increasing relevance of subrogation claims successively erodes the presence of insurance risk, which is a crucial precondition of the motor insurance business model. Given the market-wide importance of motor insurance business volume, this potential conflict of interest is especially relevant in the case that a motor insurance company has not proactively initiated a structural change to reduce the dependency on contribution margins from MTPL insurance for the financing of companies’ overhead costs. Hence, assuming that a progressive shift of liability costs on a superordinate portfolio or market level decreases the overall achievable premium volume, the motor insurer may be less likely to conduct subrogation claims. To ensure a reasonable and adequate allocation of liability costs, we propose an expansion of the obligation of a motor insurance company to conduct subrogation claims in favor of the insured party. However, this would augment the scope of MTPL insurance with a certain degree of active legal protection.
In addition to the willingness of the insurer to conduct subrogation claims, the ability of an insurer to do so depends on the legal and technical know-how and the availability of relevant (telematics) data. These resources are required to be able to provide evidence that the conditions of product liability are met. The burden of proving the presence of a product defect could be difficult, especially for accidents caused by software failure of an automated vehicle. This problem is increased by the current limited technical and engineering know-how, which is required and therefore maintained by insurance companies to underwrite retail motor insurance business today. This could lead to the outcome that a subrogation claim against an OEM is not conducted due to a lack of technical expertise and the unknown probability of success. This, in turn, could lead to inadequate allocation of liability costs at the expense of the insured owner of the vehicle.

Furthermore, the possibility of the motor insurer conducting subrogation claims against the manufacturer of the vehicle is also limited, if the potential exclusions of product liability described in section II.3 are applicable. This especially holds true for damages to own vehicles, which are generally not covered by the provisions of the ProdHG.

3. Cost-efficiency of the claims process

Regardless of the question of the current framework´s ability to allocate liability costs for accidents in a responsibility-based manner, the owner of the vehicle and even producers are indirectly exposed to adverse economic consequences if the process of allocating liability is not structured efficiently and unnecessarily causes additional processual and legal costs.

Generally, the combination of strict liability with mandatory MTPL insurance and the opportunity to claim directly against the motor insurer is appropriate to satisfy claims of a third-party arising from manually driven vehicles with low processual costs. This is reflected by average cost ratios of about 17.9 %\(^{10}\) in the German motor insurance market.

However, the efficiency of the current framework´s claims process is mainly based on the fact that the owner of the vehicle and the driver are ultimately almost exclusively liable for third-party losses caused by the usage of the insured vehicle. Therefore, the claimant directly contacts the respective motor insurance company as the institution, which also ultimately bears liability costs. Further litigation and subrogation claims\(^{11}\) are only rarely

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\(^{10}\) Source: Own calculation based on data from German Insurance Association (GDV)

\(^{11}\) Today, subrogation claims in the motor insurance business are mainly relevant for cases where one of the insured parties breaches contractual obligations that have to be fulfilled before or after a loss occurrence.
conducted by the motor insurer after the direct claim process of the damaged third-party (Schroll 2015).

However, the idea that the motor insurer is the central institution to claim and to absorb liability costs holds true for manually driven vehicles, where more than 90% of all accidents are caused by human error, but this could change for higher automated vehicles if product liability becomes more relevant. Hence, even where liability costs can adequately be allocated through subrogation claims of the motor insurance company after a single accident event, the owner of a vehicle maintaining MTPL insurance still has to pay for internal overhead costs (e.g. claims-handling, execution of the subrogation claim) and safety margins for residual legal risk. These are accounted for in the motor insurance premium.

From a macro-level perspective of both the motor insurer and producer, the two-step approach of paying the claim of the damaged third-party first and finally allocating liability costs by the way of subrogation claims potentially causes significant additional legal costs, which have to be absorbed by either the producer or motor insurance company. Ultimately, these costs are carried by the consumer either as the insured or purchaser of a car.

Hence, unaltered preservation of the current framework could turn out as inefficient, at the latest with autonomous vehicles on the road. Therefore, simplifying the process of conducting subrogation claims for an MTPL insurer, for instance, with a refutable presumption of a product defect where a vehicle caused a crash in automated driving mode, would reverse the burden of proof to the manufacturer and could increase the efficiency of subrogation claims. This is because legal costs would only incur in case that OEMs can provide evidence that the accident was caused by the fault of the owner or human driver (e.g. inadequate maintenance, unintended use, etc). Consequently, only those accidents which are verifiably caused by the fault of the owner would be taken to court. As we assume that this will be the minor share of all accidents, legal and processual costs should be reduced.

In addition, we have described how a lack of insurers´ ability or willingness could lead to inadequate allocation of liability costs. This is the case if motor insurers, either due to a lack of technical and legal know-how or because of a lack of motivation, fail to prove producer´s liability where the conditions of producer´s liability are actually fulfilled.
Here, refutably presuming a product defect could also support liability costs being allocated based on the factual responsibility for loss causation in a specific loss event.

**IV. Conclusion**

Our analysis of the appropriateness of the current insurance and liability framework shows that it largely ensures adequate protection for third-party claimants also for accidents caused by automated vehicles. Hence, this approach could generally be used as a blueprint for other jurisdictions, which base liability on the fault of the (human) driver. This, in turn, would also lead to a unification of different liability systems in the European Union and support the cross-border use of automated vehicles and, in particular, unify the legal requirements for the automotive supply side. Only minor adjustments, like the further increase of maximum liability amounts for owner’s strict liability, are suggested to increase the level of claimant protection also for accident scenarios with extraordinary high cumulated loss amounts. With this approach, the general structure of the liability framework shown in Figure 2 would also be suitable for automated vehicles so that a damaged third-party would be comprehensively protected with the existing possibility to claim directly against the motor insurer\(^\text{12}\).

Next to an adequate level of claimant protection, a central function of the liability and insurance framework is to allocate liability costs in a reasonable manner. In contrast to existing academic literature, we show that a reasonable and adequate allocation of liability costs is inhibited because of several barriers that hinder the shift of liability costs from the owner of the vehicle to the manufacturer. We outline that this shift is highly dependent on the practical application of subrogation claims and show that the ability and the motivation of motor insurers to conduct subrogation claims is potentially negatively affected because of a lack of required technical and engineering know-how and insufficient motivation to do so. This is because a market-wide conducting of subrogation claims would, in the long-term, erode the business of motor insurance. In addition, our in-depth analysis of specific provisions of the ProdHG also shows that exclusions and limitations of liability within this source of law potentially inhibit subrogation claims and thus a reasonable and adequate allocation of liability costs. In this case, the preservation

\(^{12}\) With this approach, the procedure to directly claim against the producer shown with the dashed line in Figure 2 would not required with automated vehicles on the road.
of the current liability and insurance framework would inadequately conserve a predominant allocation of liability costs to the vehicle owner.

We show this circumstance as problematic because it not only impedes the incentive function for automotive manufacturers to maximise the inherent safety of their products but also allocates an unreasonable exposure of residual liability risk to the vehicle owner. Thus, we forecast that changes already made through the amendment to the StVG are not sufficient to meet the characteristics of automated driving vehicles. As outlined in our analysis, we propose revising the ProdHG to

- a) increase the limitation of liability for personal injury losses;
- b) set clear legal standards for testing and validation to support a consistent interpretation of the exclusion that the defect was not detectable with the application of state-of-the-art methodologies;
- c) address the definition of the temporal attachment point of product circulation;
- d) address the threshold of € 500 for product liability losses; and
- e) amend the requirement that the damaged item has to be ordinarily intended for private use or consumption.

However, we also see the point that the feasibility of proposed changes based on legal theory potentially conflicts with the practical enforceable legal policy, which is influenced by the interests of single stakeholder groups. In particular, insurance companies are one of the major stakeholder groups regarding the allocation of liability for (automated) vehicles. Here, the future legal policy to allocate liability costs is a key variable determining the extent to which premium volume of traditional motor insurance premium could decrease or shift to product liability insurance. This could be one important strategic business-policy related reason why insurance companies call for a preservation of the current framework (German Insurance Association (GDV) 2017).

Additionally, assuming that vehicle manufacturers generally rather avoid carrying financial risks resulting from accidents caused by their automated vehicles, a high consensus of interests would indeed exist between the motor insurer and the vehicle manufacturer.

However, the consensus of interests also depends on the strategic approach of vehicle manufacturers of transforming their business model from a product-based sales approach to a business model which is based on comprehensive mobility-services. Some OEMs
already claim that they are willing to bear liability costs which are due to accidents caused by their automated vehicles (Volvo Car Group 2017). This would imply carrying insurance risks on their own account. In addition, most of the OEMs are already actively involved in offering their own insurance solutions, either by own risk-carrying insurance entities inside the OEM groups or joint-ventures and extended partnerships with traditional motor insurance companies. Here, the progressive connection and automation of motor vehicles could induce a broadening of this business activity and increase the competition to the traditional motor insurance market.

**Concluding statement leading the reader to the next article:**

The research conducted in this chapter provides an in-depth analysis of the German liability and insurance frameworks suitability for CAV technology from the perspective of (motor) insurers as a central stakeholder. Considering the motivation and central role of this stakeholder within the claim settlement process, the research findings particularly emphasise the interrelations of the legal framework with the business model of motor insurance and outlines the strategic importance of possible changes to the framework from an insurance perspective. Given the research objectives described in Chapter 1, the access to in-vehicle data is an equally essential legal question arising with CAV technology which shows an extensive potential impact on (motor) insurance business models. Thus, the next chapter is devoted to this research question.
References Chapter 2


German Ethics Committee (2017) *Automated and connected driving: German Federal Ministry of Transport and Digital Infrastructure,*


Chapter 3: Connected Automated Vehicles and Insurance: Analysing Future Market-Structure from a Business Ecosystem Perspective


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**Authors´ contribution**

Fabian Pütz contributed with the underlying concept of the paper and carried out the main part of the case study research and writing. Dr. Finbarr Murphy and Dr. Martin Mullins contributed to the structure of the paper and carried out major revision work. Prof. Dr. Lisa O´Malley contributed as an expert with her deep marketing know-how and as advisors for discussion of research findings and theoretical basis of the paper.
Connected Automated Vehicles and Insurance: Analysing Future Market-Structure from a Business Ecosystem perspective

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Abstract

The progressing interconnection and automation of automobile vehicles have profound implications for society and business operations. Existing business models and revenue streams in the automotive and transportation sector will be affected by this developing technology and a potential shift of societal mobility usage patterns. These disruptions will also have a far-reaching impact on the automotive aftersales service and motor insurance sector. Existing literature on the strategic impact of connected automated vehicles (CAV) for motor insurance mostly focusses on questions of liability and the potential impact on the overall premium volume of the business. Enlarging this research focus with an analysis of service-based mobility approaches and the emergence of business ecosystem platforms in the automotive and mobility sectors, this paper finds that these developments have significant spillover effects on customer interfaces and the competitive environment of motor insurance.

In particular, the ability of traditional motor insurers to integrate themselves in business ecosystem platforms built around CAV is disadvantaged due to a lack of an equal technical and legal access to in-vehicle data required for telematics-based services. Referring to this barrier, this research shows that the shift of the automobile to an interconnected smart device makes it necessary that automotive manufacturers (OEMs) open their business ecosystem platforms for third parties to maximise own value propositions. However, as this awareness seems not to be penetrated into adequate proactive action of OEMs, we suggest a timely intervention of legislative bodies to
achieve the common regulatory objective of an undistorted and fair competition in telematics-based (insurance) service offerings.

**Keywords**

Mobility Ecosystems; Connected Automated Vehicles; Automobile Services; Motor Insurance; Business Ecosystems

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I. Introduction

The continuing automation and interconnection of automobiles are expected to increase overall road safety and to induce other societal and individual benefits like improvement in mobility services for impaired people or increased travel comfort (Bunghez 2015; Bagloee et al. 2016; Harper et al. 2016). Connected automated vehicles (CAV) - vehicles that can communicate with each other and with infrastructure to provide information on location, speed etc.- generally have the potential to profoundly impact current business models and revenue streams in the automotive and transportation sectors. First, this is due to an assumed societal change in mobility, shifting from a possession-based mobility pattern to a service-based usage of shared-mobility offers (Belk 2007; Eckhardt and Bardhi 2012; Belk 2014). Second, the opportunity to create digital business ecosystem platforms around the physical core product of the automobile vehicle arises from the interconnectedness of modern vehicles (Fagnant and Kockelman 2015; Krueger et al. 2016).

These changes have far-reaching implications for the automotive and transportation sectors but affiliated downstream markets will be strongly affected as well. In fact, the insurance sector is one of the core stakeholders of the development of CAV. However, existing academic and practice-related research on CAV and insurance mainly focusses on the potential impact of CAV technology to accident liability (e.g. see (Federal Highway Research Institute Germany 2012; Duffy 2013; Schellekens 2015; Schroll 2015; Schubert 2015; Lohmann 2016; Armbrüster 2017)) and the impact of CAV’s inherent accident risk to the overall premium volume of the motor insurance market (e.g. see (KPMG 2016; Morgan Stanley and Boston Consulting Group 2016; Munich Re 2016)) rather than its impact on current and future business models. Analyses of insurance-related aspects of automotive mobility ecosystems have only been partially addressed by practice-related literature (Morawetz 2017; Catlin et al. 2018). To tackle this gap in existing research on a key strategic question for motor insurers, we use the concepts of service-dominant (S-D) logic and business ecosystems platforms as instruments to analyse the impact of CAV to the future competitive environment of the motor insurance market.

The concepts of service-dominant logic (S-D logic) and business ecosystem platforms have already been used to analyse market-structure and strategic positioning in business sectors such as computing software and hardware (e.g. Microsoft or Intel (Gawer and
or Nintendo Wii (Inoue and Tsujimoto 2018) or mobile telephony and smartphones (van Alstyne et al. 2016; Tsujimoto et al. 2018). Furthermore, digital business ecosystem platform strategies can also be found in e-commerce (e.g. Amazon), online-search (Google), mobility (Uber), hospitality (Airbnb) or bioeconomy business (Watanabe et al. 2018). We apply the concepts to a new business sector not yet covered by existing literature. This is relevant to both academic and business literature as it can also serve as an example of how the emergence of technology can potentially disrupt existing business ecosystems (Naveed et al. 2017). Also, this paper shows that the rise of Internet of Things (IoT) applications will fundamentally reshape business relationships in this sector.

By using the concepts of S-D logic and business ecosystems we show that the rise of CAV will have a profound impact on future competition in the motor insurance market. This is due in part to changing societal mobility approaches leading to a shift in customer-interfaces in the motor insurance market. This is because the potential shift of the status of the vehicle owner\textsuperscript{13} from individuals to commercial businesses (Marletto 2019) would transform the motor insurance market from a retail mass-market (B2C with demand-sided polypoly) to a more B2B market with a demand-sided oligopoly. That said, however, a material shift to “Robotaxi” services would require higher levels of automation (level 4 and 5).

Additionally, CAV will impact motor insurance competition due to new (digital) business ecosystem platforms using in-vehicle data for innovative service offerings. The current legal and technical status quo for access to in-vehicle data potentially hampers third-party providers such as insurance companies to offer their own telematics-based services. We use insurance-related use cases to show how automobile manufacturers are able to leverage their preferred access for their digital service offering. From a regulatory point of view, the use cases show that the omission of legislative intervention at this early stage could run contrary to the existing regulatory objective of undistorted and fair competition with the intention to give consumers a free choice of service (European Parliament and Council of the European Union 2015; European Commission 2016; Barbero et al. 2018).

\textsuperscript{13}We use the term “owner” for the German legal term “Fahrzeughalter”. German law distinguishes between the right of property title (“titleholder”) and the right of disposal (“owner”). The owner of a vehicle is the person, who owns the right of disposal and has the duty to maintain the vehicle in safe condition. The titleholder is the person or institution formally owning the property title of the vehicle.
These aspects are already relevant for vehicles with lower levels of driving automation with human individual drivers owning and using the vehicles.

This study is particularly directed to the actors in the automotive aftersales and motor insurance sector and presents a strategic course of action for them to position themselves in a changing market environment. In this way, this paper helps to bridge the gap between theory and practice in the field of academic research of business ecosystem platforms as claimed by Gulati (1998) and provides useful recommendations for practitioners and policy makers. In addition, this paper fills a gap in evidence-based research in the area of strategy development to support the analysis of service-dominant logic and business ecosystems with practical evidence as suggested by Vargo and Lusch (2017). While the societal impact of IoT-based and data-driven services has already been assessed with regard to their implications on individual freedom of choice and behavior (Dotson 2012; Brey 2017), information overload (Rickard et al. 2017) and surveillance (Martínez-Béjar and Brändle 2018) discussions about regulatory frameworks for these services from an economic market perspective are still underrepresented. Existing research from Foldvary and Hammer (2016) advocates that innovation in (information) technology reduces the risk of market failure due to a reduced information asymmetry between actors, but this neglects the risk of developing monopolies resulting from preferred information access.

The paper is structured as follows: Section II provides an overview of definitions and existing literature of S-D logic and business ecosystem platforms. Section III analyses the impact of a shift from a possession-based to a service-based mobility approach to customer interfaces in the motor insurance market. In section IV we assess the competition-related implications of emerging digital business ecosystem platforms in the automotive sector in relation to the strategic positioning of insurers to vertically integrate services into these business ecosystems. Finally, section V presents a synthesis of the findings and provides recommendations for the strategic positioning of motor insurers as well as for the relevant legal bodies to take prospective regulatory action to ensure the achievement of fair and equal market competition.

II. Definitions & literature review

The likely shift from a possession-based mobility approach to the usage of service-based individual mobility introduces a paradigm shift in the approach of how automotive manufacturers serve their clients’ needs. Vehicle manufacturers will not only focus on
the production of automobiles as physical products but create value to customers by offering mobility services. Thus, the shift of mobility usage patterns clearly illustrates a shift from a goods-centric to a service-centric business philosophy. However, the applicability of service-dominant logic as introduced by Vargo and Lusch (2004) is applied to (immaterial) services but also to physical goods. Applying this to automobile mobility, the vehicle is simply the physical instrument that delivers the service of mobility to the customer.

S-D logic is a meta-theoretical framework for the analysis of value (co-)creation and exchange between various actors on markets and in other networks (Vargo and Lusch 2016). Within this new logic of service, intangibles, such as skills, information, and knowledge (operant resources) become critically important for value (co)creation with customers and other institutions (partners and competitors) in the market (Vargo and Lusch 2004; Vargo and Lusch 2016; Wieland et al. 2016; Vargo and Lusch 2017).

This framework is also the basis for the analysis of (business) ecosystems. Service ecosystems are defined as “relatively self-contained, self-adjusting system[s] of resource-integrating actors connected by shared institutional arrangements and mutual value creation through service exchange” (Vargo and Lusch 2016). This quite abstract and macro-level definition emphasises the reciprocal relationships of the different actors in the system itself, which in their entirety satisfy customers needs by integrating and exchanging services in the market. In the context of automobile mobility ecosystems, the relevant actors integrating certain resources to the ecosystem inter alia are Original Equipment Manufacturers (OEMs), car dealers, repair shops, breakdown service providers, and motor insurance companies. However, this macro-level definition does not explicitly take into account the specific structure of the relationships of the different actors to each other while creating value for customers. In particular, the definition only implicitly considers competitive or cooperative relationships and the orchestrating role of single actors. Due to the focus of this paper on aspects of strategic positioning and market competition related dynamics, we use the term of business ecosystems which is intended to be broader in orientation.

On a macro-level, business ecosystems can be defined as networks of loosely interconnected entities on a market with a competitive or cooperative relationship (Peltoniemi 2006). On a micro-level, business ecosystems can be defined as a network of rather closely interacting entities, which coevolve under the guidance of a central actor.
with the aim of providing comprehensive service offerings to customers. Moore (1996) defines a business ecosystem as “an economic community supported by a foundation of interacting organizations and individuals [which] coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies.” In contrast to the preceding definition by Vargo and Lusch, this definition considers the different roles an entity can assume while acting in a business ecosystem, the competitive or collaborative relationship of different companies as well as the central role of single actors for the set up and perpetuation of these systems. Also on a micro-level, a business ecosystem can be defined as “an interconnected set of services that allows users to fulfil a variety of needs in one integrated experience” (Catlin et al. 2018). This set of complementary, integrated services in the respective business ecosystem follows the demand-side need of the target customer base and integrates either different separate main services (horizontal service-integration) or various supplementary downstream services (vertical service-integration). With this approach, the intention is to provide the customer with a seamless and quality-consistent experience under one platform brand. This integration of a whole set of comprehensive services is intended to improve the convenience of the customer, enabling the producer to take competitive advantage of strengthening relationships with its customer base (Kandiah and Gossain 1998).

The concept of business ecosystems is closely linked to the establishment of a platform that “provides the infrastructure and rules for a marketplace that brings together producers and consumers” (van Alstyne et al. 2016). In a more granular approach, Gawer and Cusumano (2014) distinguish between internal platforms “as a set of assets organized in a common structure from which a company can efficiently develop and produce a stream of derivate products” and external platforms as “products, services, or technologies that (...) provide the foundation upon which outside firms (organized as a “business ecosystem”) can develop their own complementary products, technologies, or services.” We will use this distinction of internal and external platform strategies in our empirical analysis of insurance-related services.

Referring to van Alstyne, Parker, and Choudary (2016), a platform generally comprises four key actors, which are

- the “owners” being in charge of intellectual property rights and governance,
- the “providers” serving as the (technical) interface to the consumer,
- the “producers” providing products and services and
• the “consumers” using the platform for the satisfaction of their needs.

Iansiti and Levien (2004), define the role of value dominators, which take the “*task of connecting network participants to one another or (...) [to make] the creation of new products by third parties more efficient*”. In the end, these actions aim to improve the health and prosperity of the whole ecosystem. The authors suggest a value dominator strategy in a business environment that is characterised by the need for complex networks of asset-sharing and by turbulence in (technological) innovation. In contrast to value dominators, entities taking the role of physical dominators absorb the complex network of distinct organisations (e.g. by acquiring or functional integration) and extract maximum short-term value from the assets under control. This strategy is suggested for companies acting in a market environment that relies on complex networks of (external) assets but is not affected by the turbulence of (technological) innovation. Analysing the current approaches of automotive manufacturers, we will see both value dominating and physical dominating strategies applied.

The structure of a business ecosystem is acutely sensitive to external conditions such as technological progress and legislative action. Indeed, technological and digital artefacts are best understood as operant resources (Akaka and Vargo 2013) offering a competitive advantage to actively create a business ecosystem to the owner (see also (Lusch and Nambisan 2015) and (Lusch et al. 2016)). This role of technology is also recognised by Peltoniemi (2006) who states that new technology used by a specific entity can either have competitive or complementary implications to other entities inside the same business ecosystem. In addition to the influence of technological aspects, Lappi et al. (2017) also emphasise the potential impact of governmental intervention to induce changes to the composition of ecosystems. Here, also Teece (2007) acknowledges the role of (legal) provisions imposed by regulators and standard-setting bodies to limit unfolding of competitive forces, which will be also outlined in the following of this research.

III. Impact of service-based individual mobility on customer interfaces

The ongoing automation and interconnection of automobile vehicles are generally seen as a catalyst for the enhanced adoption of various forms of shared-mobility services inducing a wider proliferation of service-based rather than possession-based mobility (Fagnant and Kockelman 2015; Krueger et al. 2016; Watanabe et al. 2016). This
assumption is supported by the decreasing importance of owning a vehicle as a symbol of status, especially for younger (urban) generations (Bratzel 2014). Here, the increasing automation and interconnectivity of vehicles are enablers to provide flexible and convenient mobility services while simultaneously reducing total mobility costs. This reduction of costs results from high fixed capacity costs of today’s owner-based mobility approach resulting from the typically low utilisation rate of vehicles throughout the day.

Even if these services show high growth rates, the current focus on urban areas and the low relevance for the total mileage driven, limit the current relevance of these mobility approaches on the motor insurance market. However, despite the relatively low relevance of service-based mobility concepts for the overall volume of traffic today, the amalgamation of the carsharing-platforms DriveNow and car2go owned by Daimler and BMW (BMW Group and Daimler AG 2018) indicates the potential growing strategic importance of service-based mobility solutions for automobile manufacturers (Boons and Bocken 2018; Skeete 2018).

If the shift from a possession-based to a service-based mobility usage pattern materialises, there are significant implications for customer interfaces in the motor insurance market. This is because of liability and insurance frameworks that apply the obligation to take out and maintain third-party motor liability insurance to the owner of a vehicle. This is not only applicable to all legal systems applying strict-liability (e.g. the Germany Road Traffic Act imposes liability without fault to the owner of a vehicle) but also to fault-based liability systems like the UK, which include the liability of manufacturers into the scope of regular motor insurance (UK Parliament 2018). Applying this to commercial carsharing or (commercial) e-hail taxi services, the capacity of being the owner of the vehicle is legally allocated to the entity providing the commercial mobility service (Schubert 2015). If the progressing automation of vehicles substantially facilitates the usage of these mobility-services, the resulting shift of the ownership status would also produce a shift in customer interfaces from a business-to-customer (b2c) relationship between the motor insurance company and the individual vehicle owner to a business-to-business (b2b) relationship between the motor insurance company and the (commercial) mobility service provider.

14 E.g. the Bundesverband CarSharing e.V. (Federal Association of CarSharing providers) in Germany indicates a growth rate of 23 % of the registered users for flexible carsharing services to 2.11 mio. people between 2017 and 2018.
Depending on the future market-structure of the mobility service sector, the number of clients could significantly scale down from today’s demand-sided polypoly (resulting from individual ownership of vehicles) to an oligopoly structure with only few mobility service providers which comprehensively satisfy societal mobility demand. Simultaneously, the motor insurance market would shift from a b2c market with a demand-sided polypoly (retail mass market) to a business-to-business market with a demand-sided oligopoly structure. This would mean a potential increasing key-account risk for motor insurance companies followed by the higher market power of the motor insurance demand side. This could foster predatory competition amongst motor insurers tightening the already low profitability of the (fleet) motor insurance business. Finally, motor insurance companies currently focussing on the retail market will have to assimilate competences and expertise regarding the product design, customer-services and actuarial pricing of vehicle fleet insurance to adequately serve the changing customer requirements.

IV. Emergence of business ecosystem platforms

The following explanations focus on an analysis of different approaches of automotive original equipment manufacturers (OEMs) to use the interconnectivity of CAVs to build up platforms for the integrated satisfaction of customer needs.

Assessing the platform strategies of two different OEM groups Mercedes and BMW, we find that they differ from each other with regard to their competition and collaboration with other ecosystem producers. Referring to their role of being platform owners, we find that Mercedes seems to act as physical dominator by fully integrating affiliated services to internal platforms (“mercedesme” service platform), while BMW gives third-party providers access to telematics data (e.g. see BMW CarData platform). In doing so, BMW allows the development of external platforms and -with limitations- tends to act as value dominator in the respective business ecosystem, enabling third-party providers to offer their own services to customers. However, this value dominator approach is limited by the fact that BMW also provides an internal platform for the offer of (telematics based) services with the BMW ConnectedDrive platform. In doing so, BMW is collaborating but simultaneously competing with third-party providers.

1. Physical Dominator Approach
In a business ecosystem built up with a physical dominator approach, the core service (supply of the car) of the OEM is expanded with various complementary downstream services offered under the brand of the OEM, who occupies the customer interface as illustrated in Figure 3.

![Figure 3: Internal mobility business ecosystem platform. The figure illustrates a possible internal business ecosystem platform based on the integration of complementary mobility services to an OEM-owned and closed business ecosystem. Source: Illustration based on (van Alstyne et al. 2016) and (Kandiah and Gossain 1998).](image)

Given the different roles in a business ecosystem platform as defined by van Alstyne, Parker and Choudary (2016), the strategic opportunities and threats arising from the emergence of internal platforms in the field of automobile mobility and telematics based services depends on the respective role of the actors and the specific design of contractual agreements for the joint value co-creation process between the owner/provider and the producers of the ecosystem platform. Being a service provider in a business ecosystem owned by a physical dominator offers the opportunity of developing new customer groups and to indirectly benefit from a strong brand reputation of the platform owner (Kandiah and Gossain 1998). By contrast, it contains the strategic threats of disintermediation from the customer and of an increasing dependency from the platform owner (Catlin et al. 2018).

The general competition amongst OEMs and third-party service providers in providing various aftersales services and especially on motor insurance is certainly nothing new. The need for (mandatory) insurance coverage arises with the purchase of an automobile. Thus, insurance companies already today face the risk of disintermediation of their clients, as the purchase process of the new vehicle precedes the process of taking out
motor insurance coverage. This, in turn, limits the ability of a motor insurance company to directly access a potential customer just at the moment where the need for purchasing motor insurance coverage arises. Already today most OEMs pursue different forms of collaboration (close partnerships, joint-ventures) with traditional insurance companies to provide own-branded insurance coverage at the point of sale when selling a new car or arranging a leasing contract. Nevertheless, this competition between traditional insurance companies and the OEM business ecosystem is largely limited to new vehicles sales or to the period of leasing and is less relevant for vehicles bought on the used-car market. After the end of the duration of financing and leasing contracts, the number of contact points and the intensity of interaction between an OEM and customer regularly lose traction for insurance-related services.

However, the increasing interconnection of modern vehicles could be a decisive game changer for the competitive environment. This is because OEMs recognise the interconnection of modern vehicles as a facilitator of telematics-based services, which are used to increase customer touch points and to strengthen and extend the duration of the active customer-relationship and the (digital) value co-creation process (Fernandes and Remelhe 2016). Referring to motor insurance, the possibility to access customers via a digital interface in the vehicle potentially expands the already existing competition between OEMs and traditional insurers from the new vehicle market also to the used car market.

Given the expanded competitive relationship between the actors, OEM-affiliated insurance companies generally have the advantage to link the stand-alone insurance product to a comprehensive set of (physically) perceptible products and services, which are based on telematics data.

Generally, competitive threats can arise from competitors from within the insurance industry that have a superior service offering by leveraging business networks. Furthermore, companies coming from outside the insurance industry that collect data which also can be used for concurrent service offerings with higher customer value also pose risks to the insurance business model (van Alstyne et al. 2016). The following use-cases show that a mixture of these two competitive threats will be the key driver for insurance-related services in business ecosystems around CAV. In these use-cases, access to relevant data is a precondition for fair and undistorted competition in the field of insurance-related automobile services.
In the short-term, data from sensors inside the vehicle can be used for the pricing of telematics-based insurance tariffs that aim to link the insurance premium to the individual driving pattern of the driver (“pay how you drive”). Whereas OEM-affiliated insurers have the possibility to use in-vehicle data transferred from telematics control units embedded into the vehicle (e.g. see the offer of Mercedes “InScore”\textsuperscript{15}), third-party insurers without access to this proprietary data only have the possibility to collect data via devices plugged into the OBD-interface (“OBD-dongles”), telematics boxes installed into the vehicle or via smartphone applications. However, due to the additional costs for installing the OBD-device hardware, a lower convenience of the customer due to a higher effort for retrofitting as well as lower quality and quantity of data, these solutions do not allow for the offer of insurance services with equal quality.

Furthermore, extended and more sophisticated breakdown services and a proactive loss management approach based on (real-time) access to in-vehicle data can be offered, for instance, in case of the automatic or manual triggering of an eCall\textsuperscript{16}. However, even if the legal framework for the implementation of the eCall system includes the possibility to transfer the emergency service to any (certified) commercial provider (European Commission 2012), this opportunity is currently technically limited to the respective car manufacturer. This is because a technical and legal framework for the design of a technical interface for data access by third-party providers does not exist yet. Thus, the technical sovereignty of the OEMs results in unequal access to relevant in-vehicle data and this favours the integration of data-driven services to business ecosystem platforms owned by them.

The increasing relevance of OEM-owned internal business ecosystem platforms for the purchase of insurance coverage and related services increases the strategic risk for the traditional insurance market on a macro-level. However, there is also an opportunity for insurance companies to co-create opportunities (Whalen and Akaka 2016) by positioning themselves as suitable partners integrating the insurance offerings under the brand of the OEM. This, however, also depends on the expertise and capabilities of the OEM platform owner to offer insurance products without external partners and the willingness of the

\textsuperscript{15} With the product “InScore” Mercedes uses access to the integrated telematics control unit of Mercedes A-, E-, and S-Class to offer own-brand telematics-based insurance coverage to the customer

\textsuperscript{16} eCall (emergency call) is an automatic emergency call system that manufacturers in the European Union must install in all new models of passenger cars and light commercial vehicles from March 31, 2018. In the event that the driver does not react after a serious accident event, the eCall system automatically issues an emergency call.
platform owner to foster innovation by allowing complementary service providers access to the own platform (Clarysse et al. 2014).

In addition, not all insurance companies have the same technical capabilities, know-how and characteristics (e.g. risk-bearing capacity) to position themselves as suitable partners. First, this is because of the technical integration required between insurance administration systems and the business ecosystem platform of the OEM (Kandiah and Gossain 1998). Second, the increasing automation of the vehicles’ driving capability could increase the risk of product liability claims against the OEM. Hence, an holistic partnership between an insurance company and an OEM group comprises private insurance products for customers of the business ecosystem platform but also commercial insurance for risks faced by the platform owner. However, the characteristics of this commercial insurance risk exposure, the demands of commercial customers and the required know-how for underwriting these lines of insurance business differ greatly from private lines of insurance business like motor insurance\(^{17}\). As a result, only insurance companies that are capable of integrating these set of insurance and risk management services will benefit from the emergence of OEM-owned business ecosystems platforms and use these capabilities as their value proposition. This is because superior value propositions determine how actors are willing to reciprocally share and integrate value in a business ecosystem environment (Frow et al. 2014). This opportunity to set oneself apart as a suitable cooperation partner of the platform provider could offer a possibility to escape from the stiff competition between homogeneous firms in the motor insurance market today (Teece 2007).

As this chance goes hand in hand with the risk of disintermediation of own former customer relationships, the value chain owned by the respective (motor) insurer would be cut back to the supply of backoffice processing and risk-bearing capacity, whereas the customer interface would be controlled by the platform owner. For retail motor insurers, this is especially relevant as motor insurance is generally seen as an entry-level product providing opportunities for cross-selling activities to other products like life and property insurance.

\(^{17}\) For instance, this is because OEM groups generally operate on a multinational basis. Thus, the risk of product liability and/or product recall claims can highly differ within certain jurisdictions. The insurance company taking over the respective insurance risk has to have adequate know-how of legal systems, whereas private motor insurance is predominantly characterised as a national business.
In addition to the risk of disintermediation, the contractual agreement on economic terms of a partnership between the insurance company and the platform owner depend on the bargaining power of both entities. Due to high competition in the motor insurance market and the strategic relevance of this business unit, an increasing concentration of opportunities to access customers on business ecosystem platforms will likely foster insurance companies’ competition for platform owners as key partners. Given this distribution of bargaining power, the platform owners will likely be in a position to negotiate a more favourable basis for the extraction of co-created value inside the business ecosystem (Frow et al. 2014).

Given the chances resulting from superior access to in-vehicle data from an OEM’s perspective, the exploitation of this competitive advantage with a physical-dominator approach might be an intuitive but not necessarily successful strategic approach in the long-term. Iansiti and Levien (2004) suggest a physical-dominator approach for a business environment not affected by turbulence caused by technological innovation (see section II). This might be applicable for motor insurance and automobile manufacturing in the analogue era but will change with the growth of digital business ecosystems around the connected vehicle. Thus, OEMs have to redefine their supply-chain relationships from a goods-dominant to a service-dominant perspective (Metallo et al. 2018). These relationships today are dominated by a top-down relationship with the aim of minimising production costs for a defined physical product. However, successful business ecosystems in an era of the Internet of Things (IoT) are required to leverage the creativity and innovation power of third-party providers to achieve a superior value proposition to customers and to create an advantage when competing with business ecosystem platforms of other players on the market (Teece 2007).
2. **Value Dominator Approach**

In contrast to the integration of services into an internal business ecosystem platform, single OEM companies also provide relevant telematics data to interested third-party service suppliers via an OEM-own server (e.g. see BMW CarData (BMW Group 2017)). As shown in Figure 4, this approach generally enables third parties to independently leverage telematics data to create own-branded services for the vehicle owner.

![Figure 4: External mobility business ecosystem platform. The figure illustrates a possible external business ecosystem platform based on the OEM acting as the supplier of relevant telematics data.](image)

Referring to the described potential strategic shortfalls of using a physical-dominating approach, setting up a business ecosystem platform with a value-dominating approach allows OEMs to not only use the creative power of the own entity or of single preferred partners but from several sources integrating their services into the platform. In general, this enlarges the network effect of the business ecosystem and increases the attractiveness of services offerings for (potential) customers.

From an operational point of view, opening the business ecosystem platform for third-party suppliers by providing them access to relevant in-vehicle data also reduces the effort for OEMs to manage multiple additional business units outside the own core activity, especially those with low margins like motor insurance. This allows them to strategically
focus on crucial core activities and initiatives to effectively design the business ecosystem platform in its entirety.

From a monetary perspective, providing third-party suppliers access to telematics data against the payment of a fee also allows the platform owner to monetarise more than only one reciprocal relationship with a preferred collaboration partner. However, to ensure that third-party suppliers are motivated to increase networking effects of the business ecosystem platform, the pricing structure for service-integration has to leave enough incentive to set-up financially successful business models.

For third-party providers such as insurers, the emergence of external business ecosystem platforms generally lowers the strategic risk of customer disintermediation and lowers the dependency from the ecosystem platform owner, as they generally have the opportunity to access customers on the digital platform. However, this requires that motor insurance companies also apply resources to find innovative services and to build systems to enable them to integrate service offerings.

From a regulatory point of view, the extent of free and fair competition between OEM-affiliated and third-party service providers to use telematics data for own service offerings crucially depends on the equality of available data as well as the pricing structure for the transfer of the data sets. Here, a pricing structure, which significantly exceeds the OEM’s internal costs of data storage, data processing, and data transfer, implies that third-party providers can only offer same services for a higher price than similar services provided by the OEM. Given this, OEMs which simultaneously establish internal platforms for the offer of telematics based services (e.g. BMW ConnectedDrive platform (BMW Group 2017; BMW Group 2018)) could have a competitive advantage compared to third-party providers.

In addition, the commercialisation of consumer data from the vehicle implies fundamental ethical and legal questions of data ownership. This is because the commercialisation of data could contradict the right to informational self-determination that attributes the ownership of (personal) data to the owner or user of the vehicle (Hornung 2015; German Ethics Committee 2017).
3. Applicable legal framework and regulatory objectives for in-vehicle data access:

The regulatory objective of equal market-competition in the field of telematics-based services is generally covered in European legislative guidelines for cooperative intelligent transport systems (C-ITS) and also discussed in the Digital Single Market- Free Flow of Data Initiative (e.g. see (European Commission 2017b)). The declared objective is to allow customers the free choice of a provider for the supply of services. This freedom of choice should be achieved through an “open and undistorted competition for the provision of these services” ((European Commission 2016), p. 72).

In fact, the European regulation concerning type-approval requirements for the deployment of the eCall in-vehicle system required to be installed in new cars from March 2018, considers the creation of “an interoperable, standardised, secured and open-access platform for possible future in-vehicle applications or services” ((European Parliament and Council of the European Union 2015), recital 16). The regulation states that the Commission shall adopt a legislative initiative regarding this platform no later than 9th June 2017 ((European Parliament and Council of the European Union 2015), Art. 12 (2)) following broad consultation with all relevant stakeholders. However, despite the initial plan for the adoption of legislative initiative in 2017, this still has not yet been accompanied by adequate legislative guidelines regarding the technical and process design of uniform access to the respective open-access platform.

This is, in part, due to conflicting commercial standpoints mainly from OEMs and insurance companies as well as other third-party service-providers during the discussions of the stakeholder consultation phase. The OEMs favour a technical solution, where in-vehicle data is transferred to an OEM-own server, which is then made accessible to third-party providers (“extended vehicle” approach as provided by BMW CarData). Third-party providers raise concerns with regard to limited and delayed access to (time critical) data and the potential monitoring of their activities by manufacturers and pleaded for a solution to ensure direct access to the vehicle ((European Commission 2016), pp. 76 f.).

As a result, the responsible working group was not able to conclude a common approach to the development and deployment of technical specifications for the interface to access in-vehicle data as the discussions about the technical design were driven by strategic commercial considerations ((European Commission 2016), p. 89). Consequently, the C-ITS platform has also not made progress on these questions during the second phase of
discussions as the final report mainly just refers to the different position papers of involved stakeholder-groups and suggest a new attempt to find a suitable agreement between the involved stakeholders ((European Commission 2017a), p. 77). The fact that the published positions papers mainly highlight the contrary standpoints during the first phase of discussions within the C-ITS platform (e.g. see (German Association of the Automotive Industry (VDA) 2016; Insurance Europe 2016; Coalition for a competitive vehicle service industry in the digital era 2017)) shows that it remains questionable, whether the different stakeholders will be able to find a common technical solution without the intervention of the legislative bodies.

We have used insurance-related use cases to show that the design and integration of telematics-based services, such as usage-based insurance and breakdown or accident services, crucially depends on access to the required data. The use cases indicate that the current regulatory framework and the technical design of the embedded telematics-interfaces potentially facilitate the evolvement of OEM-affiliated internal business ecosystems platforms at the expense of service ecosystems, which are characterised by a competitive integration of services also from external downstream service providers (e.g. motor insurance companies). As OEMs are starting to integrate telematics-based services into their own business ecosystem platforms, an insufficient legal framework to ensure a fair and equal competition favours the development of OEM-affiliated ecosystems providing strategic competitive advantages to them. We have also described approaches of keystone-like strategies of single OEMs that provide relevant telematics data to third-party providers. However, a lack of regulatory guidelines for the definition of the minimum quality and quantity and adequate pricing structures for these data sets potentially hinders the achievement of a fair and equal market-competition. Against the current background of the extensive technical sovereignty of OEMs to access relevant data, the achievement of the regulatory objective of a fair and equal market-competition has to be promoted by an adequate legal framework allowing adequate access in-vehicle data for third-party service providers.
V. Conclusion, outlook and policy recommendations

The insurance sector is one of the key downstream markets and stakeholder of the development of CAV. This article provides an in-depth analysis of the potential impacts of changing business models in the field of automobile mobility to the motor insurance market. In doing so, this analysis broadens the scope of existing insurance-related (academic) literature concerning the implications of CAV to future business models from a strategic perspective. In particular, we find two major drivers impacting structure and competition within the motor insurance market.

Firstly, a shift towards service-based mobility models will have a significant impact on customer-interfaces in the motor insurance market. This is because of a change in vehicle ownership from many individuals to some commercial fleet providers, shifting the motor insurance market structure from a retail mass-market (b2c with demand-sided polypoly) to a b2b-oligopoly structure. Given the still overall low relevance of service-based mobility for the overall mileage today, the extent of this market structure transformation, however, will depend on the future adoption of mobility services on a societal level. If effective, we show that insurance companies that today only focus on coverage of retail motor insurance risk will have to adjust their products and service-offerings to be able to position themselves as suitable partners of commercial mobility-service providers. This means a significant shift in an industry which is highly commoditised and focussed on the price of the insurance but needs to build up operant resources and strategic partnerships with mobility platform owners. Concomitantly, it is expected that the decreasing number of customers shrinking from a polypoly to an oligopoly will increase competition for these key-accounts in the motor insurance market.

Secondly, we use the concept of S-D logic and business ecosystem platforms and apply examples of insurance-related use cases to illustrate that the increasing interconnection of automobile vehicles will have a significant impact on insurance-related services offerings and processes along the whole insurance value-chain, namely distribution and customer interfaces, premium calculation of usage-based insurance tariffs, active loss management, and breakdown assistance services. We have described different approaches of OEMs to leverage superior access to in-vehicle data by integrating telematics-based insurance-related services into internal or external business ecosystem platforms.
With this approach, we illustrate that a lack of equal access to relevant in-vehicle data potentially impedes the common regulatory goal of fair and undistorted competition between OEM-affiliated and third-party providers. This finding reflects the fact that regulatory agencies have the power to apply effective measures of intervention, which indirectly shape the composition and structure of business ecosystems (Iansiti and Levien 2004). From a market perspective, this gives OEMs the opportunity to leverage their access to data, which is a crucial strategic resource in the era of growing interconnection. This finding is consistent with Gawer’s statement that “platforms that make it past a certain tipping point tend to become really hard to dislodge (...) as market share grows, so also grow their own barrier to entry” (Gawer 2009). This finding is also supported by Chakravorti stating that the challenge to dismantle a given status quo is increasing with the level of interconnection and size of membership of a given network (Chakravorti 2004). Giving this outlook, we contribute to the existing literature by using the motor insurance sector to show evidence on how (a lack of) legislative intervention and the superior access of single market-players to crucial data can influence the development of market structures in a certain direction. Here, we provide evidence that proactive regulatory intervention is required to prevent an adverse impact on market competition and freedom of choice for customers. Although single OEMs seem to be willing to supply relevant telematics-data to third-party providers, the lack of regulatory guidelines for the definition of minimum quality and quantity as well as an adequate pricing structure for this data will inhibit regulatory objectives. This also leaves basic ethical and legal questions considering the monetisation of data from the vehicle unsolved.

From a strategic perspective of OEMs, we conclude that taking the role of a physical dominator to extract maximum short-term value from the ecosystem might be an obvious but not necessarily successful approach on long-term. This is because the shift from a goods-dominant supply-chain perspective to a service-dominant perspective will need a profound redefinition of OEMs´ supply-chain relationships (Metallo et al. 2018). For the long-term success of their business model OEMs should enable third-party providers to integrate dynamic capabilities and innovative service offerings (Clarysse et al. 2014). This would also be highly desirable from a customer point of view to maximise freedom of choice and content diversity of service offerings and, if recognised by OEMs in due time, could also prevent the need for regulatory intervention (Lee and Hwang 2018).

**Concluding statement leading the reader to the next article:**
The research conducted in this chapter provides an analysis of the legal and technical status quo determining the access to in-vehicle data for different stakeholder groups such as OEMs and insurance entities. Given the research objectives described in chapter 1, this article complements the research on insurance-relevant legal factors emerging with the introduction of CAV technology. However, as this technology not only shows important insurance-relevant triggers from legal factors but also from changes of underlying risk-factors, the following chapters of this thesis focus on CAV technology’s risk aspects with a devoted focus on motor insurance risk (Chapter 4) and product recall risk (Chapter 5). This shift in research focus is required to contribute to the overarching research objective to provide an holistic assessment of CAV technology from an insurance-perspective.
References Chapter 3


Coalition for a competitive vehicle service industry in the digital era (2017) *Keeping the principles of the Treaty of Rome alive in the automotive digital age* [press release], 23.03.2017, available: [accessed 01.07.2018].


Federal Highway Research Institute Germany (2012) Legal consequences of an increase in vehicle automation: Consolidated final report of the project group, Fahrzeugtechnik F 83: Federal Highway Research Institute Germany.,


German Ethics Committee (2017) Automated and connected driving: German Federal Ministry of Transport and Digital Infrastructure.,


KPMG (2016) 'Does Motor Insurance Have a Future'.


Munich Re (2016) 'Autonomous Vehicles- Considerations for Personal and Commercial Lines Insurers'.


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Chapter 4: Driving to a Future Without Accidents? Connected Automated Vehicles’ Impact on Accident Frequency and Motor Insurance Risk

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Fabian Pütz contributed with the underlying concept of the paper and carried out most of the research, data analysis and writing of the paper. Dr. Finbarr Murphy and Dr. Martin Mullins to the structure of the paper and carried out major revision work.
Driving to a future without accidents? Connected automated vehicles’ impact on accident frequency and motor insurance risk

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Abstract

Road traffic accidents are largely driven by human error. Therefore, the development of Connected Automated Vehicles (CAV) is expected to significantly reduce accident risk. However, these changes are by no means proven and linear as different levels of automation show risk-related idiosyncrasies. A lack of empirical data aggravates the transparent evaluation of risk arising from CAVs with higher levels of automation capability. Nevertheless, it is likely that the risks associated with CAV will profoundly reshape the risk profile of the global motor insurance industry. This paper conducts a deep qualitative analysis of the impact of progressive vehicle automation and interconnectedness on the risks covered under motor third-party liability and comprehensive insurance policies. This analysis is enhanced by an assessment of potential emerging risks such as the risk of cyber-attacks. We find that, in particular, primary insurers focusing on private retail motor insurance face significant strategic risks to their business model. The results of this analysis are not only relevant for insurance but also from a regulatory perspective as we find a symbiotic relationship between an insurance-related assessment and a comprehensive evaluation of CAV’s inherent societal costs.

Keywords:
Connected Automated Vehicles, Automated Driving Accident Risk, Motor Insurance

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I. Introduction

Connected Automated Vehicles (CAV) offer both opportunities and threats to existing business models. Car manufacturers and automotive suppliers are under immediate pressure to innovate as the production of automobiles is their core business. However, direct and indirect downstream markets will also be affected by the ongoing automation and the interconnectedness of modern vehicles.

The insurance sector is acutely sensitive to the adoption of new technology as insurers cover risks resulting from the usage (motor insurance) and risks arising from the development and production of vehicles (e.g. product recall and product liability insurance). In this sense, the insurance sector assumes risks on individual and societal levels. The motor insurance business is worth €137.5 BN annually in Europe (Insurance Europe 2019) so technological changes will have major ramifications to that sector. In addition, a failure to adequately insure existing and emerging risks may slow the development and rollout of the technology and inhibit societal acceptance.

If CAV does reduce the number of road accidents significantly, this would result in a material decrease in motor insurance premium volume. This path is by no means proven and straightforward but will herald profound changes and repercussions for the insurance sector. The combination of decreasing and emerging risks will reshape the volume and characteristics of motor insurance risk exposure. Different members of the insurance supply chain (insured, primary insurer and reinsurer) typically have different capabilities and appetite to take part of this risk exposure, therefore the shift in the underlying risk landscape will likely also affect the risk allocation within the insurance supply chain.

There is an active and ongoing dialogue within academic literature on CAV from a technical, human-factor, ethical and legal perspective (Bertolini et al. 2016) (Pütz et al. 2018) (Duffy 2013) (Lohmann 2016) (Schroll 2015). In addition, initial accident research on the impact of advanced driving assistance systems (ADAS) on the frequency of accident losses exists but, with the exception of relevant legal aspects, insurance-related assessment of CAV technology is largely limited to practice-related discussions (Morgan Stanley and Boston Consulting Group 2016) (Swiss Re and HERE 2016) (Munich Re 2016) (Yeomans 2014). Therefore, this paper combines two separated research disciplines and contributes to an academic discussion of CAV’s risk aspects focussing on the insurance sector as a key stakeholder of this technology. As motor insurance is a
useful proxy of economic costs arising from motor traffic risk, this research also contributes to a risk understanding from a political and societal perspective (Claus et al. 2017). We enrich this analysis with an assessment of risks that are likely to emerge with CAV (i.e. risk of cyber-attacks (Sheehan et al. 2018)) with a special focus on their implication for the overall characteristics of motor insurance risk.

Even if this development takes decades due to the slow penetration pattern of CAV, this paper is a timely addition particularly for the early stages of strategic planning approaches undertaken by insurance companies. Where relevant, the motor insurance market data used in this paper is taken from statistics available from the German Insurance Association (GDV) and the German Federal Financial Supervisory Authority (BaFin). Data on the German market is a good candidate to examine all (saturated) motor insurance markets as the scope of the single risks covered under German motor insurance policies is similar to the scope of insurance policies in other European countries.

II. Evaluation of CAV accident risk and literature review

This section explores existing literature on the impact of CAV on accident risk starting from lower levels of automation. The fact that 90 % of all road accidents today are attributed to human error is often-used to argue that taking the human driver out of the driving task would causally reduce the number of road accidents. However, in a rationale evaluation of this figure, the high contribution of human error to accident occurrences is just a logical consequence from the fact that, for the time being, it is the human driver, who almost exclusively fulfils the driving action without the intervention of active driving assistance systems. Thus, the figure might indicate the high potential of CAV to further increase overall road safety but is useless as a proxy to quantify CAV’s potential decreasing impact on the overall number of accident occurrences. 769 billion kilometers were driven in Germany in 2016 resulting in only 5.6 accidents per million kilometres showing that humans are, in fact, very good drivers.\footnote{We use the number of collision-related insurance claims as a proxy for the total number of accidents including minor accidents. The number decreases to 3,36 accidents per million driven kilometres when selecting only police-recorded (Destatis, 2017).}

A high potential of CAV to increase road safety results from generally favourable characteristics of robotic systems like the ability to permanently keep up attention (no distraction) or to react faster and with predetermined action patterns. In addition, the
automated system is not exposed to accident risk due to physical and mental human deficiencies like drowsiness, alcohol consumption, distractions, emotional status that deteriorate the performance of the human driver. These factors are critical reasons\(^\text{19}\) for about 22 \(^\text{20}\) of all road accidents (NHTSA 2008). In contrast, it is questionable whether beneficial human cognitive abilities (e.g. anticipation, adaptability or empathy) can be adequately replicated in software-based driving systems. This is especially important as road traffic is dominated by high levels of complexity and flexibility of driving decisions. In addition to risk arising from inadequate driving software algorithms, an automated driving vehicle will also be exposed to the risk of malfunction of vehicle hardware (sensors and electronic control units). The fact that this risk cannot be neglected can be indicated by increasing numbers of product recalls resulting from defects of these components (Murphy \textit{et al.} 2019). Hence, automated driving vehicles first have to prove that they (statistically) increase road safety by reducing the overall number and/or severity of road accidents (“positive risk balance”).

Some empirical data for an indicative evaluation of CAVs’ impact on the overall accident risk can be derived from two sources. First, early findings of accident research for single advanced driving assistance systems (e.g. for Automated Emergency Braking (AEB), Adaptive Cruise Control (ACC), Forward Collision Warning (FCW) or Lane Keeping Assistant (LKA)) can be used to evaluate the potential safety impact of these systems. However, these systems focus on separated driving tasks and only represent low levels of driving automation (level 1 automation) and this data cannot be simply transposed to CAV with higher automation capability. In this paper, we will describe findings of relevant accident research for single ADAS systems to indicate the risk-lowering impact of assisted driving vehicles (level 1 automation) only.

Second, findings from real-world testing of CAV with higher levels of automation can be used to indicate the current technical reliability of these vehicles. For instance, companies testing their CAV fleet in California have to publish reports on disengagements of the tested vehicles, if they conduct tests on public streets. However, the transferability of these results is limited due to the lack of transparency of testing conditions and an only

\(^{19}\) The methodology defines the critical reason as the last failure in a causal chain. Therefore, it may not reflect the (only) cause of a crash and does not necessarily imply an assessment of fault. However, it does imply at least a contributory factor of human failure to an accident occurrence.

\(^{20}\) This share of failure due to physical or mental shortcomings could be higher because the usage of smartphones has increasingly become a contributory reason for distraction within the last years and additional factors such as alcohol and drug abuse have not been considered in this source.
limited statistical representativeness of data. We will detail these shortcomings when describing the empirical data and research findings in later sections.

In the following, we describe the specific effects of single levels of automation that are relevant to CAV accident risk in terms of probability. Equally important from an insurance point of view will be the development of average loss costs of vehicles equipped with CAV technology. Even if unit costs for the development and production of the implemented components (e.g. radar, Lidar, GPS, cameras, ultrasonic sensors, etc.) will decrease over time, these components will be implemented in addition to existing (mechanical) systems. This will promote technology driven inflation of vehicle values. In addition, the implementation of sensors and on-board electronics, especially on surfaces exposed to damage in the event of an accident (e.g. bumpers in case of rear-end crashes), will lead to an increased extent and complexity of repair work that will further increase insured loss amounts (Liberty Mutual Insurance 2017).

1. CAV equipped with ADAS systems (level 1 automation)

In vehicles driving equipped with ADAS (level 1 automation) the human driver is supported by the automated system, which can control either the lateral (e.g. LKA) or longitudinal (e.g. AEB or ACC) steering function. Because the human driver still is continuously and actively engaged in all aspects of the dynamic driving task (motion control, tactical manoeuvre planning/display of action, monitoring of driving environment) the human driver and the assistance system collectively have redundancy and the risk resulting from the inadequate interaction of the driving automation system and the human driver is limited. The assistance system generally only intervenes in critical situations. In doing so, the ADAS system achieves a non-critical driving condition through decent countermeasures (e.g. ACC, LKA) or by fulfilling an automated safety manoeuvre if a time-critical intervention is required (e.g. AEB). Thus, the system is designed as a fall-back to the human driver. By contrast, in case of an error of the assistance system, the human driver generally has the situational awareness to conduct adequate countermeasures. Thus, the human driver and the driving automation system are related by a double-sided continuous redundancy.

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21 Relevant critical situations, for example, could be driving too close to preceding vehicle (ACC), pedestrians/ stationary object standing on the driving lane (AEB), unintended departure from the driving lane (LKA).
Indeed, analyses of the efficiency of different ADAS systems have already shown significant safety benefits. For instance, Cicchino has found that Forward Collision Warning (FCW) enhanced with AEB systems demonstrate significant reductions of rear-end striking crashes by up to 50%. In contrast, the rates of receiving a rear-end strike were seen to grow (Cicchino 2017). A possible reason for this phenomenon can be that the more sudden hard braking actions of automated systems have not been anticipated by the human vehicle’s driver in the following car, thus exhibiting the potential conflicts arising from the interaction of non-automated and automated driving vehicles in the transition period of the single levels of automation. Besides the impact on accident frequency, the automated intervention of the CAV could also reduce the average severity of loss events within single accidents types (e.g. rear-end collisions) and lower the probability and severity of injuries in road accidents if the intervention of the AEB system proactively reduces impact speeds of crashes (Avery and Weekes 2019) (Kusano and Gabler 2012).

Jermakian (2011) investigates the potential safety benefits of FCW, LKA, Side View Assist and Adaptive Headlights concluding that all systems combined could potentially prevent about one third of crashes with FCW being the most effective and potentially preventing about 20%. Similarly, Harper et al. (2016) find that FCW, LKA, and Blind Spot Warning are relevant to 24% of overall accidents. However, they stress that the relevant share of accidents for the respective ADAS systems does not necessarily equal the share of accidents which are prevented. This would only be the case with full effectiveness and constant activation of the systems. With the same limitation, Kuehn et al. (2009) quantify a similar benefit to accident frequency of 25% for AEB and LKA systems. The discrepancy to the findings of Cicchino (2017) could result from technical progress between the two studies but also from the fact that the indicated safety benefits vary substantially by estimation methodology and by type of vehicle. This is demonstrated in a literature review conducted by Yue et al. (2018) and also by Blower (2014), who find that studies indicating the crash-decreasing impact of the combination of FCW, Braking Assist, and AEB vary between 9% and 72%. Deviations in the used dataset, research methodology and specific technical design of the tested systems cause these high fluctuations.
In another example, reversing accidents can be reduced significantly with the development and implementation of reverse AEB systems resulting in a reduction of the insurance claims in the near term (Grover et al. 2015) (Highway Loss Data Institute 2017). This type of accident causes about 40% of all motor third-party liability and fully comprehensive losses (Allianz SE 2015). With passive parking assistance, which only warns the driver, insurance losses have not decreased (David et al. 2015) (Keall et al. 2017) because any decrease in accident frequency was offset by an increase in average loss amounts.

Given the high potential of ADAS systems to increase road safety by active intervention in critical situations, the full risk-lowering impact will only materialise if the use of these systems does not impair human drivers’ prudence. Otherwise, increased risk-taking of the human driver (e.g. omission to look over the shoulder, lowering distance to foregoing vehicle, etc.) would increase the number of critical situations to be solved by the ADAS system and at least partially offset the positive net impact of ADAS systems. This behavior is already observed for passive safety systems such as airbags or mandatory seatbelts and led to significant rebound effects offsetting the overall increase in road safety. This offsetting effect is also especially relevant for non-occupants of the respective vehicle. This is because of an additional risk exposure if they or their vehicles are equipped with limited or only minor safety features (Chirinko et al. 1993). The risk that other travelers such as pedestrians or cyclists rely on a certain expected behavior of the automated vehicle (e.g. automated emergency braking) may negate the risk of unexpected actions (Kockelman et. al 2016).

2. Partial and conditional automation (level 2 and 3 automation)

Vehicles with level 1 automation benefit from positive attributes and abilities of both the human driver and of the driving automation system. However, in vehicles with higher levels of automation, the positive attributes of the human driver have to be adequately reflected in the capability of the hardware and software system. In addition, Level 1 automation functions generally work separately from each other, thus reducing the complexity of the vehicle infrastructure and data fusion process. Therefore, the findings on the risk exposure of vehicles equipped with ADAS only (level 1 automation) cannot be simply used as a proxy also for vehicles with partial and conditional automation. Indeed, redundancy between the human driver and the driving automation system also
applies for vehicles equipped with partial driving automation (level 2 automation) but the human driver now acts as an immediate fall-back to the system which assumes the primary task of vehicle motion control during automated use-cases. Due to the fragmentation of the dynamic driving task between the driving automation system and the human driver, the level of partial driving automation in trend introduces an additional source of risk resulting from the human-machine interaction as humans are generally not adept at keeping up an adequate level of vigilance during longer periods of passive monitoring.

In vehicles with partial driving automation (level 2 automation) this risk is generally limited due to the limited scope of automated driving manoeuvres but is amplified for vehicles with conditional driving automation capability (level 3 automation). This is because the driver technically and legally even does not have to continuously monitor the driving scene but still has to be capable of taking control as a fall-back to the automated system (Merat et al. 2014). Here, the successive decoupling of the human driver from the driving task implies decreasing human driving skills and a decreasing ability to make decisions especially in potentially risky and urgent situations, where the automated system hands back driving responsibility to the human. The required duration for completion of this process depends on the complexity of the traffic scenario set, the level of distraction of the driver and the design of the takeover request (e.g. haptic, acoustic or visual signal). Depending on these variables, drivers on average need several seconds to take over the driving action from an automated system and even longer to recover full situational awareness (German Insurers Accident Research 2016). This risk is amplified by the fact, that driver distraction (e.g. use of smartphones) is an increasingly important trigger of accidents (Choudhary and Velaga 2017) (Kubitzki and Fastenmeier 2016). To limit this risk, the driving automation system not only has to perceive information from the external driving environment but also from inside the vehicle. Through the use of sensors (e.g. contact to steering-wheel or physiological information such as heart-rate, muscle-activity, etc.) and cameras (e.g. tracking of eye blinking and head-motion) can deduce the level of tiredness and distraction so that the automated system is able to evaluate the human driver’s capacity to take over driving responsibility (Kircher and Ahlstrom 2017) (Rezaei and Klette 2011).

Due to these potential risk-increasing effects of taking the driver only partially out of the loop, it is questionable whether highly automated vehicles (level 3) benefit in higher safety and comfort and also raises difficult legal questions and could hamper societal
acceptance of automated vehicles. Recent announcements by some car manufacturers (e.g. Volvo (Volvo Car Group 2017) and Ford (Ross 2017)) have stated that they will skip the development of vehicles with conditional driving automation (level 3 automation) and target the design of vehicles with (at least) level 4 capability. For this level of automation, the risk exposure from handing-over driving responsibility will abate, because the vehicle will be capable of fulfilling an adequate security maneuvers allowing the human driver to take over driving responsibility from a safe status.

3. CAV with high and full automation (level 4 and 5 automation)

Vehicles with higher levels of automation are already driven on urban roads but limited to testing purposes. As the technology is still immature and largely used in test mode only, caution is required when using current statistics to predict the future impact of these vehicles on the number of accident occurrences. Manufacturers testing fully automated vehicles in California are legally obliged to publish yearly disengagement reports. Disengagements are defined as “a deactivation of the autonomous mode when a failure of the autonomous technology is detected or when the safe operation of the vehicle requires that the autonomous vehicle test driver disengages the autonomous mode and takes immediate manual control of the vehicle” (see California Code of Regulations Title 13, Article 3.7, § 227.46 (a)). For this, the vehicle manufacturers have to report the total number of disengagements, the total number of miles driven of each test vehicle and the circumstances of the disengagements including the location and reason for the disengagement (e.g. weather or road conditions, accidents etc.) (see California Code of Regulations Title 13, Article 3.7, § 227.46 (b)).

As the human drivers’ accident risk can be measured by accident rate per driven kilometre a statistically reliable equivalent indicator is missing for the comparison group. Even though the Waymo vehicle test fleet already completed over four million kilometres without any accident caused by the (sole) fault of the automated vehicles is often used as an argument to underline the superior performance of automated vehicles (Teoh and Kidd 2017). Also, Blanco et al. (2016) in their study (commissioned by Waymo) show that the Waymo test fleet only shows superior performance after (upper bound) scaling of accident rates.

Given that human-drivers only cause about 3.3 (police-reported) accidents per million kilometres (see Figure 5 and Figure 8) indicates that the mileage of the automated fleet is
not yet sufficient to provide a statistically reliable comparison (Kalra and Paddock 2016). In addition, a comparison of accident rates has no scientific significance since information about testing conditions (e.g. road, traffic and weather condition) are not transparent enough to standardise and compare with representative traffic-scenarios. Also, the fact that a specially trained safety driver is taking over driving responsibility if needed makes it impossible for third parties to assess how many accidents the vehicle would have caused if the human driver had not intervened. In addition to the comparison of accident rates, an analysis of the disengagement reports of Waymo can be used to analyse the reliability of highly/fully automated vehicles in their current state of development. As disengagements describe critical situations, which do not necessarily lead to an accident, a comparison of this risk indicator with human drivers’ accident frequency rates (see Figure 8) only allows for an indicative assessment.

![Figure 5](image.png)

*Figure 5: Accident of human drivers versus disengagement rate of Waymo test fleet. The graph shows the development of accident rate per million driven kilometres of (manually) driven vehicles in Germany and the disengagement rate per million driven kilometres of Waymo’s fully automated test fleet vehicles tested in California. Source: Illustration based on numbers provided by (Destatis 2017) and (Waymo 2017).*

Analysing the number of disengagements of automated vehicles, it can be argued that self-driving software will successively learn from each disengagement so that actually a high number of disengagements at the early stages of development are actually desirable
from a testing perspective. However, given the proportion of $33^{22}$ disengagements of Waymo’s test fleet per (police-recorded) accident of a human driven vehicles, the comparison indicates that these systems (at least for the time being) are not yet capable of adequately replacing human driving capability (Favarò et al. 2017). However, it remains questionable and ambiguous whether a state of superior driving by automated vehicles can technically be achieved. This is not necessarily due to the bad performance of the technical system but due to the fact that the human driver shows very low failure rates measured by accidents per given mileage. Thus, the highly or fully automated driving vehicle first has to prove that it is capable of exceeding human performance. The technical system is exposed to other (partially new) risk sources like hardware and software failures or the risk of malicious cyber-attacks (Koopman and Wagner 2017) (Kockelman et. al 2016). For instance, the analysis of relevant root causes for automotive product recalls also stresses that these risks cannot be simply neglected (Murphy et al. 2019). Thus, significant sources of accident risks will still persist so that ex-ante claims of significant decreases of road accidents remain largely unqualified and largely untested (International Transport Forum (ITF) 2018). It is not clear, how the frequency and even severity of accident events will actually develop in the future, especially given risk-relevant interdependencies to non-automated road users (Sivak and Schoettle 2015).

III. Description of the current characteristics of motor insurance risk

Motor insurance is worth € 26.9 BN (2017) and accounts for about 40 % of the total premium volume (non-life) in the German insurance market. Measured by premium volume, it is the most important line of (non-life) insurance business (GDV 2018). In the following, we will describe the relevance of single risks to the overall risk exposure and the characteristics of the single risks covered with regard to the frequency and severity of risk occurrences.

1. Composition of the overall motor insurance risk exposure

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22 This factor is the result of the ratio of 111 reported disengagements of Waymo’s test fleet per million driven kilometres and 3.36 accidents per million driven kilometres in Germany in 2016.
Motor insurance can be separated into three types of insurance coverage:

- **Motor third-party liability (MTPL):** Compensates for property and bodily injury claims of damaged third parties against the owner, keeper, and driver of a car and accounts for € 16 BN premium income (59.5 %).

- **Partially comprehensive insurance coverage:** Compensates for property losses to the insured vehicle due to fire, breakage of glass, animal-vehicle crash, theft, hail, storm, and flooding. It accounts for about € 1.7 BN premium income (6.6 %).

- **Fully comprehensive insurance coverage:** Compensates for all losses covered by partially comprehensive insurance and in addition for property losses due to vandalism and (self-inflicted) own-car damages. It accounts for about € 9.2 BN premium income (33.5 %).

Given the scope of the different types of coverages, we separate these single insured risks into the subordinate categories of accident risk, natural perils and other perils as shown in Table 1.

<table>
<thead>
<tr>
<th>Accident risk</th>
<th>Natural perils</th>
<th>Other perils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor third party liability</td>
<td>Hail</td>
<td>Fire</td>
</tr>
<tr>
<td>Animal-vehicle crash</td>
<td>Storm</td>
<td>Breakage of glass</td>
</tr>
<tr>
<td>(self-inflicted) own car damages</td>
<td>Flooding</td>
<td>Vandalism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Theft</td>
</tr>
</tbody>
</table>

*Table 1: Risks covered under motor insurance policies. The figure shows the risks commonly covered under motor insurance policies (MTPL and fully comprehensive) in Germany.*

Simplistically assuming that the net risk premium for the single covered risks corresponds with the (expected) average insured loss amount incurred for each risk, Figure 6 indicates the relevance of each risk for the overall (net risk) premium income of motor insurance. It shows that accident risk is the most prevalent driver of overall motor insurance net risk premium contributing to about 87 % of all loss payments. Following from this, material

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23 Premium figures are based on figures for year 2017 provided by GDV (2018) *Statistical yearbook of the insurance industry 2017*
changes to the number of road accidents induced by CAV would have significant impacts on the overall motor insurance premium volume.

![Pie chart showing the split of overall insured loss per single risks covered.](chart.png)

**Figure 6:** Split of overall insured loss per single risks covered. The graph shows the average share of insured losses for the single risks covered by (MTPL and fully comprehensive) motor insurance in the German market between 2006 and 2015. **Source:** Own calculation based on data published by German Insurance Association (GDV 2016).

## 2. Characteristics of motor insurance risk exposure

Overall, motor insurance risk exposure is characterised by a stable loss pattern. However, in a more granular assessment, the single risks covered show different characteristics regarding the frequency and severity of loss events. This can be illustrated by the mean annual amount, the standard deviation and the variation coefficient of annual insured losses per type of risk as shown in Table 2.

<table>
<thead>
<tr>
<th>Type of risk covered</th>
<th>Mean (in € 1,000)</th>
<th>Standard deviation (in € 1,000)</th>
<th>Variation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MTPL (property loss only)</strong></td>
<td>6,903,143</td>
<td>289,054</td>
<td>4.19%</td>
</tr>
<tr>
<td><strong>MTPL (incl. personal injury)</strong></td>
<td>4,536,305</td>
<td>333,397</td>
<td>7.35%</td>
</tr>
<tr>
<td><strong>Animal-vehicle crash</strong></td>
<td>517,761</td>
<td>46,993</td>
<td>9.08%</td>
</tr>
<tr>
<td><strong>(self) inflicted own car damage</strong></td>
<td>3,792,456</td>
<td>220,320</td>
<td>5.81%</td>
</tr>
<tr>
<td><strong>NatCat</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Storm, Hall</strong></td>
<td>618,243</td>
<td>306,011</td>
<td>49.50%</td>
</tr>
<tr>
<td><strong>Flooding</strong></td>
<td>12,061</td>
<td>5,638</td>
<td>46.74%</td>
</tr>
<tr>
<td><strong>Fire</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Breakage of glass</strong></td>
<td>1,147,331</td>
<td>89,794</td>
<td>7.83%</td>
</tr>
<tr>
<td><strong>Theft</strong></td>
<td>498,454</td>
<td>52,518</td>
<td>10.54%</td>
</tr>
<tr>
<td><strong>other</strong></td>
<td>10,585</td>
<td>1,930</td>
<td>18.23%</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td>18,143,273</td>
<td>611,942</td>
<td>3.37%</td>
</tr>
</tbody>
</table>

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Table 2: Mean value, standard deviation and variation coefficient of total insured losses of single risks. The table shows the mean value, standard deviation and variation coefficient of annual insured losses per type of risk covered under (MTPL and comprehensive) motor insurance in the German market between 2006 and 2015. Source: Own calculation based on data published by German Insurance Association (GDV 2016).

Using the variation coefficient as the indicator of the volatility of the annual loss amount of the single risks covered, the value of 3.4% shows that overall motor insurance risks exposure is characterised by quite high stability.

This is mainly due to the stability of annual loss amounts due to accident risk, which is characterised by high frequency and low severity of single loss events. The only exception of the only limited severity of insured accident losses is MTPL insurance, where losses can indeed be exposed to financial tail-risks. This is because MTPL insurance not only covers liability claims for a damaged third-party vehicle (property damage) but also further liability claims of third parties (i.e. bodily injury claims). This amount, especially in case of death or (severe) bodily injuries, can exceed property damages several times. Thus, MTPL coverage is exposed to financial tail-risks, due to potentially high loss amounts of single accidents (e.g. in case of permanent disability of claimants). As a result, MTPL insurance’s overall insured loss expenditure is indeed affected by a higher financial tail-risk than the other insured accident risk categories as illustrated in Figure 7.

![Distribution of total insured loss expenditure per insured loss amount](image)
Figure 7: Distribution of total insured losses per insured loss amount. The graph shows the distribution of overall loss expenditure per insured loss amount for MTPL, partially comprehensive and fully comprehensive motor insurance in the German market for the year 2015. Source: calculations based on data published by German Insurance Association (GDV 2016).

However, even in case of a higher financial tail-risk of MTPL insurance, the still relatively low variation coefficient of this risk shows that the general independency of single insured MTPL loss events leads to a risk balancing effect in a homogenous and sufficiently large risk portfolio. Accumulation events are largely only limited to those instances where the probability of losses for (a part of) the portfolio is increased by external effects (e.g. black ice on the streets).

In contrast, losses due to natural perils (NatCat risks) are characterised by low frequency but potentially high severity of loss events leading to a high variation coefficient of the annual insured loss amounts of 49.5% (storm and hail) and 46.7% (flooding). The high severity results from the correlation of single insured objects affected in one loss event. Even if the loss amount to a single insured vehicle is regularly limited to (a fraction of) its property value, natural perils typically affect multiple insured objects in their sphere of activity. Hence, natural perils regularly lead to events with high accumulated loss amounts. Because of this, it is more difficult to balance NatCat risk throughout a year, especially within a regionally limited risk portfolio. Therefore, NatCat risks have to be balanced within the own portfolio through time or by a (partial) risk-transfer to an external party (e.g. reinsurer).

IV. Potential impacts on accident risk characteristics

The low volatility of annual insured losses is mainly due to the fact that accident risk is only exposed to a limited risk exposure from accumulation or series loss events. However, with CAV on the roads, this could change due to series loss events arising from the correlation of software-based driving decisions and due to accumulation loss events arising from cyber-attacks.

1. Correlation of accident-risk losses of CAV

When a fleet of CAV (e.g. from the same manufacturer) is fulfilling the automated driving task based on the same deterministic algorithm, the driving behaviour of these vehicles is directly correlated with each other. This means that CAVs are programmed in the way
that every vehicle will decide uniformly on how to fulfil a driving-action within a given scenario set.

Driving algorithms that can unilaterally adopt themselves to input from the dynamic environment could potentially introduce severe legal risks for vehicle manufacturers, as the obligation to monitor (unknown risks of) the products after bringing the vehicles into the market could be inadequate, complex and costly. This is because the duty to monitor should increase, as the potential risk resulting from the system carrying out safety-crucial driving actions autonomously will increase. Therefore, a centralised adjustment of the algorithms by the vehicle manufacturer based on the input data of the CAV fleet is a realistic solution and fulfils legal requirements to ensure adequate safety monitoring processes.

With this assumption, series accident losses become manifest, if single vehicles of the affected fleet face the same risk scenario set. The extent of series loss exposure depends on the period of time the car manufacturer needs to discover and fix algorithmic errors by applying patches via (over the air) software-updates.

In addition, the risk of accumulated accident loss events could arise from several vehicles jointly travelling in platoons, where accident risks might turn from crashes of single or two vehicles to more severe multi-vehicle crashes, This is because a cohort of vehicles is driving close to each other, at high speed and dependent on information received by the foregoing vehicle increases correlation risk.

2. Cyber risk

The automation of the vehicles’ driving action technically does not need to be accompanied by an (over-the-air) communication interface (local navigation through on-board sensors) but the interconnection enables parts of the expected benefits of comfort and safety features brought by automated vehicles (global navigation of the vehicle fleet). In this way, the automation and interconnection of CAV are complementary and interrelated technologies.

Cyber-attacks against road-vehicles are not yet common but modern vehicles already possess several communication interfaces that can be used as access points for cyber-attackers. In general, these communication interfaces can be separated into (indirect) physical access and short-range or long-range wireless access channels (Checkoway et
al. 2011). Short- and long-range wireless connections (e.g. Bluetooth, WiFi, broadcast connection) open access points for (external) remote cyber-attackers.

If it is possible for cyber-attackers to hack not only one, but a fleet of CAV or traffic infrastructure, losses to single vehicles would be directly correlated and exposed to accumulation risk. Depending on the probability of cyber-attacks and the financial losses due to each affected CAV, the loss pattern of the inherent risk could be both volatile and high in severity. As a result, cyber-attacks on a fleet of CAV could induce a second source of accumulation loss events (in addition to NatCat risk) and shift the characteristics of overall accident risk to higher volatility and severity of loss occurrences. In addition, cyber-attacks to digital infrastructure show the phenomenon that they are not only limited to one specific line of business (e.g. motor insurance) but could also affect several lines of the insurance business (e.g. business interruption). This characteristic even presents special challenges to enterprise risk management of vehicle manufacturers but also accumulation risk control of insurance entities. Due to the NatCat-alike characteristics of cyber-risks, again the need for risk-transfer of motor insurers (e.g. via reinsurance coverage) gains in relevance but is not limited to smaller and mid-size motor insurers with an only regionally focused portfolio but also insurance companies with a portfolio, which is regionally diversified. This is because of the described phenomenon of cyber-risks to be neither limited to single regions nor to single lines of insurance business.

V. **Effects from a shift to service-based mobility solutions**

The increasing penetration of CAV technology is generally expected to accelerate a change in societal mobility approach shifting away from the ownership of vehicles to the use of shared on-demand mobility services (Krueger et al. 2016). This shift would strongly affect customer interfaces because a (commercial) entity providing the mobility service assumes the role of the vehicle owner and is obliged to maintain adequate insurance coverage. This produces a shift in customer interfaces from a business-to-customer (b2c) relationship between the insurer and the individual vehicle owner to a business-to-business (b2b) relationship between the insurer and the (commercial) mobility service provider.

The progressive usage of shared-mobility services could also facilitate the penetration of CAV technology into the overall vehicle fleet because of a potential decline of the required fleet size (Morency et al. 2015) and because the relatively high acquisition costs
of CAV\textsuperscript{24} could be balanced by more efficient use of the vehicles. In turn, this would shorten the traditionally slow-moving penetration patterns\textsuperscript{25} of driving assistance systems and would catalyse the impacts of CAV technology on the overall road safety and insurance-specific risk exposure.

In a potentially shrinking vehicle fleet, the extent of (insured) loss events due to natural perils such as storm, hail or flooding events decline in line with the reduction of the number of vehicles affected in the spatial sphere of activity of the respective natural peril. This potentially risk-lowering impact is especially relevant as the adoption of shared-mobility higher in urban areas where the concentration of exposed vehicles in a relatively small area is especially high. Resulting from this, the absolute risk exposure resulting from NatCat events would decrease due to the indirect effects of CAV on societal mobility patterns, which would (partially) counterbalance or even overcompensate expected increases of average loss amounts to single affected vehicles due to technical inflation.

By contrast, the impact of the shift to a service-based mobility approach to the overall accident risk exposure strongly depends on the future amount of overall driven vehicle kilometers (Ahangari \textit{et al.} 2017). This is because of the strong correlation between the total mileage driven and the overall number of road accidents which can be indicated by a Pearson correlation coefficient $r = 94\%$. The following graph shows that the number of accidents per mileage remains stable and on already very low levels with currently the human-driver taking over driving responsibility.

\textsuperscript{24} It is assumed that vehicles equipped with CAV technology especially in the beginning of market penetration will be relatively expensive due to required hardware (e.g. cameras and sensors) and software components.

\textsuperscript{25} For instance, the anti-lock braking system (ABS) and electronic stability control (ESC) took about twenty and fifteen years until more than 80\% of all newly registered vehicles were equipped based on figures of the Deutsche Automobil Treuhand GmbH (DAT 2018).
Figure 8: Mileage-adjusted number of police-recorded accidents. The graph shows the development of the overall number of police-recorded accidents events per million driven kilometers in Germany between 1991 and 2016. Source: Own illustration based on numbers provided by (Destatis 2017), (Radke 2014) and (Bundesanstalt für Straßenwesen 2017).

Indeed, there are different reasons why the wider adoption of shared service-based mobility solutions could lead to an increase of the overall vehicle mileage and thus increase risk exposure (Wadud et al. 2016) (Litman 2018). First, an increase in mobility participation for impaired or elderly people could stimulate additional mobility demand by these user groups. Assuming, that these groups today have to use public transport services, higher individualisation of mobility solutions for this cohort could increase the total mileage driven. In addition, increasing use of individual mobility services instead of centralised public mass transport could also be applicable for broader user groups that today satisfy their individual mobility demand with public transport services (e.g. commuters) if shared-mobility solutions reduce mobility costs. Second, assuming that the trip planning of two independent individuals is unaffected by a shift in societal mobility approach, the total mileage driven increases because of empty journeys of the shared automated vehicle between two successive users. Depending on different assumptions and scenarios, for instance (Trommer et al. 2016) expects increases in total mileage between 2.5% to 8.5% by 2035. This would mean that increased mileage would likely offset parts of potential safety gains in absolute terms, even if automated vehicles would turn out to be safer per mile than the average human driver today (Groves and Kalra 2017).
VI. Conclusion

A lack of empirical data and suitable proxies to assess the CAV impact on accident risk makes decisions by policymakers, society, and businesses very difficult. As a result, public and political debates of CAV’s future implications on society and risk tend to be based on simplified and biased assumptions, which are (not yet) based on scientific evidence. From an insurance point of view, this presents a fundamental challenge, as the business model of motor insurance is directly dependent on accident risk.

Given these challenges, we have described current motor insurance risk exposure and risk characteristics and have used findings from accident research as well as available data on Waymo’s CAV fleet to qualitatively assess the (insurance-relevant) risk implications of this technology. In doing so, our research shows important findings for insurers and regulators.

Empirical data indicates that vehicles equipped with ADAS systems of level 1 automation indeed contribute to road safety. However, from an insurance perspective, the decreasing impact on accident frequency will likely be (partially) balanced as the average loss amounts will increase due to technologically driven inflation and the higher complexity of repair work as well as risk compensation resulting from more intensive driving. We describe why those findings for lower levels of automation cannot just be applied analogously to vehicles with higher levels of automation capability and we use a comparison of disengagements (automated Waymo vehicle fleet) and accidents (human-driven fleet) per million driven kilometers to illustrate that (at least the current) performance of automated driving vehicles does not seem to be superior to human drivers.

From a regulatory point of view, this comparison is not able to precisely quantify the future risk exposure of vehicles with high and full automation but indicates that the promise of accident-free traffic is based on fragile grounds. We propose that CAV vehicles should be subject to close monitoring of their actual risk impacts. This monitoring should be conducted by independent and interdisciplinary institutions. Here, the insurance industry is one of the key stakeholders and bridging the gap between accident research and insurance industry knowledge can ground considerations of the inherent societal costs of CAV technology (Casualty Actuarial Society 2018) (Finkel and Gray 2018). Stating this, the current approach of disengagement reporting does not allow for a transparent assessment of possible risk implications and opens the risk that regulatory and economic decisions to introduce CAV technology are based on illusive
assumptions. This could turn out to be negligent if potential faulty assumptions lead to a reallocation of investment budgets for conventional road traffic safety strategies also taking into account vulnerable manual road users (e.g. pedestrians, bicyclists, motorcyclists, etc) in a more realistic scenario which is highly exposed to mixed-traffic scenes.

Due to the surrounding uncertainty related to CAV insurance risk analysis, further actuarial analysis and research are needed to prepare the insurance sector for a possibly changing risk landscape in the future. To proactively prepare for these changes, a more short-term measure of motor insurance companies is to explore accident data sets of different ADAS systems (level 1 and level 2 automation) already covered insured fleets. That said, a major challenge for this is the granularity of data gathered for traditional motor insurance pricing, which does not always allow identification of the technology’s presence in vehicles (Casualty Actuarial Society 2018). With a long-term focus on vehicles with higher levels of automation, the adjustment of pricing models that currently focus on proxies to account for human-driver’s individual risk has to be replaced with a pricing model to reflect the reliability of the automated driving system. As transparent and longstanding loss data for this is missing, insurers have to build up interdisciplinary know-how to expand today’s actuarial driven pricing knowledge with deep technical know-how about CAV hard- and software vulnerability. Furthermore, as driving capabilities of CAV could fluctuate with newly introduced software updates, pricing data could be exposed to higher variability.

With describing risk relevant aspects, this paper provides a qualitative but more granular assessment of CAV’s potential risk impact than existing quantitative forecasts of CAV’s impact on the motor insurance premium. The results of the existing forecasts highly differ from each other contingent on the publisher (i.e. consulting firms or German Insurance Association) indicating that a lack of empirical data leaves space for a highly biased debate on the issue. This paper provides additional value to the insurance-related discussion by broadening the scope from a focus on absolute premium volume to crucial strategic questions such as the characteristics of risk exposure and customer interfaces. Here, our analysis shows that CAV will have a significant impact on the inherent risk characteristics of the motor insurance business. Beyond that, a shift in societal mobility approach with a changing customer interface will also have a strong impact on the risk exposure of the motor insurance market.
Referring to the possible changes of motor insurance risk characteristics, we emphasise the current smoothing impact of accident risk to the overall volatility of annual motor loss insurance loss expenses. The relevance of this risk could decrease with CAVs on the road but this is still uncertain and accompanied by significant adverse side effects. In addition, the volatility could further increase due to possible correlated accident events and the emerging risk of cyber-attacks as well as accumulation loss events resulting from platooning. A declining relevance of regular accident occurrences would just enhance this volatility-increasing effect. This means the required risk-capital for a given volume of written motor insurance premium will also increase.

The increasing volatility of losses and the potential correlation of emerging (automotive) cyber-risks with other insurance lines of business present challenges for the management of loss accumulation risk of insurance companies. It is important that the changing loss pattern of the future motor insurance business adequately matches the risk-appetite and capacity of the risk-taking insurance company. For (smaller) insurance groups with a focus on retail property and casualty insurance risks and limited risk-taking capacity, risk-transfer to reinsurers will likely be more relevant to smooth the unbalancing impact on the net risk portfolio.

Given the already competitive environment of the motor insurance market in saturated markets together with the low profitability\(^{26}\) and the expected increasing volatility of losses, we expect the return on risk adjusted capital (RORAC) to decline and lead to a higher consolidation within the motor insurance market. This is even fostered by the described potential shifts in societal mobility leading to changing customer interfaces towards commercial customers. As a result, we find that primary insurers focusing on private retail motor insurance face strategic risks to their business model. However, the development and penetration of market-ready CAV especially of these with higher levels of automation required for fully service-based mobility approaches (level 4 and 5 automation) take several years or even decades so that the significant changes described in this analysis will proceed on an evolutionary rather than a disruptive basis.

\(^{26}\) The average gross combined ratio of the motor insurance business between 2010 and 2016 in the German market is 102.2 %. The combined ratio is the ratio of expenses for insurance operations and insurance claims to premiums.
Concluding statement leading the reader to the next article:

The research conducted in this chapter provides a granular analysis of CAV technology’s potential impact on accident risk exposure for the single levels of automation. Furthermore, this chapter provides an analysis of further relevant risk-factors relevant to the motor insurance business. In this sense, the research contributes to a more transparent and unbiased understanding of probable changes to the future motor insurance risk landscape.

However, even if motor insurance is the most important line of (non-life) insurance business also other business lines are potentially affected by shifts in the underlying risk-landscape. As the adequate mitigation of (liability) risks resulting from the production process is acutely relevant to foster innovativeness of the sector, the probable impact of CAV technology on the risk of automotive product recall is highly relevant for OEMs but also insurers. Therefore, the following chapter is devoted to the analysis of legal and technical drivers which emerge with the progressing penetration of CAV technology and which could affect the future product recall activity. In this sense, the following chapter complements the analysis of insurance-relevant risk-factors and contributes to an holistic understanding of the overall risk balance of CAV technology.
References Chapter 4


GDV (2016) 'Loss Type Statistics - Development of loss costs motor insurance 2015'.


German Insurers Accident Research (2016) Handing over from highly-automated driving to manual control.


Munich Re (2016) 'Autonomous Vehicles- Considerations for Personal and Commercial Lines Insurers'.


Swiss Re and HERE (2016) 'The future of motor insurance- How car connectivity and ADAS are impacting the market'.


Yeomans, G. (2014) 'Autonomous Vehicles- Handing over control: Opportunities and risks for insurance'.

Chapter 5: The Impact of Autonomous Vehicle Technologies on Product Recall Risk

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**Authors’ contribution**

Dr. Finbarr Murphy contributed with the basic concept and revision of the paper. Fabian Pütz carried out the main part of the literature review, data analysis, and writing. Dr. Martin Mullins and Prof. Dr. Torsten Rohlfs contributed with ideas from insurance and corporate risk management perspective. Dennis Wrana carried out the initial underlying literature review of the paper. Michael Biermann contributed as automotive supply-chain and insurance expert with his deep knowledge of automotive supply-chains and manufacturing and automotive product recall insurance as an advisor for discussion of research findings.
The Impact of Autonomous Vehicle Technologies on Product Recall Risk
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Abstract
Complex Advanced Driving Assistance Systems (ADAS) and Autonomous Vehicle (AV) technology are increasing the number of vehicle recalls. At the same time, financial risks resulting from extensive product recall events can severely affect vehicle manufacturers and their suppliers, exposing the automotive supply chain to business continuity, legal and reputational risk. However, these risk implications are under-appreciated by large segments of the supply chain. This study shows that product recall events are increasing in general but recall events associated with ADAS/AV technology form an increasingly large percentage of these recall events. Based on this analysis, we describe ADAS/AV-specific aspects of risk mitigation and present a multidimensional approach, combining production-centric risk mitigation avenues in the automotive supply chain with the transfer of residual financial risks via insurance. We find that this comprehensive risk mitigation approach benefits in higher transparency of total production costs and increased resilience of the automotive supply chain. Against the background of an increasing product recall risk resulting from the increasing automation and interconnectedness of modern vehicles, we therefore suggest a closer, more strategic cooperation between insurance companies, car manufacturers and automotive suppliers for the benefit of all parties.

Keywords: RISK ANALYSIS, SUPPLY CHAIN RISK MANAGEMENT, AUTOMOTIVE INDUSTRY; PRODUCT RECALL, AUTONOMOUS VEHICLES

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I. Introduction

Human errors are responsible for ninety percentage of road accidents (DG GROW 2016). As computers progressively take more control over cars they are expected to reduce the number of car accidents significantly. Despite the potential benefits of these new technologies, associated emerging risks must be considered. In particular, car manufacturers face the risk of ADAS failures precipitating product liability and product recall losses.

The rapid development of ADAS/AV technology has been driven by car manufacturers, technology companies and academic research groups. In parallel, the medium to long-term impact on the economic value chain of the transportation and automotive sector as well as legal and social implications have already been covered by extensive discussion (Fagnant and Kockelman 2015; Bagloee et al. 2016; Harper et al. 2016; Wachenfeld and Winner 2016). In contrast, the impact of ADAS/AV technology to product recall risk has not gained the attention of industry and academic literature yet. The low level of attention to product recall risk is surprising, given that the cost of an extensive product recall can trigger heavy financial imbalances to the affected company. Here, the most significant recent example of the automotive supplier Takata strikingly shows that product recalls can directly lead to business continuity risk (Fukase and McLain 2016).

Existing developments in ADAS/AV technology illustrate that the growing interconnection and complexity of the embedded vehicle subsystems is an inevitable requirement of further automation. Therefore, this paper looks specifically at the resulting impact on automotive product recall risk and combines a qualitative assessment with a quantitative statistical analysis of product recall activity. For this, we use recall statistics from the European and US-market to analyse historical events and to anticipate future developments in product recall activity. We find that overall automotive recall activity grew in both markets between 2008 and 2016. Using product recalls resulting from a failure of sensors, software and electronic control units (ECU) as a proxy for ADAS/AV technology, we find that these product recalls exceed the growth of overall product recall activity especially since the year 2012. We expect that increasingly complex vehicle infrastructure within ADAS/AV-enabled vehicles together with a potentially stricter recall approach by public authorities will lead to a further rise of product recall occurrences. This finding is generally applicable to all levels of driving automation, but it is assumed that the level of complexity of the vehicle infrastructure increases with
higher levels of driving automation. Additionally, we analyse statistical data to evaluate the potential severity of the financial risk of product recall events and use this as a basis to propose a comprehensive risk mitigation approach combining ADAS/AV-specific elements of risk mitigation on a production level with risk mitigation of residual financial risks.

With this approach, the paper broadens the assessment of ADAS/AV technology from a risk management point of view and contributes to the understanding of future expected changes in product recall risk exposure, which is highly relevant for the automotive, transportation and insurance sector. In addition, by combining the emerging issues of automated vehicles and product recall risk, it provides a basis for the appliance of further scientific methodology on this issue. Furthermore, the paper contributes to an holistic risk mitigation approach combining production-oriented risk mitigation with financial risk transfer. Thus, this research provides a link between hitherto largely separated disciplines of production and supply chain research and academic research related to general (financial) risk management and insurance. In doing so, the paper provides pathways to increase the robustness and resilience of supply chain and production systems.

In the following section, a review of existing academic literature in the field of (automotive) product recalls, supply chain risk management and supply chain resilience is provided with the aim of positioning this paper in academic literature. Following from this, we define and categorise different types of automotive product recall events and describe the accompanying economic risks. Subsequently, reasons for an expected increase in product recall activity due to ADAS/AV technology are qualitatively deduced and supported by a quantitative analysis of historical product recall statistics for the European and US-market. This quantitative analysis and recent examples of specific product recall events are then used to derive inherent characteristics of product recall risk. Based on these findings, we finally propose a comprehensive risk mitigation approach, which combines elements of risk mitigation on a production level with risk mitigation of residual financial risks.
II. Relevance to production research and literature review

The scope of this paper is relevant to the academic research in the fields of (automotive) product recall as well as supply chain risk management and supply chain resilience.

In the field of automotive product recall, there is limited academic research existing but we are not aware of any research specific to product recall activity with a dedicated focus on ADAS/AV technology. Indeed, the research that exists generally considers superordinate product recall patterns (Rupp and Taylor 2002; Bates et al. 2007; Ahsan 2013) or the impact on shareholder value (Rupp 2004; Shin et al. 2014). In general, these analyses show that overall automotive product recall numbers are increasing and that product recall events can have severe adverse impacts on the financial health of the affected companies. Similar results are found for other industries like toy and food production (Zaho et al. 2013; Ni et al. 2014; Ni et al. 2016). Existing frameworks for managing product recall risk generally focus on organisational and (production-oriented) operational measures only (Kumar and Schmitz 2010) even if literature referring to general corporate risk management frameworks already includes measures of financial risk mitigation (Miller 1992). In addition, an increasing number of product recall events show evidence that residual product recall risk still remains despite all preventive organisational and operational actions. Because of this, the limited scope of existing instruments to mitigate product recall risks has to be broadened by incorporating financial risk mitigation tools into existing frameworks.

Suppliers often account for a high proportion of the production chain in the automotive sector (Ciravegna et al. 2013) therefore research on product recall and supply chain risk management should be closely related. Indeed, a solid number of research papers dealing with supply chain risk management in the automotive industry exists (see literature reviews by González-Benito et al. (2013) or Ho et al. (2015)). However, existing related research focuses on organisational aspects of risk management process implementation (Thun et al. 2011; Sharma and Bhat 2016; Chen et al. 2017) or the material and information flow integration within the automotive supply chain (Coronado Mondragon and Lyons 2008; Makris and Chryssolouris 2013). In addition, there is a good deal of work on risk assessment techniques but these do not include mitigation instruments (Trkman and McCormack 2009; Ceryno et al. 2015; Davarzani et al. 2015; Marasova et al. 2017; Zimmer et al. 2017; Prakash et al. 2018).
With regard to instruments for product recall risk mitigation inside the automotive supply chain, existing papers only occasionally cover product quality issues (Singh et al. 2005; Thun and Hoenig 2011). A limited number of research papers also deals with financial risk mitigation in automotive supply chains, but only in the context of market risks such as currency fluctuation or commodity price risk (Huchzermeier and Cohen 1996; Hofmann 2011). Some papers indeed indicate the relevance of debt and liquidity risks to a disruption of the automotive supply chain but do not provide approaches to mitigate these risks accordingly (Blos et al. 2009). Stating this, insolvency risk and proactive measures of risk management are examined by Grötsch, Blome, and Schleper (2013) but only on an organisational level not considering specific financial instruments to bridge disruptive events that impact financial stability.

Research in general supply chain risk management stresses the role of suppliers in highly fragmented production chains, but also only occasionally tackles product recall events as one possible form of product quality issues (e.g. see (Li et al. 2010; Marucheck et al. 2011; Ou and Nurmaya 2011)). Specific literature on mitigating product recall risk in the supply chain is still underrepresented. Also, the existing literature of supply chain risk management generally distinguishes between internal and external risks affecting a supply chain. While risks resulting from internal activities are generally characterised as relatively high in frequency but low in impact, macro-risks affecting the supply chain from the outside (e.g. natural or man-made risks like earthquakes, floods or war) are ascribed as being rare and potentially severe (Ho et al. 2015). However, this classification turns out to be unspecific and induces the danger of a structural misperception of product recall risk as this research paper shows that product recall events arising from the inside of the supply chain potentially show a similar severity as external disruptors.

Finally, comprehensive literature reviews carried out by Tukamuhabwa et al. (2015) and Kamalahmadi and Parast (2016) show that existing strategies to enhance supply chain resilience focus on measures to increase flexibility and redundancy. Here, sourcing from multiple suppliers, back-up suppliers and keeping safety stocks are described as key practices to achieve redundancy inside the supply chain (Schmitt and Singh 2012; Mishra et al. 2016; Brusset and Teller 2017; Kırılmaz and Erol 2017). Indeed, these approaches are useful to increase the resilience of supply chains producing physical goods. However, looking at products whose key functionalities are based on software, these instruments
are not applicable. Consequently, considering measures to enhance the individual financial resilience of key suppliers will become even more important in the future.

### III. Key risks in case of a product recall

The risks resulting from a product recall event can generally be categorised into financial, reputational and legal risks. Based on the assumption of shareholder value orientation in the automotive market, a simplified risk definition can be applied shortening the term to negative impacts on the entities’ financial goals. Hence, reputational and legal risks are measured as triggers of financial risk, which directly or indirectly affect either profitability, capital structure or liquidity of the entity (Thommen and Achleitner 2009).

As shown in Table 3, we therefore consider reputational and legal risks as subcategories of cost sources, which can be distinguished into (direct) recall and repair costs, legal costs and (indirect) equity costs.

![Table 3: Cost components of a product recall event. This table categorises the different cost components a company affected by a product recall event.](image)

Recall and repair costs can also be described as direct product recall costs and include replacement parts, labour costs (e.g. failure investigation, solution finding, removal, and installation work), increased marketing and notification costs or additional distribution and logistics costs (Shin et al. 2014). Depending on the underlying technology failure, the composition of recall and repair costs can vary significantly. For example, product recalls induced by a software failure require costs for reprogramming software code whereas the costs of replacement parts apply to recall events resulting from a (physical) component. For ADAS/AV technology, this is especially relevant for LIDAR and radar sensor technology, which still have high unit costs. The marginal costs of software-based recalls could be lower as the costs for reprogramming the software do not depend on the
number of affected vehicles and with the effective use of over the air software updates (see section VII 1.) also marketing and distribution costs could significantly be lowered for software-related recall campaigns.

Legal costs can include legal advisory fees, compensation payments to customers, legal or contractual obligations and punitive penalties. Equity costs are not typically related to direct payments or cash-outflows from the affected company but are costs that -at least for the short term- reduce the enterprise value. Assuming that the company value reflects the present value of future profits, this cost category comprises indirect costs attributed to losses of future income triggered by the product recall event (Rupp 2004). For example, equity losses can arise because no products can be produced (“loss of production capacity”) or sold (“loss of sale”) if error-free components are not available in stock. Equity losses can also arise because of reputational damages leading to a decrease in consumer demand or investor interest. Product recalls due to the failure of highly safety-relevant components potentially attract higher public and regulatory attention implying higher reputational damage and higher impact on the company value. Hence, this cost component potentially could gain in relevance with ADAS/AV-enabled vehicles. This is especially applicable if just an accident event exhibits inadequate safety of the vehicle so that the affected company faces even higher reputational risk and additional legal costs resulting from product liability claims.

IV. Reasons for increasing product recall exposure of ADAS/AV technology

ADAS/AV technology is quickly advancing, bringing with it several emerging risks to be addressed and managed. Indeed, the progression from “no automation” to “full automation” will take time, though different kinds of ADAS technology are already integrated into modern vehicles. Overall, we anticipate that the implementation of ADAS/AV technology will be accompanied by an increasing product recall risk exposure resulting from a changing software and hardware infrastructure, aspects of market competition and production approaches as well as increased surveillance by supervisory authorities.

On the hardware side, ADAS/AV-enabled vehicles will not only be equipped with additional hardware components (sensors and ECUs) but also with a more complex hardware infrastructure due to the interconnection of formerly separated subsystems (Stout Risius Ross 2016). Already today, the number of electronic control units and
Cabling within cars is enormous, reaching up to about 100 ECUs and up to 10 kilometres of cabling. However, common driving assistance and safety enhancing systems (e.g. ABS or ESC systems) only activate in separated vehicle functions (Stiller 2005). In contrast, ADAS/AV technology will fulfil driving actions automatically, which requires a dynamic and proactive assessment of driving scenarios and the ability to coordinate cross-functional control commands. These cross-functional interdependencies could lead to unintended feature interactions, which in turn could issue hazardous autonomous driving commands (fortiss 2010). Similarly, modern vehicles can already today have up to 100 million lines of code. Stating this, the automated fulfilment of driving actions requires a sharp increase in extent and complexity of the embedded software. As a result, the changing vehicle infrastructure increases not only the number of potential failure sources by adding additional hardware components or lines of codes but also the susceptibility of failure because of higher complexity.

Also, ADAS/AV technology will successively liberate the driver from the responsibility to attentively steer the vehicle. This allows the driver to use the time travelling for other activities such as entertainment. Although entertainment systems are not directly linked to the driving task, they nevertheless open gateways for product recalls resulting from cyber-security risks (Currie 2016). An example of this risk was shown with an experimental hack of a Jeep Cherokee, where hackers used the wireless interface of the on-board radio to remotely take over driving functionalities (Miller and Valasek 2015). This triggered the recall of 1.4 million vehicles.

The competition for innovation between (traditional) car manufacturers and automotive suppliers themselves and technology companies from outside the traditional car manufacturing market is fostering a technological selection process, which increases the pressure on companies’ innovation capacity (Stout Risius Ross 2016). At the same time, the vast set of possible driving scenarios, where ADAS/AV technology has to execute adequate driving decisions, potentially needs a high effort of testing and validation to ensure functional safety. Hence, the necessary trade-off between competitive market dynamics and the reliability of the systems in trend evokes residual technological risk, which potentially materialises in an increasing product recall probability. Customer demand for a growing variety of products and options of product individualisation additionally increases the complexity of the development, testing and manufacturing process, while development cycles are shortened (van Venrooy 2015; Göpfert and Schulz...
This again increases the residual technological risk, which potentially culminates in product recall risk.

Finally, we anticipate that regulators will demand and apply increasingly cautious and proactive product recall approaches because of the impact of ADAS/AV technology on safety-crucial functionalities. Regulatory authorities and car manufacturers will need to devise a strict product recall approach when required. We expect that regulatory authorities impose higher legal fines where automotive manufacturers do not adequately comply with this obligation.

V. Data Analysis

Building on the preceding qualitative analysis, we posit that ADAS/AV technology will increase the complexity of embedded vehicle systems, which will, in turn, increase the probability of product recalls. To this end, we analyse historical product recalls to determine overall product recall development. As software, sensors or electronic control units (ECU) are crucial components for ADAS/AV-enabled vehicles, we use these as proxies for ADAS/AV technology.

1. Methodology

We use product recall statistics from the German, European and the US-automotive markets. In Germany, the Federal Motor Transport Authority (Kraftfahrtbundesamt; KBA) publishes data of product recalls within their annual reports. European data is extracted from the central online database, RAPEX (European Commission n.d.), where alerts on dangerous products are reported by the 31 national authorities on a weekly basis. The US-market data on product recalls is derived from a database provided by the National Highway Traffic Safety Administration (NHTSA n.d.). We analyse product recall activity between the years 2006 and 2016, as this is the longest period for which information is provided by the databases for the European and US-market.

Automotive companies are legally obliged to publish information on safety-relevant recall campaigns (European Parliament and Council 2001 rule 5 (3)) and as the respective authorities can generally be seen as reliable and independent data aggregators, these databases are the most comprehensive and reliable sets of secondary data for information about product recall activity. The databases do not contain data about silent recall
campaigns but we expect that ADAS/AV technology mainly relates to safety-functionalities and so we do not expect this to detract from the validity of the results of this paper.

The extent of available data differs widely for each market. The German market data is limited and only enables an analysis of product recall pattern at a high level. In contrast, the European and US-market data provide explanatory texts indicating the reasons behind the single product recall events. To analyse the automotive product recall activity in Europe, we extract raw data by downloading an export file with product recalls of the category “motor vehicles” from the Rapex homepage. We retrieved product recall data for the USA by importing a text data file from the website of the NHTSA. The data for the USA also contains product recalls not affecting the vehicle itself but automotive equipment such as tyres and child restraint systems, which we excluded. We excluded all product recalls for the years 1966 to 2005 to coincide with data for the European region. Also, we assume that ADAS/AV technology had only a limited role prior to 2006. In addition, the data set of the NHTSA contains redundant records with the same product recall campaign identification number where recall campaigns affect different vehicle models of the same OEM or OEM group or if product recall campaigns affect the same vehicle models with different model years. As the relevant data within each data set is redundant, we cleared up the data set to avoid multiple counting.

Finally, the European and US data sets provide a narrative “description of risk” (Rapex) and “defect summary” (NHTSA) for each recall campaign. We analysed these by manually searching for recall campaigns, which are caused by software, sensor or ECU failure. For this, we searched for the key words

- “software, program(ed), code, coding, algorithm” for product recalls caused by software failure,
- “sensor” for product recalls caused by sensor failure and
- “ECU, control unit, control module, control device, controller, electronic unit, electronic module, electronic device, computer” for product recalls caused by ECU failure.

High annual variations in the data are a feature of product recall statistics and for this reason, we smooth the data using an annual 3-year moving average. To estimate the future recall activity, we base our forecast on a polynomial regression based on historical
product recall data. Given the limited dataset, a sophisticated estimation model would be excessive.

2. Results

The KBA reports 1,560 product recall events between 2006 and 2014\textsuperscript{27}. The development of the overall number of product recall campaigns per year gives clear evidence that product recall activity in the German market increased throughout the period, starting with 157 product recall campaigns in 2008 and ending with 192 recall campaigns in 2014. This development corresponds to an average annual growth rate of about 3.4 %.

The European database (RAPEX) contains 2,107 data points for product recalls of motor vehicles for the period between 2006 and 2016. Of these only 1,250 data sets are related to passenger cars, the balance being other vehicles (e.g. bicycles, motorcycles). RAPEX statistics show less product recall campaigns than the KBA data\textsuperscript{28} because the KBA database also contains low-risk product recalls, where car manufacturers used address data of the KBA to inform vehicle holders about a (voluntary) product recall campaign (Kraftfahrtbundesamt 2016).

The statistical data of RAPEX shows that recall activity increased within the period under investigation. Between 2008 and 2016 the number of product recalls per year increased from 81 to 173, corresponding to an average annual growth rate of about 9.9 %. This growth rate is larger than the German rate because of a sharp increase in product recall activity in 2016. Comparing the growth rate within the same period (2006-2014), the compounded annual growth rate (CAGR) shows a growth of 4.57 % and is more aligned with the KBA data.

The automotive product recall data from the USA is based on 7,197 product recall campaigns for the period between 2006 and 2016. The statistical data of NHTSA also shows evidence that the overall product recall activity increased within the period under investigation. Between 2008 and 2016 the number of product recalls per year increased from 587 to 831. This development corresponds to an average annual growth rate of about 4.4 %.

\textsuperscript{27} At the time of writing, KBA data set does not yet contain product recall figures for 2015 and 2016.
\textsuperscript{28} The German statistic shows 1,560 product recalls in the same between 2006 and 2014 while the European data shows 900 product recalls.
Figure 9 shows the development of product recall activity of each region with the 3-years moving annual average number of product recalls per year.

Figure 9: Number of product recall campaigns per year. This graph shows the overall development of the 3-years moving average number of product recall campaigns in Germany, Europe and USA between 2008 and 2016. The dashed lines show a polynomial regression forecast as an indication for future product recall activity. Sources: KBA, RAPEX and NHTSA.

Using a polynomial regression to forecast the overall product recall pattern based on the development of product recall activity since 2008, we expect the number of product recall campaigns to increase further over the coming years. As figures from the KBA database for 2015 and 2016 are not available, we assume that they grew in line with the European market. The expected annual growth rates vary between the regions.

3. Development of product recall activity due to software, sensors and ECU

In contrast to the available KBA recall statistics, the RAPEX and NHTSA statistics contain descriptions of each product recall campaign. With these descriptions, it is possible to analyse the component causing the product recall. In this manner, the share of product recalls caused by defects or safety-risks in software, sensors, and ECU can be deduced. These components are crucial for further development of ADAS/AV technologies and are used as proxies for their associated product recall risk.
Within the RAPEX database 109 of the total 1,250 product recalls (8.72 %) were caused by software, sensors or ECU. The pattern of product recalls is not clear until 2012 when the trend increases, perhaps an indication that these components increasingly influence product recall events (see Figure 10 below). Since 2012 the 3-years moving annual average number of product recalls due to software, sensors and ECU increased from 6 to 20, which corresponds to an CAGR of 37.5 %. The total product recalls grew by 10.3 % p.a. from 117 to 173 recalls in this period. Hence, the share of product recalls caused by software, sensors and ECU increased from about 5.1 % in 2012 to about 11.6 % in 2016.

![Development of product recalls due to software, sensors, ECU in Europe](image)

**Figure 10: Product recall campaigns (only software, sensors and ECU) in Europe.** This graph shows the development of the 3-years moving average number of product recall campaigns due to software, sensors, and ECUs in Europe between 2008 and 2016. The dashed line represents a polynomial forecast. Source: RAPEX

Based on a polynomial regression, we estimate an annual 23.3 % growth rate of product recalls due to software, sensors, and ECU compared to an overall recall growth of 16.9 % in Europe. We expect the share of product recalls due to software, sensors, and ECU to increase up to 13.7 % by 2020.

Conducting the same analysis with the NHTSA data, a slightly different trend is observed as shown in Figure 11. The number of product recalls due to software, sensors, and ECU since 2012 increased from 62 to 88. This corresponds with an annual growth rate of 9.2 % outstripping overall product recall activity growth of 8.1 % p.a. The share of product
recalls due to software, sensors and ECU grew slightly from 10.2% in 2012 to 10.6% in 2016.

Comparing these findings with the Automotive Warranty & Recall Report provided by the advisory company Stout Risius Ross (2016), the share of product recalls related to software, sensors and ECU is relatively low. They analysed the data provided by NHTSA regarding software-related product recalls only and attributed 15% of the overall product recalls in 2015 to this category. The difference can be explained by the fact that the report not only counts product recalls caused by software but also product recall campaigns caused by other components but solved with a software update. Hence, this approach leads to a higher share of product recalls attributed to this category.

![Figure 11: Product recall campaigns (only software, sensors and ECU) in the USA. This graph shows the development of the 3-years moving average number of product recall campaigns due to software, sensors, and ECUs in USA between 2008 and 2016. The dashed line represents a polynomial forecast. Source: NHTSA](image)

Based on a polynomial regression, we estimate an annual 13.6% growth rate of product recalls due to software, sensors, and ECU compared to an overall recall growth of 10.2% in the USA. We expect the share of product recalls due to software, sensors, and ECU to increase up to 11.8% by 2020.

On a more practical level, these statistics underscore how these technologies will impact different risk areas. We cite two examples here for indicative purposes. First, the number of potential access points to the data and actuator controls in a vehicle will increase the
probability of a cyber-attack. The risk of such an attack could include both a data breach and bodily injury, the latter posing potentially significant liability costs. As a second example, LiDAR consists of a laser beam emitter and a sensor to see what the laser beam is impacting. Low resolution LiDAR may need to be upgraded to match future software upgrades to increase safety requirements that may involve a complex recall campaign.

VI. Characteristics of product recall risk

We use the information provided by the NHTSA to analyse the possible extent of the resulting financial risks (“financial tail-risk”) and the average delay between vehicle production and failure notification (“temporal tail-risk”). Additionally, we support this analysis with examples of recent extensive product recall campaigns in the automotive sector.

1. Financial tail-risk

The data for the US-market provided by the NHTSA also indicates the potential number of vehicles affected by each product recall campaign. Assuming that the costs of a product recall campaign increase with the number of affected vehicles we use this number as a proxy for the financial impact of a product recall campaign. For this, 942 recalls due to software, sensors, and ECU since 1995 are assessed. The distribution of the number of affected vehicles is then used to derive the inherent financial tail-risk (see Figure 12 below).
Figure 12: Distribution of the number of potentially affected vehicles (software, sensors, and ECU only). This graph shows the distribution of the number of vehicles potentially affected by a product recall campaign due to software, sensors or ECU since 1995 and the cumulative share of these product recall campaigns. Source: NHTSA

On the one hand, we find that 86.8% of the product recall campaigns due to software, sensors, and ECU affected 25,000 or fewer vehicles, which shows that a high share of the product recall event has likely only limited financial impact on the affected company. On the other hand, we also find that about 5.3% of the vehicle recalls affected 150,000 or more vehicles, including 1.1% of product recall campaigns affecting more than one million vehicles. Hence, the distribution of the number of affected vehicles shows that although there are only relatively few large-scale product recall events, these can lead to catastrophic losses endangering business continuity. That said, it has to be noted that the number of potentially affected vehicles only include vehicles in the USA. However, a globally active OEM group is also exposed to accumulative losses from recalls in different countries.

The inherent financial tail-risk can also be illustrated by single recent automotive recall events. Stating this, the following examples are only a selective illustration of particularly extensive recent product recall events, which show the potentially severe costs of these events. The most recent and most significant recall event was by the automotive supplier Takata. Defective airbags affecting about 100 million vehicles with a cost of two billion USD led to the insolvency of (parts of) the business group. In a second example, Toyota
was hit by a severe recall event in 2010 as failing accelerator pedals and floor mats caused unintentional acceleration. Toyota anticipated costs of about 2 billion USD for the direct recall costs and loss of sales. In addition, Toyota was fined punitive damages of about 1.2 billion USD in the USA. In a third example, General Motors recalled about 30 million vehicles in 2014 due to a series of safety-relevant failures in connection with problems of the ignition switches leading to costs of about 4 billion USD accounting for repair costs, victim compensation, and legal expenses.

2. Temporal tail-risk

Temporal tail-risks occur because of the time delay between the manufacturing process and the notification of the defect or safety-risk. This risk enlarges the impact of a product recall on the financial stability in terms of liquidity and financing options when high cash-outflows and losses are not covered with positive cash-flows and profits from sales in the period where the product recall is announced. This adverse impact on the companies’ profitability is exacerbated because of the asymmetric profit and loss pattern. The profit per vehicle of high-volume car manufacturers is below 1,000 Euros (Dudenhöffer 2016), backward distribution costs in case of a product recall can exceed the costs of forward distribution by several times. Ahsan (2013) finds backward distribution costs can exceed forward sale distribution income by a factor of between two and three because of small and single quantities of replacement component shipments and the urgency of the recall process. Additionally, subtracting costs for error-free replacement parts and their reinstallation, a product recall can quickly exhaust the original profit from the sale of the car.

The NHTSA database specifies the commencement date of manufacture of a model series and the creation date of the respective recall report. Assuming, that a vehicle recall report is created swiftly after the recognition of a safety-relevant product failure, we use the time delay between these two dates as an indicator of temporal tail-risks. This approximation of the average time delay is quite conservative as it does not take into consideration that only single model years or batches of the model production are recalled. Taking all vehicle recalls between 2006 and 2016 into consideration, the average time delay between the manufacture and the introduction of a product recall campaign is 3.0 years. Considering only vehicle recalls attributed to software, sensor and ECU failure, the average time delay between the manufacturing begin and the introduction of a product
recall campaign is 2.86, which implies that these failures are detected and remedied slightly earlier.

VII. Risk mitigation avenues for ADAS/AV-enabled vehicles

A comprehensive risk management process comprises methodologies and instruments to identify, evaluate, mitigate and monitor risks resulting from various internal or external sources (Ho et al. 2015). Instruments of risk mitigation generally reduce the risk exposure of an identified risk by influencing either the probability or the severity of a loss. Based on the timing of their effect, these instruments can be categorised in proactive or retroactive instruments. Proactive instruments influence the risk exposure before the risks occur by reducing the probability of a loss occurrence and/or by limiting the probable maximum loss. Retroactive instruments retrospectively reduce the risk exposure by limiting the extent of the loss event after the risk has manifested. We propose an holistic risk mitigation approach combining proactive production risk mitigation with proactive and retroactive financial instruments for the reduction of financial losses.

1. Production risk mitigation approaches

Product recall events basically result from failures of a product or its components. These failures can be attributed either to the design of the product, to defects within the manufacturing process or to software problems (Marucheck et al. 2011). Therefore, risk mitigation of product recall events is highly linked to quality management processes. The high proportion of production outsourcing in the automotive sector makes it necessary that an integrated approach to risk mitigation and quality management is not only applied on a corporate level but throughout the whole supply chain (Vanichchinchai and Igel 2011). For example, the trade-off between cost and quality (Kumar and Schmitz 2010) also affects the purchasing behaviour when suppliers are chosen for component parts. A strong emphasis on quality is considered indispensable for safety not only to reduce the direct risk of product recalls but also as a protection from loss of consumer confidence. This is especially relevant for ADAS/AV vehicles, as failures in their safety-relevant features potentially induce higher legal and equity costs (see section III).

In addition, a traditional instrument to decrease sourcing risk of a manufacturer is spreading orders among suppliers (Kırlımaž and Erol 2017). However, for ADAS/AV-
enabled vehicles, the ability to diversify risk across suppliers may not be applicable because of the central role of specialised software, which has to be integrated and calibrated with the embedded hardware.

Supplier contract design is also an instrument to protect from (financial) risks resulting from recall events. For example, cost-sharing agreements, which define an allocation formula between the manufacturer and the respective supplier for costs arising from product recall events can be used to limit costs and to increase the transparency and speed of cost allocation. In addition, cost-sharing agreements also contain an incentive function for suppliers to ensure on quality management. However, the distributed manufacturing process means that even though the supplier responsible for the recall is identified, the OEM may still be subject to financial loss. For instance, even if the supplier is liable for recall, repair and legal costs, the company at the end of the value chain nevertheless might face serious equity losses because of the adverse reputation damage.

Kumar and Schmitz (2010) emphasise the relevance of testing and inspection procedures to ensure the quality of components. For ADAS/AV technology, software-centric quality inspections, such as code-reviews and static or dynamic code-analysis, accompanied by rigorous testing of the integrated hardware and software infrastructure is required. Due to the increasing relevance of integrated safety-relevant OEM cloud-services and V2X-communication also the quality of these services will be crucial (Ding et al. 2014; Ding et al. 2018). However, the dynamic and complex environment in which ADAS/AV vehicles operate has a nearly unlimited number of possible risk scenarios. Therefore, a commonly agreed framework for testing these vehicles before market circulation would support the achievement of a minimum level of reliability and safety and limit the extent of residual risk driven by market competition (see section 4). Similarly but from a legal viewpoint, the application of technical standards and norms can be taken into account to assess if a product complies with safety requirements (European Parliament and Council 2001 rule 3). However, current standards and norms for designing and testing vehicles (e.g. ISO 26262 on the functional safety of road vehicles, IATF 16949:2016 as the standard for quality management in the automobile industry) do not necessarily consider ADAS/AV characteristics.

Marucheck et al. (2011) describe the necessity for innovative solutions to address product recall risk in the field of product lifecycle information management and traceability. Here, the interconnectedness of ADAS/AV-enabled vehicles provides pathways to reduce the
probability and/or severity of losses resulting from product recall events. Vehicle connectivity increases the amount of data that can be proactively used to identify potential safety-relevant failures in the vehicles’ software and hardware. If effective, this possibility does not necessarily reduce the probability of the occurrence of a product recall but still can reduce the number of affected vehicles and resulting costs, e.g. reputational costs due to proactive recall management (Magno 2012) or logistics costs due to the possibility of better planning. This proactive recall approach also supports the avoidance of punitive damages if failures are discovered before they materialise in personal or property damage. Finally, the possibility to remotely carry out over the air software updates has the advantage of lower distribution and labour costs for installation work and potentially improves the traceability of defective vehicles on the market. Looking at the “defect summaries” and “corrective summaries” of the NHTSA-data, the share of product recalls remedied by software updates (9.36 %) is more than twice as high as the share of product recalls caused by software failure (4.78 %) between 2006 and 2016, including product recalls, which are originally caused by hardware failure but can be circumvented by a software update.

2. Financial risk mitigation approaches

Despite existing efforts to mitigate product recall risk through production processes, the analysis of historical product recall activity (see section V) implies that (undetected) residual risk still remains and is likely to grow in the future. Because the potential financial instability resulting from product recall events can have a detrimental impact on product-flow in the automotive supply chain, a comprehensive risk mitigation approach has to couple production-oriented with financial-oriented risk mitigation instruments.

Financial risk mitigation can either be applied proactively (e.g. insurance coverage or contingent equity capital options) or retroactively (e.g. ad-hoc capital increases, issuance of subordinated bonds, credit-based financing). The design of efficient financial risk mitigation depends on the extent of financial losses resulting from a product recall event, internal factors of the affected company (e.g. self-bearing capacity, solvability and access to capital-market) and external factors such as interest rate level and the capacity of the insurance market.

Since our analysis has exhibited severe potential financial tail-risks of a product recall event (see section VI 1.), we propose a three-level risk mitigation approach for financial
risks resulting from these events, combining self-retention of lower parts of the risk exposure with retroactive and proactive financial risk mitigation. On a first level, risks beneath the threshold of a company’s self-bearing capacity, which can be carried without external financing, are retained at the company’s own risk. The self-bearing capacity determines the threshold beneath which losses can be carried without financial instability. As most recall losses are quite low in severity (Figure 12 shows that 86.8 % of product recalls affected 25,000 or fewer vehicles), we expect that a relatively high share of product recalls can be carried internally.

Risks which exceed the self-bearing capacity of the affected company have to be financed externally either by retroactive financial risk mitigation or proactive financial risk mitigation through insurance. Assuming, that the cost of capital for retroactive financing increases with higher loss amounts and that additional margins for proactive risk mitigation are fixed in advance, the efficiency of proactive risk financing ceteris paribus increases with increasing probable loss amounts. In addition, it also has to be taken into account that retroactive financing may not be available in that case where the financial loss of a product recall may jeopardise the viability of the affected company to an extent that external financing options are not offered by third parties anymore. By contrast, proactive instruments of financial risk mitigation are paid in advance regardless of whether a trigger event actually occurs. As a result, proactive risk mitigation is suitable particularly for financial peak risks resulting from extensive product recall events whereas retroactive financial risk mitigation is efficient for middle layers of risk exposure. The distribution of the number of potentially affected vehicles shown in Figure 12 and the given examples of recent product recall events indeed indicate that loss events with severe financial tail-risks exist, so that the described layering of financial risk mitigation instrument is useful for efficient risk management approaches.

Furthermore, we find synergies between insurance coverage and corporate risk mitigation as insurance not only increases the resilience of the automotive supply chain but also enhances the transparency during purchasing decisions and improves corporate risk and quality management by validating risk evaluation and benchmarking internal processes.

An OEM can be affected indirectly by the product recall event on a production level if passing the costs down the supply chain leads to the instability of a crucial supplier. Here, insurance is an instrument to increase the financial stability of the production process preventing spill over effects due to the product recall event. In addition, the exchange of
the (potential) financial costs of a product recall with the payment of a fixed insurance premium increases the transparency of total costs of production. The contractual obligation to maintain insurance coverage thus helps to make informed purchasing decisions (Flynn and Flynn 2005) by assuming insurance premiums as an additional price component.

Finally, we find close synergies in the process of risk evaluation between corporate risk management and insurance premium pricing. Here, the price quotation of an external insurance company can be used to validate and benchmark internal risk assessment. Insurance companies usually use quantitative methods with an analysis of soft factors such as the adequacy of corporate risk management structures. In this way, insurance can increase the validity of own internal evaluations but also serve as a benchmark for the adequacy of quality and risk management processes on a corporate or supply chain level with a suitable comparison group (“risk advisory function”).

VIII. Conclusion

Based on a quantitative analysis this paper finds that product recall risk has been successively increasing in both probability and severity. Combined with a qualitative assessment of ADAS/AV technology’s potential impact on future product recall risk, we show that the increasing complexity of the vehicle software and hardware infrastructure will increase the number of failure sources that will, in turn, increase the risk of product recalls.

We anticipate that the technological drivers of product recall risk will be accompanied by increasing legal and reputational risks as ADAS/AV-enabled vehicles will take over safety-crucial driving tasks. Because of this, members of the automotive supply-side have to implement adequate measures of product recall risk mitigation to support the common societal acceptance of ADAS/AV technology and to protect themselves from financial risks resulting from extensive product recall events.

We describe a comprehensive risk mitigation approach consisting of proactive and retroactive risk mitigation tools on a production- and financial-level. With regard to production-related risk mitigation, we focus on ADAS/AV-specific aspects and find that common standards and norms for the design and testing of this technology are necessary to technically and legally support a consistent level of reliability and safety in the future.
We also find that the connectivity of future vehicles can be leveraged in an holistic risk mitigation framework. However, connectivity is a double-edged sword which indeed can improve traceability of product failures and enable proactive monitoring as well as remote repair, but also increases vulnerability resulting from cyber-attacks.

Despite all measures to mitigate the risk of safety-relevant product failure on a production level, residual risk remains. Hence, a comprehensive risk mitigation approach requires the implementation of financial risk mitigation approaches. With a special focus on financial risk mitigation via insurance, we find that insurance cannot only be used as an instrument for risk transfer but offers additional benefits, such as an increased transparency of purchasing decisions, the validation of risk assessments and the benchmarking of risk management processes. Both insurance companies and vehicle (component) manufacturers will inevitably be affected by the automation of vehicles and changing mobility demands, so we suggest a more strategic cooperation of insurance and automotive supply chains with a focus not only on product recall but also on product liability risk management.
References Chapter 5


Dudenhöffer, P.D.F. (2016) 'Carman’s profits and sales', *CAR-Center Automotive Research (University Duisburg-Essen)*.

European Commission (n.d. ) 'European Rapid Alert System for dangerous non-food products (Rapex)', n.d.


NHTSA (n.d.) 'Vehicle Safety Recall Download Data'.


Chapter 6: Research Conclusion

While the introduction of new technology advances societal progress and economic opportunities, it simultaneously poses significant challenges to society, businesses, research, and regulatory bodies. In particular, major challenges obtains to long-term risk assessment forecasts and to the adequate adaption of relevant regulatory frameworks.

As the business model of insurance is to assume and balance risks in sufficiently large portfolios over time, an adequate quantification of risk-factors is a strategic core competence determining the economic success of an insurance company. Yet, due to an ongoing lack of empirical data and the inherent fluctuations of technological design and adoption in the formative years, such risk assessment is inevitably prey to varying degrees of uncertainty. This effectively means that relevant stakeholder decisionality rests on speculative assumptions which may give rise to misjudgments in terms of implementation. Since the real impact of emerging technologies can only be fully revealed over time, an iterative approach of re-assessment is required to minimise the risks. As it stands, the development and real-world application of CAV technology are at an early stage, rendering the level of ambiguity around CAV risk factors evenly high. Such ambiguities around the risk-factors used during pricing processes are particularly challenging for insurance entities.

In addition to the challenges posed to risk-assessment, emerging technology may also expose certain idiosyncrasies which have been formerly overlooked or subsumed by prevailing legal frameworks. The adaption of legal frameworks to the new context is, therefore, necessary to ensure both a smooth penetration of technology and proper consideration of the legitimate interests of all stakeholders involved. In terms of CAV technology, in particular, axiomatic legal questions concern the allocation of liability for accidents caused by automated driving vehicles and access to in-vehicle data. These matters are of equal importance to the insurance sector.

Due to the insurance sector’s pivotal role in facilitating the penetration of CAV technology, this thesis presented a comprehensive analysis of the insurance-relevant implications from both legal and risk-factors and advances knowledge in this area through

- a farsighted and proactive customisation of liability and insurance frameworks,
- a farsighted and proactive design of legal frameworks which determine the access to in-vehicle data,
• a transparent and comprehensive assessment of CAV technology’s probable risk-factors, which taken together contributes to an holistic assessment of CAVs’ implications to the insurance sector. The findings resulting from the present research objectives equip insurance carriers to take proactive strategic measures for adapting business models to a potentially changing environment and enable regulatory bodies to make proactive preparations for the legal frameworks which obtain to CAV technology.

To provide a more comprehensive understanding of potential CAV technology impacts on the insurance sector, this thesis offers a multidimensional research approach that combines findings from a diverse range of academic disciplines and research methods. This is deemed most appropriate as the field of insurance research is inherently interdisciplinary. The overall contribution of this thesis is that, in focusing on CAV technology, it forges links between formerly segregated research disciplines and provides an holistic analysis of insurance-related implications from an academic perspective. The specific research findings and contributions to academic literature per research objective are as follows:

• **Research objective:** *Contribute to a farsighted and proactive customisation of liability and insurance frameworks for accidents caused by CAV technology which considers an adequate level of protection for accident victims and a reasonable allocation of liability costs*

Prior research on liability for automated vehicles fails to consider the central role of motor insurers within the claim settlement process and therefore neglects the motivational aspects of motor insurers. Moreover, it overlooks crucial interrelations between liability law and motor insurance law. As they are inextricably linked to each other, motor insurance law is vital to the efficient processing of motor liability claims and a comprehensive analysis must also include the potential shortcomings of this law source. As such, this thesis contributes to academic research by considering the (economic) interests of involved parties in order to evaluate the adequacy of the existing framework with an behavioural law and economics perspective.

The in-depth analysis of the legal provisions of the current German motor insurance and liability framework in *Chapter 2* consolidates existing research which states that the
strict-liability approach of the vehicle owner is generally capable of covering the peculiarities of CAV technology since it facilitates an efficient and clear path of compensation for third-party claimants regardless of the level of automation and the status of the vehicle owner (individual or mobility service-provider). However, only an analysis of the interrelations to motor insurance law and the motivational aspects of motor insurers within the claim settlement process can properly ringfence those shortcomings of the existing framework which have not been addressed by existing research to date. In particular, this thesis concludes that minor adjustments to the existing liability and insurance framework are necessary to maintain an adequate level of claimant protection for accidents caused by automated driving vehicles. This can be achieved by further increasing the maximum sum of the vehicle owner´s strict liability and by aligning the minimum sums insured determined by motor insurance law with the adjusted maximum liability of the Road Traffic Act.

With reference to the ultimate allocation of liability, the assessment of motor insurers´ motivation shows that a material shift of liability costs by the way of regress claims against the vehicle manufacturing side is neither realistic nor efficient within the existing framework. While such a finding may comply with the legal justification of applying strict-liability to the vehicle-owner, it could nonetheless limit the preventive function of liability law which incentivises vehicle manufacturers to undertake exhaustive pre-sales testing. As such, the findings of this thesis are subject to normative legal valuation since a material shift of liability exposure to the vehicle manufacturer side could also hamper innovation. That said, the guiding principles for the normative legal valuation presented in this thesis are based on the two basic functions of liability systems, namely the adequate indemnity and preventive function. Contrary to this perspective, a normative legal valuation based on different guiding principles and considerations of political pragmatism could partially also lead to an opposing assessment of the given framework.

The findings regarding the gap in claimant protection as well as the adequate allocation of liability costs gain practical relevance already with vehicles equipped with conditional automation functionalities (level 3 automation) as the fault of the human-driver might not be a relevant trigger for accident occurrences anymore. However, as this automation level is still exposed to challenging questions surrounding the retrospective reconstruction of specific human-machine interaction in a given accident scene, it is to be expected that a clear omission of human fault can only be efficiently proven with automated vehicles of higher levels of automation (level 4 and 5).
Given the shortcomings of the existing liability and insurance framework, this thesis not only adds to existing academic discussions but also supports regulatory bodies in a farsighted design of risk regulation frameworks. This is particularly the case in terms of the suggested adjustments to the existing framework which could be considered during the re-evaluation process of the German Road Traffic Act planned for 2020.

Limitation of research does arise from the fact that the German liability and insurance framework is used for in-depth analysis but no similar assessment has been conducted for different jurisdictions. Due to this, the specific findings regarding the shortcomings of the framework are not necessarily applicable to other jurisdictions. In spite of this, however, the German framework has already proved largely applicable for automated driving vehicles, and this comprehensive examination clearly supports the preparation of a blueprint framework which could be adopted by other jurisdictions in the future. This is particularly significant, as a certain level of amalgamation of national liability and insurance frameworks will be required to ensure a consistent level of legal certainty of users and producers of CAV technology in Europe and beyond. Despite this limited focus on German liability and insurance framework, the analysis of potential legal barriers in the Product Liability Act is generally also applicable to other European jurisdictions which have adopted the regulations. That said, the Product Liability Act still leaves some freedom in the specific adoption of legislation (e.g. regarding the limitation of liability for personal damage due to one and the same defect) so that the findings within this thesis are referring to the legislation adopted by the German legislator.

- **Research objective:** *Contribute to a farsighted and proactive design of legal frameworks which determine the access to in-vehicle data so as to ensure an undistorted and fair competition of parties involved*

This thesis presents accessibility to in-vehicle data as a core strategic question of the insurance sector which remains largely overlooked by academic and practice-related research. By examining insurance-related use cases, the present thesis raises awareness of the relevance of an in-depth academic discussion in this field, particularly, as the example of CAV and insurance holds as a proxy for a broader discussion about access to data from connected smart-devices in an IoT-driven business environment of the future. That said, the societal impact of IoT-based and data-driven services has been largely assessed with a focus on the implications for individual freedom of choice and customer
behavior, information overload and surveillance only but discussions of the design of regulatory frameworks for these services from an economic market perspective remain underrepresented.

To redress this gap the concept of business ecosystem platforms is used for the analysis of OEMs’ approaches to leverage their superior access to in-vehicle data as a means to expand their traditional business model of vehicle production with complementary digital services. The analysis of insurance-related use cases confirms that the increasing interconnection of modern automobile vehicles will significantly impact insurance-related services offerings. This will affect services and processes along the whole insurance value-chain, namely distribution and customer interfaces, premium calculation of usage-based insurance tariffs, active loss management, and breakdown assistance services. Clearly then, the central strategic question of an adequate access to in-vehicle data for motor insurers is not yet adequately protected by legal frameworks and actively constrained by OEMs. Whereas this finding is generally relevant for connected automated vehicles of all automation levels, the relevance of the specific services in scope might vary by automation level. For instance, usage-based insurance-tariffs also measuring driver’s performance (“pay how you drive” tariffs) might be especially relevant for partial and conditional automation levels (level 2 and 3) but would be less relevant in case that the insurance risk is mainly determined by the reliability of the vehicle itself (level 4 and 5). In addition, if higher levels of automation would induce a shift towards the use of service-based mobility of commercial fleet-providers, the relevance of direct customer-interfaces between the motor insurer and individual mobility user might be trimmed anyway.

An analysis of the status quo from a business ecosystem perspective underscores that taking the role of a physical dominator to extract maximum short-term value from the ecosystem might be an obvious but not necessarily successful approach for OEMs on the long-term. This is because the shift from a goods-dominant supply-chain perspective to a service-dominant perspective will also need to be accompanied by a profound redefinition of OEMs’ supply-chain relationships. This finding supports the resolution of contrasting positions of OEMs and third-party providers and facilitates an unbiased and farsighted approach of regulatory bodies to ensure that the inadequate advantages of single actors do not result in market failure to the detriment of customers.
• Research objective: Contribute to a transparent and comprehensive assessment of CAV technology’s probable risk impacts to enable both insurance industry and regulatory bodies to base decisions on a firm and unbiased ground

Existing literature focusing on CAV risk-factors from an insurance perspective is dominated by practice-related publications which are sourced from two author groups. On the one hand, consultancy firms’ forecasts on the impact of CAV technology on motor insurance market premium predict sharply decreasing premium volumes due to a significant expected decline in the number of road accidents. On the other hand, the more moderate projections of insurance-affiliated institutions (e.g. German Insurance Association) underline the perennial importance and economic legitimacy of the motor insurers’ business model. Unsurprisingly then, practice-related literature with an insurance-specific perspective is arguably biased by the (economic) interests of specific publishing parties. Apart from this literature, an academic assessment of CAV risk-factors from an insurance perspective is largely missing.

Indeed, academic literature on CAV risk-factors already exists but stems from accident research with a focus on overall accident activity. Even if both perspectives show overlap, divergent research needs result from the fact that loss scenarios contributing to major parts of insurance loss expenditures are not necessarily relevant for accident research. Given that traditional pricing approaches in the (motor) insurance industry are based on largely stable historical loss-data, a stronger link between research disciplines must be established to allow for proactive and scenario-based risk-assessment approaches. This change in risk-assessment is imperative as retrospective risk-pricing approaches cannot be applied in an environment characterised by incomplete information and ambiguity of risk-factors. Here, a lack of proactive risk-assessment methods gives rise to the threat of mispricing of inherent CAV risk.

In order to redress the aforementioned gaps in existing academic and practice-related research, the present thesis provided a comprehensive qualitative and semi-quantitative analysis of CAV risk-factors including motor and product recall insurance. In so doing, it contributes to a more comprehensive academic assessment of CAV risk-factors which supports not only insurance companies in a proactive risk-assessment approach, but also raises awareness of the need for proactive risk management frameworks for manufacturers of CAV technology. Moreover, the qualitative risk-assessment approach
applied in this thesis forms a credible basis for further interdisciplinary quantitative assessments of CAV inherent risks, which currently is still hampered by a lack of reliable and transparent empirical data. Due to this limitation of available data in general, the findings of this thesis are suitable to improve the overall risk governance in the domain and to provide guidance in general directions of risk mitigation but is not already capable of determining the precise design of specific risk management frameworks.

This thesis contributes to a more granular assessment of CAV accident-risk by foregrounding the risk-relevant peculiarities of single levels of automation. Through this approach, the study contributes to a more precise delineation of CAV risk-implications. Furthermore, it lends proportion to the often exaggerated perception of increased road safety linked to CAVs with higher levels of automation. By so doing, the thesis encourages a more rational academic and public discussion of the potential benefits of CAV technology. Furthermore, it supports better informed and evidence-based decisionality on the part of regulatory bodies and business entities as a means to lessen the risk of missteering of (public) investments due to incomplete and/or biased information.

- **Research objective:** *Contribute with an holistic assessment of CAV implications for the insurance sector in order to support insurance entities to take proactive strategic measures to adapt business models to a changing competitive environment*

With reference to the scope of strategic implications of CAV technology to the insurance industry as outlined in Chapter 1, it is held that potential disruption of existing insurance business models could result from material changes in the

- **Allocation of liability:** Does a shift of legal allocation of liability for accidents caused by automated vehicles lead to a significant shift of liability costs to vehicle manufacturers and consequently to a material decline of premium volume in motor insurance?

- **Future risk landscape:** Does the expected increase in overall road safety lead to a sharp reduction of residual (financial) insurance risk?

- **Change of customer interfaces and market structure:** Does a shift of societal mobility behaviour to a service-based mobility approach lead to a shift of customer interfaces in the (motor) insurance market?
Based on academic research approaches, this thesis provides strong links to practice-related research questions on CAVs and insurance. In considering the perspective of a key stakeholder, this research approach facilitates a smooth introduction of CAV technology. From an insurance business perspective, this thesis contributes to proactive strategic planning not only by identifying the potential challenges and risks to existing business models of (motor) insurance but also by suggesting strategic measures to confront them.

Referring to the risk-factors of motor insurance, this thesis ultimately concludes that a reliable quantification of future risk-exposure is not yet possible. Even if automated driving vehicles have the potential to decrease the number of road accidents caused by human-error, there is still insufficient evidence which confirms the reliability of automated driving systems in a real-world application. Thus, to assume a causal link between taking the human driver out of the driving action and the reduction of road accidents is a statistical fallacy since the high contribution of human fault to accident activity is just a logical outcome of the fact that the human currently assumes the driving action almost exclusively. On the contrary, the average human is a reasonably reliable driver. As such, automated driving vehicles must first prove comparably higher performances before a positive impact on overall accident activity can be scientifically presumed. In light of this, the present thesis contributes to a more rational and fact-based discussion of the probable impact of CAV technology on both road safety and motor insurance loss activity. Even if no disruptive impact on motor-insurance risk is anticipated, motor insurers must nevertheless devise adequate solutions to map the probability of changing risk-factors into their pricing-models since these will successively shift from driver-centric to technology-centric risk-factors with increasing levels of automation. Moreover, this is relevant as emerging risks such as automotive cyber-attacks potentially even introduce unprecedented catastrophe-alike risk exposures to MTPL insurance.

In addition to a sophisticated understanding of future motor insurance risk, this research enriches the academic and practice-related analysis of CAV technology’s inherent risks by elucidating the impact on automotive product recall risk to the academic discussion. The analysis undertaken in this thesis yield important initial findings which may serve as a cornerstone for future interdisciplinary research in this field.
With regard to the existing German liability and insurance framework, this thesis confirms that the methodology to allocate liability based on the strict liability of the vehicle owner is compatible with the peculiarities of automated driving vehicles. However, this does not necessarily mean that the business model of motor insurance will remain unaffected by adjustments to future liability and insurance frameworks. While the central role of motor insurers within the claim settlement process generally enables them to absorb liability costs in order to manufacturers in order to preserve premium volume of the own business, for instance, if regulatory bodies come to regard this as an undesirable market failure resulting in an unreasonable allocation of liability costs, additional regulatory intervention could ensue.

By pointing out the contrasting and synchronous interests of different stakeholders, namely insurance companies and OEMs, this thesis encourages market players from different sectors to consider the development of holistic strategic alliances with suitable business partners to leverage complementary capabilities to foster innovation. However, in order to be considered as a potential candidate for strategic collaboration, insurers must be conversant with emerging business models and must develop value propositions for potential business partners within the mobility space.

This will be essential if changing mobility approaches lead to a material shift from possession-based to service-based mobility which, in turn, impacts customer-interfaces in the motor-insurance market. Due to a probably changing risk-landscape, especially insurance companies with the capabilities to provide holistic risk management services and risk-transfer solutions for OEMs and mobility service providers may also benefit from the opportunities afforded by the emerging risks of product recall and product liability exposures. This finding especially gains relevance with vehicles of level 3 automation as it is expected that not only the legal risk of product liability claims by the way of regresses could increase -if adequate measures are taken to adjust the given liability and insurance framework accordingly- but also as the product recall risk exposure is likely to further increase. This is because of the increasing complexity of vehicle hardware and software but also as strict regulatory approach to recall vehicles is pivotal if vehicles are capable to take driving decisions independently. Therefore, it is expected that the finding of emerging risk exposure will progressively take effect with conditional automation (level 3) onwards.
Finally, the high level of ambiguity regarding not only the rate and extent of deployment but also the inherent risk levels of CAV technology during its formative years, mean strategic (investment) decisions to exploit potential business opportunities must be made under conditions of uncertainty. Given such circumstances, the holistic assessment of strategic implications of CAV technology on the insurance sector supports the identification of both challenges and opportunities and facilitates the design of more resilient business models to counter the still uncertain changes in the business environment.
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APPENDIX B  STATEMENT OF ARTICLE CONTRIBUTION


Authors` contribution

Fabian Pütz carried out the main part of legal analysis and writing of the case study. Dr. Finbarr Murphy and Dr. Martin Mullins contributed to the structure and concept of the paper and carried out major revision work. Prof. Dr. Karl Maier and Prof. Raymond Friel contributed as experts with their deep legal knowledge as advisors for discussions of research findings. Prof. Dr. Torsten Rohlfs contributed with ideas from an insurance perspective and revision.


Authors` contribution

Fabian Pütz contributed with the underlying concept of the paper and carried out the main part of the case study research and writing. Dr. Finbarr Murphy and Dr. Martin Mullins contributed to the structure of the paper and carried out major revision work. Prof. Dr. Lisa O`Malley contributed as expert with her deep marketing know-how and as advisors for discussion of research findings and theoretical basis of the paper.
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Authors’ contribution

Fabian Pütz contributed with the underlying concept of the paper and carried out most of the research, data analysis and writing of the paper. Dr. Finbarr Murphy and Dr. Martin Mullins to the structure of the paper and carried out major revision work.

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Authors’ contribution

Dr. Finbarr Murphy contributed with the basic concept and revision of the paper. Fabian Pütz carried out the main part of the literature review, data analysis, and writing. Dr. Martin Mullins and Prof. Dr. Torsten Rohlfs contributed with ideas from insurance and corporate risk management perspective. Dennis Wrana carried out the initial underlying literature review of the paper. Michael Biermann contributed as automotive supply-chain and insurance expert with his deep knowledge of automotive supply-chains and manufacturing and automotive product recall insurance as an advisor for discussion of research findings.

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