THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

Are We There Yet?

Combining qualitative and quantitative methods to study the introduction of CAVs in Sweden, and potential travel demand effects.

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ABSTRACT

By law, Sweden must reach net-zero emissions of greenhouse gases (GHGs) by 2045. Domestic transportation is one sector in which GHG emissions can be reduced substantially. Connected and Autonomous Vehicles (CAVs) could potentially help with this and with the transition to a more efficient transportation system, but they could also instead make meeting the target harder. The issues of how CAV technology will be introduced to the general public and what the effects will be are fraught with uncertainty.

Thus far, much policy research has been informed by technical, quantitative studies, such as the one in Paper 1 of this licentiate thesis. The study analyses the impact CAVs may have on travel demand. The methodology is based on an induced travel demand model that simulates the effects on Vehicle Kilometres Travelled (VKT) related to changes in Value of Travel Time (VoTT) and the cost of CAV technology. In our most conservative scenario—with the smallest change in VoTT and highest CAV cost—we estimate an average increase in travel distance by car of 5% once CAVs are a mature technology on the market, while this increase reaches 61% in the least conservative scenario. Our results also show that income matters: Under certain conditions, those who are able to work remotely and have a relatively high income have a greater economic incentive to purchase a CAV and extend their travel distance.

In Paper 2, we identify and map the broader societal drivers and pressures for the introduction of CAVs in cities. The approach taken in the paper has a theoretical basis in transition management and stakeholder theories and uses a combination of the Drivers, Pressures, State, Impact, and Response (DPSIR) framework and force field analysis to analyse interview transcripts. Survey data complement this analysis. The results provide in-depth knowledge about how actors in different parts of society perceive the introduction of CAVs and the mechanisms behind the expansion of these vehicles. It is clear from the interviews and survey that CAVs are not seen as unconditionally positive; instead, many stakeholders believe CAVs need to be connected to mobility planning and public transport strategies.

Key words: Connected and Autonomous Vehicle, Value of Travel Time, travel demand, DPSIR, drivers, pressures, force field analysis, sociotechnical transition

ABSTRAKT PÅ SVENSKA

Sverige ska enligt lag nå netto noll utsläpp av växthusgaser till år 2045. Inrikes transporter är en sektor där växthusgasutsläppen kan minskas avsevärt och självkörande fordon kan både eventuellt försvåra och hjälpa till med denna nödvändiga minskning av utsläppen och övergången till ett mer effektivt transportsystem. Det finns dock många osäkerheter om hur tekniken kommer att införas för allmänheten och vad dess effekter kommer att bli.

Hittills har mycket politisk forskning informerats av tekniska, kvantitativa studier, som t.ex. Papper 1 i denna licentiatuppsats. I den studien analyserar vi vilken inverkan självkörande bilar kan ha på reseefterfrågan. Metoden baseras på en modell av inducerat resebehov som simulerar effekterna på körsträcka relaterade till förändringar i värdet av restid och kostnaden för den självkörande tekniken. I vårt mest konservativa scenario uppskattar vi en ökning av reseefterfrågan med 5% efter att tekniken (mer specifikt: connected and autonomous vehicles eller CAV) har blivit en mogen teknik på marknaden, medan ökningen av reseefterfrågan är 61% i scenariot med de största effekterna. Under vissa förhållanden visar resultaten större ekonomiskt incitamentet att köpa en CAV och förlänga körsträckan för den som kan arbeta på distans och har relativt hög inkomst.

I Papper 2 identifierar och kartlägger vi de bredare samhälleliga drivkrafterna (drivers) och trycket (pressures) för införandet av självkörande bilar i städer. Tillvägagångssättet i uppsatsen har en teoretisk grund i transition management och stakeholder theories och använder en kombination av ett Drivers, Pressures, State, Impact and Response (DPSIR) ramverk och force field analysis för att analysera intervjuer. Denna analys kompletteras med enkätdata. Resultaten bidrar till ökad förståelse om hur aktörer i olika delar av samhället uppfattar införandet av självkörande bilar och mekanismerna bakom expansionen av dessa fordon. Det framgår tydligt av intervjuerna och undersökningen att självkörande bilar inte ovillkorligt ses som något positivt, utan att många intressenter snarare anser att självkörande bilar måste kopplas till mobilitetsplanering och strategier för kollektivtrafik.

APPENDED PAPERS

I. **Rebalski** E., and Johansson D.J.A. (2021). Value of Travel Time and Induced Travel Demand: An analysis of how CAVs Could Influence Travel Distances in Sweden. Paper submitted to the Journal of Travel Behaviour and Society.

ER and DJ developed the idea and analysed the data. ER wrote the paper with contributions from DJ.

II. **Rebalski** E., Adelfio M., Sprei F. and Johansson D. J. A. (2021) Too Much Pressure? Driving and Restraining Forces and Pressures relating to the State of CAVs in Cities. Paper to be submitted.

ER, MA, FS, and DJ developed the idea. ER and MA carried out the interviews and survey with contributions from FS and DJ. ER and MA wrote the paper with contributions from FS and DJ.

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This thesis would not have been possible without the guidance of my supervisor, Daniel Johansson. I want to express my gratitude (conceptually) as such:

$$\int_{?}^{Lic} \left((VoTT) learning + SPSS - SPSS + discussions + deadlines^{delays} + (whiteboard_{text})^{-\varepsilon} + \left(whiteboard_{pictures}\right)^{\varepsilon} \right) patience dW$$

Thank you as well to Frances Sprei, my secondary supervisor, for your insights on mixed methods research, and also everything I have learned working with you as a teaching assistant. Thank you to Marco Adelfio, it has been a pleasure working with you and I look forward to continuing the collaboration.

Thanks to my examiner Sonia Yeh for making sure my work is up to snuff, and the rest of the Physical Resource Theory division for a fun and challenging work environment where it's always ok to ask questions.

Xiè xiè to my office roommates, Yuan, Xiaoming and Ahmet, sláinte to Gavin, and tack to the rest of the "junior" staff who make this strange job where we are constantly learning how much we don't know bearable.

Ett stort tack till alla på Rampen. I am sure that playing football with you has caused an increased flow of oxygen to my brain, and that has likely had a positive effect on my research. Also, it's a blast.

To my family, I am so glad to share genetic material with you. Thank you for supporting my work in so many different ways, not least getting up before dawn to watch my licentiate seminar!

To Mathias, thanks for making me laugh throughout.

Ella Rebalski
Gothenburg, 2021

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Chapter 1

Introduction

On January 1, 2018, Sweden's Climate Policy Framework came into effect as national law. The Framework consists of a Climate Act, a policy council, and a set of goals that all contribute to Sweden's main climate goal: net-zero emissions of greenhouse gases (GHGs) by 2045 and negative emissions after that (Bonde et al., 2020). This Framework is the result of domestic negotiations and research going back many years as well as Sweden's commitments according to the 2015 Paris Agreement.

What does this have to do with Connected and Autonomous Vehicles, i.e., CAVs? Well, that depends. The two articles in this licentiate thesis examine the potential effects that this technology could have on Swedish society, and if one looks at it purely from the perspective of reaching the net-zero carbon goal by 2045, CAVs[1] could matter a lot. More specifically, they could help to reduce the 10.1 million tonnes of carbon dioxide equivalent currently emitted each year by passenger cars in Sweden (Naturvårdsverket, 2020, p. 6). They could also contribute to a new transportation system that is more accessible, efficient, and affordable. However, this depends on how the technology is used. For example, potential user groups who were previously unable to drive could now use car; passengers could drastically increase the length and frequency of car trips because they would be able to use the time in the car for other activities; and when passengers are deposited at their destination, the empty CAV would continue driving to its next stop, therefore driving much farther than a conventional car (Annema, 2020). Put together, these trends could cause a huge increase in emissions from passenger cars as well as other negative effects such as suburban sprawl (Moore et al., 2020; Pernestål et al., 2020).

In order to avoid potential large-scale problems and steer towards the potential benefits of the technology, the introduction of CAV technology needs to be carefully planned and executed. And this planning would hopefully benefit from being informed by scientific research that carefully studies the possible scenarios that could be created by this yet relatively untested (at a societal level) technology. The papers included in this licentiate contribute to this research.

1.1 Aims

This licentiate thesis examines some of the potential indirect effects that CAVs could have on energy requirements and GHG emissions in Sweden, focussing, in particular, on answering the following questions:

1. How might a change in Value of Travel Time induce an increase in travel demand?
2. Which driving and restraining forces and pressures are important for the introduction of CAVs in cities?

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[1] In this licentiate thesis CAVs are defined as level 4 vehicles as described by the SAE guidelines: https://www.sae.org/standards/content/j3016_201806/. We assume that these vehicles would exist as part of an interconnected system, thus we use the term Connected and Autonomous Vehicle or "CAV".

1.2 Contributions

In Paper 1, we analyse the impact CAVs may have on travel demand under certain conditions. The conceptual approach is based on a technology adoption model as well as an induced travel demand model that simulates the effects on Vehicle Kilometres Travelled (VKT) related to changes in Value of Travel Time and cost of CAV technology. This research builds on work by, for example, Wadud et al. (2016), Wadud (2017), and Taiebat et al. (2019). The results from the study could potentially be useful for transport and energy system planning and policy design.

In Paper 2, we identify and map the broader societal drivers and pressures relevant to the introduction of CAVs in cities. The approach taken in the paper has a theoretical basis in transition management (Loorbach, 2010) and stakeholder theories (Caputo, 2013). The method combines the Drivers, Pressures, State, Impact and Response (DPSIR) framework—to analyse interview data (Adelfio et al., 2018)—and force-field mapping (Burnes & Cooke, 2012)—to complement this with survey data. The results from the second study provide in-depth knowledge about how actors in different parts of society perceive the introduction of CAVs and the mechanisms behind the expansion of these vehicles.

1.3 Disposition

The disposition of this thesis is as follows. Section 2 begins with a contextual explanation of the history of passenger cars in Sweden, mechanisms by which CAVs could affect energy use and CO_2 emissions, Sweden's goal for zero net GHG emissions by 2045, and a brief summary of where this thesis fits within those background topics. Sections 3 and 4 summarise the methodology and results of the appended papers. Section 5 discusses the scientific contributions of this thesis. Finally, Section 6 offers a brief outlook on future work.

Chapter 2

Background

2.1 The historical context: Sweden as a car-producing and car-driving nation

Sweden has a long history of automobile production that has evolved into an industry based around cars, trucks, and other engines, with a focus on domestic innovation and technology development, while some of the production has moved abroad (Statistics Sweden, 2017). In 2019, the automobile industry was responsible for BSEK 235 in exports, which is minimal on a global scale but represents 15% of Swedish exports (Bil Sweden, 2020, p. 36).

The strength of the automobile industry is reflected in the broader Swedish economy. If the number of jobs in the automobile industry[2] were to increase by 1 000, this would result in an additional 1 000 jobs in other industry sectors; this effect is among the largest in the manufacturing sector (Statistics Sweden, 2017).

Automobile ownership is common in Sweden. In 2019, 4.9 million passenger cars were in use (Bil Sweden, 2020, p. 9), i.e., one car for every two people. The average distance travelled by a car owner was 11 710 kilometres (Trafikanalys a, 2020). In 2017, 35% of Swedes reported that they were completely dependent on a car (Bil Sweden, 2020, p. 19).

Cars have also had a strong influence on Swedish infrastructure after World War II. In his 2014 doctoral thesis "The Car Society: Ideology, Expertise and Rule-Making in Post-War Sweden", Per Lundin studied the class of planning experts that appeared during the 1950s and 60s who were fascinated with the American model of a society built around cars (Lundin, 2014). These experts, according to Lundin, also viewed the technical advancement and uptake of the automobile as a foregone conclusion, and thus the concept of urban and larger-scale national infrastructure planning based on cars was not considered to be a political matter, but simply a technical one. This is not an unknown phenomenon in the transportation literature. Mattioli et al. refer to it as "the creation of an apolitical facade around pro-car decision-making" (Mattioli et al., 2020, p. 1). In addition to the assumed impartiality of car technology, the separation of cars and other modes of traffic, especially pedestrian, was viewed as the best and safest way to guide planning.

Lundin's critique of this self-fulfilling planning process is that the problems of traffic accidents and congestion, which were already present in the 1950s and something that planning experts were trying to address, could have been solved in a number of other ways that did not give priority to cars. Many of the problems that resulted from mass car ownership, such as noise, air pollution and CO_2 emissions, and what Lundin refers to as "torn-down and demolished city centres" (2014, p. 279) could thereby have been avoided.

This interpretation of the development and subsequent effects of the "car society" is important to be aware of when studying today's CAV development, because many of the same effects are already observable. In fact, the foregone conclusion that CAVs will be developed and used by everyone in society, and the push towards creating special lanes just for CAV technology (Yu et al., 2019) are two examples of obvious parallels. Stayton and Stilgoe (2020) summarise the issue:

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[2] The automobile industry here includes suppliers and subcontractors, as well as automobile companies.

"A schema for innovation that points in one direction and says nothing about the desirability of the destination makes for a poor roadmap" (p. 1). They suggest that the levels of automation created by the Society for Automotive Engineers, originally as a common way for the accepted technical hierarchy of CAV technology to be widely understood, are now used in a way that suggests that full autonomy is the ultimate end goal, rather than as a tool for exploring different context-based scenarios that encompass more diverse-use cases.

However, today there is a much more diverse international research apparatus studying CAV technology, policy, and potential societal effects. For example, there is already a push from the Swedish government for policy to be developed that will regulate CAVs in a socially equitable manner. In 2015, the government commissioned a public inquiry (*offentlig utredning*) to analyse which legal changes would be needed for an introduction of driving-supporting, and partial or fully self-driving, vehicles (Bjelfvenstam et al., 2018). The public inquiry suggests a number of changes to specific laws and provides context in terms of technological capabilities, societal effects, international law and policy, and vehicle use in Sweden.

The public inquiry also suggests short-term and long-term actions that the government could take that are straightforward but mapped on a tight timeline. The report recommends that by 2023, Swedish laws should be prepared for automated driving, most importantly to allow for the possibility of projects utilising advanced automated functions for platooning, goods transportation, and personal transportation (Bjelfvenstam et al., 2018, p. 35).

More recently, the Swedish National Road and Transportation Research Institute (*Statens väg- och transportforskningsinstitut*, VTI) published a working paper that looks at policy instruments for self-driving vehicles. This report is a useful overview of the existing literature on the subject and offers suggestions for how to internalise the externalities that could be caused by CAVs, as well as how to support their introduction, with the explicit acknowledgement that the requirements for this support remain unclear (Hammes, 2019).

This section has provided a broad introduction to the historical context of passenger cars in Sweden and has shed light on the span of societal issues that can be affected by CAVs. In addition to providing relevant background information, this scope is in line with the aims of the second appended paper in this thesis. The next sections will further clarify the specific CAV-related effect on GHG emissions and the academic and political forces already focussed on this issue.

2.2 Climate policy: CAVs and the 2045 net-zero emissions goal

The 2045 goal is not the first national Swedish GHG reduction goal. In 2009, the Swedish government voted to reduce GHG emissions by 40% by 2020, compared to 1990 levels. Sweden reached this goal (according to the calculation mechanisms in that particular framework) in 2012 (Bonde et al., 2020, p. 10). However, this was largely due to actions commonly referred to as "low-hanging fruit". The largest part of the reduction came from changes to heating systems in buildings, and relatively little came from transportation (Naturvårdsverket, 2020).

Since 1990, the GHG emissions from domestic transportation in Sweden have fluctuated, peaking in 2007 and then mostly sinking slowly. In 2019, transportation emissions were 17% lower than 1990 levels (Naturvårdsverket, 2020). But if Sweden is going to reach the transport-related targets that contribute to the net-zero goal, these emissions need to sink at a much faster pace.

When measuring transportation emissions, the Swedish Environmental Protection Agency (*Naturvårdsverket*) breaks this category into all the different modes of transportation used in Sweden. Passenger cars are by far the largest emitter, as can be seen in **Error! Reference source not found.**.

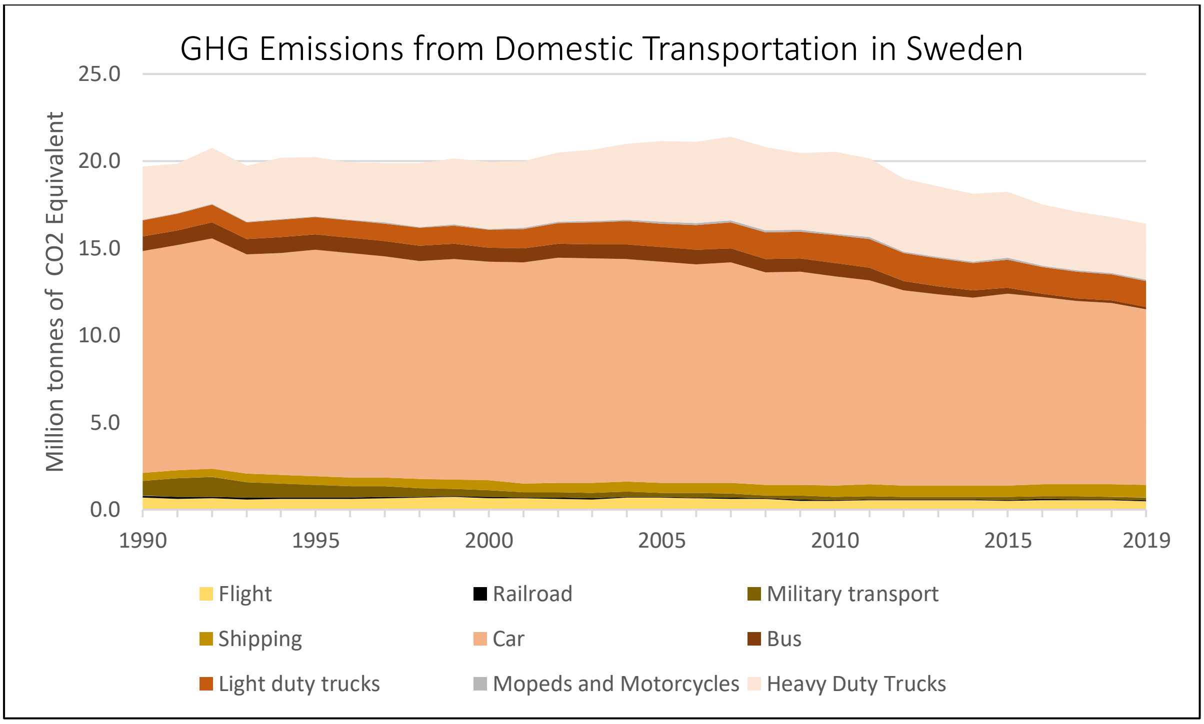

Figure 1: GHG Emissions from Domestic Transportation in Sweden (Statistics Sweden, 2020).

Until now, much of the reduction in emissions from passenger cars has been attributed to increased use of biofuels and more energy-efficient vehicles (primarily through a larger share of diesel cars) (Naturvårdsverket, 2020). Electric vehicles have historically been a small part of emissions reductions, but the number of electric vehicles (including battery, plug-in hybrid, and hybrid electric vehicles) on the road in Sweden is increasing rapidly; their share of new vehicle registrations reached above 20% in 2019 (Trafikanalys b, 2020).

In 2019, the Climate Policy Council recommended that the Swedish government "…begin preparing for a reform of road traffic taxation based on increased electrification and the use of autonomous vehicles, while promoting regional fairness" (Bonde et al., 2020, p. 51). CAVs do not feature prominently in these government reports about emissions reductions, but the technology has become salient enough to be mentioned. However, in their 2020 report, the Council noted that the while the government had planned to put a CAV-related tax within a larger tax reform, no concrete steps had been taken (Bonde et al., 2020).

2.3 Mechanisms by which self-driving cars may affect GHG emissions

A more formulaic way to look at how CAVs can affect emissions is to utilise the Activity, modal Share, energy Intensity of mode and carbon intensity of Fuel (ASIF) model, which is the basis for most calculations of transportation emissions. The formula is stated as (Schipper & Marie-Lilliu, 1999):

$$E = A \cdot S \cdot I \cdot F$$

Where E is emissions, A is travel activity, S is structure, often represented as modal share, I is energy intensity of the mode, and F is carbon intensity of fuel.

ASIF was first published in a report by the International Energy Agency in 1999. The formula is based on years of empirical analysis on the links between energy intensity, transportation, and emissions in IEA member countries (Greening et al., 1997) and was also part of a larger effort to examine methods for analysing disaggregated energy indicators across different sectors in addition to transportation.

The approach to mathematically analyse the relationship between human activity and GHG emissions in a simplified framework is perhaps best known through the IPAT formula, which was developed by Ehrlich and Holdren (1971). In 1990, Kaya created a formula that came to be known as the "Kaya Identity", which applied IPAT specifically to carbon dioxide (or carbon dioxide equivalent), and explicitly considered energy consumption as one term of the equation, thus opening the door for ASIF and other decomposition formulas (Kaya, 1990). The two formulas are written out below.

$$\mathrm{I} = \mathrm{P} \cdot \mathrm{A} \cdot \mathrm{T}$$

IPAT, where I is environmental impact, P is population, A is affluence, and T is technology.

$$F = P \cdot \frac{G}{P} \cdot \frac{E}{G} \cdot \frac{F}{E}$$

The Kaya Identity, where F is global anthropogenic CO_2 emissions, P is population, G is GDP, and E is energy consumption.

The ASIF formula provides a tidy structure for reviewing existing academic literature that connects CAVs with GHG emissions. The articles discussed below do not all make explicit mention of ASIF, but they provide insight into the makeup of each term in the formula and thus create an important background for understanding how transportation in general, and CAVs in particular, contributes to changes in energy use and GHG emissions. As noted by Schipper and Marie-Lilliu in their original 1999 report, the ASIF terms are interrelated, and it can be difficult to separate them into distinct, quantifiable categories. But it is helpful to try and do so in order to at least identify the components of each term and then address how those components can change and affect one another.

It is important to note here that there is an extra level of difficulty involved when trying to understand how CAVs could impact the [A] and [S] parts of the ASIF formula, because the research is effectively about a technology that, despite the ostentatious advertisements (Hildebrand & Sheller, 2018), does not exist in everyday life. CAV technology has not yet been disseminated at a societal level. Very few people can say that they have experienced fully automated vehicle technology, beyond what are considered to be level 2 characteristics such as lane-centring and adaptive cruise control[3]. Those who have used fully automated vehicle technology will have done so on a closed course, which is a far cry from the system of connected vehicles that the most optimistic models describe.

However, as discussed below, many researchers have addressed this by using stated preferences, proxies in the form of chauffeured vehicles or other forms of transportation, or acceptance levels for other technology.

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[3] For more information on the SAE levels see: https://www.sae.org/standards/content/j3016_201806/

By definition, all literature examining transportation behaviour looks at the [A] and the [S] terms travel activity and modal share. Our key interest here is travel activity with passenger cars, which then is [A]*[S], and we go less into how [A] and [S] separately may be affected by CAV. One recent study on how CAVs may affect activity analysed how chauffeur services provided to subjects affect mobility patterns, finding that total VKT across the sample group increased by 83% during the time that the research subjects had access to a chauffeur (Harb et al., 2018). In their 2019 study, Wadud and Huda surveyed people in two cities in Bangladesh to find out what passengers are most likely to do while being chauffeured, as a proxy for what people might do with their time in a CAV. They found that there was a correlation between what the research subjects did in their chauffeured vehicles and what researchers have suggested people might do in CAVs, in particular that "the travel time in a car is used by travellers to conduct work-related or other worthwhile activities" (Wadud & Huda, 2019, p. 1), which suggests that passengers could have an incentive to increase their VKT.

Some studies collect stated preference data about specific scenarios involving a CAV, after providing respondents with some kind of written explanation of what the technology looks like (Moore et al., 2020) or a video that demonstrates the scenario (Pudāne et al., 2019). Moore et al. (2020) used survey data to model how different behavioural dimensions could affect the decision to relocate if the individual can commute with a private CAV, and found that the resulting potential urban sprawl could be as large as a 68% increase in the horisontal spread of some cities. Pudāne et al. (2019) took data from focus groups to model the re-arrangement of daily activities resulting from on-board activities in a CAV and found that time pressure could be eased depending on the re-arrangement of daily activity patterns.

Others have circumvented the collection of data by creating models based on existing information and literature. Lavasani et al. (2016) developed a market penetration model for CAV adoption, based in part on past acceptance of technology such as the internet and cellphones. Their results show that a larger market is connected to a higher adoption rate, and CAV cost did not strongly influence diffusion. Other findings from theoretical modelling include those produced by Wadud et al. (2016) on the potential changes in energy demand caused by different levels of CAV adoption and Wadud (2017) on the levels of CAV adoption in different transportation sectors and subsequent changes in travel demand. In the latter study, the value of the travel time, VoTT, emerges as an important characteristic (due to its relatively large share of GTC). Taiebat et al. (2019), who use a similar methodology to Wadud (2017), also find VoTT to have a significant influence on travel demand.

The energy intensity [I] component is intrinsically related to the number of passengers (this has been empirically demonstrated across different travel modes by Schäfer and Yeh, 2020). There is much research on the effects of shared versus private CAVs (Pernestål & Kristoffersson, 2019), and also passenger preferences in terms of sharing (Malokin et al., 2019). The human behavioural factor is potentially more important than any technological gains in efficiency, because the largest calculated emissions reductions have been shown to come from vehicle sharing. For example, Pernestål and Kristofferson found that in 26 simulation studies of CAVs, only those that looked at taxis and shared taxis produced reductions in VKT (2019).

Some of the emissions reductions that fall under the energy intensity component are related to eco-driving habits that humans could implement themselves, but usually do not. When the majority of vehicles on the road are CAVs, emissions reductions are also expected as the vehicles will work together to drive more efficiently, for example through platooning, more efficient intersections, etc., and through smaller, more efficient vehicles as these become more realistic, especially if the CAVs are shared and the right size of vehicle is matched to the requirement of the ride (Wadud et al., 2016).

Lee and Kockelman (2019) estimate a net energy reduction of 11-55% compared to current ground transportation conditions in the US, based on different use and technology scenarios for CAVs. This includes the possibility of CAV electrification, which is also related to the fuel carbon content [F] term of ASIF, since in this case the electricity would be the vehicle's fuel, and if it comes from a renewable source the electricity could have a very low carbon content. Much research about CAV electrification tends to be part of studies that examine systemic effects of, for example, automated, electrified, and shared vehicles. For example, Fulton (2018) warned that while electrical and autonomous vehicles could create important benefits, they could also contribute to congestion and urban sprawl if not combined with shared transportation systems. Arbib and Seba (2017) suggested a very optimistic scenario where autonomous and electric vehicle fleets could drastically lower travel costs. Looking at a more specific group of scenarios, Compostella et al. (2020) found that battery electric vehicles could be cost-competitive with internal combustion engine vehicles by around circa 2030-2035.

Finally, there are studies that examine broad societal effects of CAVs and thus extend beyond the ASIF framework. Milakis et al.'s 2017 article on the interrelated ripple effects of CAVs is a good example of this. There, the effects of CAVs are organised into first-, second-, and third-order effects, and visualised by concentric circles with the CAVs at the centre. The first-order effects, closest to the centre, include traffic, travel cost, and travel choices, the second-order effects include vehicle ownership and sharing, location choices and land use, and transport infrastructure, and the third-order effects are "wider societal implications", such as energy consumption, air pollution, safety, social equity, economy, and public health (Milakis et al., 2017, p. 326). The ripple effect concept is applied in such a way that the effects can be interrelated across widely ranging time frames, and the authors conclude that first-order, short-term benefits are expected to be beneficial, while third-order effects are unclear (Milakis et al., 2017).

One more example of a study that examines broader effects of CAVs is that by Pernestål et al. (2020). They took a novel approach in this field and used causal loop diagrams to map the systemic effects that CAVs could have, in order to inform policy suggestions with respect to working towards the UN sustainable development goals. The findings suggest that vehicular-level benefits of CAVs, such as fewer accidents per vehicle, are negated at a system level where an increase in VKT results in an increase in total accidents (Pernestål et al., 2020).

In this licentiate thesis, when examining the case of CAVs for personal transportation in the first article, the focus is on $A \cdot S$, in terms of the estimation of induced travel demand. The other factors are not directly analysed in Paper 1. In the second article, the study touches on all of the components, though it does not provide quantitative measurements and tends to focus on A and S.

However, the results of Paper 2 could be used as the basis for future work that would inform quantitative assumptions. For example, the A component could be informed by the driving forces that came up in the interviews, such as urban planning, which is related to city-level policies that encourage CAV use; the S component could be informed by market economy, which is related to vehicle sales and mobility-as-a-service (MaaS) business models; the I component could be related to sociocultural habits, which include uptake of shared CAVs; and the F component could be related to the driving force of technological advance, which includes CAV and its potential synergies with vehicle electrification.

2.4 Context for this licentiate

We can now reason that there is an empirical basis for the theory that CAVs could help reduce GHG emissions from transport in Sweden, given that (1) Sweden has historically been, and still is, a car-dependent country, where passenger cars have historically contributed, and continue to contribute, to a large share of GHG emissions; (2) there are many theoretically proven scenarios (based on the academic literature reviewed in Section 2.2) for how CAVs could help to reduce GHG emissions from passenger cars; and, further, (3) there is an incentive for the Swedish government to reduce emissions as much as possible.

To reach the 2045 goal, GHG emissions must be reduced by an average of 6-10% per year in Sweden. The Swedish Environmental Protection Agency states that domestic transport is "crucial" for this trajectory (Naturvårdsverket, 2020, p. 13). As described in detail in Section 2.3, CAVs could have large effects in terms of reducing or increasing VKT, energy use by passenger cars, and also CO_2 emissions, either from end-of-pipe if the vehicles are fuelled by fossil fuels or through electricity generation needed for powering electric vehicles as well as the carbon footprint of vehicle and battery production. The research in Paper 1 examines in more detail one way that CAVs could contribute to an increase in VKT and consequently energy use and CO_2 emissions. The research in Paper 2 places the introduction of CAVs within a broader sociotechnical context and examines the underlying forces that could lead to different CAV scenarios within cities.

Chapter 3

Paper 1

3.1 Introduction to research questions

As noted in the previous section, there is a need for empirical and theoretical insights on potential CAV-introduction and -adoption scenarios. In Paper 1, we make a contribution to this strand of literature by analysing the impact that CAVs may have on travel demand under certain conditions, using a technology adoption model linked with an induced travel demand model to simulate the effects on VKT related to changes in Value of Travel Time and the cost of CAV technology. This work builds on that done by, primarily, Wadud et al. (2016), Wadud (2017), and Taiebat et al. (2019).

The central question is how much not needing to actively drive could affect VoTT, and how this in turn will affect travel demand. Wadud et al. (2016) did an analysis based on the potential relative reduction in VoTT for US drivers due to CAV adoption, and an assumption about GTC elasticities. Their estimated changes in travel demand ranged from a 4% increase with low levels of automation, to a 60% increase with CAV adoption. Taiebat et al. (2019) used data from the US National Household Travel Survey (NHTS) to create an empirically estimated demand function and found a 2-47% increase in travel demand.

These studies assume that CAVs will be adopted by the whole population. However, Wadud (2017) analysed under which conditions in terms of costs and income level CAVs would be cheaper than conventional vehicles using a break-even net present value calculation. They found that CAV “adoption” (that is, the cost of CAVs being favourable to that of conventional vehicles) is closely influenced by income level since the VoTT is strongly dependent on income.

VoTT can be examined as one part of a greater range of variables that could be affected by CAVs, for example by causing ripple effects through society (Compostella et al., 2020; Milakis et al., 2017). This type of analysis has provided inspiration for our study, but we first focus on conditions for CAV adoption and then on the first-order effects (as referred to by Milakis et al.) of changes in travel demand, in a Swedish context. The research questions that we seek to answer are:

1. What is the relationship between income, value of travel time, and break-even costs for CAV adoption?
2. How could CAV adoption have an impact on travel distance for individuals in Sweden, based on historical data from the Swedish Travel Survey?

3.2 Methodology and reflection on methodology

3.2.1 Generalised Travel Cost

The Generalised Travel Cost (GTC) captures the full levelised cost of travelling per unit distance. In a high-income country such as Sweden, the VoTT tends to make up a large portion of a person’s Generalised Travel Cost (GTC) (Small & Verhoef, 2007). This can be seen in Figure 2, showing the estimated GTC for different income quintiles in Sweden for a scenario representing year 2050.

GTC includes the fixed cost, meaning vehicle depreciation with respect to calendar age, and variable cost, meaning fuel cost and vehicle depreciation with respect to mileage, operation and maintenance, and VoTT. The vehicle depreciation with respect to mileage is assumed to be one-third of the annual depreciation for an average car (Trafikverket, 2018). There are two key components of GTC that could change because of CAVs: the VoTT and the capital cost of the vehicle. The extra capital cost is likely to be associated with the sensors (lidars, radars, cameras, etc.) and the processing power needed for automated driving.

While the use of GTC for estimating changes in travel behaviour has been criticized by some (Wardman & Toner, 2018), its use is justified here because it has some theoretical and empirical support and is used in many traffic simulation models employed by national transport authorities (Ortúzar & Willumsen, 2011; Trafikverket, 2018; UK Department for Transport, 2019).

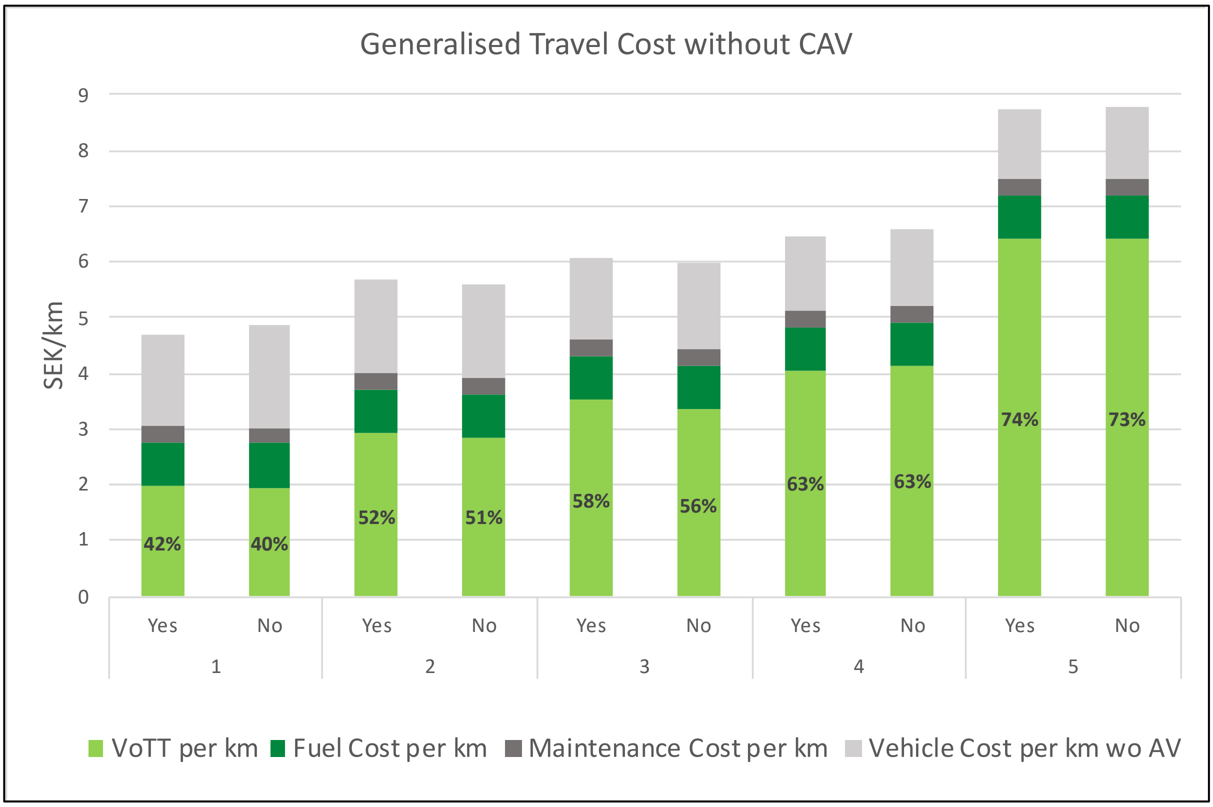


Figure 2. Generalised Travel Cost (GTC) for a conventional car measured per kilometre, without CAV technology, in 2050 by Swedish income quintiles. The percentage shown in the light green sections is the share of GTC represented by VoTT. *Yes* indicates ability to work remotely; *No* indicates inability to work remotely.

3.2.2 Modelling based on Value of Travel Time (VoTT)

Much of the economic benefit expected to result from the introduction of CAVs (and thus much of the hype as well) is related to the change in use of time for the person who may no longer have to actively drive the vehicle. In a CAV, the (former) driver would instead be able to work, relax, or engage in other activities (Pudāne et al., 2018; Wardman et al., 2019), and this could change how their time spent travelling is valued (Becker, 1965; DeSerpa, 1971), i.e., could change the VoTT. The VoTT, how much the time that a person spends travelling is worth, i.e., its cost, is usually given in monetary units per unit time. The VoTT per km is a component of the GTC.

VoTT is already commonly used in many countries as a part of the method for assessing potential transportation investments (Ortúzar & Willumsen, 2011), often as part of a larger cost-benefit analysis (CBA). In Paper 1, we assume that passengers will use VoTT as part of a personal CBA when they decide whether to purchase a self-driving car. We assume the traveller would purchase a CAV if the levelised GTC is lower than the corresponding estimate for a conventional car. As mentioned above, the two key aspects of GTC expected to be different between a conventional vehicle and a CAV are VoTT and the capital cost of the vehicle.

The concept of time valuation was developed by Gary Becker in 1965 when he proposed that the opportunity cost of time is equal to a person's wage rate (Becker, 1965). Johnson (1966), Oort (1969), and De Serpa (1971) further developed the theory and differentiated between, for example, the value of leisure time and that of time spent travelling. How VoTT is calculated, disaggregated, and used in transport appraisal projects has been studied in detail by, for example, Börjesson and Eliasson (2014, 2019), in particular regarding how VoTT can be differentiated amongst population groups in terms of transportation mode, income, and other circumstances. Nordström (2020) has gone a step further and examined "…the actual justifications of the assumption of complete transferability between money and time…".

Paper 1 is based on a theoretical model of VoTT and how it may be affected by CAVs; the model is mainly built on the reasoning developed by Oort (1969). The VoTT that we use can be understood as the marginal value of leisure time plus the monetary value of the disutility of spending time in the vehicle. The marginal value of leisure is equal to the wage rate less the disutility of working. Therefore, the formula for our calculated VoTT can be conceptually summarised as:

$$VoTT = opportunity\ cost\ of\ time + disutility\ of\ spending\ time\ in\ the\ vehicle$$

The opportunity cost of time in this case is the value of giving up a leisure activity (or work, which is wage rate less the disutility of working) that could have been done instead. The VoTT could change if the vehicle is a CAV, since the person might not need to "give up" the leisure or work activity they would otherwise be doing. The monetary value of the disutility of spending time in the vehicle is, if possible, more intangible, but one can suggest that this value could change with CAV technology because the person might enjoy their time in the vehicle more, implying a reduced disutility. Thus, in absolute terms, both components could be decreased, and so their sum (VoTT) would also decrease.

Many academic studies examine changes in VoTT in relation to CAVs (Bansal & Kockelman, 2017; Gao et al., 2019; Harb et al., 2018; Pudāne et al., 2018, 2019; Pudāne & Correia, 2020; Wadud & Huda, 2019; Wardman et al., 2019). A change in VoTT can be analysed in terms of the reason for the change, which depends on what the traveller is able to do in the vehicle, and the magnitude of the change, which depends on the utility that the traveller gains from that activity. The reason for a change in VoTT could be related to an increase in subjective well-being (Singleton, 2019), multitasking (Malokin et al., 2019), or work (Correia et al., 2019). The magnitude of the change is very difficult to approximate, and there is considerable debate about the usefulness of travel-based multitasking and a connection to lower VoTT (Cyganski et al., 2015; Singleton, 2019).

Without explicitly considering CAVs, the International Transport Forum (ITF) suggests that VoTT could be reduced by 20-25% if travellers were able to do something with their time. Gao et al. (2019) analysed stated preference survey data on ride-hailing services and found a 13-45% reduction in VoTT with use of ride-hailing services compared to a personal vehicle during commuting trips. In terms of assumptions on VoTT changes, Singleton (2019) reviewed a number of studies that made VoTT assumptions in relation to CAVs, and found that the assumptions spanned a wide range based on different contexts, ranging from no change to a 100% change.

The scenarios presented in this article assume that there are differences between VoTT for commuting and for other activities, following Correia (2019), who found VoTT during a commute should be lower using theoretical and empirical (stated choice) methods. The reduction in VoTT during commuting is assumed to be larger in some of the scenarios, which then is reflected in the modelled changes in GTC and travel distances. We also assumed that VoTT increases linearly with income. The elasticity of VoTT with respect to income is uncertain, though some empirical studies suggest that it could be close to or slightly below unity (Mackie et al., 2001; Wardman et al., 2016). Börjesson & Eliasson, (2014) analysed two Swedish VoTT studies performed 13 years apart and found that income elasticity with respect to VoTT increases with income, being close to zero when below the median income and unity or higher above the median income.

In addition to this, some transport authorities assume an income elasticity of unity to account for income growth when they analyse projects that will have an impact on travel over a longer time frame (Trafikverket, 2018; UK Department for Transport, 2019). Thus, we adjust VoTT to reflect different income quintiles, using the Swedish Transportation Authority's VoTT for the median income quintile and a VoTT income elasticity of unity.

3.2.3 Elasticities and induced travel demand

There are two important effects that connect a change in GTC to a change in travel demand: (1) the rebound effect, in which increased fuel efficiency tends to lead to a lower marginal cost of travel, which in turn leads to increased mileage (Small & Van Dender, 2007); and (2) the induced travel effect, where improved "speed" in going from A to B by, for example, new highway capacity and/or reduced congestion, tends to generate more travel (Goodwin, 1996). In the first case, the fuel cost component of GTC is reduced; in the second, the VoTT per km is reduced, in that less time is needed.

The theoretical and empirical findings for the price-responsive behaviour to fuel-price changes, the rebound effect through energy efficiency improvements, and induced travel demand through infrastructure and congestion-mitigation projects show that a reduced GTC will have an impact on travel demand. Results that suggest that the rebound effect declines as income declines offer one example of components of GTC interacting with the mechanisms stated above, since fuel cost as share of GTC typically declines as VoTT increases (Greene, 2012; Small & Van Dender, 2007). In terms of empirical effects, studies have shown a long-run rebound effect of around 0.1-0.3, (elasticity of travel distance with respect to fuel cost per km), meaning that a 10% increase in fuel efficiency would generate a 1-3% increase in annual VKT (D. Andersson et al., 2019; Dimitropoulos et al., 2018). The long-run induced travel demand elasticity has been estimated to be in the order of -0.5 to -1 (elasticity of travel distance with respect to travel time from A to B), in the sense that a 10% reduction in travel time tends to induce a 5-10% increase in travel volume from (M. Andersson & Smidfelt Rosqvist, 2011; De Jong & Gunn, 2001; Goodwin, 1996).

The concept of elasticity of travel distance with respect to GTC (Goodwin, 1996) unifies the rebound effect and the induced travel effect (see Supplementary Materials Section 2) at the end of Paper 1 for further analysis of this). The derived relationship between the induced travel demand elasticity (ε_T) and the elasticity with respect to fuel cost (ε_C) is:

$$\frac{\varepsilon_T}{\varepsilon_C} = \frac{T \cdot VoTT}{C}$$

Where T is time per unit of distance, VoTT is value of travel time per unit of time, and C is fuel cost per unit of distance.

Furthermore, the relationship between change in distance travelled, change in GTC, and therefore demand elasticity with respect to GTC would look as follows:

$$\frac{\Delta D}{D} = \varepsilon_G \frac{\Delta G}{G} = \varepsilon_G \frac{\Delta(C + O + T \cdot VoTT)}{C + O + T \cdot VoTT}$$

Where D is distance, G is variable general cost of travel per unit of distance, and O is other variable travel costs per unit of distance. Using estimates from the literature discussed above and the derivation in Paper 1 SM2, this formula gives a demand elasticity with respect to variable GTC (ε_G) of about -1 (with a substantial uncertainty interval).

3.3 Results

We created three scenarios, each based on a different VoTT and cost of CAV technology, see Table 1. For each scenario, we applied the changes in VoTT and technology cost to the existing data on travel patterns and GTC, disaggregated by income quintile. *Little* is a scenario that loosely follows the results described in the 2019 ITF report (ITF, 2019), where automation has a relatively small effect on travel patterns. Following the findings of Correia et al. (2019) and Gao et al. (2019), *Little* assumes that time spent commuting will see a greater change in VoTT from CAV than time spent travelling for other reasons. In *Medium*, we assume the same reduction in VoTT from CAV for commuting as for other travel, in line with Wadud et al (2016) and Taiebat et al. (2019), who assign the same impact due to CAVs on VoTT irrespective of trip purpose. In *Large*, we reflect the findings of Harb et al. (2018), in which CAV technology has a great impact on utility and causes a substantial reduction in VoTT. The cost of the technology is low in *Large*.

Scenario	Reduction in VoTT Other*	Reduction in VoTT Commuting and working in the car	Cost of CAV technology
Little	15%	25%	100 000 SEK
Medium	35%	35%	50 000 SEK
Large	50%	60%	30 000 SEK

Table 1: Scenarios for induced travel demand in Paper 1. Column two shows the reduction in VoTT for non-commuting trips for everyone, and for commuting trips for those who cannot work remotely.

3.3.1 Changes in GTC

The changes in GTC in each scenario illustrate which groups benefit versus lose from investing in CAV technology. The groups are divided into different income quintiles, which are further divided into those who can work remotely or not, as mentioned above in the Table 1 caption. The ten different groups have different annual travel distances and different VoTTs. The cost of CAV technology differs across scenarios, but not, for a given scenario, among the ten groups.

The effect of CAV usage on VoTT differs across scenarios and, for the *Little* and *Large* scenarios, between those who can work remotely or not.

The benefit and cost of investing in a CAV can be seen in Figure 3. In both *Large* and *Medium,* investing in a CAV is beneficial for all income groups, while in *Little*, the results are mixed. One important point to look at is quintile 4 in *Little*, for which investing in a CAV yields a negative net benefit for those who cannot work remotely, while it is positive for those who can work remotely. This demonstrates the potential break-even point where it becomes economically beneficial for the representative person in each group to purchase a CAV, given the scenario assumptions.

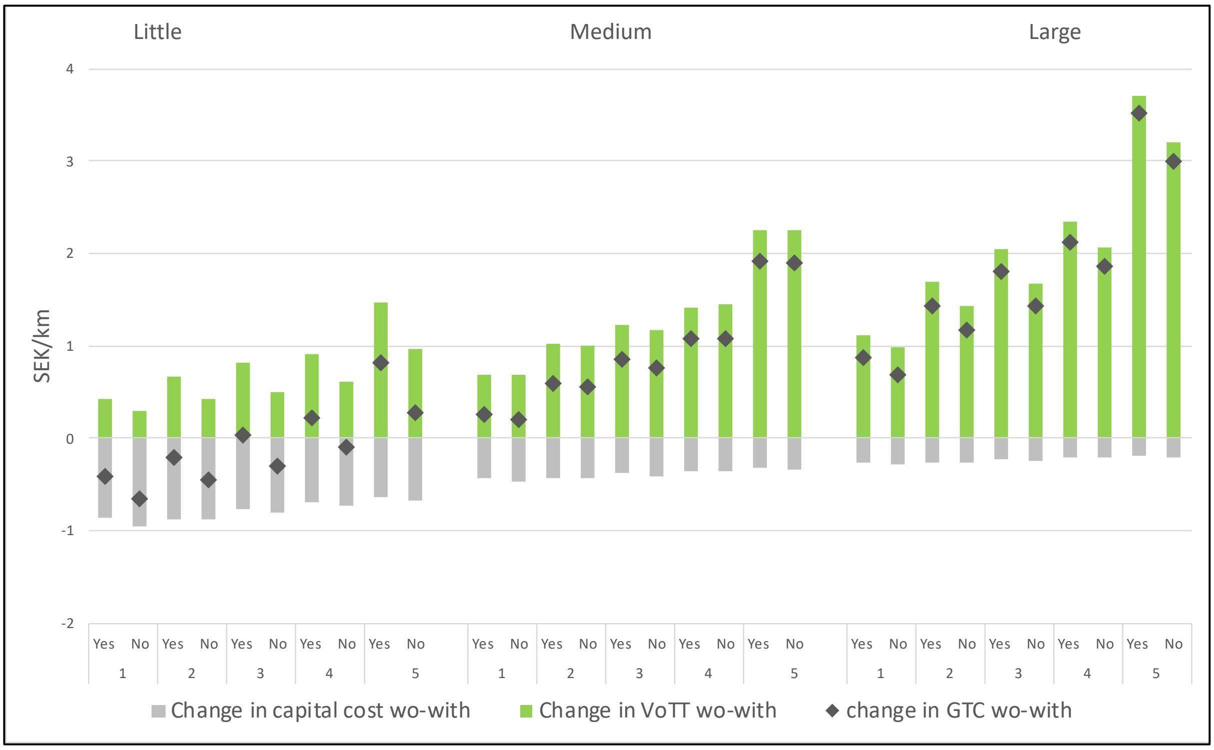
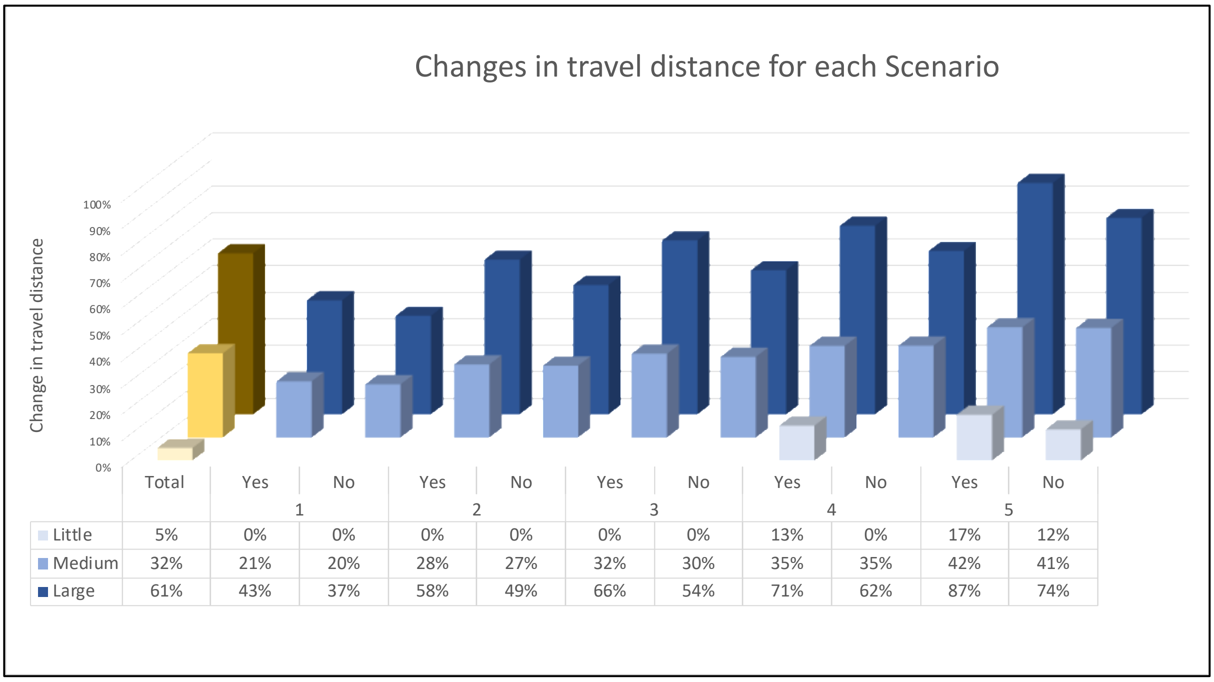


Figure 3: Change in GTC due to CAV in each scenario. The green bar shows the net reduction in VoTT per km due to operating a CAV as compared to a conventional car, the grey bar shows the increase in cost per km due to the CAV technology, while the black diamond shows the difference in GTC (positive indicates that GTC is lower with a CAV). ***Yes*** **indicates ability to work remotely;** ***No*** **indicates inability to work remotely.**

3.3.2 Changes in travel demand

The changes in total travel demand are greatest in *Large*, with a 61% increase overall, while *Medium* shows an increase of 32% overall, and *Little* has just a 5% increase overall, see Figure 4. Generally, higher income groups show a larger change in travel distance irrespective of scenario. This is because these groups have a larger VoTT and thus have both stronger incentive to adopt a CAV even if the relative impact on VoTT is small and the cost of technology is high. The incentive to adopt as well as the relatively smaller reduction in VoTT is why we in *Little* only observe travel distance increases in the higher income groups and also relatively small impacts within these groups.

The connection to income exposes a potential inequality among income groups that can most clearly be seen in *Little*, but also in the other scenarios though impact of travel demand may be greater in these groups. In *Little*, the average increase in travel demand is just 5%, but the increase for those who are able to work remotely in the car in the fifth (highest) income quintile is 17%.



	Total	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
		1		2		3		4		5	
Little	5%	0%	0%	0%	0%	0%	0%	13%	0%	17%	12%
Medium	32%	21%	20%	28%	27%	32%	30%	35%	35%	42%	41%
Large	61%	43%	37%	58%	49%	66%	54%	71%	62%	87%	74%

Figure 4: Changes in travel distance for each scenario. This shows the increase in travel distance for each group and scenario, in blue. The first column on the left (*Total*) shows the total daily increase in travel distance averaged across all groups in each scenario, in yellow. *Yes* indicates ability to work remotely; *No* indicates inability to work remotely.

We performed a sensitivity analysis on the elasticity with respect to the variable part of the GTC to see how sensitive the changes in travel demand are due to different assumptions. The analysis showed that the higher the elasticity, the larger the induced travel difference between scenarios. This holds for all scenarios and all income groups when a CAV is adopted.

3.4 Conclusions

In Paper 1, we model and analyse the effect that CAV technology could have on travel demand in Sweden based on travel habits as reported in the national travel survey and changes in the GTC, given a change in VoTT and the cost of vehicle technology. Our results show that:

- It was found in the initial data analysis that those in the higher income quintiles, and those who are able to work remotely, tend to have longer travel distances. The groups with a higher income also tend to have a higher VoTT, based on our assumption of a linear relationship between VoTT and income.

- Thus, as long as all income groups have the same change in technology price (i.e., the CAV technology cost) and relative change in VoTT, the higher income groups will in all cases we analysed have a larger (absolute) economic incentive to adopt a CAV, due to the larger absolute change in VoTT and the fact that the cost of CAV technology can be levelised over a longer travel distance.

- Any prolonged increase in travel distance, such as that shown in our model, could eventually lead to serious effects on congestion, increased overall energy needs of the transport sector, and increased CO_2 emissions from fossil fuels used in operating the vehicle as well as in the production of energy carriers and the vehicle itself. These results could be useful for policymakers when future scenarios involving CAVs are being considered and also useful for future research on travel demand and CAVs.

Chapter 4

Paper 2

4.1 Introduction to research questions

Exploring the perceived causes behind the introduction of CAV technology can provide a better understanding of what assumptions are reasonable for models that simulate CAV use. On a societal level, the introduction of CAVs "not only entail[s] new technologies, but also changes in markets, user practices, policy and cultural meanings" (Geels, 2010) and will imply transitions that intervene at different levels—e.g., cultural, structural, and practical—within different time frames and different geographic scales (Loorbach, 2010, p. 171).

With this context in mind, in Paper 2 we examine the introduction of CAVs in cities in terms of the indirect or underlying processes (drivers) and the direct expressions of interest that are related to specific actions, events, or processes (pressures) (Adelfio et al., 2018). In order to capture perspectives from all parts of society, the drivers and pressures are identified by stakeholders from across the quadruple helix: academia, industry, government, and civil society. We use a composite analytical framework that combines parts of DPSIR modelling and force field analysis to map the driving and restraining forces and pressures behind the introduction of CAVs in cities, and to identify which stakeholders are involved in this sociotechnical transition.

The research questions we seek to answer are:

1. What are the driving and restraining forces and pressures that facilitate or hinder the sociotechnical transition towards the introduction of CAVs at the city level?

2. What stakeholders, representative of the aforementioned driving/restraining forces and pressures, are involved in such a sociotechnical transition?

4.2 Methodology and reflection on methodology

4.2.1 A qualitative approach to studying CAV introduction

Cohen et al. (2020) argue for the increased use of social science in CAV research. They suggest that "failing to anticipate a wider range of profound social implications may have serious negative consequences", and that "social scientists from a range of disciplinary perspectives can provide invaluable insights". Much of this reasoning is based on the idea that CAVs will be introduced in diverse circumstances, even when just examining one country, and public engagement will be crucial for a just and safe dissemination of the technology.

In relation to this, it is interesting to consider suggested alternatives and criticisms of traditional cost-benefit analysis and other quantitative analysis of transport-related impacts (such as those occurring from the introduction of CAVs). Van Wee and Roeser have made a case for a "context-sensitive approach", which considers multiple morally relevant features in a given situation (2013), largely using deontological ethics and contractarianism. One of their suggestions is that by addressing the ethically relevant aspects of a situation and selecting an ethical theory by which to evaluate it, the moral implications of the situation (e.g., a transportation policy or infrastructure project) become clearer and can hopefully be addressed. I would argue that before one can identify the ethically relevant aspects of a particular situation, one must first examine how different stakeholders perceive (for example) the introduction of a new technology, as we do in Paper 2.

We study the salient sociotechnical aspects involved in the introduction of CAV technology by applying a framework that looks at the drivers (D), pressures (P), states (S), impacts (I), and responses (R) related to the introduction of CAV technology in Sweden, primarily in Gothenburg. This framework is known as DPSIR, and it was originally created by the European Environment Agency as a tool to give "structure within which to present the indicators needed to enable feedback to policy makers on environmental quality" (Kristensen, 2004, p. 1). It is a causal-chain framework that has traditionally been used for identifying driving forces related to land-use change. DPSIR is mainly used in environmental assessment projects, but we apply it to the introduction of a new technology in order to capture the types of insights discussed by Cohen et al. We also merge it with a second analytical tool, force field analysis, to create a composite analytical framework where we can map the strength of the D and P elements of DPSIR (Adelfio et al., 2018).

We conducted eleven semi-structured interviews with stakeholders from all parts of the quadruple helix structure—academia, government, industry, and civil society—and then used directed content analysis (Hsieh & Shannon, 2005) to identify drivers and pressures in the interview transcripts. We used the resulting pressures to create a survey that asked respondents to assign a level of strength—weak, medium, or strong—to each pressure.

Both the identification and subsequent mapping of the drivers and pressures are included in the force field analysis process. Field theory, which is the basis for force field analysis, suggests mapping psychological forces that influence the behaviour of an individual or group in order to understand said behaviour (Lewin & Korsch, 1939). We combine force field analysis with DPSIR, and in doing so we address some of the criticisms of DPSIR; the most common being that it does not address the complexity of the processes that it attempts to analyse (Niemeijer, 2008). The DPSIR framework was useful in that it allowed us to capture the breadth of perspectives that we were searching for, and to organise the interview data in a way that made it possible to do further analysis, without reducing the diversity or quality of information.

There are many other frameworks traditionally used to examine technological transitions, two of the most prominent being the Multi-Level Perspective (MLP) (Rip et al., 1998) and Technological Innovation Systems (TIS) (Bergek et al., 2008). TIS examines the dynamics of systems and is certainly a good tool for looking at system-wide introduction of CAVs but does not encompass the more granular perspective that we were aiming to take.

MLP has its base in sociology, innovation studies, and institutional theory and explicitly categorizes the system in question into levels in order to better examine the forces at play. It is complementary to DPSIR in a sense, in that both examine directional forces of change. However, while the theory behind MLP was helpful for framing parts of this work, it was less useful for the practical organisation and analysis of the extensive information we were collecting. Our research here was perhaps one or two steps too early for the full application of MLP because our goal was to identify and map out the relevant factors that have a noticeable expected effect when imagining the introduction of CAVs in cities. DPSIR was a useful framework to organise all the information and to portray it without having to further categorize the drivers or pressures. Instead, we used force field analysis together with the DPS components to evaluate the drivers and pressures affecting change (Thomas, 1985). This combination of DPS and force field analysis is represented in Figure 5.

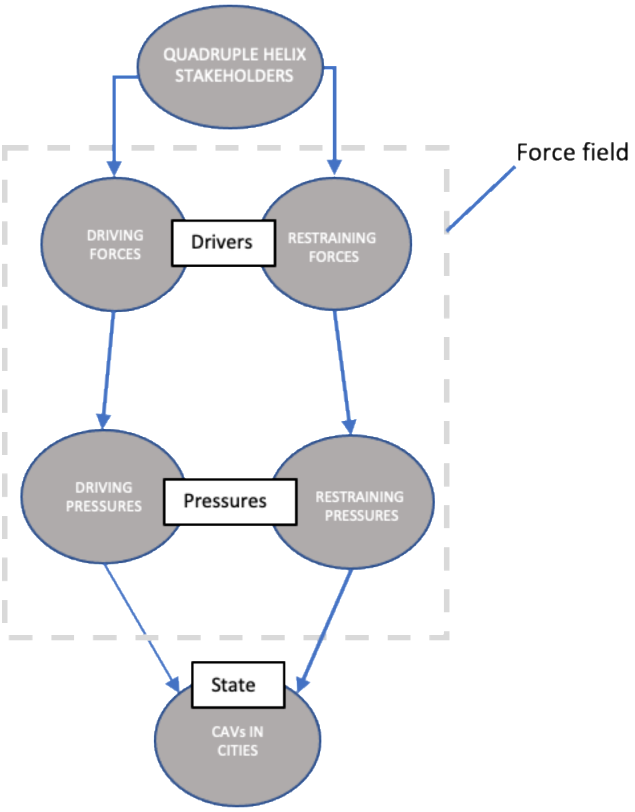


Figure 5: A simplified diagram of the composite analytical framework we used in Paper 2, combining force field mapping and the DPS components of DPSIR.

When using MLP, the interactions between different aspects of the framework are very important, and while we discuss interactions in our conclusions, we do not explicitly consider them in the analysis. In fact, we had such rich data that we abbreviated the framework to only include the drivers, pressures and state in Paper 2 and plan to write a separate paper on the state, impacts and responses.

4.3 Results

In this section, I will first provide an overview of all the driving and restraining forces and pressures that were identified in the interviews, first in a brief summary and then in a longer table format. The tables show how the forces and pressures relate to one another and which stakeholders have an interest in or are affected by the specific pressures.

4.3.1 Driving and restraining forces and pressures and associated stakeholders

The driving pressures related to each driving force emerge in the interviews as expressions of the interests of different stakeholders such as companies, environmentalists, citizens, or authorities. Therefore, the terms interest and pressure are used as synonyms in this section. The driving pressures that appeared in the interviews are: environmental concerns, market economy, technological advance, urban planning, politics and policy, health, and sociocultural habits. Table 2 summarizes the driving forces, associated driving pressures, and stakeholders who exert or have an interest in the associated pressure.

Table 2: Driving forces, pressures, and key stakeholders.

Driving Force	Driving Pressure	Key Stakeholders
Environmental Concerns	CAVs expected to drive smoother and slower, using less fuel	Car User, politician
	Car sharing would make CAVs more acceptable for environmentally-sensitive people	Generic citizen
	People selling their cars and using shared CAVs	Car user
Market Economy	Economic interest of car producers	Car producer
	Interest from Mobility-as-a-service providers e.g. car sharing companies, Uber... (saving money by not paying drivers)	MaaS provider
	Promotion and marketing shaping idealized, futuristic imagery of CAVs	Car producer
	Cheap land away from city centre can become more accessible with CAVs (attractive for land owners and developers)	Land developer, Land owner
Technological Advance	Expected efficiency advantages with self-driving and self-parking technology	Car producer, land developer?
	Expectation of improved safety with CAVs	Car user
	IT industry interested in partnership with car industry	IT industry, car industry
	New technologies' (such as CAVs) usefulness taken for granted	IT industry, car industry, car user
	Electrification of cars helps CAV promotion (as it provides multiple benefits for CAVs such as energy efficiency, money saving, less noise)	Car producer, transport provider, car user
Urban Planning	Mobility consultants supporting local authorities shape visions for the mobility of the future	Mobility consultants
	Need for improved mobility in rural areas (public transport not currently economically efficient)	Urban planners
	Pilot studies are being conducted which anticipate CAVs introduction	Multi-stakeholder
Politics and Policy	Politicians need to understand the implications of CAVs in cities	Politicians
	Government economically dependent on (or, at least, tightly intertwined with) car industry	Politicians
	Authorities with a history of continued investments in upgrading infrastructure can be more responsive when adapting to CAVs	Politicians
Health	Covid-19 exacerbating need for flexible transport	Generic citizen
	Covid-19 makes public transport drivers feel unsafe	Public transport provider
Socio-cultural habits	People using taxis and public transit are prepared for CAVs, especially shared CAVs	Generic citizen
	Demand for productive use of time (work or recreation) while driving	Car user
	Some urban dwellers prefer not to own cars (and instead demand shared CAVs)	Generic citizen
	People interested in cars and new technologies in general can be interested in CAVs	Generic citizen
	People who cannot drive (e.g. elderly, disabled…) have more opportunities with CAVs	Generic citizen
	Ongoing work on legislation and regulations as preparatory work for CAVs	Multi-stakeholder

The restraining forces appearing in the interviews are: technological advance, environmental concerns, sociocultural habits, health, urban planning, market economy, and politics and policy.

The restraining pressures are also connected to a set of stakeholders and pose a series of challenges to the development and subsequent introduction of CAVs in cities. Table 3 summarizes the restraining forces, associated restraining pressures, and associated stakeholders.

Table 3: Restraining forces, pressures, and stakeholders.

Restraining Force	Restraining Pressure	Key Stakeholders
Technological Advance	New technologies need to be mature and safe before being introduced to users (e.g. safety concerns from fatal CAV accidents).	Car producer, car user, IT industry
	Fear of CAV technology being hacked	Car user
	Fear that cities become built around CAVs, rather than creating a liveable city and adapting CAVs to that	Urban planner
Environmental Concerns	The sustainability agenda of local authorities can go against the introduction of CAVs, as their environmental impact is unclear	Politicians and urban planners
	More cars means increased energy demand	Car producer and car user
	If CAVs are electric: Environmental movement concerned that increased electricity supply will come from fossil fuels	Generic citizen
	If CAVs are not electric: both air quality norms and climate policy could restrict the increase of CAVs based internal combustion engine vehicles	Generic citizen
	Anti-sprawl opinions against CAVs as they may encourage people to move away from dense urban centres	Generic citizen
Socio-cultural habits	Conspiracy theories and misinformation about new technologies	Generic citizen
	The group of people who do not want to give up control of their vehicle	Car user
	People who do not like cars	Generic citizen
	Elderly people who are sceptical of new technology	Elder people
	Cyclists are particularly sceptical about CAVs, in terms of safety and access to urban space	Cyclist
Health	Concern that CAVs may increase congestion	Generic citizen, urban planner
	Covid-19 pandemic and fear of shared vehicles	Generic citizen
Urban Planning	Walking, biking and public transit as planning priority, not CAVs	Urban planners
	In urban development policies the shared use of cars is deemed as more important than the self-driving aspect	Urban planners and politicians
	Streets are not currently designed for CAVs	Urban planners
Market Economy	Public transport providers see CAV as competitors, and thus want to hinder CAV introduction	Public transportation providers
	Dual infrastructure (for CAVs and conventional vehicles) is expensive	Politicians and urban planners
	Risk of investing in a technology that fails on the market (e.g. if users don't purchase CAVs or subscribe to programs that use CAVs)	Multi-stakeholder
Politics and Policy	Current international and national laws and regulations are not suitable for CAVs	Politicians
	Lack of political consensus on visions for the future in cities	Politicians
	Lack of knowledge and agreement about strategies from local authorities	Politicians
	The ethical question of who has priority when there is a risk for collision between a pedestrian and a CAV	Generic Citizen

4.3.2 Survey results: Selected force field map

The survey results show the strength that respondents assigned to each driving or restraining pressure—on a scale of weak (1), medium (2), or strong (3)—in terms of the effect of the pressure on the introduction of CAVs in cities. To analyse and present this data we first took the median strength of each pressure and then removed all pressures that had a median of 2. The rationale for this step is that all pressures with a median of 2 are not interesting because they are not salient in terms of being strong or weak. They are understood as relevant, but do not stand out in any way.

The remaining pressures are salient, i.e., they are identified as stronger or weaker by survey respondents. Figure 7 shows the median and standard deviation for each of these pressures. Some of these results are unsurprising, for example the driving pressure with the highest median value is “Interest from mobility-as-a-service companies”; these companies could save money by not having to pay drivers, while “Safety concerns relating to fatal accidents” is one of the restraining pressures with the lowest median value (i.e., a median of -3). Both concepts have been discussed at length in the media and academic literature, so it makes sense that respondents would identify these as important in terms of CAV introduction.

Taking into account the reasoning behind the pressures (i.e., the interview context and background that explains the pressure) reveals a potentially interesting relationship. That CAVs could use less fuel by driving smoother and slower is identified as a weak driving pressure, meaning a pressure that is not perceived by respondents as having a strong effect on CAV introduction (see Figure 6: median = 1, s.d. = 0.79). By contrast, the potential for increased energy demand (median = -3, s.d. = 0.68) is seen as a strong restraining pressure. This makes sense from an engineering perspective since CAVs are expected to reduce specific energy consumption (Wh/km) since they may drive smoother and interact in a more efficient way with other vehicles and with infrastructure but could increase the demand for car mobility (Taiebat et al., 2019), as is also discussed in this thesis and in Paper 1. Hence, one could argue that most respondents do not see CAVs as a way of reducing emissions. Our interpretation of this is that the respondents believe that the demand impacts override the potential impacts of increasing the energy efficiency of the individual vehicle or vehicle system.

These survey results should be viewed as complementary to the interview data. Figure 6 gives an idea of how the different pressures brought up in the interviews are perceived at a more general level. These results are not meant as standalone quantitative evidence of the importance and variance of pressures.

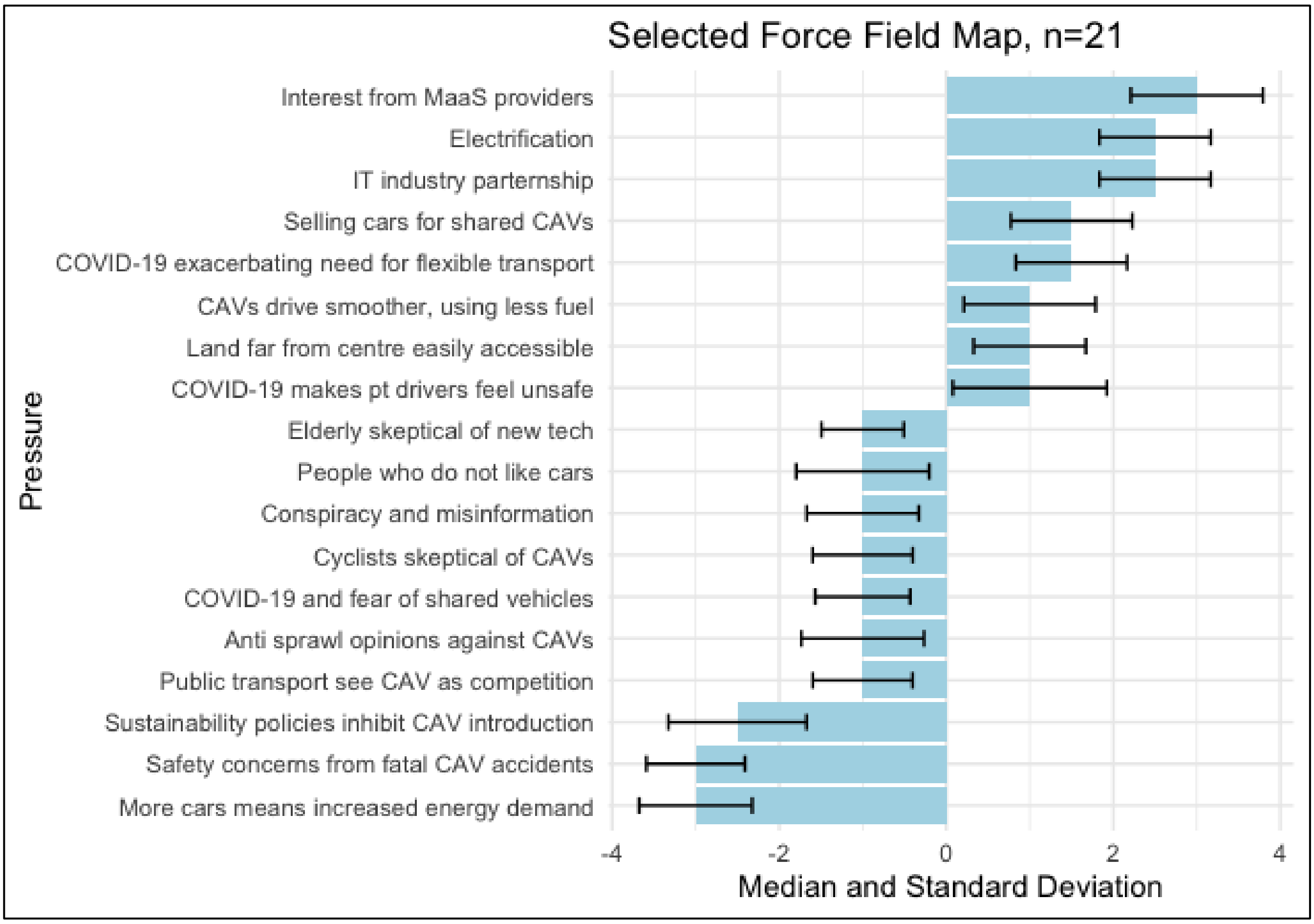


Figure 6: Selected force field map, showing all survey results for all pressures that did not have a median value of 2.

4.4 Conclusions

In Paper 2, we use a composite analytical framework of the DPS elements of DPSIR and force field analysis to analyse interview and survey data in order to identify both the relevant drivers and pressures relating to the introduction of CAVs in cities and the stakeholders who exert, or have an interest in, those drivers and pressures. Our results show that:

- CAVs are not seen as unconditionally positive; instead, many stakeholders believe CAVs need to be connected to mobility planning and public transport strategies.

- The societal economic dependence on the car industry, related to the Swedish context and particularly evident in Gothenburg, is an important driving pressure identified in the interviews. Dominance on the part of one actor, such as the car industry, can lead to one-sided development, which is why frameworks that reconcile private technology development and public-led development of city planning are important.

- Important stakeholders in terms of the Gothenburg context, but also internationally, include pilot projects and consulting firms that promote the introduction of CAVs. Politicians, mobility consultants, and urban planners emerge from the interviews as very active parts of an ecosystem of funding and expertise created around these projects.

- Scepticism toward new technology is certainly not a new phenomenon, but in this case the convergence of different stakeholders is potentially unique. Elderly people, cyclists, people who are concerned because of conspiracy beliefs related to new technology, and those who are concerned about environmental effects form quite a broad range, encompassing both technology sceptics and optimists as defined by Neilsen and Haustein (2018).

Chapter 5

Contributions to science and policy

Academic research on the introduction and effects of CAVs has become a mainstream subfield of study, especially within technical and engineering fields (Milakis et al., 2020). More and more research is beginning to happen in relation to policy instruments for CAVs (Cohen & Cavoli, 2019; Docherty et al., 2018; Pernestål et al., 2020) and on less easily quantifiable effects that the technology could have on society. Thus far, much policy research is informed by technical, quantitative studies that simulate patterns of adoption or use (McLeod et al., 2020). This relationship between qualitative and quantitative is important and useful, because hard numbers are necessary in order to understand the direction and magnitude of the impacts of CAV technology before trying to create appropriate regulation.

Paper 1 provides a relatively simple model that shows the potential effects of changes in technology cost and changes in how people use their time in passenger cars, and also shows how and why these two variables are considered so important when modelling CAVs. In terms of contributions to theoretical academic literature, this method of decomposing the components of a system in order to better understand them is related to what was done with IPAT, the Kaya Identity, and ASIF. More specifically, this work adds to existing analytical research by taking the studies by Wadud et al. (2016), Wadud (2017), and Taiebat et al. (2019) one step further and integrating an investment model and a travel demand model as well as considering the heterogeneity with respect to income classes and the option to work remotely in the vehicle.

This paper is reductionist in the sense that it removes some of the complexities involved by focussing on just a few key variables. This kind of inductive research is arguably important in the early phase of the transition to CAVs (or the early stages of any sociotechnical transition) because we need to grasp a range of plausible outcomes of consequences of CAVs at this point, before a single outcome is "locked in" (Arthur, 1989, p. 117). Despite the push for new policy to meet the speed at which the technology is being developed, the field of user opinions and perspectives in relation to CAVs is very new. Exploring how wide its boundaries are is important, so as not to miss any potential implications. Essentially, this is the opposite of the movement in the 1950s and 60s in Sweden that Lundin identified. Rather than assuming that there is only one way forward for the development and societal introduction of this type of technology, this composite analysis framework allows us to explore multiple alternatives.

One of the final take-away messages from Paper 1 is that more research into the studied variables as well as others that could have an effect on induced travel demand resulting from CAV adoption is important. Paper 2 focusses on a broader set of variables, but these are identified rather than quantified. Using two completely different methods for the first two articles of my doctoral studies was not by any means a simple or easy process, but doing so illuminated the strengths and weaknesses of each method and clarified the circumstances under which each is useful.

Paper 1 uses current travel data, combined with assumptions about use of travel time and theoretical relationships when modelling how travellers would use CAVs. The pros of this approach are that it is based on empirical data, similar models have been used successfully in other country contexts, and the approach is relatively simple to present and communicate, thus making it a good option for future researchers to build on. The cons, however, are that many assumptions have to be made and the relationships used are heavily simplified. Going back to Lundin's criticism of the "car society", these assumptions can lead to the same foregone conclusion that Lundin cautions us of in his thesis: If it has already been decided that the technology will be useful for everyone in one specific format (i.e., the privately owned passenger car), then other plausible future scenarios are left out of the equation, and this will cause problems later on when the one decided-upon scenario does not work for all of society.

Paper 2, on the other hand, explores what other actors perceive as critical for the introduction of CAVs in cities, and the insights obtained could be used as a starting point for developing a plethora of scenarios. The paper contributes to and moves beyond the analysis about the governance of CAVs in cities (Cohen & Cavoli, 2019; Freemark et al, 2019; Gavanas, 2019; Hess, 2020; Hopkins & Schwanen, 2018; Legacy et al., 2019) by identifying salient drivers and pressures regarding the introduction of CAVs in cities, as well as the stakeholders who exert or have an interest in the pressures.

The pros of the combined DPSIR and force field analysis framework being used to analyse interview and survey data are that diverse perspectives can be analysed and commonly held beliefs about CAV adoption can be challenged. This method allows for the identification of drivers and pressures that could potentially be applied in future work on the introduction of CAVs in cities, and due to the rich nature of the data we collected there are opportunities for the work to be applied to many different contexts, both in terms of geographical size and location. The con with this type of research, however, is that as a whole it is very difficult to apply to any one location. Even for the city of Gothenburg, the data that is collected comes from such diverging sources that it would be difficult to create one single scenario (e.g., to be used in a city transportation policy strategy) that fits all the identified drivers and pressures. This is not necessarily an insurmountable issue, as it is not the goal of this research to create one "solution", but it does mean that more knowledge in regard to context and purpose is necessary in order to apply this work elsewhere, or to build upon it.

An understanding of research methods is crucial for continued research on the same or related topics, in order to build on previous results. For example, if someone wanted to use the results of Paper 2 to inform a quantitative modelling study on the effects of CAV in a city, it would be important for that researcher to understand DPSIR and force field analysis, in order to be able to accurately apply the results of a study using those methodologies. This type of understanding relies on the clear communication of ideas, concepts and theories between academic or professional fields. It is particularly interesting in regard to the introduction of CAV technology and the growing field of research into its sociotechnical implications (of which potential GHG emissions from CAVs are a part), because this field encompasses researchers from many different disciplines, including but not limited to engineering, sociology, physics, and political science. In Section 2.3, I described how the qualitative results of Paper 2 could inform the quantitative components of the ASIF formula, which is one example of how mixed methods can provide a broader understanding of a situation. Communication and understanding between academic fields is important for thorough research on the sociotechnical implications of CAVs, because it produces the possibility for different methods to be combined and tested, thereby creating new ways to study this new technology.

Chapter 6

Future Work

Following the DPS(IR) analysis done in Paper 2, my next research will use the same interview data to identify the IR components, i.e., the impacts and responses, related to the state of CAVs in cities. In a separate study, this could be applied to the demand model used in Paper 1, in order to expand the model and take more diverse aspects into account and analyse policies to avoid potential negative consequences of CAVs.

Another fascinating and important direction that builds on existing research and is closely tied to potential emissions as analysed by ASIF or other decomposition tools would be to explore scenarios that are able to show the interaction dynamics of increased transportation accessibility from CAVs, VKT, and shared mobility. This could be done by analysing how different use cases for CAVs (e.g., car sharing privately or publicly, transporting children to activities, transporting people who cannot drive themselves) contribute to increased system energy efficiency in transportation, or how the same use cases contribute to increased car reliance with an increase in car traffic volume.

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Paper I

Value of Travel Time and Induced Travel Demand: An analysis of how CAVs Could Influence Travel Distances in Sweden.

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Abstract

In a high-income country like Sweden, the (Value of Travel Time) VoTT constitutes a large portion Generalised Travel Cost (GTC). If the cost of travel decreases (*ceteris paribus*), the demand for travel will likely increase. Our model analyses this relationship in two steps. The first step calculates the GTC of an income group using a conventional vehicle, and the GTC for the same group using a Connected and Autonomous Vehicle (CAV). If the GTC for the CAV is lower, we assume the group would adopt a CAV. The second step calculates how much those who purchase CAVs will change their travel distance. Our results show that when all income groups see the same CAV technology cost and the same relative change in VoTT, the higher income groups will have a larger (absolute) economic incentive to adopt a CAV. Given that a CAV is adopted, the travel distance will see a larger change in relation to larger incomes. However, if the impact of VoTT is large enough or the technology cost low enough it will be beneficial for all income groups to adopt a CAV and consequently affecting the traveling distance for all groups. Further, some studies indicate that the relative impact on VoTT is larger for commuting trips and for people who can work in the car. Taking this into account shows that a potential effect on CAV adoption. Thus, it is important in future scenario analysis to consider other non-income factors affecting VoTT, and subsequently CAV adoption.

Key Words: CAV, VoTT, value of travel time, generalised travel costs, travel demand, travel distance

1. Introduction

Connected and autonomous vehicles[1] (CAVs) are a key trend in the transport sector today. CAVs are expected to affect travel behaviour significantly as the need for an able driver may disappear, freeing up travellers to perform different activities in the vehicle (Fosgerau, 2019). Today, some vehicles already have technology that makes it possible for the driver to enter some version of

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[1] "Connected and Autonomous Vehicle" refers to a level 4 vehicle as described by the SAE guidelines: https://www.sae.org/standards/content/j3016_201806/. For the purposes of this study, the vehicle is assumed to have a steering wheel and pedals, but they are only used under some conditions. We assume that these vehicles would exist as part of an interconnected system, thus we use the term Connected and Autonomous Vehicle or "CAV".

autopilot mode, thus relieving the driver from the stress of navigating congested traffic (as one example) (Bansal & Kockelman, 2017). The Swedish government has recognized the large impact that CAVs could have on the transportation system, on individual travellers, and on urban infrastructure, and is in the process of researching appropriate policies to govern these potential changes (Hammes, 2019).

CAVs could radically change the way that we spend our travel time, potentially leading to changes in travel demand. If the car can drive reliably by itself under most conditions, the driver will theoretically be able to do much more than simply minimizing the stress associated with irritating driving tasks. They will be able to make use of their time in the vehicle by doing work-related tasks on a laptop or other connected device, watching television, or even sleeping (Pudāne et al., 2018; Wadud & Huda, 2019). This will likely affect the way that the time spent travelling in vehicles is valued, i.e. the Value of Travel Time (VoTT) (Becker, 1965; De Serpa, 1971). In fact, a recent International Transport Forum (ITF) report suggested that lower VoTT could be used for transport appraisal if "the mode of transport and its supporting environment enable a range of activities (work or leisure) to be carried out while travelling" (2019, p. 16).

In a high-income country such as Sweden, the VoTT typically makes up a large portion of a person's Generalised Travel Cost (GTC) (Small & Verhoef, 2007). Following the general logic of price responsive demand, if the cost of travel decreases (*ceterus paribus*), then the demand for travel will likely increase. Thus, if the VoTT decreases, causing the GTC to decrease, the demand for travel will increase.

The big question is by how much VoTT may drop, and to what extent this will affect the travel demand. Wadud et al. (2016) did an analysis based on potential relative reduction in VoTT for US drivers and an assumption about GTC elasticities. Their estimated changes in travel demand ranged from a 4% increase with low levels of automation, to a 60% increase with CAV adoption. Taiebat et al. (2019) used an approach based on demand elasticity estimates and empirically based demand function from the US National Household Travel Survey (NHTS). They estimated a 2%-47% increase in travel demand, based on assumptions on how CAVs would affect fuel economy and the VoTT (Taiebat et al., 2019).

These studies build on the assumptions that CAVs will be adopted by the whole population. However, Wadud (Wadud, 2017) analysed under which conditions (costs and income level) CAVs would pass a break-even Net Present Value calculation and finds that this depends strongly on income level since the VoTT is strongly dependent on income.

In some studies that look at future scenarios, VoTT is examined as one part of a larger range of factors that will change because of CAVs, causing ripple effects through society (Compostella et al., 2020; Milakis et al., 2017). This type of analysis provided inspiration for our study, but we apply these ideas to the Swedish situation; first focussing on conditions for CAV adoption, and then on the first-order effect (as referred to by Milakis et al.) of changes in travel demand. The research questions that we seek to answer are:

1. What is the relationship between income, value of travel time and break-even costs for CAV adoption?
2. How could CAV adoption have an impact on travel distance for individuals in Sweden, based on historical data from the Swedish Travel Survey?

2. Methodology

This paper develops and applies an economic travel demand model in order to fulfill the two research questions stated above. Methodologically, it follows a two-step process and is built upon 4 central concepts: (1) generalised cost of traveling (GTC) , (2) Value of travel time (VoTT), (3) break even cost calculations and (4) demand functions.

Firstly, the model calculates the GTC of an income group when travelling with a conventional vehicle, and the GTC for the same group travelling with a CAV. If the GTC for the CAV is lower, it is assumed that the people in that income group would purchase the CAV. When calculating GTC we used similar methods to those in (Wadud, 2017), and many numerical assumptions are based on the Swedish Transport Authority's approach on calculating GTC in their modelling (Trafikverket, 2018c).

Secondly, the model calculates how much those who adopt a CAV according to the approach in step will change their travel distance. For this we used travel demand calculations similar to those used by Wadud (2017) and Taiebat et al. (2019).

2.1 Generalised travel costs

The Generalized Travel Cost (GTC) captures the full levelized cost of traveling per unit distance, see Table 1 for the vehicle related parts of GTC.

Generalized Travel Costs	
Assumed 2050 Values	
Fuel cost	0,78 SEK/km
Maintenance cost	0,3 SEK/km
Capital depreciation-fixed	1,37 SEK/km
Capital depreciation-variable	0,68 SEK/km

Table 1: Components of GTC, for a driver of a non-CAV in 2050.

The vehicle related parts of GTC can be divided in the fixed cost, being vehicle depreciation with respect to calendar age, and variable cost, being fuel cost and vehicle depreciation with respect to mileage. The vehicle depreciation with respect to mileage is 1/3 of the annual depreciation for an average car (Trafikverket, 2018a). In addition to vehicle related parameters VoTT is a critical part of GTC (see section 2.2)

While the use of GTC for estimating changes in travel behaviour has been criticized by some (Wardman & Toner, 2018), it is justified by that it is used in many traffic simulation models such as many models used by national transport authorities such (Ortúzar & Willumsen, 2011; Trafikverket, 2018a; UK Department for Transport, 2019). There are two key aspects GTC that will change because of CAVs: the VoTT and the capital cost of the vehicle. The extra capital cost is likely to be associated with the sensors (lidars, radars, cameras etc.) and the processing power needed for automated driving.

2.2 VoTT: background and empirical assumptions

The value of travel time (VoTT) can be described as how much the time that a person spends travelling is worth, usually given in monetary units per unit time. VoTT is an important part of economic appraisal of transportation infrastructure projects, and other forms of government spending affecting people's use of time (Ortúzar & Willumsen, 2011). The concept of value of time dates back to Becker who suggested that a person's opportunity cost of time was equal to their wage rate (Becker, 1965). The value of time concept was later reformulated and developed by Johnson (1966), Oort (1969) and De Serpa (1971). In the supplementary material (SM 1) we present a theoretical model of the VoTT and how is may be affected by CAVs based primarily on the reasoning by Oort (1969).

Hence, based on the analysis in SM 1 and related analysis in Fosgerau (2019); Correia et al. (2019) and (Pudāne & Correia, 2020), the VoTT can be seen as the marginal value of leisure time plus the intrinsic cost of spending time in the vehicle where the marginal value of leisure is equal to the wage rate minus the disutility of working. Hence, the VoTT is the sum of the value of giving up a leisure activity (or work) that could have been done otherwise (i.e. the opportunity cost of time) and the value of spending time in the vehicle. The sum of these could be reduced by making it possible to do meaningful activities in the car and/or by increasing the comfort of the car. Both these terms are likely to be affected by autonomy.

Furthermore, the methods for measuring VoTT continue to evolve and are not as straightforward as indicated by the theoretical model in SM1. More qualitative factors are being taken into account, moving away from Becker's wage-based estimations (Jain & Lyons, 2008). The value of different trip purposes, for example shopping, commuting, driving children to various activities, is now considered to be important for determining an accurate valuation (Correia et al., 2019), as well as the level of comfort that the person experiences during travel (Kouwenhoven & de Jong, 2018).

An exact value of VoTT is of course hard to pin down and differs both in terms of travel situation and comfort, but also in terms of the statistical approach used to estimate the number (Wardman et al, 2016). For example, for commuting trips Börjesson & Eliasson (2012) estimated a value of 9.8 €/hr in Sweden, Correia et al 7.47 €/hr in Netherlands and Wardman et al (2016) 7.12 €/hr. Furthermore, the value of the VoTT can both be estimated from stated preference surveys as well as revealed preference studies. Wardman et al. show in their 2016 meta-analysis of VoTT studies in Europe that there are differences between revealed and stated preferences for VoTT, and that revealed preferences tend to be somewhat higher.

The most recent official evaluation on Swedish VoTT was compiled in 2010 (WSP, 2010). A series of stated preference surveys between 2007-2009 were used to determined values of travel time for different segments of the Swedish population, and how those values differed according to trip purpose and safety levels of the traffic environment.

The use of VoTT in transportation infrastructure appraisal is often disaggregated for different modes and other circumstances, but for distributional reasons not disaggregated with respect to income for different individuals (Börjesson & Eliasson, 2014, 2019). However, when using VoTT to "simulate" and analyse consumer adoption and associated travel impact of technologies it makes sense to link VoTT to income, since this better represents behaviour.

Wadud et al (2017) and Taiebat et al (2019) in the context of CAVs differentiate VoTT according to income level using a VoTT income elasticity of unity. The elasticity of VoTT with respect to income is uncertain, but there exist some empirical support that it is around unity or somewhat less (Mackie et al., 2001; Wardman et al., 2016). Many transport authorities do for example assume an income elasticity of unity for accounting for income growth when analysing projects impacting traveling over several years (Trafikverket, 2018; UK Department for Transport, 2019). Further, Börjesson & Eliasson, (2014) analysed two Swedish VoTT studies that were performed 13 years apart and found that income elasticity with respect to VoTT increases with income, being close to zero when below the median income and unity or higher above the median income. Thus, we adjust VoTT to reflect different income quintiles of that society, using the Swedish Transportation Authority's VoTT for the median income quintile and an VoTT income elasticity of unity.

For calibrating the consumer group characteristics we use the most recent version of Swedish travel survey, which stretches over the period 2011-2016. We used the finest grained self-reported data on mode of transportation and trip distances (i.e. trip elements) together with information on driver income, employment, trip purpose and whether or not the driver was able to work from distance. Using all these variables we were able to identify the type of travellers and travel patterns that we wanted to explicitly consider.

Using the income data from all the respondents who drive a car on the measurement day, have an employment and non-zero income, we disaggregated them into five income quintiles and divided each quintile into one group who could work from distance and one who could not work from distance (being a proxy for if the respondent could potentially work in the car or not). The reported income in the national travel survey was adjusted for inflation using the consumer price index. Within each quintile we calculated the average travelling distances of car drivers for commuting and other purposes, for both long (>100 km) and short distance (≤100 km) trips, as shown in Table 2. We then applied VoTTs from the Swedish Transportation Authority, which we assumed was representative for an average driver in 2016, to the respective trips and adjusted those VoTTs in relation to the calculated income in each of our five income quintiles together with the assumption that average income in each quintile grows with 1.5% per year up to 2050 (see Table 3). Hence, our calculation intends to represent a scenario around 2050 the annual income growth of 1.5% is in line with the Swedish Transportation Authority (Trafikverket, 2018b).

Quintile	Annual average income by quintile	Work remotely	Average Daily					
			≤100km Commuting	≤100km Other	>100km Commuting	>100km Other	>100km Total	Total km
1	210 608	Yes	17	22	0	11	11	50
		No	20	18	0	7	7	45
2	299 506	Yes	22	15	3	9	12	49
		No	22	17	1	8	9	49
3	349 825	Yes	22	16	3	14	17	55
		No	23	19	1	10	11	52
4	415 471	Yes	25	20	1	14	16	61
		No	24	18	4	13	17	59
	642 387	Yes	24	21	5	17	21	66
5		No	20	21	3	18	22	62

Table 2: Average daily travel distance by income and ability to work remotely, from the 2011-2016 RVU data.

Income quintile	VoTT (SEK/hour)		
	≤100km Commuting	≤100km Other	>100km Both
1	97	66	121
2	138	93	172
3	161	109	200
4	191	129	238
5	295	200	368

Table 3: Estimated VoTT in 2050.

When analyzing the impact that CAVs may have on VoTT one needs to consider both the reason for the impact, and its magnitude. The reason for the impact depends on what the traveller is able to do in the vehicle, and the magnitude depends on utility they gain from that activity. It is important to remember here that there are no revealed preference studies available yet for VoTT in CAVs, but there is a wealth of research based on different proxies (Bansal & Kockelman, 2017; Gao et al., 2019; Harb et al., 2018; Pudāne et al., 2019; Wadud & Huda, 2019; Wardman et al., 2019; Yap et al., 2016).

They key reason for a reduction in VoTT is that the former driver is now enabled to use the time in the vehicle for something useful. Some authors suggest that changes in so-called subjective well-being may cause notable changes in VoTT (Singleton, 2019), as travellers gain utility from relaxing or enjoying passing scenery. Others suggest that the changes will come from being able to multitask in the vehicle (Malokin et al., 2019). This is of course dependent on the traveller using their travel time for work, which might not always be the case (Cyganski et al., 2015; Wadud & Huda, 2019).

The size of impact on VoTT is even more difficult to approximate since there exist no actual on-road experience of operating a CAV in an everyday situation and it is difficult to generalise insights from stated preference studies regarding a yet-to-be experienced technology. However, without considering CAVs explicitly, VoTT could be reduced 20-25% if the traveller was able to put their time to worthwhile use (ITF, 2019). Many articles present different assumptions of VoTT reduction, but because the size of the reduction depends largely on the scenario context, the assumptions range from 100% - 0% reductions (Singleton, 2019). There are a very limited number of studies that estimate a potential reduction in VoTT based on stated preferences, such as Correia et al. (2019) who found that if the interior of a CAV was designed as an office, the VoTT was lower than that of a conventional vehicle with a normal interior, but if the interior of the CAV was designed for leisure activities the VoTT did not decrease. In addition, Gao et al. (2019) suggest a 13-45% reduction during commuting, according to results from a stated preference survey on ride hailing services. In the scenarios presented later in the article we have assumed that there are differences between VoTT for commuting and VoTT for other activities. The reduction in VoTT during commuting is assumed to be larger in some of the scenarios, which then is reflected in the modelled changes in GTC and travel distances.

2.3 Criteria for CAV adoption: Break even calculations

We use a type of Cost Benefit Analysis (CBA) to determine whether or not each income group would adopt a CAV. We use CBA in the sense that the criteria of adopting a CAV is based on the individual economic costs and benefits of owning a CAV, according to income, usefulness of travel time, and extra cost of CAV technology. Hence, the GTC of normal is assessed relative to that of a CAV when including both the fixed and variable parts of the GTC. We assume that the driver/owner would purchase a CAV if the levelized GTC are lower than the corresponding estimate for a conventional car. However, note that we only consider personal costs and benefits for the driver of the vehicle. We do not consider any other potential users of the car, nor do we consider external costs such as congestion and emissions. The GTC for a normal car is based on Trafikverket (2018) and Trafikverket's Analytical Methods and Socioeconomic Calculations (ASEK) Recommendations (Bångman, 2016). It is assumed that every traveller has the same costs in terms of vehicle price, maintenance, and fuel.

Error! Reference source not found. Critical for the adoption of CAVs are the technology costs. There is a large uncertainty around what the necessary CAV technology actually costs today and how that cost will develop over the coming decades. For example the CEO of Volvo Cars has said that level 4 technology would add $ 10 000 to the vehicle cost in 2021 (Edelstein, 2017; Lesage, 2016). Further, the price of the "self driving capability" newly ordered Teslas as of February 2020 is $7 000, and while technically these vehicles are level 2, there is official Tesla rhetoric that the system has a hardware capability of level 4 (Hawkins, 2019). However, it is difficult to know how accurate these statements and prices are for the actual costs, much information around technology costs are safeguarded by most automobile manufacturers. There are also estimates of the additional costs for CAV technology in the academic literature (see Table 4). Note that the costs for CAV technology presented in Table 4 is considered to be in addition to the price of a conventional vehicle. In our scenarios presented below we will assume a range between 30 000 and 100 000 SEK in the year 2050.

Study Author	Low cost	Medium cost	High cost	Year
Bansal & Kockelman, 2017	--	80 600 SEK	--	2045
Wadud, 2017	112 500 SEK	136 400 SEK	179 400 SEK	2020
Lavasani et al., 2016	28 000 SEK	50 000 SEK	94 000 SEK	2025
Compostella et al., 2020	30 500 SEK	95 000 SEK	280 000 SEK	2030-2035

Table 4: Costs of CAV Technology in different academic studies.

2.4 Elasticities and induced travel demand

Cheaper travel tends to induce more travel. As for all normal consumer goods the demand for the good (i.e. travel) tend to increase if the price (generalized cost of travel) drops. This is clear from for example, (1) the rebound effect, where increased fuel efficiency tends to lead to a lower marginal cost of traveling, which in turn leads to increased mileage (Small & van Dender, 2007), and by (2) the induced traveling effect, where improved "speed" from going to A to B by, for example new highway capacity and/or reduced congestion, tends to generate more travel (Goodwin, 1996). In the latter example the general cost of traveling is reduced due to reduced VoTT per km since the speed is higher. Hence, the rebound effects of the induced travelling phenomena are interlinked aspects of impacts on the general cost of traveling (Hymel et al., 2010; Small & Van Dender, 2007).

The theoretical and empirical findings for rebound effect and induced travel demand (through infrastructure and congestion mitigation projects) clearly indicate that a reduced GTC can have an impact on travel demand. For example, studies point towards that the rebound effect declines with income (Greene, 2012; Small & Van Dender, 2007). This is surely what one should expect given a constant demand elasticity with respect to GTC since the share of fuel cost in the GTC declines as VoTT increases with income (Small & Van Dender, 2007; Greene, 2012).

Regarding the rebound effect there are a plethora of studies that try to empirically estimate the size of the rebound effect. The empirical findings suggest a long-run rebound effect of around 0.1-0.3, (an elasticity of travel distance with respect to fuel cost) meaning that 10% increase in fuel efficiency generates a 1-3% increase in annual vehicle mileage (Dimitropoulos et al, 2018; Andersson et al, 2019). Regarding the long-run induced travel demand elasticity other studies have estimated it to be in the order of -0.5 to -1 (an elasticity of travel distance with respect to travel time), in the sense that a 10% reduction in travel time tend to induce 5-10% increase in travel volume (Andersson & Smidfelt Rosqvist, 2011; De Jong & Gunn, 2001; Goodwin, 1996).

These two elasticities; elasticity of travel distance with respect to fuel cost and elasticity of travel distance with respect to travel time, are related and can be unified through the concept of elasticity of travel distance with respect to general cost of travel, see for example Goodwin et al. (1996) and our Section 2 in our Supplementary Materials where this is analysed in brief. The empirical evidence based on the rebound effect and the induced traveling points towards an elasticity with respect to variable GTC of about -1, but could be substantially smaller or larger. This is also roughly in line with the mid-assumption in Wadud et al. (2016).

2.5 Additional assumptions

In order to model the choices and behaviours of individual travellers, we needed to make some assumptions. Most of these assumptions relate to rational behaviour-based decision-making: we assume that the traveller considers only economic factors when choosing to adopt a CAV or not, and we assume that they are aware of the savings that could be made from a CAV in terms of reduced VoTT. Further, there could be many more factors that could sway the decision of the traveller towards adoption, such as social status or pressure (Rezvani et al., 2018) as well as safety aspects. There could also be factors that pushes the decisions in another direction, for example lack of trust in AV technology (Gao et al., 2019; Yap et al., 2016).

When calculating the GTC of a CAV, we assumed there would be no changes in fuel, maintenance, or insurance cost as a result of potential increased efficiencies the car being fully autonomous and connected. This could underestimate the benefits associated with CAV adoption, thus potentially making our calculations slightly conservative. We made these assumptions because wanted to isolate the effect of VoTT and make our calculations as transparent as possible.

2.6 Scenario parameters

We develop three scenarios called “Little”, “Medium” and “Large” aimed to cover three rather different cases on how CAV technology has developed over time in terms of cost and the impact the technology has on the VoTT. The numerical assumptions in the three scenarios we model are shown in Table 5. The “Little” scenario relates to a future scenario similar to that which was described in the 2019 ITF report (ITF, 2019), where automation does not have a large effect on individual commuting patterns (and other travel patterns). Following the findings of Correia et al. (2019) and Gao et al. (2019) we assume that time spent commuting will have a larger change in VoTT than time spent travelling for other reasons. The “Large” scenario is closer to the patterns described by Harb et al. (2018), where the CAV technology largely impacts the utility leading to a substantial reduction in VoTT and the cost of the technology becomes low.

Scenario	Reduction in VoTT Other	Reduction in VoTT Commuting	Cost of CAV technology
Small	15%	25%	100 000 SEK
Medium	35%	35%	50 000 SEK
Large	50%	60%	30 000 SEK

Table 5: Scenario descriptions.

3. Results

In order to understand the results and the importance of VoTT, we first show the GTC broken down into components for different income groups and as well for how the GTC differs for those who are able to work remotely and those who are not, see Figure 1. In the higher income quintiles, VoTT makes up a larger percentage of the overall GTC per km than lower income quintiles, because the people in those quintiles have a higher income and consequently a higher VoTT (due to the assumption of a VoTT income elasticity of unity). Further, there are only very slight differences in GTC between those who are able to work remotely since there are no reason to expect that the VoTT or other components of the GTC would differ dependent if a person can work remotely or not. The small differences in GTC within an income quintile are a result of different travel distances as found in the RVU.

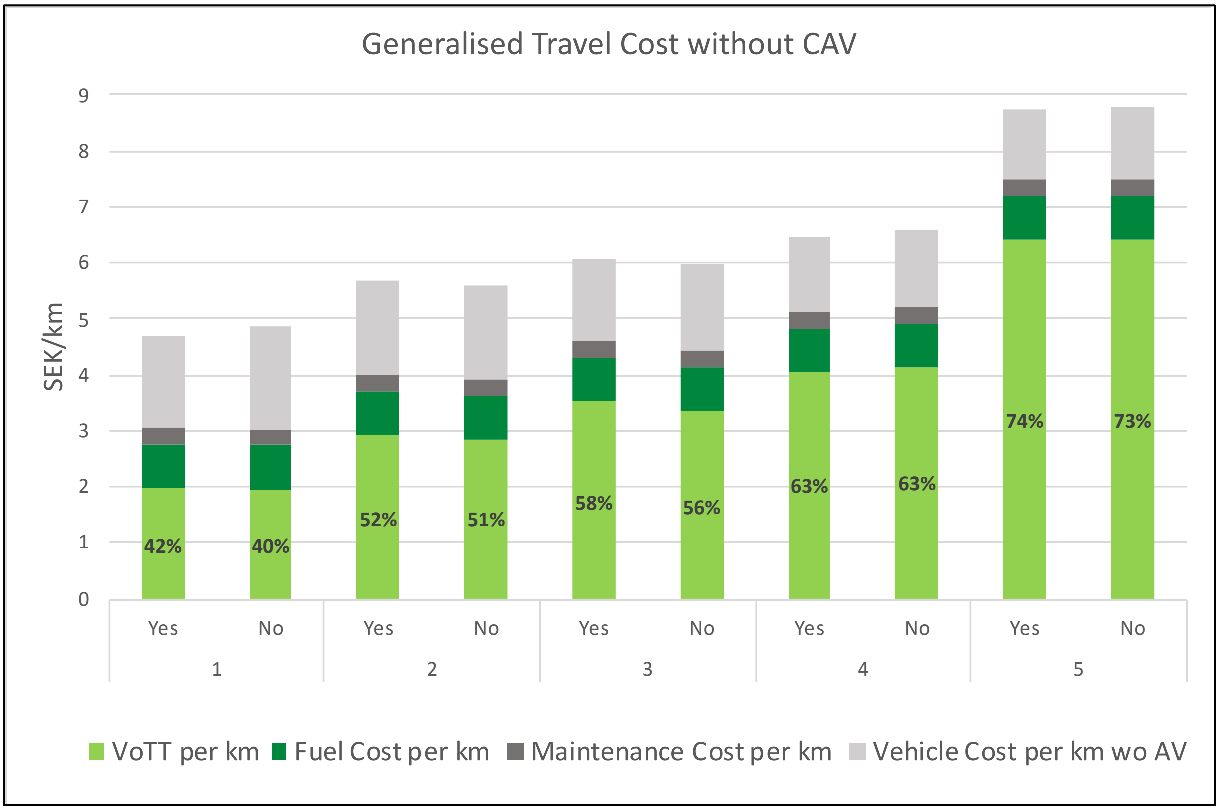

Figure 1: Generalized Cost of Travel (GTC), measured per kilometre for a vehicle without CAV technology in 2050. The percentage shown in the light green sections is the percent of GTC that is represented by VoTT. "Yes" and "No" refer to ability to work remotely, 1-5 refer to income quintile.

3.1 Changes in Generalized Travel Costs

Figure 2 shows the change in capital cost, the change in VoTT, and the change in GTC (net of capital cost and VoTT change) per kilometer for each scenario, quintile and each case of ability to work remotely. All else the same the higher income quintiles have a stronger incentive to adopt CAVs, because adoption of a CAV would cause a larger absolute drop CAV in their VoTT as compared to the case for those with a smaller income s. This holds for all scenarios. It is clear that in both the “Medium” and “Large” it is beneficial for all average drivers in each income quintiles to adopt a CAV, it is only in the “Little” scenario where it differs between income groups and between groups who can and cannot work remotely.

In scenario “Little” and “Large” those which are able to work from distance have larger impact on VoTT than those who could not work remotely. Consequently, people belonging to these groups have a stringer incentive to adopt a CAV than those who in the same income quintile who cannot work in the car. This is for example clear in Figure 2 and the “Little scenario” were we find a positive benefit-cost difference for the average person in income quintile 4 that can work remotely and a negative benefit-cost difference for the average person in income quintile 4 that cannot work remotely.

In the medium scenario, where we do not differentiate the VoTT reduction between those who can and cannot work in the car the change in GTC is slightly smaller for those who can work remotely (Figure 3). This is primarily because the average person this group drives fewer daily kilometres in total causing the capital investment to be levelized over fewer kilometers. Note though that also in other income quintiles there are cases those who cannot work remotely drive slightly more in one disaggregated category, but in these cases the average person in the same income quintile who can work from home has more the long-distance trips and by assumption VoTT is larger for long distance trips than short distance trips (see Table 2).

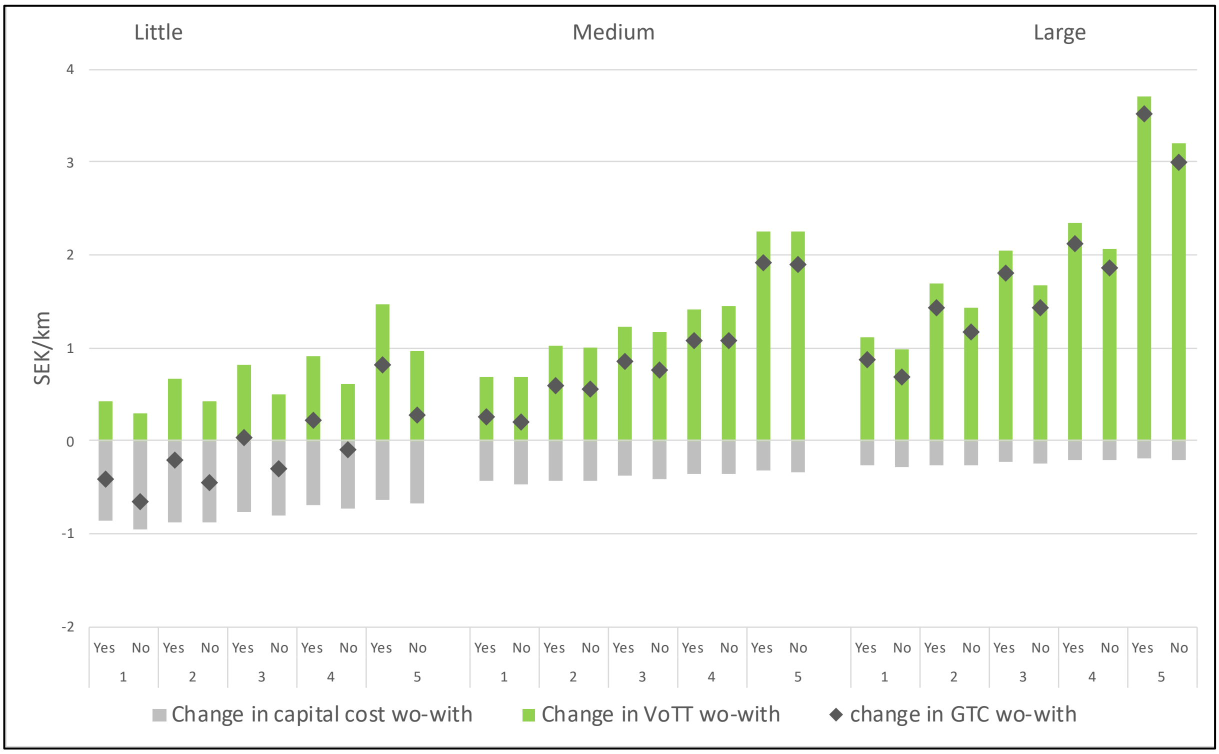

Figure 2: Change GTC due to CAV in each scenario. The green bar shows the net reduction in VoTT per km due to operating a CAV as compared to a conventional car, the grey bar shows the increase in cost per km due to the CAV technology, while the black diamond shows change in GTC.

3.2 Changes in Travel Demand

If the GTC_{CAV} is lower than the GTC_{CONV} for an average driver in each income and work category we assume that a CAV will be adopted for all drivers in that category. The subsequent step in the modeling is to estimate the increase in the travel demand for an average driver in each category. The extra cost of the CAV technology will have a relatively smaller effect on the variable GTC than the total GTC. Hence, the cost that affects the travel demand is based on variable part of the GTC, which includes VoTT, fuel and maintenance costs, and variable depreciation costs[2]. Given a demand elasticity of -1 with respect to variable GTC we estimate the impact of CAVs on traveling distance.

As expected, the changes in travel distance are most dramatic for the "Large" scenario (Figure 2), being a 61% increase overall for the assessed population. The "Medium" scenario shows an increase in traveling of 32% and the small scenario has a relatively small increase 5%. Further, looking into the different categories of drivers we see a heterogenous picture regarding impact on travel distance of CAVs. Generally, higher income groups show a larger change in travel distance irrespective of scenario. The reason is twofold. First, the higher income quintiles have a stronger incentive to adopt a CAV since they have a larger VoTT and for that reasons may have an incentive to a adopt a CAV even if the relative impact on VoTT is relatively small and the cost of technology is high. This is why we in the "Little" scenario only observe travel distance increases in the higher income groups. Second, the relative share of VoTT in GTC is higher the larger the income is (Figure 1) and the estimated travel demand given that a CAV is adopted depends on the relative change in GTC.

Given this heterogeneity it is interesting to observe that even with a relatively high price for CAV technology, and a small change in VoTT (as in the Little scenario), an average driver in the group consisting of those with the highest income and who can work remotely would increase their travel distance by as much as 17% which can be compared to 5% that is the average increase in distance for this scenario.

Regarding the possibility to work in the car, we observe that the travel distance impact is larger for those who can work in the car compared to those who cannot (given that a CAV is adopted in the first place). This follows from the assumption that relative reduction in VoTT due to CAV use are largest for commuting trips where the operator of the vehicle can work in the car.

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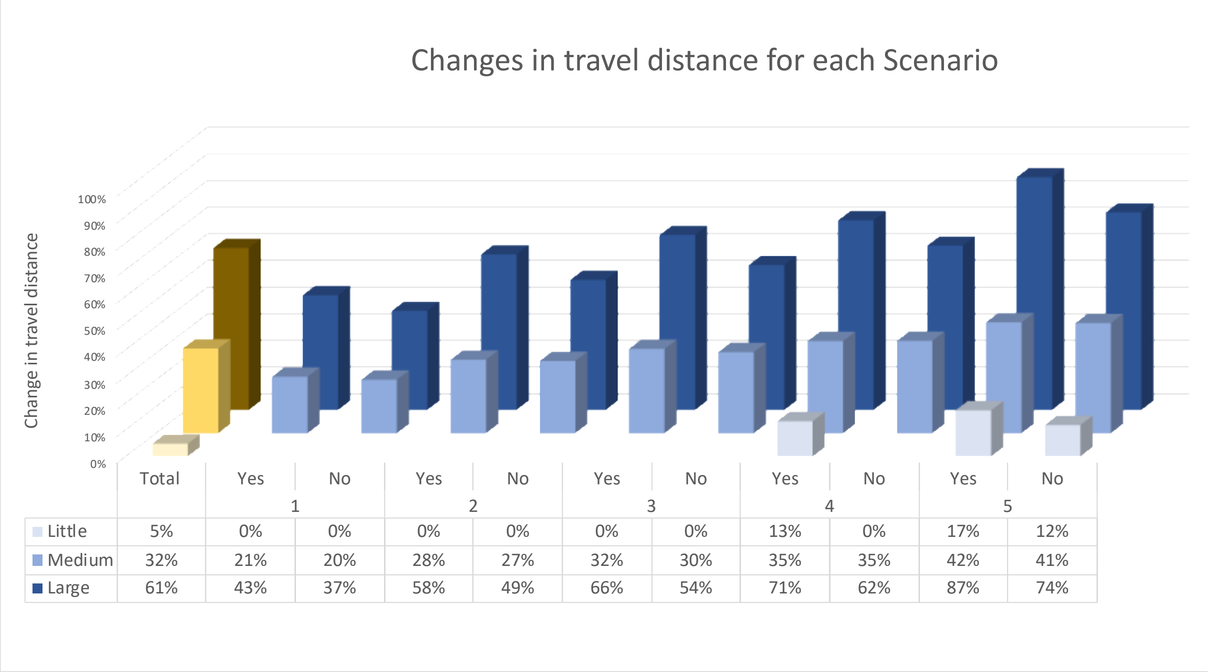
[2] We assume that 2/3 of the depreciation of capital costs are fixed, and 1/3 are variable, according to Trafikverket's 2018 ASEK calculations *Kapital 13: Operativa trafikeringskostnader för persontrafik*. Figure 2 shows the overall depreciation of capital costs, including variable and fixed costs.

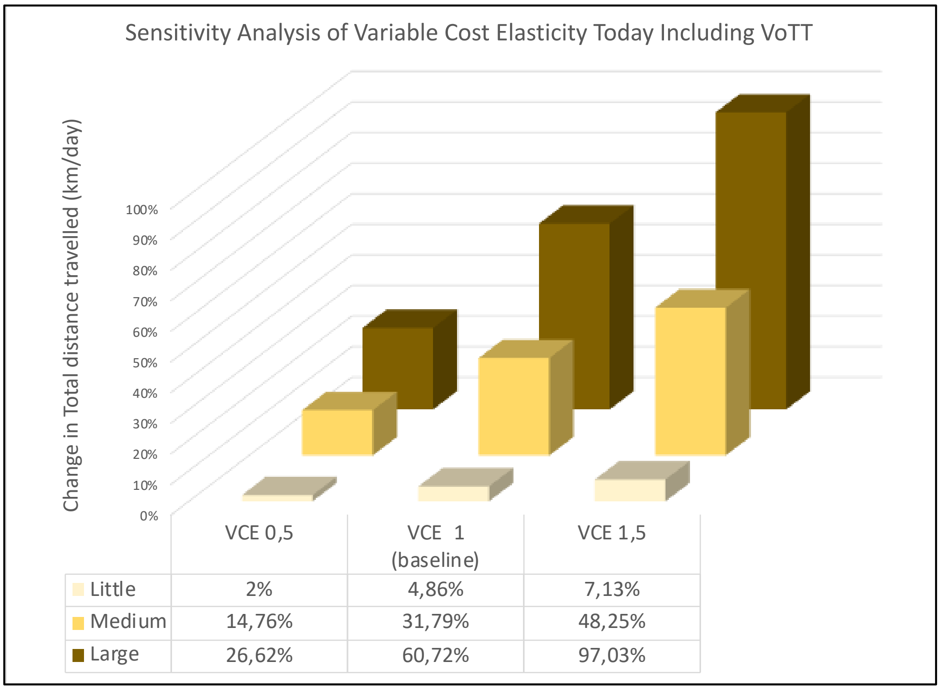


	Total	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
		1		2		3		4		5	
■ Little	5%	0%	0%	0%	0%	0%	0%	13%	0%	17%	12%
■ Medium	32%	21%	20%	28%	27%	32%	30%	35%	35%	42%	41%
■ Large	61%	43%	37%	58%	49%	66%	54%	71%	62%	87%	74%

Figure 3: This shows the increase in travel distance for each group and scenario in blue. The first column on the left ('Total') shows the total daily increase in travel distance across all groups in each scenario in yellow.

3.3 Sensitivity Analysis of travel distance elasticity with respect to travel cost

We performed a sensitivity analysis on the travel distance Elasticity with respect to variable part of the GTC, to see how sensitive the changes in travel demand is due to different assumptions. Figure 4 shows the results of the sensitivity analysis with elasticity values of -0.5, -1 (baseline) and -1.5. The higher the elasticity, the larger the induced travel difference is between scenarios. This holds for all scenario and all income groups in cases where a CAV is adopted.



	VCE 0,5	VCE 1 (baseline)	VCE 1,5
■ Little	2%	4,86%	7,13%
■ Medium	14,76%	31,79%	48,25%
■ Large	26,62%	60,72%	97,03%

Figure 4: Sensitivity Analysis of Variable Cost Elasticity

4. Discussion about model simplifications

One weakness of the model approach is the assumption the capital cost of the vehicle and the CAV technology is the same irrespective if income group. In reality, it is likely that those with higher incomes would purchase more expensive vehicles (and the opposite for those with a low income) and thus vehicle capital cost per km would make up a larger (smaller) portion of the total GTC per km than what is estimated in Figure 1. However, if the traveller has already purchased a more expensive ordinary vehicle, then the extra cost that will be associated with CAV technology (given that it is the same technology for all vehicles) will be smaller (larger) in proportion to the capital cost of the conventional car for high (low) income groups. If we did consider this in our modeling it would not affect the adoption criteria analysed in section 3.1 since it compares the impact on VoTT with the cost of the CAVs technology, i.e. the same groups (i.e., income and eligibility to work remotely) would find it beneficial to adopt the CAV technology. However, given that there is a positive correlation both between income and the cost of car purchased and the income and VoTT, respectively, the impact of travel demand would be smaller (larger) than for the high (low) income groups than what is estimated in section 3.2 and shown in Figure 5.

5. Conclusion

The aim of this study was to analyse the relationship between GTC, travel distance, possibility to work remotely and VoTT, with specific regard to plausible changes that could occur because of adoption of CAV technology. It was established in the data collection and the related analysis that those in the higher income quintiles, and those who are able to work remotely, tend to have longer travel distances as for now. Also, given typical findings people with a higher income tend to have a higher VoTT.

As long as all income groups have the same change in technology price (i.e. the CAV technology cost) and relative change in VoTT, the higher income groups will in all cases we analysed have a larger (absolute) economic incentive to adopt a CAV. The key reason is that they have a higher VoTT, but also due to that their average daily driving distance is on average longer, which in turn causes the CAV technology cost to be levelized over a larger distance.

For future research, it would be interesting to further study technology variations between income groups, variations in travel distance and technology within income groups, in order to better understand what other factors besides income can contribute to understanding for which groups it would be beneficial to adopt a private CAV.

If it is beneficial for the specific group to adopt a CAV, it is likely to increase travel distance for that group. We see that CAVs could have a large impact in average travel distance across all income groups, but likely to have a larger impact on the travel distance for a high-income group due to a larger share of VoTT in their GTC. Thus, it would be interesting for future research to consider other scenarios where changes in VoTT differ within income groups in a more diverse aspect than the consideration if they can work in the car or not, or in relation to other factors. However, the statistical information on the behavioural related aspects of CAVs are still in its infancy.

We already saw here how the ability to work from home, when used as a proxy for being able to work in a CAV, can have significant effects on CAV adoption and increased travel demand under certain conditions. The literature on the size of CAV-related reductions in VoTT for commuting and VoTT for other activities is still quite limited, and of course based on stated preferences, and so it is very difficult to know how well this reflects reality. But it is important to explore the scenarios that could emerge if certain groups have the advantage of more “useful” time in CAVs, because this can demonstrate how relatively innocuous characteristics, such as being able to work from home, can lead to unexpectedly large increases in travel demand. It is also important to remember that our model is relatively simple. There are most likely many more such characteristics (such as household composition, geographic location, and local transportation infrastructure) that, when combined, could have even larger effects on travel demand and related environmental issues.

Any prolonged increase in travel distance, such as that shown in our model, could eventually lead to serious effects on congestion, both tailpipe and particle emissions from vehicles, and overall energy needs of the transport sector. These results could be useful for policymakers when future scenarios involving CAVs are being considered, and also useful for future research on travel demand and CAVs.

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Supplementary Material

S1. Theoretical exposition of how CAVs may affect the value of travel time

In order to elucidate on how the value of time may be affected due to introduction of Connected and Autonomous Vehicles (CAVs) we present a simple theoretical model on the Value of Travel Time concept based on utility maximization with an income budget as well as time use budget. We resort to simplest model possible to capture to capture the key insights in how CAVs may affect the value of time. A similar exposition was presented in Pudane & Correia (2020), were our model is slightly simpler since we do not take into account that it takes time to consume purchased goods. Still the general insights are similar.

S1.1 Normal vehicle

We assume that all wage income, being the product of the wage rate (w) and working time (T_w) is spend on consumption (C) and that the available time (τ) can either be spent on traveling (T_t), working (T_w) or as leisure (T_l). $T_{t,min}$ is the minimum amount of time needed for traveling. The constrained utility (U) maximising problem can be stated as

Max

$$U(C, T_w, T_t, T_l)$$

s.t

$$\begin{gathered} w \cdot T_w - X = 0 \\ \tau - T_w - T_t - T_l = 0 \\ T_t - T_{t,min} = 0 \end{gathered}$$

The Langrangian is

$$\mathcal{L} = U(C, T_w, T_t, T_l) + \lambda \cdot (w \cdot T_w - X) + \mu \cdot (\tau - T_w - T_t - T_l) + \kappa \cdot \left(T_t - T_{t,min}\right)$$

were λ, μ and κ associated with each respective constraint.

Analysis of the first order conditions gives that

$$\begin{gathered} \frac{\partial U}{\partial C} = \lambda \\ \frac{\partial U}{\partial T_w} + \lambda \cdot w = \mu \\ \frac{\partial U}{\partial T_l} = \mu \\ \frac{\partial U}{\partial T_t} - \mu + \kappa = 0 \end{gathered}$$

Rewrite

$$\frac{\partial U}{\partial T_l} = \frac{\partial U}{\partial T_w} + \frac{\partial U}{\partial C} \cdot w$$

Which says that the marginal utility of leisure is equal the marginal utility of work (likely negative) + marginal utility of money multiplied with the wage rate.

κ is the shadow value of the travel time constraint, i.e. how much would the utility change if the constraint on traveling time change by one unit. Hence, $\kappa/\frac{\partial U}{\partial C}$ is the VoTT

$$VoTT = \frac{\frac{\partial U}{\partial T_l} - \frac{\partial U}{\partial T_t}}{\frac{\partial U}{\partial C}} = \frac{\frac{\partial U}{\partial T_w} + \frac{\partial U}{\partial C} \cdot w - \frac{\partial U}{\partial T_t}}{\frac{\partial U}{\partial C}} = w + \frac{\frac{\partial U}{\partial T_w} - \frac{\partial U}{\partial T_t}}{\frac{\partial U}{\partial C}}$$

The value of time is the wage rate, plus the money value of the marginal utility of spending time working (likely a negative number) minus the marginal utility of spending time in the vehicle (likely a negative number). Alternatively, the VoTT can also be interpreted as the marginal money value of leisure time minus the marginal money value of spending time in the vehicle.

S1.2 CAV

For CAVs the constrained utility maximising problem is reformulated as the follow

Max

$$U(C, T_w + \alpha \cdot T_t, T_t, T_l + \beta \cdot T_t)$$

s.t

$$w \cdot (T_w + \alpha \cdot T_t) - X = 0$$
$$\tau - T_w - T_t - T_l = 0$$
$$T_t - T_{t,min} = 0$$

Where α and β represent the quality adjusted share of time in the vehicle that is spent on work and leisure, respectively. $\alpha + \beta \leq 1$, since the sum of them has to be smaller than the total travel time. It is quality adjusted time in the sense that the work or leisure activity may be limited various ways or be of less quality compared to the corresponding activity taking place outside the vehicle. Hence, if the quality of the work and/or lesiure in the vehicle is less than what it is doing if outside the vehicle $\alpha + \beta < 1$ even if all the time in the vehicle is spend on work and/or leisure. Further, the quality and share of time spent working in the car will be reflected in the wage.

The Langrangian is

$$\mathcal{L} = U(C, T_w + \alpha \cdot T_t, T_t, T_l + \beta \cdot T_t)$$
$$+\lambda \cdot (w \cdot (T_w + \alpha \cdot T_t) - X) + \mu \cdot (\tau - T_w - T_t - T_l) + \kappa \cdot (T_t - T_{t,min})$$

Analysis of the first order conditions gives that

$$\frac{\partial U}{\partial C} = \lambda$$
$$\frac{\partial U}{\partial T_w} + \lambda \cdot w = \mu$$
$$\frac{\partial U}{\partial T_l} = \mu$$

$$\frac{\partial U}{\partial T_t}+\frac{\partial U}{\partial T_l}\cdot\beta+\frac{\partial U}{\partial T_w}\cdot\alpha+w\cdot\alpha\cdot\lambda-\mu+\kappa=0$$

Rewrite in order to get VoTT

$$\kappa=-\frac{\partial U}{\partial T_t}-\frac{\partial U}{\partial T_l}\cdot\beta-\frac{\partial U}{\partial T_w}\cdot\alpha-w\cdot\alpha\cdot\lambda+\mu$$

$$\kappa=-\frac{\partial U}{\partial T_t}-\frac{\partial U}{\partial T_l}\cdot\beta-\frac{\partial U}{\partial T_w}\cdot\alpha-w\cdot\alpha\cdot\frac{\partial U}{\partial C}+\frac{\partial U}{\partial T_l}$$

$$\kappa=-\frac{\partial U}{\partial T_t}-\frac{\partial U}{\partial T_w}\cdot\alpha-w\cdot\alpha\cdot\frac{\partial U}{\partial C}+\frac{\partial U}{\partial T_l}\cdot(1-\beta)$$

$$\kappa=-\frac{\partial U}{\partial T_t}-\frac{\partial U}{\partial T_w}\cdot\alpha-w\cdot\alpha\cdot\frac{\partial U}{\partial C}+\left(\frac{\partial U}{\partial T_w}+\frac{\partial U}{\partial C}\cdot w\right)\cdot(1-\beta)$$

If you only work in the car ($\beta=0$) we get

$$\kappa=-\frac{\partial U}{\partial T_t}-\frac{\partial U}{\partial T_w}\cdot\alpha-w\cdot\alpha\cdot\frac{\partial U}{\partial C}+\left(\frac{\partial U}{\partial T_w}+\frac{\partial U}{\partial C}\cdot w\right)$$

$$\kappa=-\frac{\partial U}{\partial T_t}+\frac{\partial U}{\partial T_w}\cdot(1-\alpha)\cdot+\frac{\partial U}{\partial C}\cdot w\cdot(1-\alpha)$$

Hence, the VoTT for trips were you work part of the time in the car and do nothing else

$$VoTT=\frac{\kappa}{\frac{\partial U}{\partial C}}=w\cdot(1-\alpha)+\frac{\frac{\partial U}{\partial T_w}\cdot(1-\alpha)-\frac{\partial U}{\partial T_t}}{\frac{\partial U}{\partial C}}$$

If you only do leisure (part of time) and no work in the car ($\alpha=0$) we get

$$\kappa=-\frac{\partial U}{\partial T_t}+\left(\frac{\partial U}{\partial T_w}+\frac{\partial U}{\partial C}\cdot w\right)\cdot(1-\beta)$$

$$VoTT=\frac{\kappa}{\frac{\partial U}{\partial C}}=w\cdot(1-\beta)+\frac{\frac{\partial U}{\partial T_w}\cdot(1-\beta)-\frac{\partial U}{\partial T_t}}{\frac{\partial U}{\partial C}}$$

And a combination of both work and leisure we get

$$\kappa=-\frac{\partial U}{\partial T_t}-\frac{\partial U}{\partial T_w}\cdot\alpha-w\cdot\alpha\cdot\frac{\partial U}{\partial C}+\left(\frac{\partial U}{\partial T_w}+\frac{\partial U}{\partial C}\cdot w\right)\cdot(1-\beta)$$

$$\kappa=\frac{\partial U}{\partial C}\cdot w\cdot(1-\alpha-\beta)+\frac{\partial U}{\partial T_w}\cdot(1-\alpha-\beta)-\frac{\partial U}{\partial T_t}$$

Hence,

$$VoTT = \frac{\kappa}{\frac{\partial U}{\partial C}} = w \cdot (1 - \alpha - \beta) + \frac{\frac{\partial U}{\partial T_w} \cdot (1 - \alpha - \beta) - \frac{\partial U}{\partial T_t}}{\frac{\partial U}{\partial C}}$$

If the car operator spends all the time in the car either on work or leisure activities (or both) and these are of equal quality as doing these activities outside the vehicle the sum$1 - \alpha - \beta$ would be 0. Hence, under these conditions

$$VoTT = -\frac{\frac{\partial U}{\partial T_t}}{\frac{\partial U}{\partial C}}$$

Hence, VoTT would be equal to the money value of the intrinsic discomfort of being in a vehicle, and there would be no lost opportunity of using the time in the vehicle in a productive and/or meaningful way.

S2. Relationship between the rebound effect, induced travel demand and elasticity with respect to generalised travel cost

In the modeling presented in the main paper we argue that our demand elasticity with respected to variable Generalised Travel cost of -1 is consistent with a rebound of about 0.2. In this SM we will derive this relationship similar to Goodwin (1996).

TableSM 2.1: Explanation of variables used the analysis showing the link between different demand elasticties.

G	Variable General cost of travel
D	Distance
C	fuel cost
T	Time
VoTT	Value of Travel Time per unit of time
O	Other variable travel cost
ε_C	Fuel cost elasticity (rebound effect)
ε_T	Induced travel demand elasticity
ε_G	GTC demand elasticity

From the definition of demand elasticity we have:

$\frac{\Delta D}{D} = \varepsilon_C \frac{\Delta C}{C}$, where ε_C is approximately -0.3 to -0.2 (Dimitropoulos et al, 2018) .

$\frac{\Delta D}{D} = \varepsilon_T \frac{\Delta T}{T}$, where ε_T is approximately -1 to -0.5 (Andersson & Smidfelt Rosqvist, 2011; De Jong & Gunn, 2001; Goodwin, 1996).

If we start from the perspective of generalised travel cost G assuming an elasticity of ε_G we get:

$$\frac{\Delta D}{D} = \varepsilon_G \frac{\Delta G}{G} = \varepsilon_G \frac{\Delta(C + O + T \cdot VoTT)}{C + O + T \cdot VoTT}$$

If the only change happens in fuel cost we have the relationship:

$$\frac{\Delta D}{D} = \varepsilon_G \frac{\Delta G}{G} = \varepsilon_G \frac{\Delta C}{C+O+T \cdot VoTT} = \varepsilon_C \frac{\Delta C}{C} => \varepsilon_G = \varepsilon_C \frac{C+O+T \cdot VoTT}{C}$$

Hence, given the estimates of the situation today in Sweden regarding costs of traveling (see the main text) and were the rebound effect has an elasticity of -0.2 the demand elasticity with respect to GTC (ε_G) estimated from the rebound effect would be roughly about -1.

Finally, if the only change happens in time we have the relationship:

$$\frac{\Delta D}{D} = \varepsilon_G \frac{\Delta G}{G} = \varepsilon_G \frac{\Delta T \cdot VoTT}{C+O+T \cdot VoTT} = \varepsilon_T \frac{\Delta T}{T} => \varepsilon_G = \varepsilon_T \frac{C+O+T \cdot VoTT}{T \cdot VoTT} => \varepsilon_G = \varepsilon_T \frac{C+O+T \cdot VoTT}{T \cdot VoTT} = \varepsilon_C \frac{C+O+T \cdot VoTT}{C}$$

This leaves us with:

$$\frac{\varepsilon_T}{\varepsilon_C} = \frac{T \cdot VoTT}{C}$$

Paper II

Too Much Pressure?

Driving and Restraining Forces and Pressures relating to the State of CAVs in Cities.

Ella Rebalski, Marco Adelfio, Frances Sprei, Daniel J.A. Johansson

Abstract

Connected and Autonomous Vehicles (CAV) are predicted by many analysts to transform the transport system over the coming decades. Which direction and path this transformation will take is today highly uncertain. In this research we examine the introduction of CAVs in cities in terms of the indirect or underlying processes (drivers) and the direct expressions of interest that are related to specific actions, events or processes (pressures). The drivers and pressures are identified in interviews with stakeholders from across the quadruple helix (academia, industry, government and civil society). We then use a composite analytical framework that combines drivers (D) and pressures (P) of DPSIR model and force field analysis. This framework is used to map survey data on the strength of the driving and restraining forces and pressures behind the introduction of CAVs in cities, and to identify which stakeholders are involved in this socio-technical transition. Results showed that there was a strong belief across stakeholder groups that CAVs need to be connected with mobility planning and transportation strategies. Furthermore, frameworks that reconcile private technology development and public-led development of city planning were considered important, and politicians, mobility consultants, and urban planners emerged from the interviews as very active parts of an ecosystem of funding and expertise in pilot projects.

Key Words: socio-technical transition, connected and autonomous vehicles, DPSIR, force field analysis

1 Introduction

Connected and Autonomous Vehicles (CAV) are predicted by many analysts to transform the transport system over the coming decades. Which path this transformation will take is today highly uncertain and the plausible, yet divergent, directions that this development may take are plentiful (Papa & Ferreira, 2018). Following Loorbach (2010) it will imply transitions that intervene at different levels - e.g. cultural, structural and practical levels - that have different time frames and scales.

These processes of transition can be facilitated or hindered by the indirect or underlying processes (drivers) and the direct expressions of interest that are related to specific actions, events or processes (pressures) (Adelfio et al., 2018). These drivers and pressures can in turn be represented by multiple stakeholders, and there is a knowledge gap on these matters which needs to be filled as they can impinge on the introduction of CAVs in cities. Therefore, this article aims at exploring the role, responsibility and perceptions of different stakeholders on the implementation of CAVs for passenger transport in a sustainable direction at the local level, with special focus on the city of Gothenburg, Sweden. The following research questions (RQ) have been identified:

RQ1: What are the driving and restraining forces and pressures, that facilitate or hinder the socio-technical transition towards the introduction of CAVs at the city level?

RQ2: What stakeholders, representative of the aforementioned driving/restraining forces and pressures, are involved in such a socio-technical transition?

The remainder of this paper will first, in Section 2, provide some background information on the state of the art regarding CAVs and cities, stakeholders, and socio-technical transitions. Section 3 explains the theoretical and analytical frameworks behind the methodology, and the methods used in this study. Section 4 gives a more detailed contextual background on the city of Gothenburg and CAV-related projects. Section 5 shows the empirical interview and survey data, and Section 6 finishes with a discussion and conclusion.

2 State of the Art

2.1 CAVs and Cities

Previous research has been devoted to various scenarios where CAVs are introduced into cities. However, the extent to which and the reasons why cities are considering facilitating the introduction of CAVs differ greatly depending on their size, geographic location, and political leaning (Freemark et al, 2019).

The policy-related aspects of CAVs are affected by multi-level governmental institutions working to create integrated policies across all parts of the world. In Europe this means EU-level with country-level coordination (Gavanas, 2019), and in the USA it means state- or federal-level coordination with municipal-level (Freemark et al, 2019). On a more local level, the lack of municipal government preparedness for CAVs is an issue that has arisen in the literature, but the lack of preparedness seems to stem from different perspectives and causes. In some cases, municipal officials have stated that they do not think their city is prepared for CAVs in terms of policy (Freemark et al, 2019), while in other cases this dearth is expressed as a need for more data to inform policy planning (Gavanas, 2019), or a lack of investment in and understanding of the necessary infrastructure for CAVs (Duarte & Ratti, 2018).

2.2 CAVs and Stakeholders

When considering the introduction of CAVs to be a socio-technical transition, there arises an implicit need to engage with a multiplicity of stakeholders. However, the specific roles of different stakeholders in the transition are still underexplored, leaving a research gap regarding the role of stakeholders in the socio-technical transition towards CAVs being introduced in cities. Among the few studies relating CAVs to stakeholders, Hess (2020, p. 9) discusses the different strategies that are used by civil society organisations in the USA in relation to a CAV transition, and finds that many of these groups support a "modest political goal". In contrast, KPMG released a report in the early days of CAV popularity that discussed how CAVs could "…be profoundly disruptive for almost every stakeholder in the automotive ecosystem" (KPMG, 2012, p. 3).

In terms of stakeholders who are commonly associated with CAVs, people with impaired mobility are often mentioned as being interested in the technology (Templeton, 2020). However, Fraedrichs et al. (2016) found that this group could be even less interested in CAVs as compared to those with full mobility. Nielsen and Haustein (2018) discuss the expectations of CAVs in regard to stakeholders in Denmark who are categorized as enthusiasts, indifferent stressed drivers, and skeptics. The enthusiasts were "typically male, young, highly educated, and live in large urban areas", and the sceptics were " older, car reliant and more often live in less densely populated areas" (Nielsen & Haustein, 2018, p. 1).

Legacy et al. (2019) discuss the importance of action on the part of transport researchers, in terms of creating new frameworks that can reconcile the private development of CAV technology, and the public-led development of city and transportation planning. In this case the researchers have a somewhat symbiotic relationship with municipal governments and industry, since the actions of government and industry provide material for the researchers. The final result of this research, as Legacy et al. describe it, could also provide guidance to government and industry as they work to create new regulations.

2.3 CAVs as leading to socio-technical transitions

Geels (2004) suggests that by studying socio-technical systems, one can focus on the dynamic relationship between technology and society within a larger transition. When the transition to CAVs is viewed as a socio-technical system, the relationships between stakeholders and the evolving technology can be viewed as connections that channel driving forces, but also viewed as connections which create barriers. For example, Hopkins & Schwanen (2018) discuss how incumbents, in terms of industry and politics, have until now largely led the AV transition in the UK, and how this has led to lower levels of openness, democracy and participation from other groups. In this case the barriers are not necessarily against technological development, but rather barriers to inclusion.

Cohen & Cavoli (2019) take a different perspective on CAV transition, looking at the consequences of government intervention or lack thereof. They start from the hypothesis that a "laissez-faire" government approach to CAV regulation could create traffic issues and discuss which interventions might be most effective under certain conditions. This approach reflects much of the literature on CAV transitions and policy, which is focused on when and how governments should start creating regulations and policies for CAVs in cities (Legacy et al., 2019; Li et al., 2019; Milakis et al., 2017; Pernestål Brenden et al., 2017).

3 Methodology

3.1 Theoretical Framework

This research is theoretically underpinned by a combination of transition management (Loorbach, 2010) and stakeholder theories (Caputo, 2013). The former supports the idea that the introduction of CAVs will imply a socio-technical transition that "not only entail[s] new technologies, but also changes in markets, user practices, policy and cultural meanings" (Geels, 2010, p. 508).The need for stakeholder engagement stems from the fact that, when new technologies are emerging but still not implemented, such as the introduction of CAVs, their implications for society are connected to the future and difficult to conceptualize in the present (Geels, 2010).

Another theoretical resource, in which this paper is grounded on, is field theory, originally conceived by Kurt Lewin within gestalt psychology and recently rediscovered by several contemporary scholars and applied in a broader context of organisation and social change (Burnes & Cooke, 2012; Cronshaw & McCulloch, 2008). This relates to the social dimension of transitions because it was "Lewin's belief that all behaviour arises from the psychological forces in a person's life space and that behavioural change arises from changes to these forces" (Burnes & Cooke, 2012, p. 412). Lewin's field theory is the underpinning theory behind force-field analysis, although its translation into the analytical technique used here has been claimed to reduce the level of complexity, or even overcomplexity, embraced by Lewin (Burnes and Cooke, 2012). To counteract this, force-field analysis is here integrated in a more composite analytical framework described in the following section.

3.2 Analytical Framework

This paper utilized a composite analytical framework which uses force-field analysis as a mapping technique of driving and restraining forces for the transition towards the implementation of CAVs, using the DPS (Drivers, Pressures and States) components of the DPSIR model (Adelfio et al., 2018). The DPS are taken from interviews with stakeholders.
Force-field analysis is intertwined with DPS as a "technique for evaluating forces affecting change" (Thomas, 1985, p. 54) in relation to their positive and negative influence on the socio-technical transition towards the introduction of CAVs in cities.

In detail, the DPS components, where D and P can be negative or positive through a force-field perspective, are interpreted and used in the following way (based on previous work from Adelfio et al. 2018):

Drivers: they can be driving (positive) or restraining (negative) forces, and are described in terms of broadly expressed factors or processes, e.g. environmental concerns.

Pressures: related to each driver, pressures emerge in the interviews as expressions of more specific interests of different stakeholders. Some pressures related to the driving force of environmental concerns could be the need for less fuel use, shared cars easing CAV acceptance, and CAVs marketed as reducing the number of cars.

State: the State, projected into the future, is the introduction of CAVs in cities.

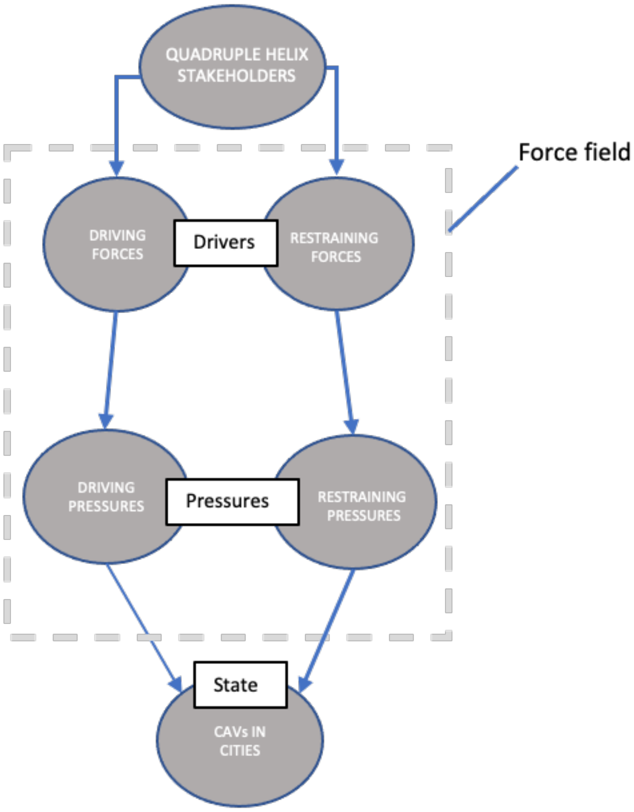

Figure 1. A simplified diagram of the composite analytical framework, including quadruple helix, force field (driving and restraining forces and pressures), and the DPS (Drivers, Pressures and State) components of DPSIR.

The stakeholders are grouped according to the Quadruple Helix, which is "an enhancement of the triple helix perspective that not only focuses on the actors from academia, government, and industry, but also recognizes the increased role played by civil society" (Hasche et al., 2020, p. 525).

3.3 Materials and Methods

This paper adopts a mixed method research approach, with a qualitative dominance. The research process goes through different steps. First, to achieve a sufficient diversity of perspectives, Gothenburg-related stakeholders have been categorized by using a Quadruple Helix Model (society, industry, academia and government), based on the model described by Carayannis & Campbell (2009).

Second, eleven semi-structured interviews were conducted covering with a diversity of stakeholder categories reflecting the Quadruple Helix. The interviewees answered questions from an interview guide, but the interviewers also followed up on topics that were uniquely salient in specific interviews. All interviews were carried out in English, though the first language of many of the interviewees is Swedish. Due to the restrictions caused by Covid-19, all interviews took place via video call.

Third, content analysis (Hsieh & Shannon, 2005) is used then to analyse the semi-structured interviews. The interview transcripts have been analysed to explore the DP components of the DPS framework, which have been described in Section 3.2.

Fourth, and lastly, after the interview analysis an online survey was distributed to an expanded list of respondents, including interviewees and additional stakeholder categories which were mentioned in the interviews. A total of 21 people submitted responses. The survey asked respondents to rank driving and restraining pressures extracted from the stakeholder interviews on a 1 to 3 scale (weak, medium, strong). This ranking served to weight the force-field analytical mapping (see Section 5.3). The descriptions of each driving and restraining pressure used in the survey are the same as those in Table 4 and Table 5.

The survey is used as a complement and to deepen the insights of the information that was extracted from the interviews, rather than a purely statistical validation of the interview data; we do not aim for any statistical significance from the survey. The data gathered from interviews was unexpectedly dense, and thus the first two sections of the survey exceeded 50 questions on the subjects of driving and restraining pressures. For this reason, in the findings, we will display the median value of each pressure to demonstrate its overall strength according to the respondents, and standard deviation to show the variation or dispersal of responses. Due to the large amount of information, the full results of survey are displayed in Appendix 1, while a simplified version including the most relevant data are showed in Section 5.3.

4 Context Background

4.1 Gothenburg: a city with a car-oriented tradition

Gothenburg is a city historically linked to the production of cars, mainly associated with the Volvo brand. Statistics show that Volvo Cars and AB Volvo are both the largest employers in the Gothenburg Region (data from 2017) and those reporting the largest turnover in 2016 (Business Region Göteborg, 2018). Despite Volvo's presence, the motorization rate of Gothenburg is lower than the two other major cities in Sweden (327 passenger cars per 1000 persons against 352 in Malmö and 361 in Stockholm), see Table 1.

Table 1: Passenger cars in use in the biggest Swedish municipalities, Västra Götaland and Sweden at the end of year 2019

Place	Passenger cars in use	Total number of cars per 1000 persons
Stockholm	352 138	361
Malmö	120 967	352
Göteborg	189 565	327
Västra Götaland Region	789 311	458
Sweden	4 887 904	474

(Trafikanalys, 2020)

In 2014 The City of Gothenburg created a transportation strategy for the city with the target year 2035. The *Gothenburg Transport Strategy for a Close-Knit City* covers a range of transportation-related measures, including increasing public transportation use so that it makes up 55% of motorized trips (Helleberg et al., 2014). The city started measuring the breakdown of trips by private car, public transportation, bicycle and on foot in 2011. Since then, public transportation has increased by approximately 33% to become 30% of total trips. Table 2 shows the breakdown between different forms of transportation for trips to, from, and within Gothenburg (Trafikkontoret, 2019).

Table 2: Percentage of different transportation modes out of all the trips taken in, to, and from Gothenburg.

Transport mode (% of total number of trips)	2011	2019	2035 goal
Car	48%	43%	29%
Public Transportation	25%	30%	36%
Bicycle	5%	7%	12%
Pedestrian	22%	21%	23%

Figure redrawn from (Trafikkontoret, 2019)

The *Gothenburg Transport Strategy for a Close-Knit City* makes a passing mention of CAVs, but they are not explicitly stated as a tool for helping to reach the 2035 goals. Since 2014, however, the city of Gothenburg has been involved in a number of projects that examine potential effects of CAVs (see Table 3). These projects are diverse in scope, some relate specifically to freight, others to liveable neighbourhoods, and others to completely digitalised solutions to CAV regulation. Taken all together, this shows that the City of Gothenburg is emphatically engaged in developing plans for CAV use in Gothenburg.

Perhaps the most well-known of these is a project called Drive Me, which included many partners, but was best known for being a collaboration with Volvo Cars that aimed to loan families in Gothenburg self-driving Volvo cars and observe their travel behaviour (Rothoff et al., 2019). Drive Me did not reach as many families as originally planned and the level of automation was less than planned (level 2 instead of level 4). Volvo Cars presented the results from the project in spring of 2020, stating that most of the findings were safety-related (SAFER, 2020).

Another finished project that focused on CAVs in Gothenburg was CoEXist. The “Shared spaces” use case examined the potential traffic effects if last mile service were to be implemented in Kungsportsplatsen, a square in the city centre where cars, pedestrians, cyclists and other forms of travelers share the area. The simulation showed that CAVs could take longer than conventional vehicles “to cross a shared space, due to the speed limit compliance that is assumed for [CAVs] but also due to their ‘passiveness’ in comparison to a conventional car”(CoExist, 2020, p. 19). But the simulation also showed that pedestrians would not experience much difference compared with today’s traffic, since they are given the right of way in situations with and without CAVs (Ibid).

Table 3: CAV-related projects related to the City of Gothenburg.

Project name	Start	Main Partners
AD Aware Traffic Control	2016	Ericsson, Carmenta, Swedish Transport Administration
Drive Me	2017	Volvo Cars
Coexist	2017	VTI, and more
Virtual Reality Lab in Gothenburg	2016	Drive Sweden, RISE, Vinnova
DenCity	2016	Vinnova, Closer, RISE, Swedish Traffic and Public Transport Authority, and more
Digitalized Infrastructure - Environmental and Speed Zones	2018	Volvo Cars, AB Volvo, Scania
NordicWay2	2018	Public and private actors in Finland, Norway, Sweden and Denmark
S3: Shared Shuttle Services	2017	RISE, and more

(Göteborgs Stad, 2020)

5 Empirical Work

5.1 Stakeholders

The empirical work section shows the interview and survey results. The driving and restraining forces and pressures presented are extracted from the interview transcripts based on the application of the DPS model. It is important to know which stakeholders identify different driving and restraining forces and pressures, because future analysis can be done in future research on the levels of legitimacy, urgency, and power of each stakeholder (Mitchell et al., 1997), using the same interview data. In the following section Table 4 and Table 5 display the connections between driving and restraining forces, pressures, and stakeholders. The following stakeholder types were identified in the interviews as being relevant in this context:

- Car user (passenger or driver)
- Car producer (individual companies)
- Car industry
- Mobility users who cannot drive
- Generic citizen
- Public transport provider
- Private transport provider
- Private transport driver

- Land owner
- Land developer
- Urban planner
- Politician
- Mobility consultant

6 Analysis and Findings from the application of the DPS model

6.1 Driving forces and pressures

In the interviews the following driving forces were identified: environmental concerns, market economy, technological advance, urban planning, politics and policy, health, and socio-cultural habits.

The driving pressures, related to each driving force, emerge in the interviews as expressions of interests of different stakeholders such as companies, environmentalists, citizens, or authorities. Therefore, the terms interest and pressure are used as synonyms in this section.

Table 4 summarizes the driving forces, associated driving pressures, and associated stakeholders. In this section, each interviewee is connected to their quadruple helix category, but not identified in a more granular stakeholder group (like those described in the previous section) in order to preserve anonymity.

Environmental concerns

Within the environmental concerns as a driving force, the pressure to reduce fuel consumption comes from both car users and the car industry. CAVs could do this by potentially driving slower and more smoothly as compared to human drivers, with one interviewee pointing out that "[CAVs] will not speed or accelerate very rapidly" (Interview 8, Industry).

Another pressure is exerted by environmentally concerned citizens. Here one interviewee suggested that CAVs as shared cars would be more accepted by "people concerned about the environment of citizens and our sustainable neighbourhoods and cities because if every person should have its own self-driving vehicles, then it's not the right way, in my personal opinion, to reach a sustainable society" (Interview 10, Industry). Another interviewee highlighted that existing shuttle bus pilot projects could be considered shared rides, so "if we can leverage the head start of shared rides, that might mitigate against a lot of the negatives associated with if just everybody who drives a regular car swaps it for a private AV" (Interview 3, Academia).

Among citizens, a pressure with positive environmental effects is expressed by those who are inclined to replace cars with a mix of travel modes for economic reasons, for example "people who are on the edge of trying to choose to save a lot more money and engage in biking … that would be a group that should have a vested interest in either the AV shuttles... and in some combination with the AV taxis" (Interview 3, Academia).

Market Economy

The market economy system emerged clearly as a major driving force. In this case, market economy as force is expressed as market capitalism in a broader sense involving supply and demand of products, profit seeking and accumulation of wealth.

Particularly relevant as an expression of pressure are "companies, of course, if wanting to produce the cars" (Interview 1, Industry). One interviewee mentioned an event where car industry actors were asked "how many of you are working on a product you want cities to buy?" (Interview 3, Academia) and every person raised their hand. Therefore, it is reasonable to assume that the car industry is a source of pressure and has an interest in collaborating with local authorities to facilitate CAV introduction.

One specific part of this is the interest from the car industry in adapting streets to CAVs, since, for example "if you look at the experiment of Volvo, currently ongoing, it is limited to certain streets because they're the streets that are relatively simple to manage from a technology point of view" (Interview 4, Civil Society).

The pressure from the car industry is also expressed through marketing and advertisement techniques as commercials shape the imagery of CAVs. One interviewee even mentioned that "it's quite hard to separate how I envision them from the commercials" (Interview 7, Government).

Another pressure is represented by mobility companies who stand to gain from CAV development, such as "Robo taxis, mobility as a service (MaaS) fleets … it's really the companies that have most of the interest" (Interview 3, Academia). For MaaS providers, the "financial benefit is if you pay wages to your cab driver or to your bus driver or to your lorry driver and you can replace them with technology" (Interview 4, Civil Society).

In the countryside, the interest of developers and property owners can be a source of pressure as cheap land away from the city centre can become more accessible with CAVs. One interviewee put forward that "I think it will be inevitable that private interests buy cheap land outside of cities" (Interview 1, Industry), as CAVs make longer car travel easier.

Technological advance

When considering CAVs an expression of technological advance, one pressure is exerted by the possibility for "more effective with parking and driving closer – the vehicles can get closer to each other" (Interview 1, Industry). This pressure comes from car users, who stand to gain in terms of time and reduced stress if they no longer have to park their own vehicle, and property developers who may be able renovate or redesign parking garages to be smaller and use the excess space for other purposes.

Another expression of interest from a user perspective constituting a pressure is that CAVs "tend not to take larger risks as humans do, when they drive … so they expect to not be involved in as many accidents as humans" (Interview 8, Industry).

A specific pressure comes from IT industry, where much of the technology development for CAVs started. As one interviewee phrased it: "The IT industry really kicked all this off. There were already plenty of folks in computation, working on mapping and they kind of said, 'hey, we've got enough infrastructure in the computation field. We think we can really make driverless cars happen' " (Interview 3, Academia). The IT industry has historically been interested in creating a partnership with car industry, and "that's where an amazing amount of money and human intelligence effort has gone" (Interview 3, Academia).

A rather surprising pressure that emerged is that citizens tend to take for granted that new technology is necessary and useful, and daily routines should be adapted to use that new technology rather than the other way around. This was expressed by the interviewee as:

"Instead of having the technology that's new and then making up the need for it… what does the city need or what does its people need and then what is the role of autonomous vehicles?" (Interview 6, Industry).

The emergence of electrification of cars represents another pressure towards the introduction of CAVs. In fact, those actors involved in electrification of cars can also have an interest in CAVs, as emerging from in the interviews, in which electrification of CAVs is deemed as positive from an economic perspective but also leading to quieter and cleaner city centres. As this interviewee said: "there's so much economic sense for [CAVs] to be electric, but that might take some time before they really all are, but if they all are electric, that means that the denser parts of cities will be quieter, have less emissions and suddenly, our urban streets will be so much more liveable" (Interview 3, Academia).

Urban planning

Urban planning as a driving force is related to multiple stakeholders exerting different types of pressures. One example is consultants that support local government in understanding the role of CAVs in city mobility. One interviewee explained how consultants "could do more projects like we've already done like helping cities develop a strategy on how they should react to these kinds of vehicles and how they should plan for them and benefit from them" (Interview 6, Industry).

Town planners of rural areas can be also interested in the introduction of CAVs. The question of rural areas and the need for more viable public transport is linked both to market economy as driving force but also to urban planning in a broader sense, including mobility. In fact, rural areas for which public transport is not economically effective, "could have self-driving mobility service systems" (Interview 6, Industry).

Lastly, those actors involved in CAV pilot studies exert pressure towards introduction of CAVs. The interviewee mentioned that "One thing that's already happening in this city is gaining knowledge from these pilot studies" (Interview 6, Industry).

Politics and policy

Sometimes intertwined with urban planning, politics and policy issues also emerged as a driving force per se. In particular, politicians are an expression of pressure as they enable CAV introduction in cities. One interviewee stated that "[city bureaucrats] also have, as a response to the wishes of all our politicians, independent or whatever political party they represent, we produced this strategy for how we, as an administration, will work with electrification, digitalisation and automation of the transportation system over the next coming three years" (Interview 9, Government).

On another political level, "the Swedish government has supported the car industry for a long time because they're very dependent on them (…) and at the same time, making people drive less because it's bad for the environment and for health…" (Interview 6, Industry).

Moreover, the car industry has historically been reliant on local authorities to create the infrastructure for mobility, so their pressure will impact on local authorities as enablers of a transition towards CAVs implementation: "The traditional car industry, if you call it that, they have been very reliant on governments and cities building infrastructure to make people having to buy a car to survive … so governments and planners will still be powerful actors in this transition" (Interview 6, Industry).

Those authorities that are keen on periodically upgrading infrastructure, are also exerting a positive pressure towards the introduction of CAVs. The latter is facilitated by "the quality of their infrastructure and the likelihood of their continued investment in infrastructure" (Interview 3, Academia).

Health

The question of health was mentioned with regards to the ongoing Covid-19 pandemic, which can also be a source of pressure. For instance, autonomous vehicles can give necessary adaptivity during health crisis situations. One interviewee spontaneously brought up the Covid-19 pandemic, saying "I was just reflective of how that will impact [the introduction of CAVs], the total that drive and the public transport, that goes in different directions, right?" (Interview 2, Industry), meaning both that the pandemic could cause more people to use private cars, but if there was a need for different public transportation patterns (e.g. more frequent busses so that there could be fewer people on each bus), CAVs could help facilitate that need.

Public transport drivers have been mentioned as they can feel unsafe in a pandemic. Moreover, “that’s a whole lot of discussion of how any form of shared rides, really, how does it adapt to the virus and even still, post virus, if people continue to feel pretty nervous about it for quite some time” (Interview 3, Academia).

Socio-cultural habits

Society and social culture constitute a major driving force. Within the group of users that can be interested in CAVs, those who are accustomed to using cabs or public transit as driven by someone else, they could be prepared for CAVs because “in terms of services, it’s nothing new because we already have taxis and public transport” (Interview 4, Civil Society).

Time saving convenience is also a reason for individuals to be interested in CAVs since while the car is moving, “you can do other things, as a single person” although there can be “a big risk that the autonomous self-driving vehicles could lead to extensive use of single person transport because it becomes very convenient and you don’t lose any more working time or leisure time while being in transport” (Interview 5, Government, Academia and Civil Society).

Other types of interests stem from diverse kinds of demands of societal groups. For instance, “People living in the central areas would have an interest in that they could use a car when they need to and not have to own one” (Interview 6, Industry).

Other groups exerting pressure are represented by “groups in society that would like to have new cars, flash and shiny with the new kind of cars and vehicles” (Interview 7, Industry) .

Mobility users who are not able to drive could exert a pressure towards CAV, since “one third of the population, approximately, can’t drive, they’re too young, too old, too disabled, they’ll have an enormous interest, I think, in autonomous vehicles of any kind, especially the private” (interview 3, Academia).

Finally, a more complex type of societal pressure stems from multi-stakeholder collaboration, including different levels of government, academia and industry, all working together on vehicle legislation and new regulatory systems. This can be summarized by one of the interviewees who said: “In Sweden, we work very much with the vehicle legislation work, both within the United Nations Economic Commission for Europe regulatory work, but also in the EU and we also have discussions and meetings together with (…) the Swedish Transport Agency” (Interview 8, Industry).

Table 4: Driving Forces, Pressures and key stakeholders.

Driving Force	Driving Pressure	Key Stakeholders
Environmental Concerns	CAVs expected to drive smoother and slower, using less fuel	Car User, politician
	Car sharing would make CAVs more acceptable for environmentally-sensitive people	Generic citizen
	People selling their cars and using shared CAVs	Car user
Market Economy	Economic interest of car producers	Car producer
	Interest from Mobility-as-a-service providers e.g. car sharing companies, Uber... (saving money by not paying drivers)	MaaS provider
	Promotion and marketing shaping idealized, futuristic imagery of CAVs	Car producer
	Cheap land away from city centre can become more accessible with CAVs (attractive for land owners and developers)	Land developer, Land owner
Technological Advance	Expected efficiency advantages with self-driving and self-parking technology	Car producer, land developer?
	Expectation of improved safety with CAVs	Car user
	IT industry interested in partnership with car industry	IT industry, car industry
	New technologies' (such as CAVs) usefulness taken for granted	IT industry, car industry, car user
	Electrification of cars helps CAV promotion (as it provides multiple benefits for CAVs such as energy efficiency, money saving, less noise)	Car producer, transport provider, car user
Urban Planning	Mobility consultants supporting local authorities shape visions for the mobility of the future	Mobility consultants
	Need for improved mobility in rural areas (public transport not currently economically efficient)	Urban planners
	Pilot studies are being conducted which anticipate CAVs introduction	Multi-stakeholder
Politics and Policy	Politicians need to understand the implications of CAVs in cities	Politicians
	Government economically dependent on (or, at least, tightly intertwined with) car industry	Politicians
	Authorities with a history of continued investments in upgrading infrastructure can be more responsive when adapting to CAVs	Politicians
Health	Covid-19 exacerbating need for flexible transport	Generic citizen
	Covid-19 makes public transport drivers feel unsafe	Public transport provider
Socio-cultural habits	People using taxis and public transit are prepared for CAVs, especially shared CAVs	Generic citizen
	Demand for productive use of time (work or recreation) while driving	Car user
	Some urban dwellers prefer not to own cars (and instead demand shared CAVs)	Generic citizen
	People interested in cars and new technologies in general can be interested in CAVs	Generic citizen
	People who cannot drive (e.g. elderly, disabled…) have more opportunities with CAVs	Generic citizen
	Ongoing work on legislation and regulations as preparatory work for CAVs	Multi-stakeholder

6.2 Restraining forces and pressures

The restraining forces appearing in the interviews were: technological advance, environmental concerns, socio-cultural habits, health, urban planning, market economy, and politics and policy.

The restraining pressures are also connected to a set of stakeholders and pose a series of challenges to the development and subsequent introduction of CAVs in cities. Table 5 summarizes the restraining forces, associated restraining pressures and associated stakeholders.

Technological advance

In relation to technological advance, several pressures contribute to it as a restraining force. One example is related to the user perspective, as new technologies need to be mature and safe before being introduced. An interviewee stated that “the vehicles, of course, need to be safe, secure and they also need to be trusted, both for the users, but also for other persons around in the traffic environment” (Interview 8, Industry)

There is also a security risk from the ICT developer side, given the risk of CAVs being hacked. It was pointed out in an interview that “It’s been already proven, if somebody wants to get in [digitally] and turn off the vehicle, they can do that super easily” (Interview 3, Academia).

Finally, from a city perspective, the interviewees detected the fear that cities become built around CAVs, rather than the other way around, which constitutes also a restraining pressure. The interviewees suggested that “Most cities have actually been adapted to the car technology, rather than the other way around and I think there is a certain risk that this will be repeated” (Interview 4, Civil Society)

Environmental concerns

The first example of a restraining pressure related to the restraining force of environmental concerns is that the sustainability targets of local authorities could go against the introduction of CAVs, but since the little is known yet about CAVs “it’s very important to see the environmental impact from those because the environmental impact will most likely play an important role in the political agenda” (Interview 2, Industry).

In particular, from the consumer/user side, the question of energy efficiency has emerged, phrased as such: “If the autonomous vehicles get so effective that people use them a lot, meaning you see more energy, then we have to produce more energy somewhere” (Interview 1, Industry). Furthermore, the interviewees also underline the risk of having electric CAVs due to an increase of energy demand, stating that “…even if we go for electrical, we have to produce the electricity in some way” (Interview 5, Government, Academia and Civil Society).

From the perspective of local authorities, environmental quality norms in cities can represent a restraining pressure, especially if CAVs are not electric. One interviewee mentioned that "We still have some challenges in the City of Gothenburg, at least, to the local environmental quality norms. We have some challenges, day to day, (…) and here, I think that the self-driving vehicles cannot, in themselves, contribute to an increased air quality" (Interview 7, Government)

Lastly, specific environmental concerns are expressed by those who are worried about urban sprawl. This restraining pressure was stated very clearly: "These self-driving vehicles could contribute to urban sprawl more than densification." (Interview 7, Government)

Socio-cultural habits

Society (and more specifically, socio-cultural aspects of it) functions as a driving force, delineated through a set of restraining pressures, primarily related to the car user perspective.

Other specific societal groups are mentioned as a source of restraining pressures against the introduction of CAVs. Among them, the interviewees have posed the question of people passionate for conspiracy theories: "People who often see conspiracies don't often like big corporations, monopolies, anti-technology of any kind and I think there's a part of society who would be against them for those reasons" (Interview 3, Academia). Another group that "could be against it, it could be people who are very fond of driving themselves" (Interview 5, Government, Academia and Civil Society), meaning that, among other things, these people may not want to give up the control associated with driving a vehicle.

Furthermore, another segment of the population simply dislikes automobiles per se and would certainly not contribute to a diffusion of CAVs, as detected in the interviews: "… a lot of people who don't like cars" (Interview 9, Government). The context in this particular interview was a longer discussion about a widely negative reaction from at a workshop presentation involving a car-centric plan for the introduction of CAVs.

An even more specific societal group generating restraining pressure against the introduction of CAVs is represented by elderly people, who are often reluctant or skeptical towards technology. It was suggested in the interviews that "As everything about technology, it can be harder for elderly people, to learn and to trust, of course" (Interview 10, Industry).

Finally, cycling organisations are mentioned as they do not trust CAVs to be in the street. For instance, one interviewee mentions "cycling organisations" as "you need to build trust in the society, can we trust to have vehicles running out on the street?" (Interview 10, Industry)

Health

Concerns about health have emerged as a restraining force. A restraining pressure is exerted by urbanists who associate car-dependency with public health issues. There is a specific concern that

AV may increase congestion, as stated by this interviewee: “I think urbanists, at least some of them, thinking of health issues and being stuck in cars all the time” (Interview 1, Industry). The ongoing Covid-19 pandemic could also generate pressure against vehicle sharing, interviewees noted that “when the Corona Virus showed up, I thought that maybe people won’t like to share items at all in the future, unless there is some disinfection procedure” (Interview 5, Government, Academia and Civil Society).

Urban planning

From an urban planning perspective, a restraining pressure against CAVs stems from the goal of prioritizing walking, biking and public transit. It was suggested in the interviews that it is an important urban planning goal to prioritize “towards walking, biking and public transit … so we don’t have a complete car-oriented city all over again” (Interview 1, Industry).

In general, urban development is considered to be geared more towards sharing than self-driving, this could generate a restraining pressure against the introduction of CAVs, since “The implication(s) on the urban development are far more on the sharing side than on the actual self-driving technology side” (Interview 4, Civil Society).

Finally, “what kind of streets should be designed for [CAVs] is a problem” (Interview 6, Industry), constituting negative pre-conditions and therefore, a restraining pressure against them.

Market economy

Despite its value as a propeller or driving force, the market economy can also act as a restraining force, connected to different restraining pressures. In the interviews, for instance, CAVs are mentioned as competitors with providers of public transport, so the latter can be a source of restraining pressure against them. One interviewee, while reflecting on the interests of different stakeholders, stated that “we ultimately can see that self-driving passenger cars can also be a competitor for the public transport needs” (Interview 2, Industry).

From a financial perspective, a negative pressure can stem from local authorities, “in terms of the city itself which will be an obstacle because they simply can’t afford dual infrastructure.” (Interview 4, Civil Society). It can be excessively expensive for public finance to invest in dual infrastructure for conventional public transportation and also for CAVs.

Lastly, other multiple stakeholders “must also make sure that [they] reduce the risk of mis-investment” (Interview 9, Government), meaning these stakeholders could contribute to the set of negative pressures against CAVs, if they consider CAVs in terms of risks for wrong investments.

Politics and policy

As current regulations and laws might not be suitable, the need for their adaptation can constitute a negative pressure against CAVs introduction in cities. One interview pointed out that “all of the regulations on all of this, so I think we're just still at a pretty early, early steps." (Interview 3, Academia). This causes "standardisation issues, but in terms of rules and regulation, they need to be internationalised" (Interview 4, Civil Society).

In general, the interviews have highlighted the lack of consensus on what authorities want for cities, which can be a remarkable restraining pressure. Stated clearly: "Well, there's no consensus, is there. There's not a given answer of what kind of cities we want and of course, there is a political question as well because they're different views" (Interview 4, Civil Society).

A still insufficient knowledge from local authorities constitutes a significant restraining pressure, where "[local authorities] want to know and need to know more about what does this mean for our city and our region, how can we contribute or how can we benefit from it? That's in an early phase, I would say, even in Gothenburg" (Interview 6, Industry).

Finally, there are many important ethical challenges related to CAV policy design that have yet to be resolved, "if the vehicle has to make a decision between hitting and killing a pedestrian or hurting the people inside the vehicle and possible killing them in the vehicle, which way do you want it to go?" (Interview 3, Academia).

Table 5: Restraining forces and pressures

Restraining Force	Restraining Pressure	Key Stakeholders
Technological Advance	New technologies need to be mature and safe before being introduced to users (e.g. safety concerns from fatal CAV accidents).	Car producer, car user, IT industry
	Fear of CAV technology being hacked	Car user
	Fear that cities become built around CAVs, rather than creating a liveable city and adapting CAVs to that	Urban planner
Environmental Concerns	The sustainability agenda of local authorities can go against the introduction of CAVs, as their environmental impact is unclear	Politicians and urban planners
	More cars means increased energy demand	Car producer and car user
	If CAVs are electric: Environmental movement concerned that increased electricity supply will come from fossil fuels	Generic citizen
	If CAVs are not electric: both air quality norms and climate policy could restrict the increase of CAVs based internal combustion engine vehicles	Generic citizen
	Anti-sprawl opinions against CAVs as they may encourage people to move away from dense urban centres	Generic citizen
Socio-cultural habits	Conspiracy theories and misinformation about new technologies	Generic citizen
	The group of people who do not want to give up control of their vehicle	Car user
	People who do not like cars	Generic citizen
	Elderly people who are sceptical of new technology	Elder people
	Cyclists are particularly sceptical about CAVs, in terms of safety and access to urban space	Cyclist
Health	Concern that CAVs may increase congestion	Generic citizen, urban planner
	Covid-19 pandemic and fear of shared vehicles	Generic citizen
Urban Planning	Walking, biking and public transit as planning priority, not CAVs	Urban planners
	In urban development policies the shared use of cars is deemed as more important than the self-driving aspect	Urban planners and politicians
	Streets are not currently designed for CAVs	Urban planners
Market Economy	Public transport providers see CAV as competitors, and thus want to hinder CAV introduction	Public transportation providers
	Dual infrastructure (for CAVs and conventional vehicles) is expensive	Politicians and urban planners
	Risk of investing in a technology that fails on the market (e.g. if users don't purchase CAVs or subscribe to programs that use CAVs)	Multi-stakeholder
Politics and Policy	Current international and national laws and regulations are not suitable for CAVs	Politicians
	Lack of political consensus on visions for the future in cities	Politicians
	Lack of knowledge and agreement about strategies from local authorities	Politicians
	The ethical question of who has priority when there is a risk for collision between a pedestrian and a CAV	Generic Citizen

6.3 Force field Map

The survey results showed which level of strength respondents assigned to each driving and restraining pressure, on a scale of weak (1), medium (2) or strong (3), in terms of the effect of the pressures on the introduction of CAVs in cities. Using the results of the survey, we have created a simplified forcefield map to highlight which of the 52 pressures identified in the interviews were considered to be strongest and weakest by the 21 survey respondents. This was done by calculating the median strength of each pressure to determine the centre-most level of strength that respondents assigned to each individual pressure. We then removed all the pressures that had a median value of 2, following the rationale that since these pressures are not particularly strong or weak they can be accepted as relevant, but they do not stand out.

The blue bar in Figure 1 is median value of the strength of each pressure. The standard deviation of each pressures shows how large the spread of the assigned strengths was. If the standard deviation is larger, the respondent's choices formed a larger range of assigned strengths, and vice versa. The standard deviation is represented by the whisker lines in Figure 1.

We can see that the driving pressure with the highest median value was that of interest from Mobility-as-a-Service companies (median = 3). These companies could save money by not having to pay drivers when using CAVs. The general electrification trend, and the partnership between the IT industry and the car industry, were tied as the driving pressures with the next highest median (median = 2.5). On the other side, the restraining pressures with the largest negative median value were the potential for increased energy demand from non-shared CAVs being attractive to use more than a conventional car (median = -3), and safety concerns relating to fatal CAV accidents (, median = -3).

Intuitively, one of the driving pressures with the lowest median fits well with one of the restraining pressures with the highest negative median. CAVs using less fuel (median = 1, s.d. = 0.79), is identified as a weak driving pressure, while the potential for increased energy demand (median = -3, s.d. = 0.68) is seen as a strong restraining pressure. This makes sense from an engineering perspective since CAVs are expected to reduce specific energy consumption (Wh/km) by driving more smoothly and interacting in a more efficient way with other vehicles and with infrastructure, but CAV technology will likely increase the demand for car mobility (Taiebat et al., 2018). Hence, one could argue that most respondents do not see CAVs as a way to reduce emissions, and our interpretation of this is that they believe that the demand impacts override the potential impacts of increasing the energy efficiency of the individual vehicle or vehicle system level.

It is important to remember that these survey results should be viewed as complementary to the interview data, meaning that Figure gives an idea of how the different pressures brought up in the interviews are perceived at a more general level. As was mentioned in Section 3.3, these results are not meant to be self-standing quantitative evidence of the importance and variance in pressures.

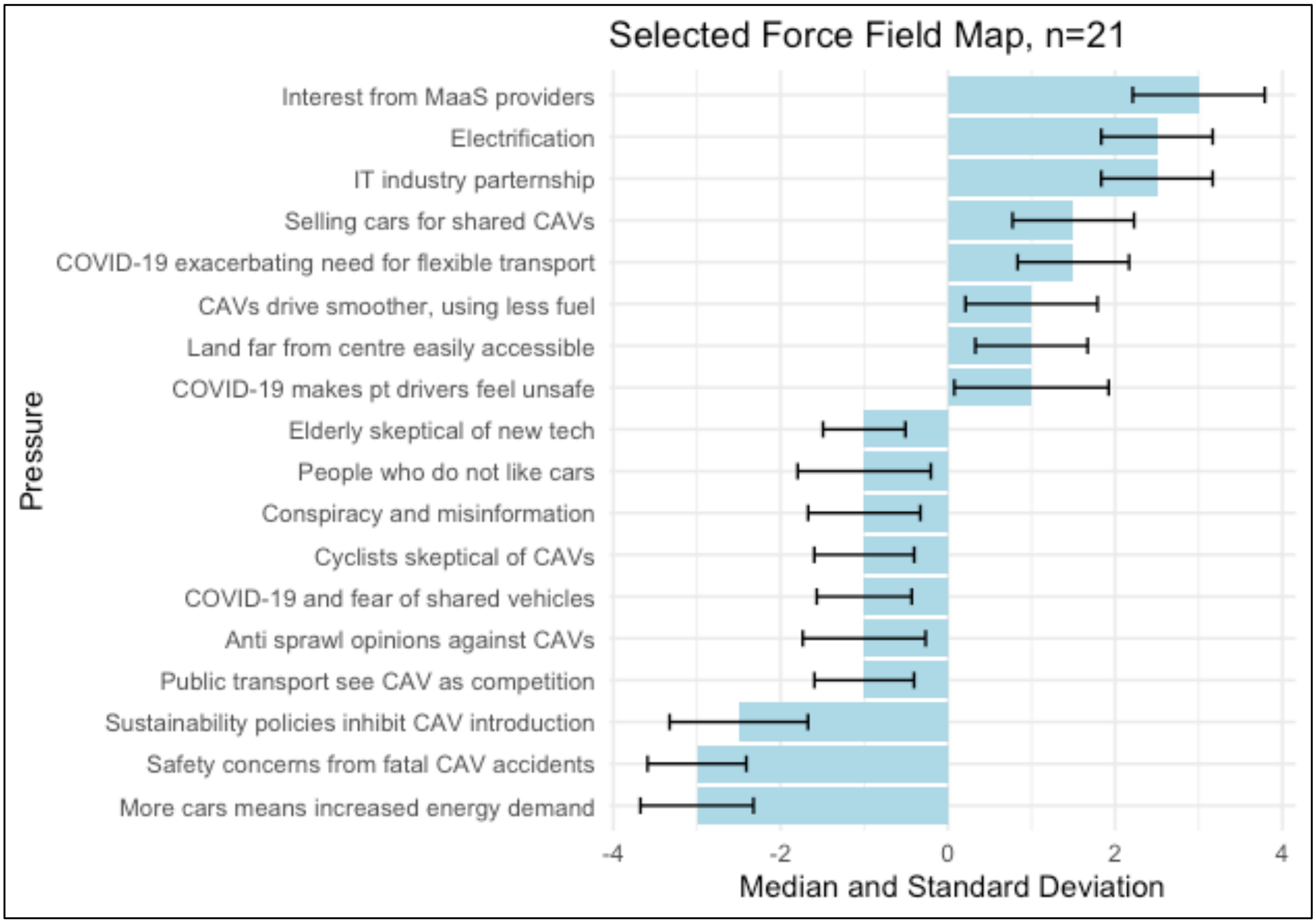

Figure 2: Selected Force Field Map showing all survey results for all pressures that did not have a median value of 2.

7 Discussion and Conclusions

This section refers back to the research questions and how empirical findings and literature contribute to the discussion.

RQ1: What are the driving and restraining forces and pressures that facilitate or hinder socio-technical transition towards the introduction of CAVs at the city level?

In general, it was clear from the interviews and survey that CAVs are not universally seen as positive, but rather that many stakeholders believe CAVs need to be connected to mobility planning and public transport strategies. This was expressed both explicitly, where interviewees mentioned specific policy actions (such as local government studies, infrastructure planning, and safety regulations); and implicitly, when they expressed worry about what could happen if CAVs are introduced without any guidance. This need for planning in other jurisdictions has been discussed at length by Freemark et al. (2019), Gavanas (2019), Duarte and Ratti (2018), and now the results of our force-field mapping show that this need is also present in the Swedish context.

An important driving pressure identified in the interviews and related to the Swedish context was an economic dependence on the car industry as being one of the largest employers in Sweden, particularly evident in Gothenburg. This is not new information, but it is important to take into consideration when analysing the forces related to the introduction of CAVs, in a similar approach to that taken by Legacy et al. (2019), where the authors compared the results of semi-structured interviews and academic literature to see if there were common concerns regarding CAV governance and planning. In our study, a common restraining pressure was a fear that Swedish cities would be designed around CAVs, as they were once designed around cars, as opposed to being designed with people in focus. This is a concern that has been brought up in literature by Lundin (2014), when examining the development of Swedish transportation and private car ownership post World War II. Dominance on the part of one actor, such as the car industry, can lead to one-sided development, which is why frameworks that reconcile private technology development, and public-led development of city planning, are important.

RQ2: What stakeholders, representative of the aforementioned driving and restraining forces and pressures, are involved in such a socio-technical transition?

The complete list of stakeholders that was identified in the interviews was discussed in the empirical work section. Within this list, there are some stakeholder types who have been discussed at length in previous academic work, for example disadvantaged people that are not able to drive (Fraedrich et al., 2016; Templeton, 2020).

Another stakeholder connection to Gothenburg, but also one that is generalizable to cities internationally, relates to the role of participants in pilot projects and involved consultancy companies that promote the introduction of CAVs. Politicians, mobility consultants, and urban planners emerged from the interviews as very active parts of an ecosystem of funding and expertise that has been created around these pilots. These pilots are also connected to the car industry, of course through the technology itself but also through the driving pressure of commercials that was identified in the interviews. This pressure was expressed as the idea that it was hard for the interviewee to imagine CAVs as anything other than how they are shown in commercials created by companies within the automobile industry. These commercials, created for the purpose of selling cars, often portray CAVs in a very positive light (Hildebrand & Sheller, 2018).

During this phase the limits of CAV technology are still uncertain, and the theoretical potential is emphasized. Drive Me (Rothoff et al., 2019) is an excellent example of a pilot that had fairly unexciting results compared to the initial expectations, but the project still served to increase awareness regarding the potential of the technology. This could arguably have had just as large of an impact as the technical findings did. Pilot projects are recognized in academic literature as being an important part of the development of CAV development, but it is important that they allow for "critical citizen engagement and participatory deliberation" (Mladenović et al., 2020, p. 258). Whether or not the pilot projects that have taken place in Gothenburg meet this threshold of citizen participation could be the basis for future research.

There are also stakeholders who are related to the socio-cultural and environmental restraining forces, who exert negative pressures against CAVs due to a variety of concerns including safety and environmental damage. Skepticism against new technology is certainly not a new phenomenon, but in this case the convergence of different stakeholders is potentially unique. Elderly people, cyclists, people who are concerned because of conspiracies related to new technology, and those who are concerned about environmental effects form quite a broad range, which encompasses stakeholders with characteristics from both the enthusiasts and the sceptics that are defined by Neilsen and Haustein (2018). It is important to note here that Neilsen and Haustein used primary data directly from the stakeholders in question, whereas the data in this study are respondent's views on these stakeholders. Nonetheless, this grouping of unlikely bedfellows could represent a new category of stakeholder who may have a significant impact on the introduction of CAVs in cities.

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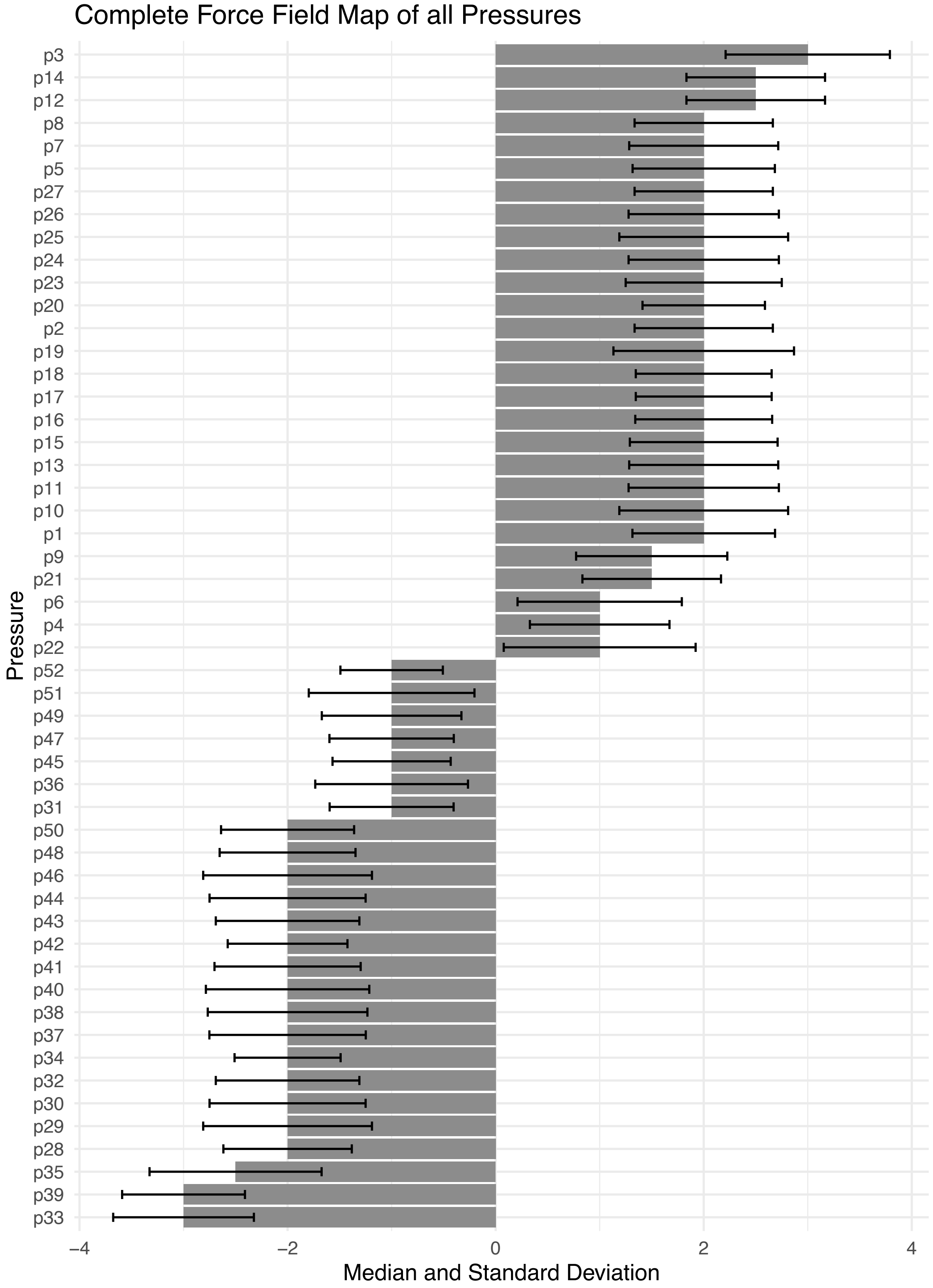
Appendix 1.


Complete Force Field Map of all Pressures
Pressure
p3
p14
p12
p8
p7
p5
p27
p26
p25
p24
p23
p20
p2
p19
p18
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4
Median and Standard Deviation

Coding for Pressures in the Force Field

Pressure Code	**Pressure**
p1	Economic interest of car producers
p2	Promotion and marketing shaping idealized, futuristic imagery of CAVs
p3	Interest from Mobility-as-a-service providers e.g. car sharing companies, Uber... (saving money by not paying drivers)
p4	Cheap land away from city centre can become more accessible with CAVs (attractive for land owners and developers)
p5	If cars drive and park further away from cities, urban parking lots can be converted into more profitable use
p6	CAVs expected to drive smoother and slower, using less fuel
p7	Car sharing would make CAVs more acceptable for environmentally-sensitive people
p8	People using taxis and public transit are prepared for CAVs, especially shared CAVs
p9	People selling their cars and using shared CAVs
p10	Expected efficiency advantages with self-driving and self-parking technology
p11	Expectation of improved safety with CAVs
p12	IT industry interested in partnership with car industry
p13	New technologies' (such as CAVs) usefulness taken for granted
p14	Electrification of cars helps CAV promotion (as it provides multiple benefits for CAVs such as energy efficiency, money saving, less noise)
p15	Mobility consultants supporting local authorities shape visions for the mobility of the future
p16	Need for improved mobility in rural areas (public transport not currently economically efficient)
p17	Pilot studies are being conducted which anticipate CAVs introduction
p18	Politicians need to understand the implications of CAVs in cities
p19	Government economically dependent on (or, at least, tightly intertwined with) car industry
p20	Authorities with a history of continued investments in upgrading infrastructure can be more responsive when adapting to CAVs
p21	Covid-19 exacerbating need for flexible transport
p22	Covid-19 makes public transport drivers feel unsafe
p23	Demand for productive use of time (work or recreation) while driving
p24	Some urban dwellers prefer not to own cars (and instead demand shared CAVs)
p25	People interested in cars and new technologies in general can be interested in CAVs
p26	People who can not drive (e.g. elderly, disabled…) have more opportunities with CAVs
p27	Ongoing work on legislation and regulations as preparatory work for CAVs
p28	Walking, biking and public transit as planning priority, not CAVs
p29	In urban development policies the shared use of cars is deemed as more important than the self-driving aspect
p30	Streets are not currently designed for CAVs
p31	Public transport providers see CAV as competitors, and thus want to hinder CAV introduction
p32	The sustainability agenda of local authorities can go against the introduction of CAVs, as their environmental impact is unclear
p33	More cars means increased energy demand

p34	If CAVs are electric: Environmental movement concerned that increased electricity supply will come from fossil fuels
p35	If CAVs are not electric: both air quality norms and climate policy could restrict the increase of CAVs based internal combustion engine vehicles
p36	Anti-sprawl opinions against CAVs as they may encourage people to move away from dense urban centres
p37	Dual infrastructure (for CAVs and conventional vehicles) is expensive
p38	Risk of investing in a technology that fails on the market (e.g. if users don't purchase CAVs or subscribe to programs that use CAVs)
p39	New technologies need to be mature and safe before being introduced to users (e.g. safety concerns from fatal CAV accidents).
p40	Fear that cities become built around CAVs, rather than creating a liveable city and adapting CAVs to that
p41	Current international and national laws and regulations are not suitable for CAVs
p42	Lack of political consensus on visions for the future in cities
p43	Lack of knowledge and agreement about strategies from local authorities
p44	Concern that CAVs may increase congestion
p45	Covid-19 pandemic and fear of shared vehicles
p46	The ethical question of who has priority when there is a risk for collision between a pedestrian and a CAV
p47	Cyclists are particularly sceptical about CAVs, in terms of safety and access to urban space
p48	Fear of CAV technology being hacked
p49	Conspiracy theories and misinformation about new technologies
p50	The group of people who do not want to give up control of their vehicle
p51	People who do not like cars
p52	Elderly people who are sceptical of new technology