Driving Without Humans

by

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Contents

Abstract

Self-driving cars may take over our urban city streets in the years to come, and this could lead to significant changes. This paper focuses on the economic impact of fully autonomous vehicles on urban cities and reviews the existing literature on the topic. The results indicate that there is no consensus in the literature on the potential impact of fully autonomous vehicles on urban cities. The outcomes are highly dependent on the assumptions made about consumer preferences, business model that is going to be implemented, and potential infrastructure costs that emerge with the introduction of fully autonomous vehicles (AVs). I also analyze the potential impact of AVs on consumers under different scenarios.

Introduction

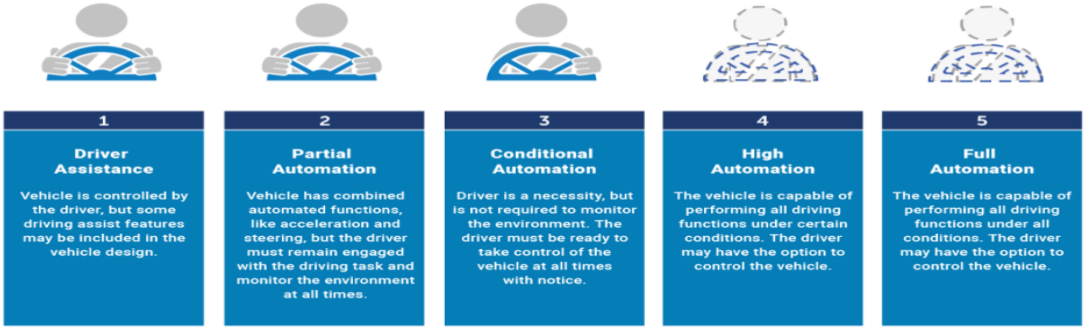
Fully autonomous vehicles also known as AVs may take over cities in the future. Companies like Tesla, Waymo, Ford, Uber and Lyft are just a few of the many companies that have taken on the challenge to achieve autonomous vehicles. Progress has been made in the development towards full automation, but its years away from being reached.

The economic impact of AVS on urban cities is the basis of this theoretical research. It is intended to find the answer of what potential economic impacts fully automated vehicles can have on urban cities. To answer this, I will explore the possible effects AVs could have on factors of land use and transportation. This paper is composed of a comprehensive literature review.

AVs are dependent on machine learning and rely on compiling large amounts of data. The more data that is analyzed, the better refined AVs become. This refinement helps to better the reliability and usability of these vehicles. The National Highway Traffic Administration also known as NHTSA, have categorized AVs into five levels of automation. Technically there is an additional level, which is level zero. But in general, it is not considered as it involves no automation. Level one and higher are the main levels considered as these are the levels that involve automation and driver aids. In level 1, the vehicle is controlled by the driver, and it may have some driving assist features. The final fifth level automation; the vehicle can perform all driving functions under all conditions (NHTSA, 2013). Image 1 provides all the levels of automation for better understanding.

Image 1 Levels of Automation

Source Automated Vehicles for Safety | NHTSA



1	2	3	4	5
Driver Assistance	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

For this research level five is the main the focus. At this level the driver is removed from operation of the vehicle, and the vehicle itself becomes a technology comprised of an array of driving systems that on their own take passengers to their desired destinations without needing human inputs (NHTSA, 2013).

As AVs develop towards level five automation, depending on how people modify their behaviors can greatly affect the sorts of impacts AVs could have on cities (Robertson et al., 2017). These impacts could be detrimental if the technology is misused or not properly implemented. Accidents have occurred as AVs are developed and serve as a reminder of how dangerous these vehicles can be. Currently, the NHTSA has about two dozen active investigations into crashes involving “autopilot” (Boudette, 2021). Incidents like these are a reminder that these vehicles need to be better understood because they can have fatal results if they are not regulated better. This potential lack of policies as well as dangerous behavioral changes leading to unsafe use of automated driver aids is beyond the scope of this research, but it is part of the development of AVs. This study is meant to help to fill in the gaps of how cities could be affected economically by using potential impacts of AV and analyze them by using economic models.

Methodology

This research is limited by the lack of empirical data. As a result of this limitation, the method is composed of a literature review comprised of studies that rely on surveys to understand consumer preferences. Also, transportation and land use models are referenced as part of the literature review. Predictions and results of the studies are affected by the assumptions made. This study will look at the effects that AVs could have on factors of transportation and land use which will be covered in the literature review found in the Literature Review section. Followed by the Economic Analysis section. This economic analysis will be done by applying the expected impacts of AVs from the literature review and seeing how they can affect consumer preferences through a supply and demand model interpretation. As well as consumer choice models to see how two different assumptions lead to different outcomes.

Literature Review

Transportation

Transportation serves as the lifeline of urban cities. To grasp the impact AVs could have on urban cities, understating how they could change transportation is key. In the future AVs could revolutionize transportation by making it more accessible. People who may not have access to car travel like the elderly or children may benefit from AVs (Meyer et al., 2017). These groups of users may choose AVs as their main form of travel once automation is reached. The reason for this change could be that currently there is a minimum age to drive, or if one does not have the ability to drive like the elderly or impaired it limits vehicle travel. Public transportation does allow for travel, but it is not as convenient. In the future having a greater ease of use could lead to AVs changing how people get around. These changes in transportation brought on by AVs could impact peoples traveling habits and things like their preferences of where to live.

Another way how AVs could influence transportation is by helping to lower cost of travel. This decrease of cost could be attributed to financial burdens like sunk capital and cost of insurance lowered (Meyer et al.,2017). This cost decrease can result from removing humans from driving. When tedious tasks become automated, this can lead to better efficiency and help lower costs. This lowering of transportation costs could also be attributed to economies of scale. As AVs have a larger presence potentially the cost of manufacturing these vehicles might decrease costs and lead to economical transportation.

Accidents

AVs could impact costs of transportation by decreasing the number of accidents (Hawkins, 2018). The NHTSA reports that, injuries are rooted in one critical and tragic fact: 94% of serious crashes are due to human error. Reduction of accidents could be a benefit of this technology. In the year 2019 there were, 36,096 people killed in motor vehicle crashes. The NHTSA conducted a study that reported that motor vehicle crashes in 2010 cost $242 billion in economic activity, and $594 billion due to loss of life and decreased quality of life due to injuries. Accidents cause a strain on the economy that could be minimized with AVs. It would be too strong of a statement to say no accidents would occur once AVs reach full automation. A better and more conservative prediction is that they will decrease the number of accidents which in turn might have positive economic impacts on urban cities. A decrease in the number of accidents may lower costs of transportation.

Trucking Industry

AVs could influence both public and private sectors. As reported by Statista the trucking industry is responsible for most of the overland freight movement in the United States, the market size was reported a worth of $791.7 billion by Statista in 2019. Statista also reports that there were 947,000 truck drivers employed in the U.S, which is less than the industry requires. AVs may be seen as a possible solution to these shortage of truck drivers. But studies on the impact of AVs on this job sector may overestimate the impact of AVs on trucking due to an overestimation of the impacts AVs could have. Also, it could be a result of misrepresentation of the job classification of the different types of truck drivers (Gittleman et al., 2020). This misrepresentation leads to confusion as to what different class of truck drivers do as part of their job. AVs may be seen as completely replacing truck drivers but that may not be the case as truck drivers do far more than driving (Gittleman et al., 2020). Nearly 63% of a heavy trucker's job could be comprised of non-driving tasks like freight handling, safety, equipment operation, paperwork, and customer service (Gittleman et al., 2020. These roles that truck drivers are responsible for outside of the driving makes it difficult to determine how AVs could affect this job segment. As AVs could probably make the driving more efficient but may not be able to fully replace the responsibilities of truck drivers.

The conclusion of Gittleman et al. (2020) suggests that at least for now any loss of jobs because of automation will be more limited than expected (Gittleman et al., 2020). A similar impact was reached by Beedee et al. (2017) in their study that revolved around the employment impact of AVs. Their conclusion was that as AVs are adopted by businesses it will be crucial to; understand and track the knowledge of these occupations. This will help indicate the extent of which AV technology will serve as a substitute for labor. Alternatively, AVs may serve to complement labor. This could be due to changing the importance of other work activates outside of driving by those workers (Beedee et al., 2017). It appears that more reserach is needed into this labor segment to understand how AVs will affect it.

The effect of AVs on the trucking industry, and the impacts AVs could have on jobs could be a topic on its own. It seems like AVs could affect the trucking industry and potentially lead to some job loss. This is unclear as some of the jobs in the trucking industry are highly skilled and are composed of much more than just driving. It can be foreseeable that AVs could lead to a more efficient trucking industry. This because of AVs serving to help deliver goods by helping with the driving aspects of trucking. It is unclear how much of an effect they would have on costs being that they can take on some of the responsibilities of truck drivers. It is unclear to what extent they can impact the labor force, being that new jobs may have to be created. These jobs would possibly be needed to adress the aspects of the deliveries that cannot be automated. These new jobs could offset the cost decrease from AVs being implemented to the trucking industry.

Business Models

The projections of how AVs could be implemented varies and may change over time. The two prevailing business models as to how AVs could be implemented are shared autonomous vehicles (SAVs) and Private Autonomous vehicles (PAVS). These two business models can then be further broken down into different forms of implementation. This reserach will only focus on these two main business models. SAVs are predicted to operate like a self-driving taxi system.

While PAVS could resemble the current conventional vehicles that we have today, but the business model would be replacing them with AVs (Zhang, 2018).

SAVs

SAVs could have the potential of lowering the cost of transportation in urban cities. For some insight into this outcome a study by Kreuger et al. (2016) conducted a survey of 435 residents of a major metropolitan area of Australia. They concluded that variables like travel time, waiting time and fares heavily impact use of SAVs (Krueger et al., 2016).

PAVs

PAVs appear to be less efficient as they potentially lead to a smaller reduction in the number of vehicles to suffice the travel demand (Zhang et al., 2018). If the demand of vehicles decreases only by a marginal amount it could potentially diminish the impacts of AVs as this would not be much different then how current conventional vehicles are used.

The potential impacts either PAVs or SAVs have can be attributed heavily to the preference of the public (Krueger., 2016). It seems that to maximize the effects of AVs, the business model to operate in urban cities should be SAVs. The intuition behind this, consists of looking at the market growth of ride-hailing and taxi segments in the past years. As reported by Statista, in the United States the ride-hailing and taxi segment has steadily grown in the past few years. Users have grown from 91.5 million users in 2017 to 95.1 as of August 2021. Users are projected to grow up to 96.9 million users in the year 2025. This growth of ride sharing and an increase in the use of ride-sharing services points to acceptability of the public towards ridesharing and potentially a preference towards SAVs. Such market growth may be attributed to the effect of Covid-19 and the inflated prices of vehicles due to shortages across multiple industries. But typically, those who live in cities do not own their own personal vehicles because of the associated costs that come with them.

One way to understand the outcomes that may result from these two business models would be to look at vehicle miles traveled also referred to as VMTs which will be addressed in the next section. This serves as a comparison between the two models as it can be used to theoretically calculate a numerical difference between PAVs and SAVS.

VMTs

The impact of AVs on vehicle ownership and vehicle miles traveled could depend on the implementation of SAVs or PAVs (Zhang., 2018). It appears that AVs might increase VMTs along with reductions of the public transport. This may occur when PAVs or SAVs without a ridesharing and a high reduction in the value of time are assumed (Soteropoulos et al., 2018).

The relationship of AVs on VMTs has only been able to be theorized. Harb et al., (2018) conducted an innovative study to adress this limitation and provide insight. This study is different from most on AVs because instead of running hypothetical scenarios they conducted a naturalistic experiment. This was done to help mimic a potential world of self-driving cars and see how their users would adjust their choices. This approach is meant to project the participants into a world of self-driving cars. They did so by providing 60 hours of a chauffeur service to each of the 13 participating households from the San Francisco Bay Area. This provided service was meant to be used within a seven-day period. The sample of this study was small, but it provides real data from people adjusting their behavior in their everyday lives. The experiment attempts to understand the potential changes in the travel behavior of their subjects. These subjects were drawn from three cohorts: millennials, families, and retirees (Harb et al., 2018). This study could only do so much to simulate a future of AVs for the participants. Harb et al., (2018) did their best to educate both the participants of the study and the drivers from chauffeur service to create as close of a representation of this distant future in our current day. They did run into some issues during the study like people not maximizing the use of the service out of guilt of bothering the drivers or sending them on mundane tasks (Harb et al., 2018).

The main results showed an increase of 83% in VMTs. Also, that participants of the study when provided with chauffeur service weren't only willing to travel longer distances at later times of the day. Also, they did not have to worry about being tired or having to drive through rush hour traffic (Harb et al., 2018). These results were seen across the different age groups of the participants. The outcomes of this small sample size study can provide an opportunity to see how people's behaviors may change when using AVs. The results of this study also line up with the general overall trend seen in other studies which is the increase of VMTs as people would be willing to travel more.

This trend towards willingness to travel more because of AVs possibly making travel more convenient can be better understood by looking at the concept of utility. Which is the subjective personal benefit people may derive from being able to focus on other things on their commute instead of worrying about driving.

Utility

Marginal utility in the field of economics refers to the additional satisfaction, or benefit that a consumer obtains from buying an additional unit of a good or service (Britannica, 2016). Measuring the additional utility consumers gets is subjective being that we have different preferences. This measurement of subjective value can directly tie to how people's preferences may shift towards using AVs as their preferred mode of transport within urban cities.

An increase of utility may seem like a possible impact of AVs. This increase satisfaction could be derived from being relieved from driving. which is a labor-intensive and tedious task, but also ensure their safety (Rui Fan et al., 2018). This possible gain in utility may affect the value of time also known as VOT. This gained utility from travel could possibly lead to an acceptance of longer commute times and again reinforcing the idea of an increase in VMTs. A decrease in VOT, could lead to a greater preference towards AVs and a decrease preference for other modes of transportation (Dias et al., 2020). This possible connection between user utility and preference of transportation mode could impact the transpiration in urban cities in the future.

Impacts of automated vehicles on travel behavior and land use

Research on AVs can become overwhelming and confusing. This being a result of studies having very different assumptions and varying results. In the process of compiling research for this study I came across a study by Soteropoulos et al. (2018). In their study, they compiled 37 modelling studies originating from the U.S.A (20 studies), Europe (14 studies), Asia (2 studies) and Australia (1 study) and spanning from 2013 to 2018.   Table 1 (see Appendix 1) summarizes the existing literature on the impact of AVs on travel behaviors and land use. The table provides the methodology, the assumptions as well as their results. Despite the studies being looked at in this table having different assumptions a general pattern can be seen. The different assumptions include investigating the impacts of PAVs, others only focus on SAVs, while other studies may study a mix of both business models. The consensus among the different studies in the table is that travel behavior changes due to AVs will lead to VMTs to increase (Soteropoulos et al., 2018).

Although, there may be a consensus that can be reached it is still not possible to quantify the travel increase. Again, the assumptions made, have an impact on the effects of AVs on cities. For example, in some cases if PAVs are to be assumed the number of hours spent traveling may increase. It is possible that there could also be a decrease in parking costs when high market shares of AVs are assumed. From Table 1, it was concluded that the studies focusing on SAVs mainly reported that SAVs could lead to an increase in VMTs due to empty trips and migration effects from other modes. It was also concluded different results are strongly dependent on model assumptions. Even more importantly different model assumptions could lead to overestimations (Soteropoulos et al., 2018).

This table helps exemplify how studies can different assumptions as to what effects AVs may have. For example, in contrast under an assumption of SAVs, in a study by Childress et al., (2015) concluded vehicle hours traveled could be reduced if they are accompanied with a high cost and there is no possibility to use PAVs. Model assumptions do affect the outcomes.

The study Soteropoulos et al., (2018) is of great reference for those looking into insights of the potential impacts this technology can have. This table can help easily visualize how different the outcomes can be, based on the assumptions made in the studies. Despite such differences it can be foreseeable that there is a trend towards longer distances being commuted, meaning a possible increase in VMTs.

Land use

Urban cities are composed of complex ecosystems. Currently, there is much that could influence the sorts impacts that AVs could have on land use within urban cities. Urban sprawl seems like the likely outcome as a consequence of AVs. This outcome would likely be due to more efficient travel and potentially an increase of capacity of current roads (Hawkins et al, 2018).

AVs implementation could lead to major changes in the everyday life of those living in urban areas as people might be commuting longer distances, and this may impact the demand for land in urban cities. (Larson et al., 2017).

Land use for Parking

AVs could affect the amount of land allocated for parking. This as a result of AVs influencing the amount of space needed for parking and the layout of parking spaces themselves. AVs effect on the land used for parking can vary depending on of businesses model used. If PAVs area assumed, the decrease in land used for parking may only decrease by a marginal amount. In contrast, under a very ambitious prediction SAVs could reduce land use for parking spaces up to 90% (Soteropoulos et al., 2018).

AVs may not only change the amount of land used for parking but will need to have these spaces redesigned, so they become better suited for AVs instead of human drivers. For example, currently most parking lots are underground parks, where the GPS signals are weak or could be lost (Othman, 2021). This may lead to having to come up with better locations for parking spaces or other technologies. Othman. (2021) mentions that parking spaces may need to be retrofitted with technology to avoid this issue, and such innovation and redesign of parking spaces may be costly.

A possible positive benefit that AVs might have on the land used for parking spaces is that there might not be a need to have as much door space needed for the vehicles and this could lead to 20% more free space (Othman, 2021). This could be a positive impact of implementing AVs as it could reduce the size of these spaces needed to park vehicles. Also, there could be a positive impact on consumers' utility who use AVs. Once spaces are redesigned for AVs rather than human drivers the occupants of the vehicles would not have to worry about finding parking spots. This could be more efficient for the users as this could save them time and effort when commuting to places.

A potential negative impact of AVs that might need be considered is that the redesigns of these spaces could be costly. AVs could be influential on the use of land in urban cities due to their impact on parking space. More research is needed to have a better measure of these effects. AVs impact on the land used for parking is part of the bigger picture, which would be the infrastructure within cities.

Infrastructure

As a result of people willing to travel longer distances and travel preferences shifting towards vehicle-based travel in cities. Urban cities infrastructure may be impacted. Research on the topic of physical infrastructure needs for AVs is in its infant stages (Othman, 2021).

Pavement might be an integral part of the infrastructure of cities that could be affected by AVs. AVs should operate with a high level of accuracy Othman. (2021) which means that AVs could accelerate the deterioration of pavement. This could be a likely outcome if AVs were to operate at a level where their path of travel would be uniform as if they were a train on rails. This constant pressure and weight over one specific path could lead to rutting, and cracking under such constant pressure. Such an impact could be costly as pavement may have to be constantly maintained or possible might need to be reinforced to handle such traffic flow and stress (Othman, 2021).

Another possible impact that AVs may have on the infrastructure of cities would be a need for a redesign of traffic signs and markings as pointed out by Othman (2021). Things like lack of highly visible curves, speed limits, signage, may have to be addressed for AVs to safely complete the tasks of driving. Navigation and signing techniques may not support AVs navigation. This may lead to having to redesign parts of the current infrastructure which can be costly.

AVs impact on the physical infrastructure of urban cities could have major impacts as it would change what cities may look like. Considering all these possible changes that would have to occur to accommodate AVs. The follow up question might be who will pay for these changes of the infrastructure. Possible these costs could be passed on to the consumers through taxes and maybe trough high costs of fares. Like some of the other sections covered in the literature revies there are too many unknown variables to have one specific outcome. But it seems like there is a potential for costs to be higher for those who commute via AVs rather than other forms of travel. This would contradict the intuition that AVs will make travel more efficient and decrease commute costs. More research would be needed to reach any conclusion, but these contradicting points could be analyzed using economic models gain some intuition.

Economic Analysis

Literature Review Findings Analysis Using Supply and Demand Model

The impact AVs could have on the trucking industry could be analyzed through a supply and demand model. Based on the findings in the literature review, AVs could affect the trucking industry. Drivers may not fully be replaced as their jobs consist of other responsibilities. But the driving itself could potentially become automated which could lead to greater efficiency. This greater efficiency could cause a decrease in cost for the producers of goods.

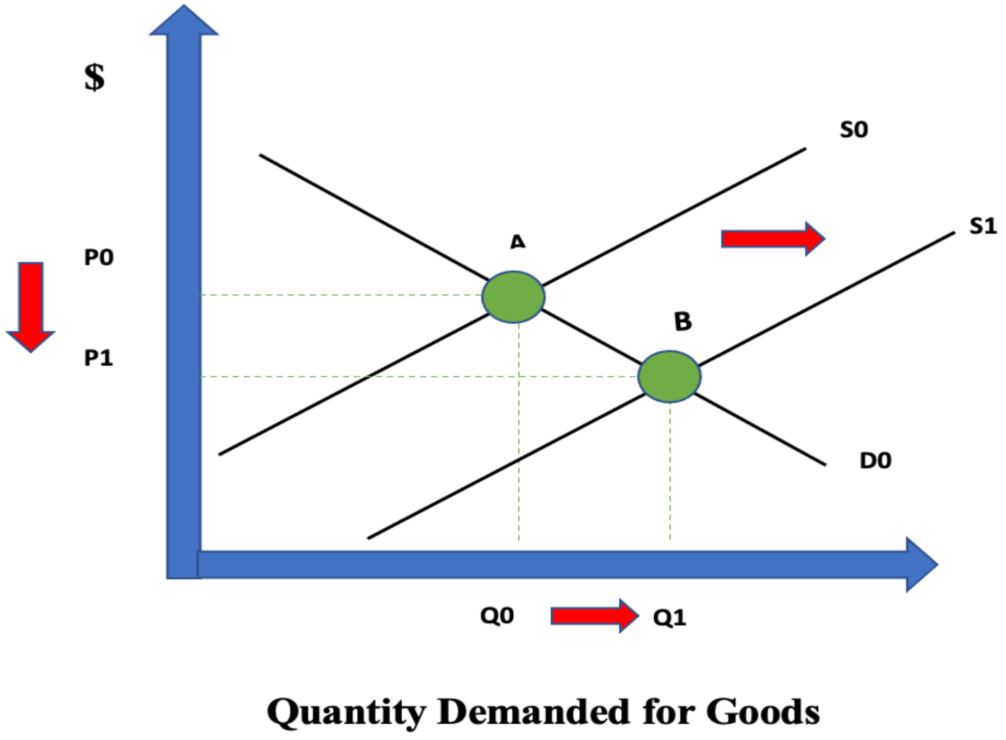
The decrease in costs to producers, could lead to a shift in supply (S0) to the right. Supply would then be available at the new curve (S1). (This would occur because of the expected impact of greater efficiency due to AVs and lowering of costs to producers). A new equilibrium (Point

B) would be reached, at a lower price (P1) and a greater quantity (Q1). where the new supply curve (D1) meets the demand curve (D0).

This new equilibrium (Point B) would suggest that demand has shifted along the demand curve (D0). Also, that the price has gone down because of AVs and their impacts on the trucking industry (all other things remaining equal ceteris paribus).

This is just one way how AVs could affect urban cities economically. These economic impacts are subject to change depending on the assumptios made. But the application of economic models can be useful to theorize the economic impacts of AVs on urban cities.

Image 2 Supply and Demand Model of Shifts in Demand as a Result of AVs

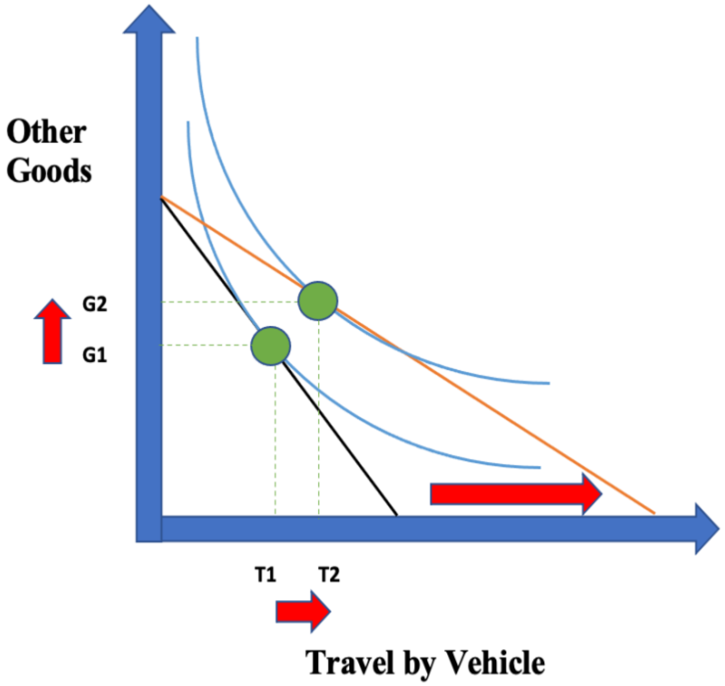


Consumer Budget Model 1: Preference Shift Towards AVs and Cost Decrease

Based on the findings from the literature review a consumer choice model could be used to understand consumers change in preference resulting from AVs. The assumptions of the model will revolve around the idea that SAVs will be the preferred business model used and the cost (price) of travelling will decrease. This drop in the cost of travel will be a result of the fact that consumers do not have to purchase a vehicle any longer, and insurance as well as a maintenance cost are likely to decrease. The cost associated with the SAV would be the cost of usage for the miles traveled but as more users use SAVs the cost goes down.

Image 3 shows the initial optimal consumer bundle, where T represents the quantity of traveling by car (measured, for example, by VMTs) and A represents all other consumer goods (including public transport). Then, introduction of SAVs lowers the cost (price) of travelling by a car, which shifts the intersection of the budget line with x-axis to the right. The new optimal bundle will allow a consumer to travel more (because now it is cheaper) and to consume more other goods (because travelling became cheaper and some budget money could be spent on something else rather than travelling). Overall, the consumer is going to end up on the higher indifference curve that will guarantee the higher level of satisfaction. This model helps to visualize how cheaper commuting due to Avs introduction will affect the consumers.

Image 3 Consumer Budget Model 1: Preference Shift Towards AVs and Cost Decrease



Consumer Budget Model 2: High Cost of Fares

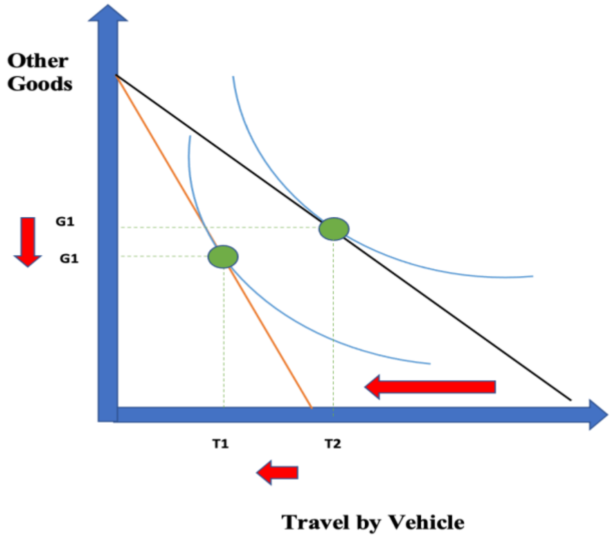
Another possible outcome that could be applied to a consumer choice model would be that AVs will be a more expensive method of travel and costs (price) would increase. Under this potential outcome, implementation of AVs in urban cities would lead to much higher infrastructure costs to accommodate for AVs in cities. These higher costs may be passed onto consumers and lead to higher commuting costs.

Image 4 shows use the same components as the Consumer Budget Model 1. What is different in this scenario is that there is an inward pivot of the budget line in the x-axis to the left (because it is now more expensive). This could lead to less travel (and lower utility of AVs).

These outcomes would be a result of high-priced fares. Such results would lead to a decline in preference towards AVs.

This theoretical scenario opposes the expected outcome that of AVs leading towards cheaper transportation. But this scenario could be possible, under the expected outcome that cities may have to go through extensive redesigns to be suited for AVs rather than human drivers.

Image 4 Consumer Budget Model 2: High Cost of Fares



Research Analysis

Limitations

It can be foreseeable that AVs will bring change to urban cities. They can affect transportation and land use which could have economic impacts as a result. AVs have not reached full automation the type of data that can be collected is limited. As this technology advances further, this limitation will hopefully become smaller. From the research I came across, in this study there are predictions that can be made but it seems unlikely that there is an exact outcome that can be predicted as to how AVs will economically impact urban cities.

Discussions

When trying to predict how AVs could revolutionize urban cities, it becomes apparent that there are too many unknowns to have one solid conclusion as to how AVs could impact urban cities. As highlighted in a Science (AAAS) article by Mervis. (2017), the conversation about AVs falls into two categories, utopian, and dystopian outcomes (Mervis, 2017). But the more a realistic idea when it comes to AVs is that there is no black and white distinction to the impacts they may have on cities. This result is due to there being too many variables involved which make it difficult to have one specific outcome. This conclusion follows the trend of what this reserach found in the literature review. Which is that it at this moment it is unknown how cities may be impacted. The development of this technology has been a lengthy process, and in the past years the predictions of a driverless future have been very optimistic.

The new current trend on this topic has shifted towards more realistic expectations. Such as, focusing on the costs to the infrastructure to make it better suited for AVs. Also, further development of AVs will be costly to the companies trying to reach full automation. Being that a driverless future is further away than what has been promised by people like Elon Musk. Companies like Uber and Lyft which have been investors in this technology have recently offloaded their automounts vehicles divisions. Developing AVs is costly, and only larger companies like Waymo, and auto giants can afford to take on the challenge of developing fully autonomous vehicles (Metz, 2021). The future of driverless cars is a long way off, research on

AVs and their impacts should continue to grow at the rate of the development of AVs to keep up with advancements and understand what is to come ahead.

Future Research

This topic has been personally difficult to take on. Composing this study has taught me a lot about taking on a developing technology. Another aspect that made AVs tricky to take on was that I had to learn to deal with conflicting papers, because of different assumptions. The lack of empirical data was the biggest challenge, it made it necessary to structure this research around that limitation.

In the future if I were to conduct a study on this topic, I would focus on having a more precise research question. This should help to have a more composed structure guiding the research. Also, the more current studies done on AVs that have been published in the last two years seem to have better projections that would serve as better resources on this topic.

These lessons learned through this project and research will not only help me do research on this topic but are integral building blocks to doing research into any other topics in the future. In the process of completing this study it has become apparent how crucial it is to have a concise research question that is quantifiable. Also, how important it is to do preliminary research to have sufficient background knowledge to ask the right questions. These lessons have been taught in my previous courses, but it is a whole different experience having to live through it by means of completing a senior project than just learning about it in a course. I appreciate the challenge of this learning opportunity and it has been very helpful.

Conclusion

The economic impact of AVs on urban cities is the focus of this study. AVs are developing technology and based off the findings in the literature review, there is no clear outcome that can be reached. Currently, what could be done is to use the possible effects AVs may have on urban cities and make conservative predictions as to what is to come. The only trend that seems like a likely outcome is that people may be willing to travel more and that VMTs will increase. That is not enough to formulate an economic impact. Consumer preferences could vary greatly, as well as possible business models that AVs may function under. All these factors could affect AVs impacts on factors of transportation and land use. Economic models can be used to better understand consumer preferences and some of the costs that may occur as urban cities transition to AVs.

Acknowledgements

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Appendix 1

Appendix A: Table 1: Impacts of automated vehicles on travel behavior and land use: an international review of modelling studies
Source: Impacts of automated vehicles on travel behavior and land by Aggelos Soteropoulos, Martin Berger and Francesco Ciari.
Citation: "Soteropoulos, A., Berger, M., & Ciari, F. (2019). Impacts of automated vehicles on travel behavior and land use: an international review of modelling studies. *Transport reviews*, *39*(1), 29-49".
Summary: In their study, they compiled 37 modelling studies originating from the U.S.A (20 studies), Europe (14 studies), Asia (2 studies) and Australia (1 study) (Soteropoulos et al, 2018.

Author(s) (year)	**Study region/area**	**Methodology**	**Main model assumptions**	**Scenarios/ assumptions on transport supply**	**Main Results**		
Burns, Jordan, and Scarborough (2013)	Ann Arbor, USA	Queuing and simulation Models	Constant travel speed with peak hour factors; Grid network; avg. waiting time: 0,4 min	Replacement of all trips of vehicles driven less than 70 miles/day with SAVs	−85% vehicles		
Kornhauser (2013)	New Jersey, USA	Activity-based-Model	Constant travel speed Grid network	Replacement of all private vehicle trips with SAVs (ridesharing) with pick-up stations	−46% vehicles		
Bourghout, Rigole, and Andreasson (2014)	Stockholm, Sweden	Hybrid micro-mesoscopic traffic simulation Model	Link speeds as 75% of free-flow speeds for trip assignment model	Replacement of all home-based work private vehicle trips with SAVs	+24% VKT; −92% vehicles		

	"Replacement of all home-based work private vehicle trips with SAVs (ridesharing); acceptable travel time increase 30% to 50%"		"−11% to −24% VKT; +13–25% VHT−95% vehicles"				
Fagnant and Kockelman (2014)	Hypothetical city, USA	Agent-based-Model	Constant travel speed for peak/off-peak; Grid network; avg. waiting time: 0,3 min	3,5% of trips served by SAVs	+11% VMT−91 % vehicles		
Gucwa (2014)	San Francisco, USA	Activity-based Modelling approach	Mode-Choice Model	+100% road capacity	+2% VMT		
	"−100% VOT for private AVs"		"+13% VMT"				
	"+10% to+100% road capacity	−25% to −100% VOT for private AVs"		"+4% to +15% VMT"			
Spieser et al. (2014)	Singapore, Singapore	Design-oriented approach	Avg. travel speed is periodically time-varying	Replacement of all private vehicle trips with SAVs	−66% vehicles		

Childress, Nichols, Charlton, and Coe (2015)	Seattle, USA	Activity-based-Model	Mode and Trip-Choice Model Capacity changes for freeways and major arterials	+30% road capacity	+4% VMT; −4% VHT		
	"+30% road capacity	−35% VOT (household trips) for private AVs"		"+5% VMT; −2% VHT"			
	"+30% road capacity	−35% VOT	−50% parking cost for private AVs"		"+20% VMT; +17% VHT−0.3 and −1.6 percentage points in PT and walk share"		
	"SAVs with cost of $1.65/mile (no private vehicle trips possible)"		"+35% in VMT; −41% in VHT+4 and +5 percentage points in PT and walk share"				
Fagnant, Kockelman, and Bansal (2015)	Austin, USA	Agent-based-Model	Hourly varying link-level travel speeds	1,3% of regional trips served by SAVs	+8% VMT−89 % vehicles		
ITF (2015)	Lisbon, Portugal	Agent-based-Model	Link travel speed based on trip assignmentR	Replacement of all motorised trips by SAVs	+44% to +89% VKT; −84% to		

			ule-based Mode-Choice Model based on existence/non-existence of PTThree different sizes of SAVs		−89% parking spaces−77% to −83% vehicles		
	"Replacement of all motorised trips by SAVs (ridesharing)"		"+6% to +22% VKT; −93% to −94% in parking spaces−87% to −90% vehicles"				
Kim, Rousseau, Freedman, and Nicholson (2015a)	Atlanta, USA	Activity-based-Model	Mode and Trip-Choice Model	+50% road capacity	+4% VMT		
	"+50% road capacity	−50% VOT for private AVs"		"+13% VMT"			
	"−50% VOT	+50% road capacity	−71% operating and −100% parking cost for private AVs"		"+24% VMT; +12% VHT;−0.8 percentage points in PT share"		
Kim, Yook, Ko, and Kim (2015b)	Seoul, South Korea	Agent-based-Model	Travel behaviour and residential location choices incl. locational	Increase in road capacity, 100% market share of private AVsPreference for road and city centre	More dispersed development of urban space		

			preference factors	accessibility and low-price regions			
Zhang, Guhathakurta, and Fang (2015)	Hypothetical city, USA	Agent-based-Model	Constant travel speed for peak/off-peak; Grid network; Avg. Waiting Time: 2 min	2% of trips served by SAVs	−90% parking spaces		
		"2% of trips served by SAVs (car- and ridesharing)"		"−91% parking spaces"			
Bischoff and Maciejewski (2016)	Berlin, Germany	Agent-based-Model	Time-varying link travel timesDemand-supply balancing dispatching strategyMax. waiting time: 15 min	Replacement of all private vehicle trips by SAVs	−91% vehicles		
Boesch, Ciari, and Axhausen (2016)	Zurich, Switzerland	Agent-based-Model	Travel times from MATSim for actual tripsMax. waiting time: 10 min	Replacement of all private vehicle trips by SAVs	−90% vehicles		
Chen, Hanna, and Kockelman (2016)	Hypothetical city, USA	discrete-time Agent-based-Model	Constant travel speed for peak/off-peak; Grid networkAvg. waiting time: 7 to 9 min	10% of trips served by SAVs	+7% empty VMT; −87% vehicles		

		"10% of trips served by electric SAVs (with recharge time and vehicle range)"		"+7% to +14% empty VMT; −85% to −73% vehicles"			
Chen and Kockelman (2016)	Hypothetical city, USA	discrete-time Agent-based-Model	Constant travel speed for peak/off-peak; Multinomial logit Mode-Choice ModelGrid network; avg. waiting time: 3 min	−65% VOT, $0.85/mile operating cost for SAVs (with battery recharge time and vehicle range)	−25 percentage points in car share−3 percentage points in PT share		
Correia and van Arem (2016)	Delft, Netherlands	Assigning private AV trips to road network	Mode-Choice ModelTravel times change after trip assignment	Replacement of private vehicles with private AVs in households	+17% VMT; +3 percentage points in car share		
	"Replacement of private vehicles with private AVs in households	−50% VOT for private AVs"		"−49% VMT; +9 percentage points in car share"			
Fagnant and Kockelman (2016)	Austin, USA	Agent-based-Model	Hourly varying link-level travel speedsAvg. waiting time carsharing: 1,9 minAvg. waiting time	1,3% of regional trips served by SAVs1,3% of regional trips served by SAVs (ridesharing)Acceptable travel	+9% VMT; −90% vehicles+2% to +5% VMT−90% to −91% vehicles		

			ridesharing: 1,2 to 1,4 min	time increase for ridesharing 20% to 40%			
Friedrich and Hartl (2016)	Stuttgart, Germany	Macroscopic and microscopic travel demand Model	Link travel speed based on trip assignmentRule-based Mode-Choice Model based on existence/non-existence of PTTwo different sizes of SAVs	Replacement of all motorised trips by SAVs	+18% to +39% VMT; −77% to −81% vehicles−77% to −83% parking spaces		
	"Replacement of all motorised trips by SAVs (ridesharing)"		"−20% to +36% VMT; −90% to −93% vehicles−90% to −93% parking spaces"				
Hörl, Erath, and Axhausen (2016)	Sioux Falls, USA	Agent-based-Model	Time-varying link travel timesDemand-supply balancing dispatching strategyMode-Choice Model; max. waiting time: 17 min	−65% VOT, $0.85/mile cost for SAVs	+60% VMT; −20 percentage points in private car share−10 and −8 percentage points in PT and walk share		
Thakur, Kinghorn, and Grace (2016)	Melbourne, Australia	Land Use and Transport Interaction Model	Travel behaviour and residential location choices with	−50% VOT for private AVs	+4% population in inner parts of the city−3% population		

			accessibility to employment as explanatory variable		in the far outer suburbs		
	"Replacement of private vehicles with SAVs (ridesharing) with 0.49€/km operating cost"		"−4% population in inner parts of the city+3% population in the far outer suburbs"				
Auld, Sokolov, and Stephens (2017)	Chicago, USA	Activity-based travel demand Model	Mode and Trip-Choice ModelLink travel speed based on trip assignments	+12% to 77% road capacity	+1% to +4% VMT		
	"−25% to −75% VOT	20% market share of private AVs"		"+2% to +18% VMT"			
	"−25% to −75% VOT	75% market share of private AVs"		"+10% to +59% VMT"			
	"+77% road capacity	−25% to −75% VOT	100% market share of private AVs"		"+21% to +79% in VMT"		
Bangemann (2017)	Munich, Germany	Microscopic travel demand Model	SAVs with two seats	Replacement of all private vehicle trips with electric SAVs (with recharge time	+14% VMT−91 % vehicles		

				and vehicle range)			
Gelauff, Ossokina, and Teulings (2017)	Netherlands	Land Use transportation interaction Model	Home and job location and commuting mode choices incl. prices, accessibility of jobs, travel costs	−20% VOT and travel time for private AVs	−1% population in big cities; −2,5% population in mid-sized cities; +1% population in non-urban regions		
	"−20% travel time (compared to private car)	−100% out-of-vehicle travel time for PT	−50% access/ egress time of trains"		"+3% in population in big cities; −3% population in suburbs of smaller cities; −2% population in non-urban regions"		
Heilig, Hilgert, Mallig, Kagerbauer, and Vortisch (2017)	Stuttgart, Germany	Agent-based travel demand Model	Combined Destination and Mode-Choice ModelAvg. waiting time: 7,5 min	−45% cost/mile compared to private car for SAVs (ridesharing), −70% cost/mile with occupation rate >=1,64	−20% VMT; −85% vehicles; +4 percentage points in PT share; +8 and +5 percentage points walk and cycle share		

Levin, Kockelman, Boyles, and Li (2017)	Austin, USA	Cell transmission model-based dynamic network loading simulator	Link travel speed based on traffic flow simulator; Waiting time: 10 min	Replacement of all private vehicle trips with SAVs	−72% vehicles		
Martinez and Viegas (2017)	Lisbon, Portugal	Agent-based Model	Link travel speed based on trip assignmentRule-based Mode-Choice ModelMax. waiting and travel time increase: 15 min	Replacement of all motorised trips by SAVs (ridesharing)	−25% VKT; −95% vehicles		
	"Replacement of all motorised trips by SAVs (ridesharing) and taxi-buses (8–16 seats	boarding at specific points)"		"−29% VKT−97% cars	+568% buses"		
Meyer, Becker, Boesch, and Axhausen (2017)	Switzerland	Travel demand Model (macroscopic)	Land use effects based on accessibility changes to work placesLink level travel speed based on trip assignments AV	+80% road capacity outside urban areas, +40% in urban areas (private AVs)	Minor gains in accessibility for rural municipalities, no change/small decrease in greater cities		

			availability for children, adults without driver license and elderly people				
	"+80% road capacity outside urban areas	+40% in in urban areas (SAVs)"		"Moderate accessibility gains in rural municipalities	decrease in larger agglomerations"		
Liu, Kockelman, Boesch, and Ciari (2017)	Austin, USA	Agent-based-Model	Time-varying link travel timesMode-Choice ModelAvg. waiting time: 3 min	−50% VOT, $0.5/mile operating costs for SAVs	+9,8% empty VMT; SAV fleet = 17 % of travellers		
	" "			−50% VOT, $0.75/mile operating costs for SAVs	+13,2% empty VMT; SAV fleet = 15 % of travellers		
	" "			−50% VOT, $1/mile operating costs for SAVs	+15,7% empty VMT; SAV fleet = 13 % of travellers		
	" "			−50% VOT, $1.25/mile operating costs for SAVs	+15,1% empty VMT; SAV fleet = 13 % of travellers		

Llorca, Moreno, and Moeckel (2017)	Munich, Germany	Agent-based-Model	Time-varying link travel timesDemand-supply balancing dispatching strategyAverage waiting time: 8 min	Replacement of 20% of private vehicle trips with SAVs	+5% VMT; −14% vehicles (overall)		
	"Replacement of 40% of private vehicle trips with SAVs"		"+7% VMT; −28% vehicles (overall)"				
Zhang (2017)	Atlanta, USA	Agent-based-Model combined with Monte Carlo simulation and UrbanSim	Residential and employment location choices determined by commute transportation cost (residential) and human capital accessibility, available commercial and industrial spaces (employment) incl. locational preference factorsConstant travel speed for different periods	Replacement of all private vehicle trips with SAVs−100% VOT, $0.3/mile operating costs for SAVs	+7% to +10% in median distance to CBD for households with young people (kids/no kids)−7% to −2% in median distance to CBD for households with old people (kids/no kids)		

	"Replacement of all private vehicle trips with SAVs−100% VOT	$0.13/mile to $0.5/mile operating costs for SAVs−90% parking spaces"		"−1.8% to −17.5% job density in inner city parts and +0.2% to +9.8% job density in suburban area for secondary sector+0.3% to +11.8% job density in inner city parts and −2.5% to −7	8% job density in suburban area for tertiary sector"		
Zhang and Guhathakurta (2017)	Atlanta, USA	Agent-based travel demand Model	Constant travel speed for different day periods; Avg. Waiting Time: 3,8 min	5% of trips served by SAVs (car- and ridesharing); −100% parking cost$0.5/minute operating costs (carsharing) and $0.3/minute (ridesharing)	−4,5% in parking land		
Zhao and Kockelman (2017)	Austin, USA	Travel demand Model (traditional trip-based four-step Model)	Hourly varying link travel speeds (congested time information) Mode-Choice Model	−25% to −75% VOT for private AVs and SAVs1$/mile operating cost (private AVs) and 1.5$/mile (SAVs)	+18% to +41% VMT		
	"−50% in VOT	−50% to −100% parking cost for private AVs and SAVs1$/mile operating cost (private AVs) and		"+26% VMT"			

		1.5$/mile (SAVs)"					
	"−50% in VOT for private AVs and SAVs1$/mile operating cost (private AVs) and 1$/mile (SAVs)"		"+28% VMT"				
	"−50% in VOT for private AVs and SAVs1.5$/mile operating cost (private AVs) and 1.5$/mile (SAVs)"		"+29% VMT"				
Auld, Verbas, Javanmardi, and Rousseau (2018)	Chicago, USA	Activity-based travel demand Model	Mode and Trip-Choice ModelFleet penetration based on model (AV cost) Link level travel speed based on trip assignments	47.8% to 100% fleet penetration of private AVs	+6% to +8% VMT		
	"−30% VOT	13.4% to 100% fleet penetration of private AVs"		"+15% to +24% VMT"			

	"−50% VOT	13.4% to 100% fleet penetration of private AVs"		"+21% to +43% VMT"			
Boesch, Ciari, and Axhausen (2018)	Zug, Switzerland	Agent-based-Model	Time-varying link travel timesMode-Choice Model	−38% VOT for private AVs, −54% VOT for SAVs+25% operating cost for private AVs (0,22CHF/km); −50% operating cost for automated PT (0,13CHF/km); 0,46 CHF/km operating cost for SAVs	+16% VMT−12 percentage points in private car share−4 and −16 percentage points in PT and slow modes share		
Kröger, Kuhnimhof, and Trommer (2018)	Germany and USA	Aspatial travel demand Model	Travel speeds constant to today Combined mode and distance choice (No traffic assignment) AV market share based on diffusion modelAV availability for teenagers, adults without driver license and mobility-impaired people	−25% VOT for private AVs, 7,5% market share	+3,4% in VKT; +1,3 and −0.2 percentage points in car and PT share		

	"−25% VOT for private AVs	29	3% market share"		"+8	6% in VKT; +3	8 and −0.4 percentage points in car and PT share"
	"−25% VOT for private AVs	10	1% market share"		"+2	4% in VKT; +1 and −0.3 percentage point in car and PT share"	
	"−25% VOT for private AVs	37	6% market share"		"+8	6% in VKT; +3	7 and −0.9 percentage points in car and PT share"
Zhang et al. (2018)	Atlanta, USA	Activity-based travel Model	Varying link travel speeds (congested time information); no trip delay	Replacement of private vehicles with private AVs in households determined by min. number of AVs to satisfy travel demand of household members	+13.3% empty VMT−9.5 % vehicles		

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