ECONOMIC EFFECTS OF AUTOMATED VEHICLES

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ABSTRACT

Connected and fully automated or autonomous vehicles (CAVs) are becoming increasingly viable as a technology and may soon dominate the automotive industry. Once CAVs are sufficiently reliable and affordable, they will gain greater market penetration, generating significant economic ripple effects throughout many industries. This paper synthesizes and expands upon analysis from multiple reports on the economic effects of CAVs across 13 different industries and the overall economy.

CAVs will soon be central to the automotive industry, with software making up a greater percent of vehicle value than it had previously and hardware's percentage value falling. The number of vehicles purchased each year may fall, due to vehicle-sharing within families/across household members or through shared fleets, but rising travel distances and a shift away from air travel may lead to greater vehicle-miles traveled (VMT) and ultimately higher vehicle sales (due to faster fleet turnover from heavy daily use). Heavy commercial trucks may be the first industry to implement CAV technology in order to increase efficiency. The opportunity for drivers to do other work or rest during long drives may allow heavy trucks to travel for longer periods of time, at lower cost, reducing the demand for rail transport. Personal transport may shift toward shared autonomous vehicle (SAV) fleet use, threatening the business of taxis, buses, and other forms of group travel. Fewer collisions and more law-abiding vehicles, due to smarter, automated vehicle operations, will lower demand for auto repairs, traffic police, medical, insurance, and legal services. CAVs will also impact infrastructure investment and land use, leading to new methods for managing travel demands and a repurposing of some land, such as curbside and off-street parking.

A reduction in crashes and tighter headways between vehicles, thanks to inter-vehicle communications and automation may decrease traffic congestion, but this improvement could be limited by increased vehicle miles traveled (VMT). CAVs will also generate savings from productivity gains during hands-free travel and a reduction in collision costs. Assuming that CAVs

eventually capture a large share of the automotive market, they will have major economic impacts, on the order of $1.2 trillion total or $3,800 per American per year. All estimates provided here are largely speculative, since the future of CAVs and the forces that will influence their adoption and use are still highly uncertain, but this paper presents important considerations for the overall effects of CAVs on the U.S. economy and quantifies the impacts.

INTRODUCTION

Over the past decade or more, advances in the automotive and technology sectors have opened up the potential for the computerized-automation of the driving task. Every major automobile manufacturer and multiple technology companies, such as Apple, Google, and Uber, have begun research and development of autonomous vehicles (AVs). AVs have on-board computers, rather than occupants, managing all vehicle movements. AVs may set off a revolution in transportation on a grand scale, across nations and continents. Any real transformation will require significant adoption or market penetration, but widespread use of AVs will generate a profound impact on many industries and markets throughout the U.S. economy and around the world. The critical level of adoption or market penetration has not been studied, but increasing levels of adoption will result in increasing economic effects. This paper anticipates AVs' effects on the most directly affected industries and on the overall U.S. economy by synthesizing existing literature and evaluating cost and sales changes.

To begin this discussion, it is useful to note that the U.S. Department of Transportation has defined five Levels of Automation (Aldana 2013). Level 0 implies no computer assistance for driving activities, while Level 1 involves function-specific automation for activities, like assistive parallel parking, adaptive cruise control (ACC), lane-keeping assistance (LKA), and electronic stability control (required on all new light-duty vehicles sold in the US since 2012). Level 2 is the combination of two or more of these features into a semi-autonomous vehicle - such as ACC plus LKA. Level 3 includes self-driving automation with full control of all critical safety functions under certain conditions - but the driver is still expected to take over in some instances (e.g., a confusing work zone or inclement weather). Level 3 will likely have significant economic impacts on the most directly related markets, such as the automotive and technology industries. Level 4 is the ultimate stage of automation, in which vehicles are fully self-driving - without need for human intervention; they can synchronize caravans of many vehicles and valet-park themselves. Connectivity between these vehicles will be developed in advance of and alongside rising automation, allowing for crash alerts, better coordination of vehicle speeds, and extended convoys. Once a large fleet of Level 4 AVs has been deployed, economic effects will increase and influence markets well beyond those directly related to AV production.

Connected and highly automated or fully autonomous vehicles (CAVs) utilize automated vehicle technology in coordination with other vehicles and infrastructure via communications devices. CAVs have the potential to generate widespread improvements in safety and time savings, but their value extends well beyond these specific factors, into the broader economy. Although CAVs will naturally cause losses in some industries, the overall impact on the U.S. economy should be positive, as Morgan Stanley estimates an overall potential value of $1.3 trillion annually, or 8% of the entire U.S. GDP (Lewis 2014). An understanding of the trajectories of the specific business sectors affected, both positively and negatively, may be critical in effectively preparing for CAVs' economic impacts. Preparation includes making strategic decisions to best harness this change.

Previous papers by companies like KPMG (2015), Morgan Stanley (2014), and McKinsey and Co. (2013), as well as research by Fagnant and Kockelman (2015), have examined different aspects of the U.S. transportation system and economy. This review paper focuses on the economic effects of fully autonomous vehicles on specific markets by compiling and integrating economic research from top articles and studies. It also expands upon past research by using data to generate estimates of industry-wide shifts as percentages of industry size, total monetary values, and dollars per capita. For the purpose of this report, these values for economic shifts are evaluated as net economic benefits to society, because the decrease in revenues to a given industry represent a decrease in cost to customer that leads to greater overall income and wealth. Analyzed industries include automotive, technology, freight movement, personal transport, auto repair, medical care, insurance, law, infrastructure, land development, digital media, police, and oil and gas. These industries were selected after preliminary research on potential effects, and are expected to experience the largest shifts from the development of CAVs. The paper concludes with a look at the more wide-ranging effects on the economy such as improvements in safety, productivity, and fuel economy. Thoughtful examination of all these industries and CAVs' more pervasive effects enables a valuable picture of likely impacts on the U.S. economy, which can significantly impact policy, planning, investment, and design decisions, by public agencies, private businesses, investors, and the public at large.

INDUSTRIES ANALYZED

Automotive

The industry most obviously and directly affected by the design, adoption, and use of CAVs is the automotive industry. The auto industry is one of the strongest forces in the U.S. economy, employing 1.7 million people, providing $500 billion in worker compensation annually, and accounting for about 3-3.5% of GDP (Hill et al. 2010). In 2015, automakers sold a total of 17.5 million cars and light trucks, at a cost of $570 billion to American consumers (Spector et al. 2016). CAVs will influence not only the use and design of motorized vehicles but also redefine business strategies of companies within and outside the automotive industry.

One likely market expansion for vehicle production will come from increase in vehicle-miles traveled (VMT). This will be due to the ability of children, persons with disabilities, and elderly people to enjoy the convenience of automotive travel without the liability of physically driving the vehicle (The Economist 2012). Childress et al. (2015) simulated four different scenarios for CAVs' VMT effects across the Seattle region, assuming added capacity (due to shorter headways between smart cars), changes in values of time, avoided parking costs, and VMT fees/road tolls. They estimated regional VMT increases of 3.6 percent to 19.6 percent, except when marginal cost tolls were applied, and VMT fell 35.4 percent, relative to the business-as-usual, no-automation case (Childress et al. 2015). Zhao and Kockelman's (2016) recent travel demand forecasting work predicts VMT increases of 20 percent or more, across the Austin region, due to CAVs and shared autonomous vehicles (SAVs), which can be accessed by many different occupants throughout the day.

However, private ownership of automobiles may fall dramatically as "on-demand" car rental fleets and services develop, similar to Uber and Lyft, but driverless (Diamandis 2014, Fagnant and Kockelman 2015, Fagnant et al. 2015). Only 12% of all U.S. vehicles are in use/on the road during the nation's peak moment (nearly 5 pm) of the average weekday, making vehicle sharing a very viable option (Silberg et al. 2013; Fagnant and Kockelman 2015). If vehicle sharing becomes a significant mode choice, it could decrease the personal demand for automobiles by millions of units every year, in the U.S. alone (Silberg et al. 2012). Forbes Magazine (Diamandis 2014) estimated that this fact could cause the cost of transportation per mile to drop five- to ten-fold, though Chen et al. (2016) put the final monetary costs at closer to 50 cents per mile (vs. the $0.57 to $0.74 per mile that AAA [2016] estimates for typical driving distances and vehicle types, as incurred by private-car owners in the U.S.). While a 50 to 90 percent drop in cost seems unlikely, especially in the near term, SAVs will lower per-mile travel costs as technology costs fall. If SAVs gain a large share of the market but people continue to ride rather independently in these autonomous taxis, VMT may increase due to unoccupied/empty-vehicle travel between consecutive travelers.

Alternatively, if carpooling and hub-and-spoke models for vehicle sharing become more widespread, VMT may decrease. According to a report by the University of Michigan Transportation Research Institute (Schoettle and Sivak 2015), if empty-vehicle driving of privately-owned vehicles is allowed, CAVs may cause many families to choose to own just one car rather than two, if there is limited “trip-scheduling overlap” for different household members (so they would share the vehicle throughout the day). In an extreme case, CAVs could cause a drop in personal ownership, from 2.1 cars per household to 1.2 cars per household, on average, representing a 43% reduction in the average number of household vehicles but much greater use of each vehicle and lots of empty VMT. Heavier use of any vehicle will mean faster retirement or scrappage – though CAVs may crash much less often, resulting in somewhat longer lifespans – and lower car-buying rates (Li and Kockelman 2016, Fagnant and Kockelman 2015).

Overall, total production and sales of passenger vehicles will probably rise, thanks to added demand for vehicle use, to more distant destinations. However, if shared vehicles are well maintained and so used for longer distances before retirement (much the way New York City taxis are used for far more miles than the typical household vehicle, before retirement), it is possible production rates will not rise as much as VMTs would suggest. New York City taxis travel approximately 70,000 miles per year, and the average age of a New York cab is 3.3 years (NYCTLC 2014). Assuming a taxi life of 5-6 years, New York taxis travel around 350-400 thousand miles in their lifetime. A similar model of vehicle care would allow shared vehicles to experience similarly lifetimes. Moreover, major fleet operators are likely to be sophisticated consumers and negotiators, and may want to purchase smaller vehicles, resulting in lower profit margins for vehicle manufacturers. Perhaps to insulate themselves from potentially big drops in demand or price, many original equipment manufacturers (OEMs) are already teaming with Transportation Network Companies – like General Motors with Lyft, Toyota with Uber, and Volkswagen with Gett (Kokalitcheva 2016). With an estimated VMT increase of approximately 10 percent (Childress et al. 2015), a corresponding increase in vehicle sales would likely range from 5-10 percent, due to some of the growth being taken up by the rise of shared vehicles. With approximately 17.5 million vehicle sales in the U.S. (YCharts 2017), the number of cars sold per year would increase by 875,000 to 1.75 million, corresponding to an increase in sales by $28.5 to $57 billion. Although it is unclear how significant the factors affecting demand in each direction will be, automobile companies will undoubtedly face a very different landscape – in demand, suppliers, and pricing.

As demands shift, companies will want to strategically re-position themselves, in order to adapt to the industry’s fundamental evolution. Once fully autonomous vehicles become pervasive, greater emphasis will be placed on software and digital media (vs. basic vehicle performance), forcing organizations to specialize in certain areas. Jonas et al.'s (2014) report for Morgan Stanley suggested that the auto industry may be completely reorganized into three key provider categories: hardware manufacturers, software suppliers, and integrated "experience" creators.

Hardware refers to the car essentially as we know it today (90% of the value of a current roadway vehicles) (Jonas et al. 2014), and companies that choose to specialize in this segment will continue to design and manufacture the body, powertrain, interior, lighting, and other basic components. This position is likely for smaller car companies without a competitive advantage in software development, because they will not be able to invest enough resources to generate competitive/comparably intelligent in-car systems. These companies will outsource the software to businesses that specialize in automotive operating systems. As software's importance increases, Jonas et al. (2014) argue that hardware will become increasingly commoditized, with only the most critical hardware components commanding significant pricing power, potentially dropping the relative value of hardware to 40% of the value of the car. In order to deal with falling margins on hardware sales, top vehicle manufacturers may add value through car sharing fleet operations, multi-modal journey planning, and other mobility-promoting services (Feick 2013).

Presently, software constitutes approximately 10% of vehicle value. While influencing many automotive functions, the software-hardware interfaces are largely independent of each other. In AVs, software components will become coordinated into a central, universal operating system, to control the powertrain, infotainment, and autonomous features, and may eventually represent 40% of the car value (Jonas et al. 2014). Jonas et al. (2014) expect that larger auto manufacturers, larger suppliers, and leading technology companies (like Google, Apple, and Microsoft) will be responsible for such production. Similar to the smartphone industry, software-focused companies are forecast to sell and install their operating systems in vehicles manufactured by companies specializing in hardware, while car companies with large sums of resources will be able to invest in their own software development to generate a cohesive, integrated experience. Although this evolution may decrease profit margins in the hardware segment, the increasing value of software gives stronger automakers a new opportunity to generate revenue and opens up the market for tech companies.

Electronics and Software Technology

As alluded to above, technology firms may have the most to gain from the development of CAVs. Technology firms may emerge as entertainment providers and/or important players in the vehicle-production process, thanks to their competitive advantages in artificial intelligence (AI) applications (Jonas et al. 2014). AI has become rather critical to making real-time/rapid human-like judgements in complex transport settings (e.g., navigating a new intersection with various bikes and pedestrians present, alongside a right-turning heavy-duty truck or bus).

Google's self-driving cars have travelled over 1 million miles in California, with only 12 accidents - and none ruled the Google car's responsibility (Google 2015). Much speculation has surrounded Apple's entering the AV game, under possible name "Project Titan" (Price 2015). Intel Capital's director confirmed that Intel recently launched a $100 million Connected Car Fund to "spur greater innovation, integration, and collaboration across the automotive technology ecosystem" (Silberg et al. 2012, p. 24). With all these big players investing significant time and capital into CAVs, it seems likely they will play important role in the transport revolution and stand to gain large profits from it.

As noted earlier, Morgan Stanley estimates software costs rising from 10% of current car values to 40% in a CAV environment (Jonas et al. 2014). IHS Technology's Juliussen (2015) estimates that the U.S. self-driving software and its corresponding updates will grow from $680 million in 2025 to $15.8 billion in 2040. Similarly, IHS projects the built-in map and map-upgrade services to grow from $530 million in 2025 to $10.6 billion in 2040 (Juliussen 2015). Together, these services may offer $26.4 billion in new revenues over a 15-year period, for the U.S. alone. Software sales and the potential to integrate software into an entirely proprietary automobile, present major profit-making opportunities for technology firms. One challenge technology companies could face is the cyclical, price-sensitive nature of the automotive industry, which has not been so obvious in electronics and software markets (Jonas et al. 2014). Overall, revenues and profits from the second most expensive item most consumers purchase, after their home or rent, are very attractive, to a number of firms, especially those in the tech industry.

Trucking/Freight Movement

The economics of the trucking and ground-shipping industry could also experience a significant boost from the development of CAVs.The next step of automation in commercial vehicles is assisted highway trucking, in which Level 1 or Level 2 CAVs will help reduce truck collisions, through features like lane centering and adaptive cruise control. After assistive systems, fully automated vehicles will allow convoying, in which the lead driver of a chain of multiple trucks is in control of driving, but the following trucks require no human input and are connected wirelessly to the lead truck. Convoy systems would allow long-distance drives with large quantities of goods and avoid many driver-based hours-of-service restrictions. Attendants may still be on board, resting, helping with drop-offs and pick-ups, and perhaps performing administrative tasks en route, but driver jobs may be eliminated in the long term. This new system would improve safety and efficiency, saving trucking companies fuel, time, and money. Convoys do create issues with other traffic merging, changing lanes, and traffic signals, but this system could reduce accident rates and cut fuel consumption by 15% (Heutger et al. 2014).

McKinsey estimates that the economic gains of driverless vehicles in the trucking industry could be range from $100-500 billion per year by 2025 (McKinsey 2013). The bulk of these savings would come from the elimination of the wages of the truck drivers. According to the American Trucking Association (2015), the industry employs over 3 million truck drivers, and the automation of driving poses a huge threat to the livelihood of these truck drivers. At this time, however, there is already a shortage of about 25,000 truck drivers because of the long hours and time away from home (American Trucking Association 2015). So, CAVs could simply increase the capacity of logistics companies, allowing for more shipments. The role of the truck driver could become more technical, as they would need to monitor the CAV system to ensure it is running properly. Such a role would likely require training and could increase the value and wage of individual truck drivers. In such a scenario, the cost per truck driver would increase, the number of hours of transportation per driver would increase, and the number of drivers would decrease. CAVs would undoubtedly be of massive benefit to the freight transportation and trucking industry but could decrease opportunities for employment of millions of truck drivers.

Personal Transport

CAVs could also transform the transportation industry beyond the automotive industry, affecting trains, planes, and public transport. When vehicles no longer require an operator, occupants will be at liberty to use that time for productive work or even sleep. This found time on car trips might decrease the demand for fast transportation (Diamandis 2014). For example, if a destination is 10 hours away by car, a family or businessman may opt to make the trip overnight, sleeping while the car takes them to the destination, instead of making the flight. Bus, airline, train, and car rental companies could all be affected by the CAVs' added convenience. Fleets of platooning CAVs could replace trains as a more fuel efficient and convenient solution to mass long-distance transit. Another possibility is that SAVs would provide easier access to these forms of mass transportation. Trains also have the added benefit of dedicated right of way, which avoids much of traffic congestion. With SAVs, passengers could be transported directly to the location of the bus, train, or plane without the need for parking their personal cars long-term. If VMT increases with the rise of CAVs, such a system could allow travelers to avoid the higher cost of riding the full distance in their personal vehicle. The expansion of such overnight transportation may be limited by customer demand, due to the desire for comfort and privacy. While costs of such travel may be cheaper and easier, many travelers may still prefer the speed of airline travel or convenience of riding in their own vehicle.

The biggest change in personal transportation as a result of development of CAVs will likely be in the mode of transportation for short commutes. With CAV technology, companies could develop an "on-demand" taxi service with SAVs that would make human-driven taxis obsolete. In fact, GM already has a fully automated taxi prototype that is summoned by a phone app, and Uber has begun operation of a self-driving shared fleet in Pittsburgh (Uber 2016). At peak vehicle usage during rush hour, around 5 PM, less than 12% of all personal vehicles are on the road (Silberg et al. 2013). The Brookings Institute makes an even bolder claim that vehicles sit unused an average of 95% of the time (Brookings 2015). Although the jobs of taxi and bus drivers will be threatened by CAVs, "outsourced" driving accounts for less than 2% of personal transportation, so the impact to the wider economy will not be particularly large (TRB 2016). Vehicle sharing also has the potential to decrease inefficiencies in our current transportation system.

While the effect on long-distance transportation is less clear, public transportation and taxi services are most directly affected by fully automated vehicles and shared fleets. The public transportation and taxi industries account for $66 billion and $20 billion in annual revenue, respectively (IBISWorld 2015, IBISWorld 2016). Ride sharing apps have already caused a 6.7 percent annual decrease in taxi service between 2011 and 2016 (IBISWorld 2016) and decreases as large as 30 percent in Los Angeles and 65 percent in San Francisco (Nelson 2016, Kerr 2014). With the addition of CAVs to ride sharing services, a 50 percent decrease in taxi revenues would cause a shift in $10 billion in revenue toward ride sharing. Ride sharing and CAVs are not as direct of a substitute for public transportation, and public transportation is less expensive compared to private driving services like taxis, so the shift would likely not be as pronounced. A 25 percent shift in public transportation revenues, however, still represents $16.5 billion in decreased public transportation revenue. In total, the changes in taxi and public transportation revenues account for $26.5 billion out of the total $86 billion in revenue, equating to a percent change of 30.8 percent. At the very least, CAVs will take a bite out of the personal transportation providers like taxis, buses, and trains, and could extend as far as redefining car usage, making vehicle ownership more of a luxury than a necessity.

Auto Repair

With 360 degree sensors, no distractions, and no drunk driving, driverless cars will be able to largely eliminate car crashes caused by human error, which amount to over 90% of crashes in the U.S. currently (McKinsey 2013). Collision repair shops will lose a huge portion of their business.

Indirectly, the decreased need for new parts for crashed vehicles would also decrease the demand for manufactured parts from steel producers and part manufacturers. In 2013, almost $30 billion in repairs were caused by vehicle crashes in the United States (Stahl 2014). Higher levels of market penetration will cause proportionally higher percent reductions in crashes. Assuming a 25% reduction in crashes, the industry would lose $7.5 billion in revenue, and at a 50% reduction, auto repair revenue would decrease by $15 billion. Finally, at 100% market penetration, in the best case scenario, we would experience a 90% reduction in crashes and a $27 billion reduction in revenue in the industry.

Some auto shops could find new opportunities in aftermarket personalization of vehicles, customizing the new, more important interior of the CAV, but this will likely not be enough to cover the losses from their usual business (McKinsey 2013). As the level of automation increases and crashes fall, a large percentage of collision repair shops will lose revenues and be forced out of business. Despite the societal gain due to decreased crashes, collision repair shops are likely to face serious losses.

One effect that could be of benefit to the auto repair industry is the increased road time of CAVs through sharing systems. Although there may be fewer total cars, the cars in use could be on the road for 12 hours per day, which will cause an increase in the miles travelled and the overall need for maintenance. CAVs will still provide an increase in safety, but this increased number of road hours allows for more opportunities for crashes or malfunctions that would give business to the collision repair shops. The size of the impact on the industry is unclear, but collision repair businesses that retain their current model will likely face revenue losses. The consumer savings from reduced repair expenses can be applied to other goods and services that will deliver greater utility and generate economic activity.

Medical

Another industry that will lose business from the improved safety of CAVs is the medical industry. Approximately two million hospital visits and 240,000 extended hospitalizations per year in America are due to traffic accidents, and driverless cars would eliminate a large majority of these emergency room visits (The Economist 2012). McKinsey & Co. (2013) estimated that the combination of auto repair and health care bills could save consumers $180 billion, which would generate proportional losses for service providers. The National Highway Traffic Safety Administration estimates that motor vehicle crashes accounted for $23 billion in medical expenses (NHTSA 2015). With a 25% crash reduction, this accounts for a loss of $5.75 billion in the medical industry, $11.5 billion at a 50% reduction, and $20.7 billion at a 90% reduction. Although there will also be savings from the decreased need for supplies and doctors, and space could be cleared in overcrowded emergency rooms, the financial situation will be altered for medical providers. Also, a large proportion of organ donations come from automobile crash victims who are registered organ donors, since they are younger and healthier at the end of their lives. While the total hospital revenue may decrease by billions of dollars, hospital care generates about $1 trillion in annual revenue (Plunkett 2016), the estimated loss only accounts for 1-2% of the market. A potential benefit for hospitals is that they could reallocate personnel to better serve other needs. With emergency rooms often overrun with patients, this would allow hospitals to better serve the public.

Insurance

Safety improvements as a result of CAVs will require insurance agencies to adapt and possibly reconstruct their fundamental business models. Currently, insurance companies sell policies to individual vehicle owners and human drivers are liable for car crashes. Insurance agencies currently net $180 billion annually in the U.S. insuring against automobile accidents and the related medical costs (Desouza et al. 2015). When driving becomes the job of computers, however, the issue of whether the driver is liable for the crash becomes more ambiguous. Automakers and the vehicle's software providers will likely become the main responsible party and will need to purchase insurance for technical failure of the automobiles, making personal policies more limited in scope (Silberg et al. 2012). Liability may be placed on the driver for authorizing driving in wet, icy, or otherwise unsafe conditions, causing a need for some coverage. However, greater responsibility, under normal circumstances, will likely shift to the software and hardware manufacturers.

Additionally, the added safety of CAVs that are nearly error-free will reduce the number of crashes significantly. According to a report by KPMG, over 90% of accidents each year are caused by driver error, and accident frequency could drop as much as 80% with commercially viable Level 4 fully automated vehicles (Albright et al. 2015). Even the automation of parts of the driving task has decreased insurance claim frequency. David Zuby, executive vice president and chief research officer of the Insurance Institute for Highway Safety, claims that "vehicles equipped with front crash prevention technology have a 7-15% lower claim frequency under property damage liability coverage than comparable vehicles without it" (Albright et al. 2015). KPMG also hypothesizes that more costly technology under the hood of CAVs could increase the average collision expense from today's $14k to around $35k by 2040 (Albright et al. 2015).

Ultimately, KPMG estimates that CAVs could shrink the auto insurance industry by as much as 60% (Albright et al. 2015). With the current revenue of the auto insurance industry at approximately $180 billion, this decrease could represent a decrease in revenues of $108 billion. Insurers will need to develop fewer but larger corporate policies to maintain profitability. Vehicle owners will still need insurance for theft and comprehensive coverage for hail, flooding, as well as more limited liability coverage which will likely cause a decrease in premium per policy (Insurance Business 2015). Overall, this could make small auto insurance companies based in personal policies less viable and give more power to large businesses based in corporate contracts. Since there are far more insurance companies than auto manufacturers, this push for large policies for automated systems will cause competitive insurance pricing and big winners and losers in the battle for these corporate contracts.

Legal Profession

The result of fewer accidents from the automation of driving will likely challenge the profession of many attorneys. Around 76,000 attorneys in the United States specialize in personal injury (Langham 2015). With a total number of around 1.3 million practicing attorneys in the United States, personal injury lawyers make up approximately 6% of the American lawyer population. Vehicle collisions are the most common type of tort case, accounting for around 35 percent of all civil trials (McCarthy 2008). Law school is already becoming a more challenging path because of a current oversupply of attorneys, and the decrease in demand for personal injury lawyers would hurt career prospects even further. With an average liability claim for bodily injury of $15,443, a total number of crashes of around 5.5 million in 2012, and an average contingency fee of around 33-40%, the revenue loss from personal claim lawsuits could be as much as $3.2 billion (Langham 2015). The detriment to the profession could be offset by population growth and an increase in tort claims. Regardless, the landscape of the legal profession will be much different, at least in the scope of personal claims.

Construction and Infrastructure

CAVs may also induce a reduced demand for construction of parking lots, a change in the development of roadways, and an increased need for technology infrastructure. A potential increase in traffic efficiency would decrease congestion and the need for new, bigger roadways. If vehicle sharing reaches a sufficient level of development, a decreased need for parking would result and, thereby, reduce the demand for new parking lots and garages and allow for the redevelopment of existing garages. Development costs for all forms of construction and living costs in these areas could also drop due to lower parking requirements. Despite these increases in efficiency, it will likely be somewhat offset by the increase in VMT due to greater vehicle access and population growth. The designers and contractors of these large structures will get less business than they are used to and might need to adapt their businesses to include other types of infrastructure as a result.

Additionally, the way in which roadways are maintained and the component structures required may change. When vehicles become fully automated, there may no longer be a need for extra-wide lanes, guardrails, traffic control signals, wide shoulder, or rumble strips among other safety measures, and manufacturers of these components will lose a source of income. With sufficient market penetration, CAVs may be safe enough to allow the government to stop investing in these costly infrastructure safety measures. Data can be used by Departments of Transportation to analyze road use patterns and better plan the maintenance and improvements that are still needed. KPMG estimates that intelligently controlled intersections could perform 200-300 times better than current traffic signals (Silberg et al. 2012). KPMG also states that platooning could increase the effective capacity of roadways by as much as 500%, resulting in an estimated 10% reduction in infrastructure investment, saving around $7.5 billion per year (Silberg et al. 2012).

The infrastructure that is needed could be revolutionized alongside automobiles. An integral part of creating CAVs is Vehicle-to-Infrastructure (V2I) communication. GPS, sensors, 3D planning, design, and construction tools can be used to help plan, design, and build more integrated and efficient transportation systems. With wireless transponders called Roadside Units or other smart embedded sensors, cars and infrastructure can exchange information about curvy roads and low bridges, risks such as construction and information about traffic density, flow, volume, and speed (Bennett 2013). In order to remain competitive, contractors that base their business on large government commissions for highway and infrastructure construction will need to be on the cutting edge of this technology.

Land Development

CAVs will change transportation for people in all parts of the nation, and, therefore, will impact personal habits and land use. CAVs will likely transform the national parking system. According to Eran Ben-Joseph, parking lots and garages cover more than one-third of the land area in some U.S. cities, creating unsustainable urban dead zones in centers where population density is increasing rapidly (Diamandis 2014). CAVs will help mitigate this issue of overcrowding by allowing people to be dropped off at their location without the need to find a parking spot. On top of this, vehicle sharing will keep vehicles in more constant use and serve more people, further decreasing demand for parking infrastructure. The land area previously used for parking could be converted into housing, parks, or other useful developments that replace these parking dead zones.

There are approximately 105 million for-pay parking spaces in the U.S. and approximately 720 million spaces including the non-paid commercial spaces, a home space, and a work space for each vehicle (Chester 2010). At an average land value of $6,300 per parking space, the total land value of parking spaces is $4.5 trillion (VTPI 2017). If the amount of parking decreases by just 1% each year, $45 billion in property value will be freed annually. Parking will become more efficient and demand will decrease with the advent of CAVs, opening up land for other uses. The commercial real estate industry generates $931 billion in annual revenue (IBISWorld 2016), so the $45 billion in land could provide opportunity for a 5% increase in land development revenue.

Another possible impact of CAVs on land development is the extension or contraction of urban sprawl. The automobile is the invention that originally caused the development of suburban neighborhoods due to the increased distance one could travel in a given period of time and the fact that land further from city center costs less per square meter. CAVs could allow for a decrease in time of commutes due to easing of congestion and an increase in productivity during the commute, as the passenger is no longer required to focus all attention on driving, which could increase the draw of suburban housing. With the ability to engage in activities other than driving during the commute, the cost of transportation declines, increasing the value of living further from the urban core (Anderson, et al. 2014). Alternatively, CAVs could cause a loosening in the urban real estate market, reducing the cost of urban living and encouraging families to move into town (Greeting 2014). The opportunity to increase urban density would also encourage development and movement into the city center. Bansal and Kockelman’s (2016) survey results determined that almost 7.4% of households expect to move more centrally, while 11.1% expect to move outward. So, while outward expansion will likely dominate, its effects may be limited by the increased efficiency of urban travel with SAVs. Additionally, the effects in different locations may differ based on local factors, such as population growth, demographics, and existing infrastructure. However, it is important to pay attention to the impact on land availability and preference going forward for the development of real estate.

Digital Media

The extension of digital media into the CAV environment will open up the market for even more users and, thereby, more sales. At the point of full automation, commuters who usually spend time vigilantly watching the road (or dangerously multitasking on their smartphones) will demand greater integration of digital media features into their automobiles. Content providers like YouTube, Netflix, and social media networks will see a large benefit from the increased time and desire for their services on commutes.

Additionally, a study by McKinsey & Co. suggests that internet shopping could receive a large bump from this added free time, stating that each additional minute occupants spend on the internet could generate $5.6 billion annually, totaling $140 billion if half of the time of the average round-trip commute (25 minutes) is spent surfing or shopping (McKinsey 2015). Even if only 5% of the average commute is spent on digital media, the annual value would total $14 billion. A possible loss due to this increase in entertainment flexibility for drivers is a decreased demand for radio and recorded music. Drivers will no longer be captive to audio-only entertainment, allowing them to forgo their usual radio programs for more stimulating visual ones. The boon for the overall entertainment market, however, could be quite significant, as a report from Morgan Stanley suggests the value of content in the automotive industry could shift from minimal to almost 20% of the value of the car (over $6,000 for the average cost of a car) (Jonas et al. 2014).

Police (Traffic Violations)

Due to a decrease in human driver error and misbehavior, the importance of traffic cops and parking wardens will likely decrease as well. Drunk driving, speeding, and other traffic violations will become less frequent and the size of the police force will decrease (The Economist 2012). A survey by the Bureau of Justice Statistics shows that 31 million people were involuntarily stopped in 2011, more than 85% of those stops traffic related, and over half of all contact between civilians and police is related to vehicles (Zagorsky 2015). Another side effect of increased traffic obedience will be a loss of revenue for governments, as traffic fines make up a significant source of money.

According to the National Motorists Association, the traffic ticket industry brings in between $7.5 to $15 billion (Bax 2008). According to The Arizona Republic, approximately $10.8 million, or 1.1%, of Phoenix's $1.03 billion budget in 2014 came from traffic ticket fines (Giblin 2015). Although $10 million is significant, a simple 1% of the city's budget is recoverable from other sources. Small towns, however, may be more strongly affected by law-abiding CAVs. While only five towns in Colorado earned more than 30% of revenue from traffic fines, the small city of Campo generated 93% of its budget from fines and forfeitures in 2013 (Kuntz 2015). These results are outliers from "speed trap" towns, but still this shift would be significant to these specific municipalities. Assuming a 50% reduction in the $10 billion in traffic ticket fines per year, CAVs would account for a $5 billion decrease in government revenue. Some of this loss may be recovered, however, through savings from the decreased need for traffic police.

Government officials in small cities will have to find a way to adapt to this revenue loss. A decreased payroll due to fewer highway patrol officers will slightly offset this, but governments could also make up for lost revenue by charging infrastructure usage fees or road tolls (Silberg et al. 2012). Toll roads have been implemented for specific highways, but expanding this systematically would require a large infrastructure investment. Traffic tickets will not be eliminated until there is 100% market penetration of CAVs, but the decrease in revenue will be felt gradually, and local and state agencies will want to prepare for this change.

Oil and Gas

A more efficient system of driving will also cause ripple effects in the oil and gas industry. Platooning, computer-controlled, and lighter cars interacting with more efficient infrastructure will contribute to an overall improvement in fuel efficiency (Silberg 2012). The Texas Transportation Institute estimated that congestion costs Americans 4.8 billion hours of time, 1.9 billion gallons of fuel, totaling $101 billion in combined delay and fuel costs (Silberg 2012). Platooning could reduce highway fuel use by up to 20% solely due to the decreased drag coefficient from drafting (Silberg 2013). The decreased need for parking will improve fuel efficiency as well, as one MIT study found that 40% of total gasoline use in cars in urban areas is spent looking for parking (Diamandis 2014). While this number may be a high estimate, the ability for SAVs to move onto serving the next occupant without needing to find parking would improve overall vehicle efficiency. Furthermore, SAV fleets could make electric vehicles a more viable option and even financially preferable for fleet management companies. Despite an increase in fuel efficiency, VMT is expected to rise by 10 percent due to the increased accessibility of CAVs and repositioning of SAVs in fleets (Childress et al. 2015). The overall increase in fuel consumption will be limited by the increases in efficiency, leading to a total fuel use increase of around 5%, resulting in an annual revenue increase of $14 billion out of the $284 billion market. The increased vehicle efficiency and increased VMT largely offset each other in the oil and gas industry.

ECONOMY-WIDE EFFECTS

CAVs will increase the capacity of the nation's transportation system due to improvements in efficiency. First, with well-developed, accurate computing systems, traffic accidents, which account for 25% of traffic congestion, will be greatly reduced as approximately 93% of accidents are due to human error (Fagnant and Kockelman 2015). This fact will increase roadway capacity and potentially save around $488 billion due to a reduction in injuries and deaths due to collisions (Jonas et al. 2014). Additionally, if VMT does not rise, congestion is likely to fall due to the increased efficiency of coordinated vehicle speeds and traffic flows, due to data sharing between cars, synchronization of traffic signals, and fewer crashes. Pinjari et al. (2013) estimate that connected CAVs will cause a 22 percent increase in highway capacity at 50 percent market penetration, 50 percent capacity increase at 80 percent market penetration, and 80 percent increase at 100 percent market capacity.

Easier travel means greater demand for travel, however. Fully automated vehicles will enable children, elderly, and disabled people greater access to meaningful destinations and activities at all times of day. Such vehicles will make longer trips seem less burdensome for former drivers. These behavioral changes will increase VMT and may worsen congestion on many if not all roadways, but the increased efficiency of smaller headways (if mandated) and coordinated movements on highways may outweigh these effects on many roadway types (Pinjari et al. 2013).

"Driver" productivity will also rise as a result of the added time that can be used for other tasks, like working during one's trip to the office. Diamandis (2014) estimates that CAVs could save over 2.7 billion unproductive hours in work commutes, generating an annual savings of $447.1 billion per year in the U.S. alone (assuming 90% CAV penetration). This time savings estimate, combined with $488 billion from collision costs amounts to total savings of $1.1 trillion in the U.S., or 8% of the U.S. GDP, and as much as $5.6 trillion worldwide (Jonas et al. 2014).

Some effects brought on by CAVs could counteract and limit these gains. Once CAV sharing is put into action, although fewer cars will be needed, those in use will accrue mileage more quickly and require maintenance more often. Additionally, the increased convenience and affordability may encourage more vehicle travel, offsetting the pollution and crash benefits (Litman 2015). The economic effects of CAVs will extend beyond the simple crash, productivity, and fuel saving into every facet of the American economy.

CONCLUSIONS

The purpose of this study was to identify the industries most impacted by the rise of CAVs and to examine the forces that affect these industries and the economy as a whole. The table below shows the 13 industries that were selected and ordered based on the immediacy and size of the impacts on each. The analysis showed an annual percentage change and overall annual dollar value change based on the size of the industry. Although individual businesses that do not adapt to this change may be hurt by the rise of CAVs, the economic effects are generally viewed as societal savings that would feed back into the economy through businesses and to consumers. On top of the effects on specific industries, everyone will experience the benefits of the time savings from decreased congestion and added productivity from the hands-free driving environment of CAVs. According to the 2015 Consumer Expenditure Report, transportation accounts for 17 percent of average household income, 7.5 percent vehicle purchases, 3.7 percent on fuel, 1.2 percent on public transportation, and 4.9 percent on other vehicle expenses, such as maintenance and repairs and insurance (Bureau of Labor Statistics 2015). Comparatively, average household expenditures also include 32.9 percent for housing, 12.5 percent on food, 11.3 percent on insurance, 7.8 percent on healthcare, 5.1 percent on entertainment, 6.9 percent for utilities (Bureau of Labor Statistics 2015). Transportation will be directly impacted by the rise of CAVs, and nearly all of the other largest contributors to household expenditures will be heavily influenced by CAVs, as well.

The economic value reflected in each of the industries and the economy-wide totals do overlap in some places, limiting the overall total economic value. The total collision reduction value is also reflected in the economic savings from the decreased spending in the auto repair, medical, insurance, and law industries. The majority of the value saved in each of these industries is due to a reduction in collisions, so a total value of $144 billion is reduced from the overall total.

CAVs will transform our economy and change the landscape of almost every industry. Although some sectors will be more significantly affected than others, ripple effects will be felt throughout most, if not all industries. As the effects compound, the overall magnitude of the impacts would multiply. The technology still has a long road of development ahead and market penetration will define the size of the impact of driverless vehicles. With the assumption that CAVs will eventually become pervasive, or at least hold a large share of the automotive market, it is assured that they will have a strong economic impact, potentially as much as $1.2 trillion or more. In order to prepare for this revolution, we must be aware of the potential effects so that we can alter our established systems to best harness these changes. Change is coming, and we must be prepared to adapt in order to thrive in the developing economic landscape.

TABLE 1 Summary of Economic Effects (Industry and Economy-Wide)

Industry-Specific Effects				
Industry	Size of Industry (billions)	Dollar Change in Industry (billions)	Percent Change in Industry	$/Capita
Insurance	$180	-$108	-60%	$339
Freight Transportation	$604	+$100	+17%	$313
Land Development	$931	+$45	+5%	$142
Automotive	$570	+$42	+7%	$132
Personal Transportation	$86	-$27	-31%	$83
Electronics & Software	$203	+$26	+13%	$83
Auto Repair	$58	-$15	-26%	$47
Digital Media	$42	+$14	+33%	$44
Oil and Gas	$284	+$14	+5%	$44
Medical	$1,067	-$12	-1%	$36

Construction/ Infrastructure	$169	-$8	-4%	$24
Traffic Police	$10	-$5	-50%	$16
Legal Profession	$277	-$3	-1%	$10
Industry-Specific Total	$4,480	$418	9%	$1,312
Economy-Wide Effects				
Type of Savings		Dollar Change in Industry (billions)		$/Capita
Productivity		$448		$1,404
Collisions		$488		$1,530
Economy-Wide Total		$936		$2,934
Collision Value Overlap		$138		$432
Overall Total		$1,217		$3,814

+ = Industry Gain   - = Industry Loss
$/per capita and Total: All values added due net economic/consumer benefit

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