Mobility: The Socioeconomic Implications of Autonomous Vehicles

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Executive Summary

Autonomous vehicle (AV) technology is developing rapidly and is poised to change all aspects of transportation and mobility. AVs are already on the road, some without backup human drivers. Widespread adoption of AVs will change the demand for labor, conceptions of private vehicle ownership, and urban land use. On the one hand, the implementation of AVs promises increased safety, efficiency, and access to transportation. On the other hand, scientists and social scientists predict that AVs will make pollution worse and exacerbate socioeconomic inequality. Policymakers must be prepared for the legislative and regulatory challenges AVs will soon bring.

This memo highlights some of the positive and negative economic, infrastructural, environmental, and socioeconomic implications of the widespread adoption of vehicles with a high level of autonomy. Each section then presents policy suggestions to address the ongoing and coming societal changes. Finally, the memo concludes with a discussion of the technological, regulatory, and ethical barriers to even getting these highly autonomous vehicles on the road as regular consumer products.

Introductions and definitions

What are AVs and what can they do? AVs are vehicles that have some degree of automation in their capabilities. [1] These capabilities range from anti-lock braking systems (ABS) to fully automated driving run by artificial intelligence (AI). [2] Proponents of AVs promise a mobility revolution in the next 20 years due to breakthroughs in AV technology. [3,4,5,6,7] However since the 1970s, car companies have built consumer vehicles containing components that function autonomously under given conditions, such as ABS and traction control systems. [2] In the 1990s, features such as adaptive cruise control, electronic stability control, and brake assist systems brought a degree of autonomy to active driving. In the 2000s, car companies incorporated parking assistance, lane keep assistance, and automatic emergency braking into their vehicles. Since then, AV developers have made incremental progress towards fully autonomous vehicles, introducing features such as automated lane changes, highway cruising, and parking. Companies such as Google, Tesla, Uber, and Ford have been working towards ultimate goal of developing connected AVs capable of operating under all road and environmental conditions without human intervention. [8,9,10,11] Connected AVs can communicate with each other to avoid accidents and traffic jams, making transportation safer and more efficient.

AV developers generally categorize AVs by Level of Automation from 0-5. [1,2,12] Level 0 vehicles have no automated functions that control driving. The vehicle may be equipped with automatic safety systems such as traffic sign detection and blind spot and collision warnings, but the computer cannot control the vehicle and human intervention is required. At the opposite end of the spectrum, Level 5 vehicles are fully automated to the point that the steering wheel is optional. In Level 5 AVs, a human passenger/backup driver is not required. For the past several decades, consumers have been able to purchase vehicles in Levels 1 and 2, equipped with the automated technologies described above. AV companies are now testing Levels 3 and 4 vehicles and pushing to make them technologically and commercially viable. [8,9,10,11]

This memo focuses primarily on the potential socioeconomic and policy implications vehicles of Levels 4 (high) and 5 (full) automation. In discussing these implications and potential solutions, it assumes widespread societal integration of such highly automated vehicles. As argued in the last section, however, societal adoption of emerging technologies is rarely a frictionless process. [13,14] Policymakers face a host of technological, political, and policy challenges before Level 4 and 5 AVs are the norm. [3,4,5,6,7]

Economic implications: AVs promise efficiency, safety, and changes to demands for labor

Connected AVs may reduce the economic burden of traffic jams and vehicle accidents. Vehicle accidents kill tens of thousands of people per year and injure many more. [15] Together, accidents and traffic jams cost billions of dollars per year (equivalent to almost 2% of GDP) due to lost productivity, medical costs, and property damage. [15] Connected AVs that constantly communicate can work in tandem to prevent traffic jams and avoid accidents. If a collision is inevitable, the AVs can react so the impact minimizes injury and damage.

The safety, efficiency, and predictability of AVs will not just benefit private automobile owners. [16] For example, industries like long-haul trucking will seek to capitalize on the benefits of AVs. Autonomous trucks will not get bored or need to sleep, so they will be safer and reach their destinations more quickly. [17] Emergency responders in connected AVs could be able to reach victims and return to hospitals more quickly because the autonomous ambulance can direct other autonomous vehicles out of the way. [18,19] Construction and mining sites might be safer and operate more efficiently. [20,21,22] Cities may be able to instantly deploy more autonomous plows over a wider area to remove snow more quickly.

AVs may contribute to a coming unemployment crisis. In the U.S., the transportation industry itself employs 3.2% of workers, [23] but introduction of AVs threatens jobs in every sector of the economy. [24] In total, AVs could affect the jobs of 15.5 million workers (1 in 9 workers). [16] This is due in part to the fact that the effects of AVs tend to snowball and the interconnected nature of the U.S. economy. Autonomous trucking does not just threaten drivers' jobs but also jobs in rest stops and motels. Centrally owned AV fleets (as discussed below) will change business models for vehicle servicing, likely forcing many mechanics out of work. As mentioned above, AVs bring safety and efficiency benefits to industries such emergency response and construction, but they will also replace human workers. However, job losses due to AVs are only part of a much larger looming unemployment crisis. Automation, and AI in particular, is displacing human labor and intelligence in every type of job. [25]

Policymakers must address the coming economic instability from AVs. Job losses from societal adoption of AVs cannot be dealt with in a vacuum. Policymakers must address the broader unemployment threat from AI. [26,27] Education and retraining offer only a temporary fix, albeit one that policymakers should take advantage of until long-term solutions can be developed. [28] Large AV companies are already pushing for federal legislation legalizing and regulating AVs. [29] These companies are seeking to avoid a patchwork of rules and regulations in each state that would hamper large-scale manufacturing and deployment of AVs. In exchange for smoothing the regulatory landscape, policymakers could enact a tax (per vehicle, per mile, etc.). In the near term, the revenue would fund education and retraining programs for workers displaced by AVs. However, policymakers must develop society-wide, long-term solutions to automation, for example, implementing a universal basic income. [30,31]

Implications for infrastructure planning: AVs will change urban land use

AVs could free up valuable urban land. AV companies currently envision fleets of on-demand AVs. [2,7,32] In theory, these convenient, accessible, and cost-effective AVs will eliminate the need for private car ownership. [32,33] As such, cities will no longer need to dedicate large amounts of valuable land to parking infrastructure. [34,35] Cities can use the newly freed up space for the public good. New businesses, consumers, and opportunities for community events in

spaces previously dedicated to parking will help to grow the local economy. As many cities become prohibitively expensive, [36] cities can use the land for affordable housing.

Policymakers can use freed up space for the public good. Policymakers should make it a priority to preserve this reclaimed space for the direct benefit of inhabitants of the city. [37,38] Real estate developers will likely try to take advantage of the reclaimed space to install expensive housing, offices, and retail space. [32] Instead, policymakers should offer significant incentives (*e.g.*, tax breaks) and install zoning regulations to ensure that land is used for affordable or mixed-income housing and public spaces. In general, the policies enacted should strongly discourage real estate and business developers from creating more urban space only accessible to and benefiting the very wealthy. Cities need to ensure that individuals of all socioeconomic strata can enjoy the benefits of AVs or face growing societal unrest.

Environmental implications: Increased convenience could come with costs

More AVs and "zombie" cars could exacerbate pollution and congestion problems. The convenience afforded by AVs may actually incentivize consumers to buy more private vehicles instead of switching to ride-sharing models. [39] Owners may be unwilling (due to high parking fees) or unable (due to no close parking) to send their AVs to park. Instead they instruct the AVs to drive around, creating "zombie cars." [35,40] On-demand fleets of AVs are subject to the rider demand, and times of low ridership will result in more AVs circling. Carbon emissions and pollution will increase unless the large majority of AVs are electric *and* consumers primarily switch to shared mobility programs. [35]

Policymakers should support the development of alternative fuel vehicles and car sharing programs. Widespread commercial and consumer adoption of alternative fuel vehicles (*e.g.*, electric vehicles) will help alleviate some of the pollution from conventional vehicles. [35,39] Policymakers should work to support the research, development, and manufacture of alternative fuel vehicles by both financial and regulatory means. Policymakers can discourage private owners and companies from adding to the problem of zombie vehicles through fines: for example, a given percentage of miles the vehicle drives must be completed with a passenger or destination. To assess these fines, vehicle route summaries must be submitted with yearly taxes.

Ultimately, fewer vehicles of any type on the road will improve the quality of life for the general population. [35] The advent of on-demand AVs may change societal conceptions of private vehicle ownership, and policymakers can encourage this change by providing a tax break for those who give up private vehicles. All parking infrastructure cannot be eliminated, but judicious application of algorithms to predict demand (already in use) and the ability to summon cars from a distance will allow substantial amounts of it to be moved to less valuable land. [41]

Implications for socioeconomic mobility: AVs will change access to opportunities

AVs provide transportation options, enabling upward socioeconomic mobility. Individuals with disabilities, the elderly, and low-income people living in areas without affordable and accessible public transportation suffer economically and socially. [42,43,44] AVs, especially on-demand ride sharing programs and public transportation networks, will expand access to employment, medical care, and social services. [2] Cities will be able to provide public transportation services (*e.g.*, autonomous buses) to currently underserved neighborhoods without hiring more drivers. As reliable and affordable transportation provides more people employment opportunities and regular income, fewer people will rely on government social services. The

elderly and disabled who wish to work will be able to work longer and maintain social connections, critical contributors to physical and psychological health. AVs will enable people to be self-sufficient, ideally contributing to general well-being. [42,43,44]

AVs may further entrench unsustainable models of wealthy suburbia. The wealthy will enjoy the majority of the benefits of AVs without active, purposeful, and directed management of autonomous public transportation systems. Without intervention, AVs will primarily help wealthy people in the suburbs who seek personal convenience and private travel, even if they access to public transportation. [35] As a result, suburban sprawl will increase because commuters can sleep, work, or relax during travel time, allowing people to live even further from their jobs. Consumer adoption of AVs may inadvertently further unsustainable use of land, resources, and energy. Expanding suburban sprawl drives private vehicle ownership and makes building accessible public transportation even more difficult. Fleets of on-demand ride sharing AVs are likely only sustainable in densely populated areas. Cities may seek to remove infrastructure related to vehicles (as discussed above), [41] but instead the cities will be forced to deal with even more private vehicles from suburban commuters. Proponents of AVs claim that the added benefit of accessible transportation will narrow the socioeconomic divide between urban and suburban areas, but in fact AVs may make it worse.

Policymakers should frame AVs as a solution to reliance on government social services. To ensure the benefits of AVs are distributed throughout society, policymakers need to support and incentivize creation of autonomous public transportation systems. [37] This includes rewarding AV companies (*e.g.* through tax breaks and exclusive contracts) who work with cities to utilize their technology to help underserved communities. If construction of new train lines is cost prohibitive, extensive networks of autonomous buses may help to close the gap. In particular, policymakers should emphasize the need for reliable and affordable (perhaps subsidized) AV fleets to help the elderly and disabled who cannot ride other forms of public transportation. In the U.S, policymakers often face a losing battle trying to gather support for taxpayer investment in public transportation systems. The key to gaining broad support for the necessary AV research and program development is to present AVs as a way to increase self-reliance. [2,37] If AVs can provide elderly, disabled, and low-income individuals with access to jobs and healthcare, their dependence on other publically funded social services will likely decrease and their well-being will increase. [42,43,44]

Policymakers should regulate and limit long-commute AVs. Policymakers should take steps to make sure pollution and congestion in cities does not get worse due to commuters from suburban areas in private AVs. [35] In designing new infrastructure, [2,37,38] cities can regulate from how far private passenger AVs can travel without incurring hefty tolls upon entering a city. In particular, policymakers should design these tolls to discourage commuting from extreme distances. These new regulations will require some new infrastructure and buy-in from AV companies, but to a large extent, the technology to implement them already exists. AVs record their route and distance traveled, and many cities already charge tolls for entering the city center or crossing bridges. Just like with systems like E-ZPass, [45] sensors attached to the exterior of the AVs can communicate with the tollbooth and automatically charge credit cards on file.

Barriers to AV adoption: policymaking challenges when algorithms make decisions

Policymakers will shape how AVs integrate into society. As with any emerging technology, the governance of AVs presents substantial challenges. [13,14] In 2016, a Tesla Model S

operating in Autopilot mode misread a situation and crashed into a truck, killing the Tesla's owner.[46] Federal investigators determined the Tesla had not malfunctioned, cleared Tesla of liability, and largely blamed the situation on human error.[47,48] This unfortunate event highlights the difficulties of planning for and regulating AVs as an emerging technology. AV developers are excited to bring new knowledge, technology, and convenience to society, but their innovation process lacks careful consideration of the potential broader implications of their work.[49] Policymakers must navigate the gaps between the promises of the technology and the outcomes. In part, this means pushing AV developers to adopt responsible innovation practices.[13,14]

The governance of AVs is particularly difficult because AVs operate using machine learning algorithms.[50,51] Programmers provide a base data set, rules, and constraints to the AI, and then the AI is free to "learn" on its own. The following two subsections highlight broad areas of regulatory challenges that are the direct result building machine learning into vehicles.

Algorithms in AVs raise ethical and moral considerations. Machine learning algorithms control the decisions the AV makes, but these algorithms are not neutral.[30] All AI algorithms are biased: programmers choose what seed information to provide. After that point, the processes by which machine learning technology makes decisions are opaque. When the technology has the capacity to injure or kill someone, the unknowable nature of the AI technology's decision making process becomes ethically and morally problematic.[52] In the Tesla fatal crash described above, the algorithm's decision process is still a mystery.[47,49]

The Trolley Problem is the most commonly cited thought experiment addressing AI technologies making ethical decisions: it considers the situations under which it is acceptable to cause the death of one person to save many people.[53,54] However, these are not straightforward questions like whether it is "better" to kill one passenger or two pedestrians. Rather, these inevitable situations AVs will face are intensely value-laden:[54] should the AV swerve to avoid the pregnant woman and toddler and put its four passengers at risk? Humans design and program the machine learning algorithms and thus determine social value. In effect, the programmers become arbiters of moral authority. Ultimately, however, capitalist markets may decide this question: consumers are unwilling to purchase an AV that will sacrifice them to protect others.[55]

AV development is creating a regulation culture clash. One of the major challenges in AV development stems from the necessity of bringing together two industries with different cultures of governance: car manufacturers and AI software developers.[49] Car manufacturers are accustomed to strict regulation and liability standards for malfunctioning or defective vehicles. The car companies also have a long history and embedded understanding of how their products interact with existing infrastructure and in social structures. Software and technology companies like Google and Tesla, on the other hand, generally operate with substantial oversight and regulation.[49] To some extent, software companies of all types operating in the digital space have not realized or been held fully responsible for the societal consequences of their creations.[56] Now, policymakers and the public must grapple with the effect of AI on data security, privacy, and the political process.[30]

With AVs, both hardware and software interact directly and immediately with the material world. For example, as discussed above, cities are now redesigning their infrastructure to prepare for the advent of AVs.[2,37,38] This slow process, undertaken variably across the country, could slow widespread integration of AVs. More broadly, the combination of novel hardware and software may foretell a shift in societal expectations of the regulation of software, particularly AI algorithms.[49] Policymakers will have to address a host of policy issues that sit at

the intersection of regulated hardware and largely unregulated (and still experimental) software. At the forefront, are questions of legal liability and how to assign responsibility when an AV malfunctions or crashes. [57] With conventional vehicles, the laws regarding liability are clear. But, the fatal 2016 Tesla Autopilot crash demonstrates the murky nature of the regulatory infrastructure of AVs. [48] AV developers and policymakers need to more carefully consider how and when they introduce and integrate AVs into society, and their potential consequences.

If AV technology develops as assumed in this memo, policymakers will further need to develop policies on a range of issues that combine technological, legal, ethical, and social aspects. [54] Many of these issues are in uncharted legal territory without substantial precedent. For example, if connected AVs can work together to prevent accidents and react faster than humans to unexpected obstacles, human drivers will slower and unpredictable reactions may actually decrease safety on the roads. In that case, policymakers must decide whether AVs should even have a steering wheel or if they should ban human operation of vehicles. [6,58] Such a decision will face public pushback because many people will not want to hand control to a machine (and some like driving). [59] Indeed, fewer people may even want an AV that expected, slowing widespread adoption and societal integration.

Policymakers should develop a universal framework of algorithmic morality. Considering the bias inherent to machine learning algorithms, this framework should address how AVs (and more generally AI technologies) act when humans can be injured or killed. [52,60] Policymakers must Germany already took a step in this direction and adopted guidelines that AI algorithms, including in AVs, cannot discriminate on the basis of "age, gender, [and] physical or mental constitution." [61] Ideally, policymakers will pursue these legislative efforts internationally to create global consensus on policies regulating these emerging technologies.

On a more abstract level, policymakers should push AV developers to create in a framework of responsible innovation. [13,14] This includes removing the excuse of the concealed nature of machine learning algorithms as a way to skirt responsibility. [49] AV developers should contend with the social dimensions of their technologies. Towards this goal, policymakers should encourage use of social machine learning technologies [62] and incentivize AV developers to build AVs that learn together in fleets. [5,63,64] Collaboration and widespread sharing of data will help to negate programmers' individual biases and develop algorithms that maximize the public good. In general, the promised public benefits of AVs are not inevitable. For any of these benefits to come to fruition, AV developers, policymakers, and the public must start to address the unprecedented implications of software making ethical decisions.

Conclusions: engaging the right experts to move forward

The future of AVs is uncertain: developers, scientists, engineers, social scientists, and scholars all predict any number of potential futures. [5,35,41,49]. This memo highlights some of the societal implications of AVs, as well as barriers to their widespread integration. Even though vehicles with high- and full-automation are likely at least a decade away, the discussion presented here highlights why policymakers must start to address the policy and regulatory issues now. [1,2]. Importantly, In addition to technical experts, policymakers should engage Science and Technology Studies and Science, Technology, and Policy scholars. These scholars have particular expertise in understanding the role of new technologies and engaging the public to guide the innovation and policymaker process. Policymakers should also utilize structures and institutions such as citizen science panels and consensus conferences [65,66,67] to help ensure society can reap the promised benefits of AVs. [68]

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