AMERICANS' PLANS FOR ACQUIRING AND USING ELECTRIC, SHARED AND SELF-DRIVING VEHICLES

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ABSTRACT

This study surveyed 1,426 Americans in January 2017 to gauge how technology availability and costs influence public opinion, vehicle ownership decisions, travel, and location choices. Example results include average willing to pay (WTP) for full automation (on a newly acquired vehicle) of $3,252 with a very high standard deviation of +/- $3,861 with a human-driven-vehicle (HV) mode option and $2,783 (standard deviation = $3,722) without that option (AV driving only). These averages rise to $3685 and $3112 for AV with and without an HV option, respectively, if responses of zero WTP are removed. Americans' average WTP for use of shared autonomous vehicles (SAVs) is $0.44 per mile (standard deviation = $0.43). If given the option, Americans expect to set their vehicles in AV (self-driving) mode 36.4% of the time. Respondents believe about 20% of AV miles should be allowed to travel empty, for both privately-owned AVs and shared AV fleets, which would be quite congesting in urban regions at many times of day. Home location decisions may also be impacted by the presence of AVs. Among those likely to move their home in the next few years, around 15% indicate that availability of AVs and SAVs will shift their new home locations relatively closer to the city center, while around 10% indicate further away.

KEY WORDS

electric vehicles; autonomous electric vehicles; dynamic ride-sharing; fleet evolution; vehicle miles traveled

JEL Codes: L91, O18, O21, R11, R14, R41

1. BACKGROUND

Autonomous, electric, and shared vehicle technologies are expected to experience rapid growth. Electric vehicles (EVs) have existed since the 1890s, and thus slightly longer than their gasoline-fueled counterparts. Current and continuing battery-cost reductions are increasing EVs' attractiveness. Shared vehicles are a more recent option, in the form of very-short-term rentals in urban areas. Cell phones, and their GPS, have made ride-hailing a key mode in many settings. Fully self-driving vehicles will impact all these options, and many more (Fagnant and Kockelman 2016).

EVs can reduce emissions and human health impacts in many power-source settings. Nichols et al. (2015) compared EV emissions vs. conventional light-duty vehicles in Texas. They estimated EVs to lower emissions of every analyzed pollutant except SO_2, thanks to coal as a power-plant feedstock. A shift away from coal, toward cleaner generation, would result in EVs lowering emissions of all pollutants. Reiter and Kockelman (2017) find emissions externalities of a typical EV to be about half that of a gasoline vehicle in Texas cities. For air quality, climate change, and energy-security purposes, many countries and states have initiatives to accelerate EV adoption, and revenues from EV charging may reduce electricity rate increases while saving EV owners money via overnight charging (Tonachel 2017).

Fagnant and Kockelman (2015) estimated (and monetized) many of AVs' benefits to society and their owners, improved safety, reduced congestion, and decreased parking needs, while noting issues of increased vehicle-miles traveled (VMT), by making travel easier, and more accessible (to those without drivers' licenses, for example). Dynamic ride-sharing (DRS) among strangers using SAVs can offset some of these issues, while improving response times and lowering SAV access costs in many contexts (e.g., at peak times of day, when an SAV fleet is heavily utilized). Litman (2015) anticipates some increased mobility shortly after introduction AV technologies, but most benefits, including improved traffic operations, safety, widespread mobility, and environmental improvements will likely take decades to become noticeable.

Harb et al. (2018) offered a free week of chauffeur service to various California households, followed by surveys and interviews. Significant VMT increases and trip-count increases were noted, especially in the evenings and with longer trip distances. Perrine et al. (2020) estimated how AV availability can reduce U.S. domestic airline passenger-miles travelled by 53%, with AV choice dominating at distances under 500 miles. Lee and Kockelman (2019) investigated application of real-time congestion-based tolls to help keep traffic moving, with AVs' flow-related benefits (due to inter-vehicle communications, tighter headways, and smoothed driving cycles) possibly negating the need for tolling in many settings. While the future is uncertain, most experts expect more congestion (see, e.g., Hardman et al. [2019]).

This research tackles topics and gaps left in past surveys regarding the technologies addressed here. Bansal and Kockelman (2017a) surveyed 2,167 Americans to calibrate a microsimulation model of U.S. light-duty vehicle fleet evolution, reflecting different technology price reductions and increases in households' WTP. Their 30-year simulation ended in 2045 but did not include electric or shared vehicles in any detail and suggested an average WTP of $5,857 for full automation. Bansal and Kockelman (2017b) then surveyed 1,088 Texans, to understand WTP for, and opinions toward connected and autonomous vehicles (CAVs). This study did not address electric or shared technologies or acquire a nationwide sample. Notably, 81.5% of those respondents (population-weight corrected) did not plan to shift home locations due to CAVs becoming available. However, those who are not already considering moving may be rather content with their home's location, and less able to thoughtfully consider moving in a hypothetical situation. Posing this question only to those considering moving, as done in this current study, may better reveal the technologies' effects.

Similarly, Schoettle and Sivak (2014) surveyed 1,533 adults in the U.S., United Kingdom, and Australia, to gauge public opinion about AV technology. Those with greater familiarity with AV technology had a more positive opinion and higher expectations of this technology. Overall, respondents expressed significant concern about AVs, especially AVs' driving abilities, security issues, empty vehicles. Females showed greater concern, as did Americans, on average. Respondents expressed desire to adopt the technology, but most indicated zero WTP, consistent with Bansal and Kockelman's (2017a, 2017b) results.

Studies addressing similar topics include Bansal et al. (2016), who estimated Austin, Texans' average WTP to be $7,253 to own an AV. They estimated how WTP for AVs and SAVs depends on various explanatory factors, and they used SAV pricing scenarios of $1, $2, and $3 per mile to gauge use estimates. Zmud et al. (2016) surveyed Austinites to better understand technology acceptance and use. They found a strong desire to own personal AVs, rather than share SAVs, and predicted AVs to increase regional VMT.

Javid and Nejat (2017) used the U.S. National Household Travel Survey to estimate adoption of plug-in electric vehicles (PEVs). And Musti and Kockelman (2011) and Paul et al. (2011) surveyed those residing in Austin, Texas, and then across the U.S. about EV purchase interests, in order to microsimulate the region's and, then, nation's fleet evolution over 25 years. Vehicle choice in the questionnaire was largely a series of choices between specific vehicle makes and models. They simulated effects of different gas and energy prices, demographics (like an aging population), and feebate programs, to incentivize purchase of hybrid and plug-in EVs. Paul et al. (2011) also simulated greenhouse gas (GHG) emissions over the 25-year period, demonstrating how higher gasoline prices provided the greatest GHG and VMT reductions. Higher population-density assumptions (for Americans' home locations, for example) also significantly reduced GHG and VMT forecasts, while lower PHEV pricing achieved little.

All previous studies lack a nationwide survey that is inclusive of electric, autonomous, and shared vehicle technologies. This study conducts such a survey and investigates the effects of these technologies on travel behavior and home location choices.

2. SURVEY DATA

This study surveyed adult Americans (age 18 and over) regarding their and their households' willingness to acquire and/or use electric, autonomous, and shared vehicle technologies. A data clean process removed respondents who completed the survey far too quickly, or whose responses indicated a lack of attention or understanding of the questions (shown by nonsensical or excessively contradictory responses), resulting in a final sample of 1,426 respondents. These Americans come from all over the U.S., thanks to a panel of over 100,000 potential respondents maintained by Survey Sampling International (SSI), with the sample's spatial distribution largely mimicking population concentrations across the nation. More detailed descriptions of the full data set can be found in Quarles (2018).

2.1. Sample Weighting

No random sample will exactly match the population intended, so a weighting process was performed to closely mimic U.S. demographics, providing weights for both individual respondents and the households they represent. The household weights were then applied to all statistics and analyses involving household decisions, and the individual weights were applied to all results for questions involving individual choices and opinions.

The sample data contained too few men (37% vs. 49% in the U.S.), younger people (27% vs. 31% for those under age 35, for example), and those with lower income and education levels. Weights were computed using the U.S. Census Public Use Microdata Sample (PUMS) for combinations of gender, age, education, marital status, race, household income, household size, household workers, and household vehicles. The sampling correction values were computed via an iterative process, across PUMS-provided combinations until the weighted samples (first at the individual level, then at the household level) matched the population. Once proper weights were available, the following results could be computed.

2.2. Modeling Approach

Model parameter estimations were performed to maximize predictive power while ensuring statistical and/or practical significance of each included covariate. In some cases, a covariate's statistical significance was low, but it was retained because of behavioral expectations for its practical relevance. (For instance, willingness to pay relates to the vehicle acquisition decision, so household income was retained in the model of vehicle ownership.) The five key models are a household's relative preference for an AV versus conventional vehicle or "HV", the factors affecting household's next vehicle purchase, the percentage of person-trips made with an AV, the share of SAV trips that use or does not use DRS (with a stranger), and factors affecting charging access in home and work/school.

3. RESULTS

As shown in Table 1, driving alone dominates all trip-purpose categories, excepting social/recreational trips, which are largely driven with others in the vehicle. SAV rides may be rather attractive for such multi-person trips, since the cost may be shared among a group.

TABLE 1 Summary Statistics (n = 1426 Americans, population corrected)

Respondents' Primary Travel Mode by Trip Type

Trip Purpose	Walk	Bicycle	Drive Alone	Drive w/ Others	Public Transport	Not Applicable
Work	3.1%	0.7%	52.0%	6.3%	3.5%	34.3%
School	1.9%	1.1%	21.5%	7.6%	2.9%	65.1%
Shopping	1.8%	0.4%	59.1%	32.9%	4.3%	1.5%
Personal Business	0.3%	0.9%	59.3%	10.4%	4.0%	25.2%
Social/Recreational	1.8%	0.6%	33.4%	53.8%	4.0%	6.3%
Other	0.5%	1.0%	57.6%	20.0%	3.6%	17.3%

How Expect Household to Acquire Its Next Vehicle (by % Respondents)

	New	Used
Purchase	54.3%	37.6%
Lease	6.2%	1.8%

Type of Vehicle for Next Acquisition Among Those Intending to Purchase a Vehicle in the Future

	% Respondents
Gasoline or Diesel-Powered Sedan	35.9%

Gasoline or Diesel-Powered Coupe or Compact Car		9.9%	
Gasoline or Diesel-Powered Minivan, SUV, or CUV		28.3%	
Gasoline or Diesel-Powered Pickup Truck		8.4%	
Hybrid-Electric Vehicle		*13.0%*	
Plug-in Hybrid-Electric Vehicle		*2.1%*	
Fully Electric Vehicle		*2.5%*	
Interest in Owning or Leasing an AV, Assuming the Price is Affordable			
Very Interested	Moderately Interested	Slightly Interested	Not Interested
21.3%	19.0%	23.5%	36.2%

DRS may ease congestion if SAV riders widely adopt DRS for work and school trips, since these are dominated by driving alone during congested times, yet many may share similar destinations (and origin neighborhoods, in the case of home-to-school trips for high school students, for example). However, respondents, on average, opted to share rides with people they do not yet know only 18.78% of their SAV miles, within the range of offsetting the 8% to 20% expected empty of SAVs' VMT (according to simulations by Fagnant and Kockelman 2015, and Loeb and Kockelman 2017), though changes in mode and destination choices, as well as trip generation rates (from those unable to drive now becoming mobile, thanks to self-driving vehicles) may cause additional VMT increase.

41.5% of respondents say their household is actively considering purchasing or leasing a vehicle in the next year, with an average probability of acquiring a vehicle in the next year of 35.3%. 92% of Americans intend to purchase, instead of lease, their next vehicle, and new vehicles are favored over used. 44.0% of all respondents say they "will definitely" sell or donate a vehicle when a new one is acquired, 21.6% are "not sure", and 20.0% probably or definitely will not. For information on timing and selection details of coming vehicle acquisitions, please see Table 6.

TABLE 2 AV-Related Statistics (n = 1426 Americans, population corrected)

Preference of Vehicle Type, Disregarding Price Premium		
Self-Driving	Human-Driven	No Vehicle Purchase
32.4%	61.8%	5.8%

Logit Coefficients for AV-related Choices						
	Prefer AV over HV, ignoring price premium ($\rho^2 = 0.077$)		% travel distance in AV mode if household vehicle is capable of both ($\rho^2 = 0.033$)		% of SAV rides with stranger, if DRS costs \$0.60 instead of \$1/mi. ($\rho^2 = 0.071$)	
	Coef.	P-value	Coef.	P-value	Coef.	P-value
Is Male	0.5000	0.007	0.0492	0.000	0.1607	0.000
Has Driver License			-0.2954	0.000	0.2396	0.000
Age	-0.0251	0.001	-0.0097	0.000	-0.0235	0.000
# Children in Household			0.0162	0.108	0.0466	0.000
Household Size			-0.0131	0.115		
# Workers in Household	0.1529	0.145	-0.0268	0.002	0.0510	0.000
Household Income ($1,000/yr)	0.0032	0.114	0.00197	0.000	0.00286	0.000
Is White	-0.3054	0.168			-0.0482	0.009
Bachelor's Degree or Higher	0.2708	0.134	0.2217	0.000	0.2975	0.000
Works Full Time			-0.2880	0.000	0.1212	0.000
Works Part Time			-0.2215	0.000	0.4418	0.000

Is Student			-0.4332	0.000	0.6608	0.000
Is Unemployed			-0.3553	0.000		
Is Retired	0.6581	0.029	-0.1125	0.000	0.4815	0.000
Is Currently Married			-0.1213	0.000	-0.2232	0.000
# Vehicles in Household			-0.0106	0.188	-0.2135	0.000
Prob. of Car Acquisition Within Year	0.00709	0.004	0.00863	0.000	0.00962	0.000
Distance to Grocery Store			-0.0057	0.000	0.0146	0.000
Distance to Public Transit Stop			-0.0074	0.000	-0.0090	0.000
Distance to Work or School	0.0164	0.077	0.00399	0.000	0.00543	0.000
Distance to Downtown			0.0118	0.000		
Not Disabled			-0.3274	0.000	-0.2624	0.000
Drives Alone to Work			-0.0444	0.002	-0.0433	0.016

Table 2 shows interest in, and preferences for, self-driving vehicles if price premium is disregarded, with 32.4% preferring an AV. As this binary logit model’s regression results suggest, younger persons (as well as retirees), non-white, males, those with a bachelor’s degree or higher, those in higher income households with more workers, and those residing farther from their work or school locations are more likely to choose an AV over an HV – everything else constant - if an AV’s added purchase price premium is disregarded. Some parameters’ statistical significance is relatively low (i.e., p-values are over 0.10), but this may be due to the stated-preference context: having to predict one’s travel future is not easy, especially with unexperienced vehicle technologies. Nonetheless, including behaviorally-defensible covariates can provide valuable insight for future fleets and future research.

If using a car that has both self- and human-driven modes, the average respondent expects to use self-driving mode for 35.9% of their distance in that car. As shown in Table 2’s second set of logit regression results, those without a current driver license, those with a disability, younger persons, unmarried persons, those with higher income and/or more education, and those who live farther from the city center or their work or school expect to use AV mode more, everything else constant. Younger and more educated people, and those with higher disposable incomes may be more comfortable with new technologies. Of course, those with driving restrictions are also more likely to need self-driving technologies.

TABLE 3 WTP-Related Statistics (n = 1426 Americans, population corrected)

Willingness to Pay (WTP) Various Purchase/Lease Premiums to make Household’s Next Vehicle Full-AV			
	$7,000/$200	$5,000/$140	$2,000/$60
Willing to Pay	23.2%	31.0%	49.5%
Not Willing to Pay	70.7%	62.7%	44.0%
No Future Purchase	6.1%	6.4%	6.5%
WTP Various Amounts to Save 30 min. on a 1-Hour Solo Drive			
	$5.00	$7.50	$10.00
Definitely willing to pay	12.4%	11.3%	5.7%
Probably willing to pay	25.9%	16.4%	9.9%
Not Sure	17.9%	20.7%	24.0%
Probably not willing to pay	16.6%	19.8%	27.5%

Definitely not willing to pay	27.3%	31.9%	32.9%
WTP Various Amounts to Save 1 Hour from a 2-Hour Solo Drive			
	$10.00	$15.00	$20.00
Definitely willing to pay	7.3%	6.8%	4.2%
Probably willing to pay	26.4%	15.9%	10.2%
Not Sure	15.9%	22.6%	27.6%
Probably not willing to pay	16.3%	18.9%	22.0%
Definitely not willing to pay	33.9%	35.8%	36.0%

Respondents were asked their willingness to pay to add full automation, both with and without retaining an option for human driving, to their household's next vehicles acquisition. Respondents indicate an average WTP of $3,117 if a human-driven option is maintained, but only $2,202 without the human-driven option. These WTP averages increase to $3,685 and $3,112 with and without the human-driven option, respectively. Bansal and Kockelman's (2017a) similar question indicated an average of $5,857 when asked 2 years earlier of 2,167 Americans. It is worth noting that respondents are willing, on average, to pay roughly $1,000 (or $500 with zero values removed) more to retain a human-driven mode on board their new autonomous vehicle.

Table 3 also shows respondents' WTP for various specific price premiums, to add self-driving technology to their household's next vehicle purchase or lease. As one would expect, price has a significant effect on adoption rates, ranging from roughly a quarter of vehicle acquisitions at a $7,000 purchase price (or $200/month lease) premium, to roughly a third with a $5,000 premium, to over half of vehicles with a $2,000 premium. However, government policy may make such technologies standard, thanks to the significant social and private benefits of such technology adoption (on the order of $10,000 to $20,000 per AV, according to Fagnant and Kockelman (2015).

Table 3 also displays respondents' WTP to save 30 minutes from a 1-hour drive (in an urban setting), and to save 1 hour on a 2-hour drive. Interestingly, their WTP does not nearly double between the two pairs of questions; as saved driving time doubles, WTP increases by just 59%, suggesting a declining marginal value of travel time (VOTT) and/or the unlikely nature of strong time penalties (for late arrival, for example) on those taking long-distance (1-hr and 2-hr) trips. Regardless, the implied values of travel time (VOTTs) range from just $6.50 to $9 per driver-hour, which is about half what the USDOT (2015) assumes. Also interesting is that average WTP does not rise by very much (8-11%) when the respondent has friends or family members in the car with him/her.

Respondents were also asked their WTP to save 30 min from a one-hour trip, and to fully automate the driving for 30 min. Their average responses are $6.21 and $5.71, respectively. This suggests that respondents feel they can recoup most (92%) of the value of their travel time if relieved of driving duties, though there may be some bias from the novelty of a car driving itself.

TABLE 4 SAV-Related Statistics (n = 1426 Americans, population corrected)

Likeliness of Engaging More in Each Activity with SAVs Available (by % Respondents)

	Very Likely	Somewhat Likely	Neither Likely nor Unlikely	Somewhat Unlikely	Very Unlikely
Go places, like downtown, where parking is an issue	14.7%	26.5%	16.6%	9.3%	32.9%
Use public transit, with SAVs as a backup	7.3%	19.7%	20.5%	14.3%	38.3%
Use bikeshare or walk, with SAVs as a backup	5.4%	17.1%	22.5%	13.8%	41.2%

Situations in which Respondents Would Use SAVs (% Respondents)

To avoid parking fees	38.9%
When personal vehicle is unavailable (maintenance or repairs)	35.1%
As an alternative to driving (e.g. after drinking alcohol)	32.8%
For long trips	23.0%
For short trips	17.1%
Other	1.8%
Never	33.9%

Transportation Choices with SAVs having < 5-min. Response Time, at Different Prices (% Respondents)

	$2 per mile	$1 per mile	$0.50 per mile
Not own vehicle, rely primarily on SAVs	3.6%	4.3%	4.4%
Not own vehicle, rely primarily on combination of SAVs & other modes	3.6%	3.7%	4.1%
Rely primarily on modes other than SAVs or personal vehicles	10.7%	9.2%	7.5%
Own vehicle(s), but primarily use SAVs	7.5%	8.5%	12.5%
Rely primarily on personal vehicle(s), but use SAVs some	29.3%	31.2%	32.4%
Rely primarily on personal vehicles, no SAV use	44.5%	42.5%	38.3%
Other	0.8%	0.7%	0.8%

Mode & Access Choice when Train Stops are 1 mile from Home & within 1 mile of Destination

Drive: 40 mins, $5+	Rail/SAV: 40 min, $8	Rail/other: 30 min, $4 + access mode	Other
48.2%	19.0%	30.3%	2.6%

Respondents show more interest in going to denser parts of town, like downtown, once SAVs can eliminate parking costs and hassles (with 42.7% stating they are very or somewhat likely to make these trips more often). The anticipated effect on mode shifts is less substantial, with only 27.0% and 22.5% feeling like they are very or somewhat likely to increase their public transit and bikeshare use, respectively, due to SAV availability as a backup mode.

Avoidance of parking costs was the most popular reason for using SAVs, followed closely by the respondent's own vehicle being unavailable, and then "after drinking alcohol". Each of these three options drew over 30% of respondents. 35% of (population-corrected) respondents indicated they believed that they would never use SAVs.

Somewhat surprisingly, the effects of per-mile SAV pricing on vehicle ownership are low, with those choosing not to own a vehicle rising from just 7.2% to 8.5% as SAV prices fall from $2 to $0.50 per mile. A larger shift occurs in those choosing to own a vehicle but use SAVs as a primary or supplemental mode. Perhaps Americans are so used to vehicle ownership that living without one currently seems like an excessively disruptive shift, though attitudes may well shift over time, as people become accustomed to a sharing economy and, hopefully, the convenience of SAV fleets that respond quickly and reliably to calls for service. The largest group of respondents, in all question scenarios, expect to rely primarily on personal vehicles once AVs and SAVs are available to them, with no SAV use. Notable shifts are evident for those primarily using other modes, indicating that America's mode shift towards SAVs may come largely from non-automobile modes, and thus those currently using public transit, bicycles, and walking.

With SAVs costing just $0.50 per mile (less than the average price of owning and operating a U.S. passenger car for those driving under roughly 20,000 miles per year [AAA 2017] but feasible under Loeb and Kockelman's [2017] recent simulations of Austin, Texas travel), Table 4 suggests only a small decrease in household vehicle ownership. Such hesitation may be due to uncertainty in SAV fleet operators being able to consistently meet respondents' households' needs. Respondents also indicated the highest price per mile they would be willing to pay to use SAVs regularly (at least once per week) to be, on average, $0.44 per mile. This is very close to the $0.45 per mile cost Loeb and Kockelman (2017) estimate in their Austin simulations, and not too far from the $0.59/mile for all-electric SAV (or "SAEV") service they simulated, with response times averaging about 5 minutes per traveler (reflecting all personal travel across the 6-county region, and assuming 1 SAV for every 5 persons making trips within the region that day).

Respondents expect 18.8% of their SAV rides (on average) to utilize the DRS option if DRS travel (with a stranger, someone they have not met before) is priced at a 40% discount, and thus just $0.60 per mile, versus $1 per mile for private use of an SAV. Table 2's third set of logit model parameter estimation results reveals that younger males, those with driver licenses, those with at least a bachelor's degree, and those in households of higher income expect to use DRS for more of their SAV rides, everything else constant. Apparently, males and those with more education tend to be more comfortable sharing rides with strangers. Those living farther from work and/or school also expect to use DRS for a higher share of their SAV rides, possibly due to the higher cost of those longer commutes. Nevertheless, results suggest that most Americans do not expect to use DRS under this $0.60 vs. $1/mile pricing scenario. The most popular situation for DRS use appears to be when already traveling with an adult friend or family member. Among the least popular is when riding with a child, suggesting respondents' safety concerns about riding with strangers, which may be alleviated by a trusted adult companion. The second most popular situation for using DRS was "only at times of day I feel are safer," thus reinforcing safety concerns many people may have, at least until they have many good DRS experiences, hopefully in the future sharing economy. DRS is one of the few ways the world's transportation future becomes environmentally sustainable (and relatively non-congesting), while still ensuring much personal travel freedom.

In Table 4's hypothetical transit scenario, the rail options attracted more responses than driving (which carried a $5 parking plus vehicle operating costs), though use of SAVs for rail station access appears unpopular. Perhaps the $4 total SAV cost was too high for many respondents, especially if many Americans assume they will still own several cars in an SAV future.

3.1. Questions on AV-related Policy

Respondents were asked their opinion on empty AV travel. 9.6% of respondents currently feel that empty AVs should be allowed everywhere, regardless of their effect on congestion. In contrast, 24.8% want empty travel banned or tolled heavily in all situations. 16.2% want empty vehicles allowed only at certain times of day, such as uncongested times (and presumably uncongested locations). 8.1% want empty vehicles allowed only in areas not prone to congestion, while 9.8% feel that empty vehicles should be allowed only on certain roadway types. 29.4% of respondents (after population correction, as with all these results) indicated feeling indifferent or unsure, and 2.2% prefer other policies, such as limiting empty driving to trips to access passengers or strictly regulating empty trips to ensure each one is necessary. Thus, many respondents are concerned about congestion effects of empty-vehicle travel. Some may also have safety concerns and wish to keep them off high-speed roads and/or away from corridors with many cyclists or pedestrians. A follow-up survey is needed to deduce such nuances.

Related to this, the average respondents indicate maximum allowable empty VMT share by AVs should be around 20% of the total, with SAV fleets being permitted a slightly higher percentage (21.2%) than privately-owned vehicles (19.6%). This slightly higher share presumably reflects respondents' understanding that some empty travel will be needed to enable SAV fleets (to pick up the next passenger, between rides), while privately owned vehicles technically could be required to travel only with persons onboard. However, this negligible difference in averages could suggests to many transport experts that Americans' understanding of such technologies' effects on future roadway operations, especially congestion, is low (which is understandable, given the technology's infancy).

3.2. Preferences on EV Purchase and Usage

As noted in this paper's introduction, the survey also emphasized EVs. Table 5 shows that most respondents do not envision driving any more or less when using an electric vehicle, but 26.0% do expect to drive more (perhaps a "rebound effect" from lower per-mile driving costs), and 22.0% expect to drive less (presumably due to range anxiety, or perhaps many EVs' seating and storage limitations).

Assuming a 200-mile range on a new EV and total cost of ownership equal across powertrain types, Table 5 shows EV charging times to significantly affect powertrain decisions for respondents' next household vehicle purchase. Rising adoption of fully electric vehicles at faster charge times comes at the expense of gasoline (53.9% at 6-hour vs. 42.8% at 30-minute charge times) and hybrid-electric vehicle (HEV) purchases (25.6% at 6-hour vs. 20.6% at 30-minute charge times)Plug-in hybrid (PHEV) shares rise (from 8.0% to 10.1%) as charge times fall to 2 hours, but falls (to 9.5%) at 30-minute charge times (presumably since a 200-mi-range vehicle with 30-minute charge time is reliable enough for many Americans to shift to a fully-electric EV).

TABLE 5 EV-Related Statistics (n = 1426 Americans, population corrected)

Powertrain Choice vs. Charge Time for 200-mi Range EV (with equal ownership costs)

	6-hour charge time	2-hour charge time	30-minute charge time
Diesel Engine	2.5%	3.0%	2.7%
Gasoline Engine	53.9%	47.2%	42.8%
Hybrid-Electric	25.6%	24.7%	20.6%
Plug-in Hybrid	8.0%	10.1%	9.5%
Fully-Electric	10.1%	15.0%	24.4%

% Respondents with Access to Charging at Home and at Work

	Charging Access	No Charging Access
At Home	56.6%	43.4%
At Work/School (among commuters)	25.5%	74.5%

Factors Affecting Charging Access

	Home Charging Access (1 = yes) ($\rho^2 = 0.102$)		Work/School Charging Access (1 = yes) ($\rho^2 = 0.126$)	
	Coefficient	P-value	Coefficient	P-value
Male	0.267	0.0332	0.436	0.005
Has Driver License	0.638	0.0270		
# Children in Household			0.3694	0.000
# People in Household	0.058	0.0627		
Household Income (in thousands)	0.004	0.0083		
White Ethnicity	0.433	0.0058		
Bachelor’s Degree or Higher	0.281	0.0274	0.3271	0.062
Employed Full Time			-0.2584	0.177
Currently Married	0.374	0.0051		
# Vehicles in Household	0.218	0.0088	-0.2639	0.016
Prob. of Acquiring Car Within Year	0.011	0.000	0.0148	0.000
Distance to Nearest Grocery Store			0.0392	0.018
Distance to Nearest Transit Stop	0.012	0.033	-0.0178	0.969
No Disability that May Affect Driving			-0.6361	0.079
Drives Alone to Work			-0.461	0.022

Will Consider Owning or Leasing Full-EV despite the Following Situations?

	Definitely Yes	Probably Yes	Not Sure	Probably No	Definitely No
No Home Charging Space	3.0%	6.9%	32.6%	15.8%	41.8%
No Work Charging Space	20.2%	26.8%	21.0%	17.3%	14.6%
No Home or Work Charging	0.9%	17.0%	16.7%	21.8%	43.6%

Will Drive More or Less if BEV is Primary Vehicle?

Definitely More	Probably More	Same/Not Sure	Probably Less	Definitely Less
9.1%	16.9%	51.9%	12.7%	9.3%
45.8%		← % Change →	45.5%	

Hybrid-electric vehicle (HEV) purchase decline is minimal between the 6-hour and 2-hour charge-time scenarios, but notable between the 2-hour and 30-minute scenarios. Thus, HEV purchasers may be environmentally-conscious, but require their vehicle be available for long drives, therefore only considering fully-electric vehicles at fast (30-min) charge times. Unsurprisingly, diesel powertrain preferences are insensitive to EV charge time variations. Those seeking large pickup trucks may be less environmentally-conscious and/or perceive EVs as incapable of serving their work needs.

As shown in Table 5, 56.6% of respondents report having EV charging capabilities at their home's parking location, a similar finding to a previous study that determined 56% of Americans have the ability to charge an EV at hone (Union of Concerned Scientists, n.d.). Also, 25.5% of workers and students can charge at their work or school location. Those without home-charging access may live in multifamily units or feel they cannot park near enough to an outlet to charge safely. Some may not be aware of charging availability at work or school.

Logistic regression results in Table 5 for predicting EV power access suggest that those with a bachelor's degree (or higher) and those more likely to acquire a vehicle within the next year are more likely to have charging access, both at home and at work or school. Those in household with more vehicles and those residing further from public transit stops are less likely to have (or know of) access to EV charging at work or school but enjoy a higher likelihood of access at home.

Table 5 shows that lacking charging ability at home appears to be a significantly greater hindrance to respondents' willingness to purchase fully-electric vehicles than does a lack of charging ability at work. Presumably Americans are anxious about trying to meet charging needs only at places away from home, or the costs of such charging. Adding charging stations reserved for neighborhood residents) may alleviate this.

3.3. Future Transactions and Travel Behaviors

Respondents were also asked to anticipate vehicle transaction and travel choices in a hypothetical scenario, 10 years in the future. The scenario includes fully self-driving vehicles available at a $5,000 price premium (or $140 above an HV's monthly lease cost). EVs are assumed to have equal life-cycle costs to their gasoline counterparts, and a BEV can be charged to a full 200-mile range in 2 hours at home or 30 minutes at widely available public stations. SAVs cost just $0.65 and $0.40 per mile, for private or DRS rides, respectively.

Under this scenario, respondents expect that 24.5% of their total travel miles will be SAV rides (on average), including rides by themselves or with friends and family, and another 14.8% will be taken as DRS rides (with persons they do not know, inside SAVs). Table 6 shows a greater propensity for women to take private SAV rides, and for men to take DRS rides, presumably because men are more comfortable riding with strangers. Disabled persons and those currently without a driver's license are more likely to use both types of SAV service, suggesting mobility benefits from SAVs to those presently facing limitations (but also some demand losses among other, non-driving modes). On average, younger and more educated respondents, and those who live farther from work or school, expect to use SAVs more. As noted earlier, those commuting long distances presumably anticipate greater effort savings from relinquishing driving duties, and younger and more educated people may be more technologically savvy, attracting them to SAVs. Perhaps higher interest from younger people will allow for faster growth in SAV use and accelerate the rate of behavioral change, as people adopt SAV-based travel habits early in life.

TABLE 6 Future Scenario Statistics

Timing of Next Household Vehicle Transactions Under Presented Scenario (by % Respondents)

	Next Vehicle Acquisition		Next Vehicle Release
	Before Scenario	With Scenario	With Scenario
Within 1 year	31.7%	27.8%	20.9%
In 2 years	22.8%	23.8%	19.9%
In 3 years	12.2%	12.0%	11.1%
In 4 years	6.6%	6.2%	5.4%
In 5 years	9.6%	9.7%	10.8%
In 6 years	2.1%	2.6%	3.0%
In 7 years	0.9%	1.9%	1.8%
In 8 years	1.1%	1.2%	1.5%
In 9 years	0.1%	0.6%	0.4%
In 10 years	3.1%	2.8%	2.0%
In more than 10 years	1.4%	4.3%	5.0%
Never	8.4%	7.1%	18.3%

How Next Household Vehicle will be Acquired Under Presented Scenario (by % Respondents)

	New	Used
Purchase	50.7%	34.4%
Lease	6.0%	2.2%

(6.7% Respondents indicated their household doesn’t ever intend to acquire a vehicle)

Factors Affecting Next Household Vehicle Purchase Decision

	Buy (vs. lease) $(\rho^2 = 0.042)$		Used (vs. new) $(\rho^2 = 0.130)$		AV (vs. HV) $(\rho^2 = 0.106)$	
	Coef.	P-value	Coef.	P-value	Coef.	P-value
Is Male			-0.4433	0.001	0.3338	0.018
Has Driver License	0.3965	0.138	-0.7938	0.020	-0.4182	0.199
Age	0.0216	0.002	-0.0152	0.006	-0.0308	0.000
Household Size	0.2626	0.008	0.0953	0.117		
# Workers in Household	-0.3565	0.009	0.2476	0.004		
Household Income ($1,000/yr.)			-0.0094	0.000	0.00327	0.038
Is White			0.5681	0.001	-0.2989	0.069
Bachelor’s Degree or Higher			-0.2970	0.027	0.2904	0.042
Works Full Time	0.4869	0.057	-0.5856	0.000	-0.3385	0.032
Works Part Time	0.4148	0.171				
Is Unemployed					-0.4785	0.020
Is Retired			-0.2836	0.198		
Is Married			-0.2271	0.111	0.2854	0.055
# Vehicles in Household					-0.1671	0.066
Probability of Car Acquisition Within Year			-0.0101	0.000	0.0112	0.000
Distance to Grocery Store	0.0726	0.002				
Distance to Work or School			0.0165	0.034		
Distance to Downtown			-0.0097	0.183	0.0131	0.066
Has no Disability					-0.7501	0.003
Drives Alone to Work			-0.3774	0.012		

	% Travel Miles in Private SAVs $(\rho^2 = 0.021)$	**% Travel Miles DRS** $(\rho^2 = 0.046)$

	Estimate	P-value	Estimate	P-value
Is Male	-0.0568	0.000	0.0702	0.000
Has Driver License	-0.1093	0.000	-0.1294	0.000
Age	-0.00402	0.000	-0.0125	0.000
# Children in Household			0.0740	0.000
Household Size	-0.0161	0.010		
# Workers in Household	0.1037	0.000	0.125	0.000
Household Income ($1,000/yr)	-0.00023	0.153	0.000856	0.000
Is White	-0.0778	0.000	-0.0869	0.000
Has Bachelor’s Degree or Higher	0.1424	0.000	0.1880	0.000
Is Employed Full Time	-0.5695	0.000	0.1512	0.001
Is Employed Part Time	-0.3018	0.000	0.3509	0.000
Is a Student	-0.2267	0.000	0.4638	0.000
Is Unemployed	-0.3101	0.000	0.1622	0.000
Is Retired	-0.1938	0.000	0.3249	0.000
Is Currently Married	0.1253	0.000	-0.0382	0.033
# Vehicles in Household	-0.0706	0.000	-0.1759	0.000
Prob. of Acquiring Car within Year	0.00725	0.000	0.00849	0.000
Distance to Grocery Store	-0.00929	0.000	0.0126	0.000
Distance to Transit Stop			-0.00728	0.000
Distance to Work or School	0.00838	0.000	0.00776	0.000
Distance to Downtown	0.000938	0.197	-0.0022	0.016
Does not Have Disability	-0.2993	0.000	-0.3902	0.000
Drives Alone to Work	0.0461	0.003	-0.0696	0.000

Powertrain of Next Household Vehicle Transaction (by % Respondents)		
	Next Vehicle Acquisition	Next Vehicle Release
Gasoline	*63.1%*	*81.2%*
Diesel	2.6%	1.8%
Hybrid-Electric	*15.5%*	4.4%
Plug-in Hybrid	5.1%	0.4%
Fully Electric	8.2%	1.4%
Never Make Transaction	5.5%	10.7%

Body Style of Next Household Vehicle Transaction (by % Respondents)		
	Next Vehicle Acquisition	Next Vehicle Release
Compact	10.2%	8.6%
Coupe	6.7%	7.4%
Sedan	*33.7%*	*34.8%*
Station Wagon	1.1%	2.2%
Minivan	4.9%	5.2%
Crossover Utility Vehicle	9.7%	5.3%
Sport Utility Vehicle	*19.6%*	*17.5%*
Pickup Truck	8.4%	8.5%
No Future Transaction	5.8%	10.6%

Table 6 shows when respondents’ households intend to complete their next vehicle acquisition and release. Under the scenario, respondents are less likely to plan to never again acquire a vehicle, suggesting sustained personal vehicle ownership despite SAV availability. However, intended vehicle transactions appear to shift slightly later, possibly due an expectation of less personal vehicle use with SAVs available. As Table 6 shows, most of the vehicles acquired/purchased in this 10-years-forward scenario are still gasoline-based, but fully electric vehicles, PHEVs, and HEVs together comprise 28.8% of intended purchases, compared to 17.6% before the scenario specifics were given (with equal life-cycle costs, $5,000 AV premium, and $0.60 and $0.45/mile SAV and DRS costs). Responses suggest that 24.0% of U.S. households will opt for a fully self-driving vehicle under this scenario, 68.7% will decline that $5,000 automation option, and 7.3% believe their household will never acquire another vehicle.

3.4. Future Home Locations

AV and SAV availability may affect household locations, with strong SAV services possibly pulling more households into denser settings, and/or lowered travel burdens pulling many households to the suburbs and exurbs. Table 7 notes how the average respondent's household is just over 10 miles from their region's or city's downtown, and 7.6 miles from the nearest public transit stop, effectively eliminating transit as a travel option for many U.S. households and fostering car dependence. SAVs could fill transit gaps, enabling more Americans mobility in suburban and rural settings.

TABLE 7 Responses Regarding Home Location

<table>
<tr><td colspan="7">Average Distance from Respondents' Homes to Select Locations</td></tr>
<tr><td colspan="4"></td><td colspan="3">Average Distance from Respondent's Home</td></tr>
<tr><td colspan="4">To Nearest Grocery Store</td><td colspan="3">5.0 miles</td></tr>
<tr><td colspan="4">To Nearest Public Transit Stop/Station</td><td colspan="3">7.6 miles</td></tr>
<tr><td colspan="4">To Respondents' Job or School</td><td colspan="3">7.9 miles</td></tr>
<tr><td colspan="4">To Nearest City's Downtown</td><td colspan="3">10.2 miles</td></tr>
<tr><td colspan="7">Expected Residence Type of Those Households Intending to Move (by % Respondents)</td></tr>
<tr><td>Detached Single Family</td><td>Duplex</td><td>Townhome</td><td>Multi-Family ≤ 6 Floors</td><td>Mixed Use ≤ 6 Floors</td><td>Multi-Family ≥ 7 Floors</td><td>Other</td></tr>
<tr><td>60.6%</td><td>1.9%</td><td>8.8%</td><td>17.3%</td><td>0.7%</td><td>5.2%</td><td>5.4%</td></tr>
<tr><td colspan="7">% of Households that Expect to Shift toward Each Residence Type if AVs & SAVs are Available</td></tr>
<tr><td>15.5%</td><td>1.0%</td><td>3.2%</td><td>2.2%</td><td>1.8%</td><td>0.2%</td><td>0.6%</td></tr>
<tr><td colspan="7">70.7% of household choices would not be affected, & 4.7% would but the respondent is not sure how.</td></tr>
<tr><td colspan="7">Expected Residence Type of Those Households Intending to Move if AVs & SAVs are Available</td></tr>
<tr><td>59.5%</td><td>2.5%</td><td>9.9%</td><td>15.9%</td><td>2.1%</td><td>4.6%</td><td>5.4%</td></tr>
</table>

Since home location questions were hypothetical, the survey asked rather few but straightforward or simple questions, to facilitate reader understanding and response. Overall, 24.4% of Americans (i.e., population-corrected respondents) claim that their household is actively considering moving soon, of which 60.6% expect to move within the next year. 29.3% of those actively considering moving plan to move closer to the city center, while 38.0% plan to move farther from the city center (and 32.7% expect to stay the same distance away). AV and SAV availability are found to influence about 25% of these near-term movers, with 14.8% believing that AV (and SAV) availability will pull them closer to the city center than they otherwise would elect, and 9.7% feeling they are likely to move farther away from the city center than they otherwise would. 16.4% of near-term movers believe such technologies will impact their new location choice, but not their distance from the city center. The remaining 59.1% (of near-term movers) anticipate no effect on their location choice. Such numbers suggests that AV availability and adoption probably will not trigger notable urban sprawl, with those expecting to move closer in (more centrally) actually exceeding those expecting to move further away, thanks to AV availability. Presumably many respondents expect better SAV service in denser urban areas and will value the convenience this offers. Additionally, some respondents may currently live away from the city center in order to avoid certain vehicle-related challenges (such as car storage/parking). Some may be less averse to living in these areas if they have reliable and rapid alternatives to private vehicles. Some may feel they can compensate for higher land rents of more central locations by lowering their transportation costs via SAVs and DRS.

Table 7 also illustrates how availability of AVs and SAVs appears to influence dwelling unit type, with respondents shifting toward duplexes, townhomes, and mixed-use complexes, while single-family homes and other multifamily housing types lose popularity. Those reducing car ownership may see more value in mixed-use settings, thanks to (presumably) lower overall transport costs.

4. CONCLUSIONS

This recent survey offers a wide range of valuable new information for anticipating transport futures and crafting policies to enhance U.S. travel choices. For example, younger and better educated respondents show more intention to use EV, AV, SAV and DRS technologies. AV adoption may affect Americans’ future home location choices, but a tendency toward urban sprawl is not evident in these survey results. However, most U.S. households appear unwilling to reduce vehicle ownership, even those with members who expect to regularly use SAVs. This suggests that a significant cultural shift may be needed to reduce private vehicle ownership. If communities wish to shift households toward shared-fleet reliance in their jurisdictions, policymakers and public agencies may need to consider new incentives, such as subsidizing SAV fleet operations, higher taxes on new-vehicle purchases and registration, discounts for dynamic ride-sharing, and/or tolling of private vehicles.

These results are useful to manufacturers and potential shared fleet operators for pricing and marketing decisions. Government agencies, including public transit providers, can benefit from understanding evolving travel choices and land use patterns, including demographic disparities, to craft policies and transit service to equitably serve the population. These results may help transportation departments and MPOs model future transportation demand and plan infrastructure projects. To reduce congestion from added VMT, empty AV travel may need to be statutorily limited below the level of the average public opinion. Alternatively, significant public support exists for heavily tolling empty travel in all situations, so a tolling scheme may be used to limit empty travel, which may be effective for fleets but cause equity disparities among private owners.

These results are limited by their reliance on stated preference data, since AVs and SAVs are not yet available for purchase or regular use. Respondents may have many false expectations of these technologies, and actual decisions will vary, as more demonstrations get underway, SAVs become accessible via ride-hailing apps, friends and family members report favorable (or unfavorable) impressions, AV technology becomes commonplace, and/or self-driving cars deliver a safety record that clearly beats human drivers. As Bansal and Kockelman’s (2016) fleet evolution scenarios simulated (without reflecting EVs and SAVs), WTP is likely to rise, as technology prices fall. But prices will start high and early access will be quite limited. A natural next step is simulating fleet evolution and AV use statistics, to get a better sense of what levels and shares of future VMT will be in AV mode, in the U.S. and around the world.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm the contribution to the paper as follows: study conception and design: Quarles, N. and Kockelman, K.; Data analysis and interpretation of results: Quarles, N. and Kockelman, K.; Draft manuscript preparation: Quarles, N., Kockelman, K. All authors reviewed the results and approved the final version of the manuscript.

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