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Generalized Costs of Travel by Solo and Pooled Ridesourcing vs. Privately Owned Vehicles, and Policy Implications

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Generalized Costs of Travel by Solo and Pooled Ridesourcing vs. Privately Owned Vehicles, and Policy Implications

A Research Report from the University of California Institute of Transportation Studies

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16. Abstract

The emergence of "3 Revolutions" in transportation (automation, electrification and shared mobility) presents a range of questions regarding how consumers will travel in the future, and under what conditions there may be rapid adoption of various services. These include individual on-demand taxi-style services, shared mobility in pooled services, and use of public transit, all with or without drivers. There is now enough data and estimates on the costs of these service combinations, and in some cases ridership data, to consider how consumers are making choices and could do so in the future as things evolve. This project involved: (a) reviewing existing literature and data on consumer mode and vehicle choice; (b) developing new "generalized cost" estimates that combine monetary and non-monetary (e.g., hedonic) components of travel choice, notably incorporating value of time; and (c) conducting a comparison of monetary and generalized trip cost for a range of trip types across travel options in the near term (2020) and longer term (2030-35). Three main travel options were considered: privately owned vehicles, ridesourced solo trips, and ridesourced pooled trips. Consideration of internal combustion vs. battery electric and, in the longer term, automated technology was also core to the analysis. The trips considered include urban and suburban types in the San Francisco metro area, using actual trip characteristics. The results suggest that in the near-term, solo ridesourcing is likely to be perceived as significantly more expensive (in terms of monetary and time costs) than pooled ridesourcing or solo private vehicle trips except for those with a very high value of time. Solo ridesourcing does better in dense, slow, urban trips than in faster suburban trips. In the longer term, with automated driverless vehicles, solo ridesourcing could become the cheapest mode for many travelers in a range of situations. This report includes an initial consideration of the implications of these policies for affecting travel choices, presumably to push choices toward pooled ridesourcing as a sustainable option. VMT-based pricing, pricing that could be adjusted with vehicle occupancy, and parking-related approaches are described. A large price signal might be needed to shift travel, given some of the differences in generalized cost found in this analysis.

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Disclaimer

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UNIVERSITY OF CALIFORNIA INSTITUTE OF TRANSPORTATION STUDIES

February 2020

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Glossary

AV	automated vehicle
BEV	battery electric vehicle
US DOT	United States Department of Transportation
EV	electric vehicle
HEV	hybrid electric vehicle
ICEV	internal combustion engine vehicle
LDV	light duty vehicle
PHEV	plug-in hybrid electric vehicle
PMT	passenger miles traveled
SUV	sport utility vehicle
TTC	travel time cost
UC Davis	Davis University of California, Davis
VMT	vehicle miles traveled
VTT	value of travel time
ZEV	zero emission vehicle

Executive Summary

California. We reviewed relevant literature; analyzed and compared monetary and hedonic (specifically travel time cost) data to estimate costs for private vehicle and ridesourced trips in various present and future situations. We have compared these costs and drawn some observations about the total generalized cost under various conditions, and what this may mean for near- and longer-term travel choices. Finally, we have developed some considerations for travel pricing policies that might influence trip choice behavior, given the generalized costs of these choices.

We have not attempted to estimate actual trip choice or mode shares, though we considered the implications of these. We also did not include a wide range of potential non-monetary cost factors, such as willingness to travel with strangers, interest in owning a car for reasons other than direct mobility (pride, storage of items in vehicle). Finally, we did not attempt to make comparisons across a broader set of modes, such as public transit, walking, bicycling, or micro-mobility.

The results indicate that in the near term, the overall (generalized) cost of ridesourcing, including both monetary and time-related costs, is likely to be higher than privately driven vehicles (Figure E-1) except for travelers with a very high value of time, and mostly in urban conditions. Also, even for travelers with average values of time, trips with long periods of time needed for parking and/or walking to and from the vehicle may provide ridesourcing with an advantage.

Figure E-1 shows a representative cost comparison of different vehicle options used for a suburban-to-urban trip in 2020 for a person with a median wage—where wage is used as a basis to estimate the cost of travel time.

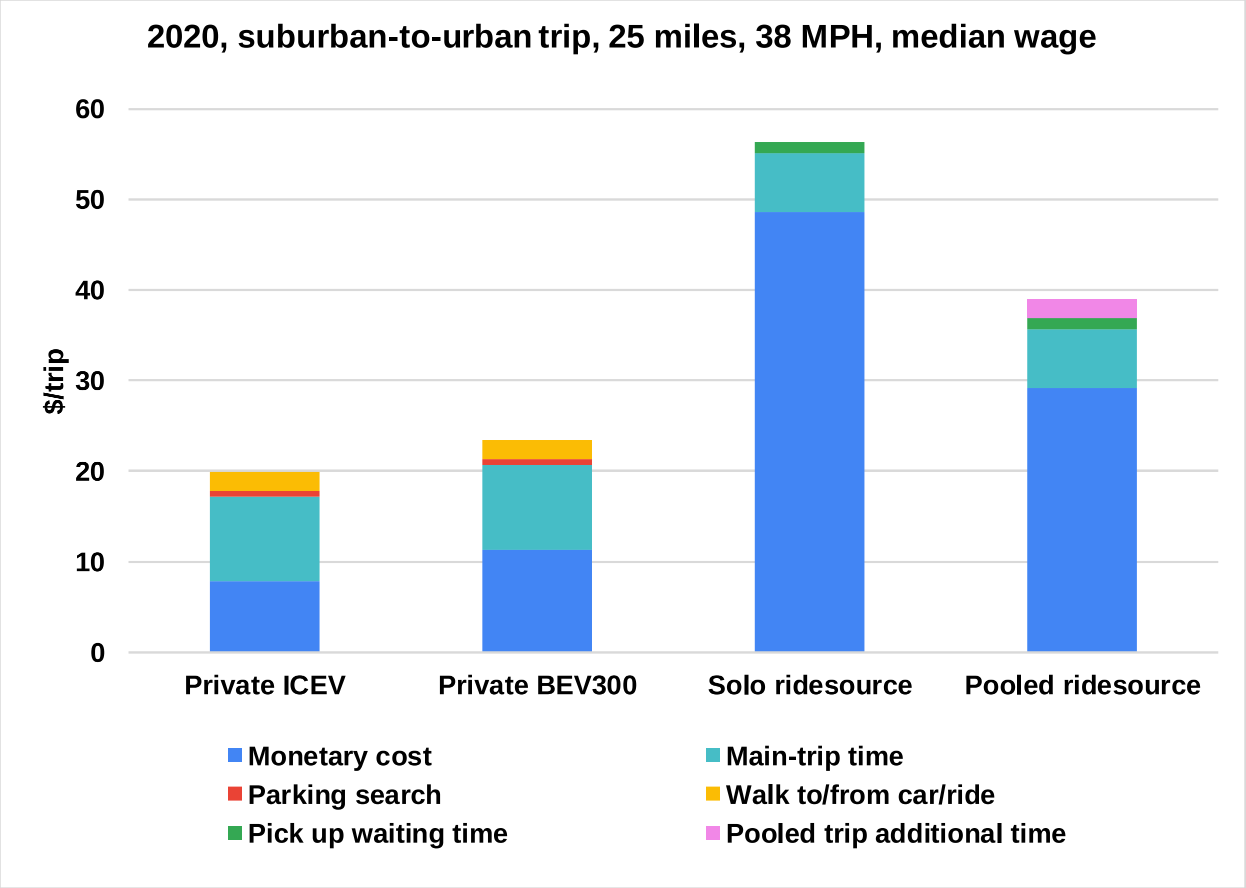

Figure E-1. Generalized costs of four travel options in a base case scenario: current year, minimal traffic congestion, suburban-to-urban trip, median wage of traveler (used to estimate cost of travel time). Abbreviations: ICEV, internal combustion engine vehicle; BEV300, battery electric vehicle with 300-mile range.

A number of other scenarios and sensitivity cases were also developed. In these other scenarios, parameters such as the following were varied: the distance of the trip, the settings of the origin and destination (urban vs. suburban), the amount of congestion (and, therefore, average speed), the year, and the presence of automated vehicles. The cost comparisons for the other examined scenarios indicate that for higher wage levels for the traveler, the value of time rises relative to the monetary cost of a trip, so faster, more expensive modes (like solo ridesourcing) become more attractive. In some circumstances, particularly shorter trips for high-wage travelers, solo ridesourcing can become the cheapest option from a generalized cost point of view.

In the future, with automated driverless vehicles, the monetary costs of ridesourcing could drop to the point where, in many situations, this option is cheaper than private vehicle trips, and cheaper than all trip types today. Implications of these findings include:

- Since a lower cost of travel is likely to lead to more travel (a "rebound effect"), as generalized costs for both private vehicles and ridesourcing modes drop, higher levels of traffic may ensue. This may particularly apply when vehicles become automated. Traveling "solo" with ridesourcing services (such as Uber X), could become the most attractive mode because it will benefit from much lower prices when drivers are unnecessary. Privately owned automated vehicles will also relieve owners of the driving burden and enable them to use their time in these vehicles more productively, adding to the rebound effect. Some have hypothesized a "nightmare" scenario (Sperling, 2018) with highly increased VMT if policies are not implemented (such as road/VMT pricing) to dissuade increased vehicle travel.

- On the other hand, there are likely to be societal benefits from shared or pooled rides (such as current Uber POOL), but with lower generalized costs in the future, pooling may not be competitive with solo ridesourcing, at least without supporting policies.

Overall, we identified multiple hedonic factors in addition to travel time cost, which we have not attempted to estimate for their generalized cost impacts, but such work is urgently needed to inform effective policy. These factors include driving stress, vehicle maintenance hassles, shared space during ridesourcing trips, private electric vehicle range anxiety, ridesourcing uncertainty (see Table 3 in the full report below). Characterizing and measuring such hedonic factors is difficult if opportunities to observe related behaviors are rare or if such factors cannot be observed, as with "car pride." However, methodologies are being developed that can help—such as a range of qualitative and quantitative interview and survey techniques. More work to better understand the policies that are needed to encourage the most sustainable travel options is also needed, including a better understanding of price (fee, tax) levels that would be needed to persuade people to change trip choices in a major way. Some of the comparisons in this report suggest that a fairly large cost differential may exist that needs to be closed. However, whether, for example, a 10 cent per mile price advantage for the "wrong" trip choice can be overcome with a 12 cent tax is not clear, at least from any analysis undertaken here. In addition, the political feasibility of such a tax—levied on trips on a per-mile basis—remains unclear. This is another important area for more empirical research.

Introduction

The emergence of “3 Revolutions” in transportation (automation, electrification, and shared mobility) presents a range of questions regarding how consumers will travel in the future, and under what conditions there may be rapid adoption of various services. These include individual on-demand taxi-style services (“ridesourcing”), shared mobility in pooled services, and use of new forms of public transit, all with or without drivers. The wide range of business models, prices and possible impacts present an array of new challenges and opportunities for policymakers. There are now enough data and estimates of the costs of these service combinations to make useful comparisons for the near- and far-term future. Here “costs” refer to “generalized cost”, including both monetary and non-monetary costs, such as “hedonic” costs. Estimation of these various costs can reveal deeper insights into likely trip choice behaviors.

This report focuses on developing generalized cost estimates for a limited range of modes, in the California context. In particular it: (a) reviews existing literature and develops data on trip cost for private vehicle trips and ridesourcing trips; (b) develops generalized cost estimates for various trip options now and in the future; (c) compares costs across these options for a range of situations; (d) discusses the implications of these cost comparisons for future travel choices; and (e) provides some initial consideration of policies that might influence trip choice behavior, given the generalized costs of these choices.

The project and this paper do not attempt to estimate actual or predicted mode choices or mode shares. However, we consider how the cost results and policy implications may affect these outcomes in travel mode.

Background

A range of new technologies and types of travel service are emerging, including electric vehicles, on-demand ridesourcing[1], and different levels of vehicle automation that will likely lead to fully driverless operation. These are still nascent trends but there is now a very important set of emerging questions regarding the conditions under which these may become important parts of the transportation ecosystem. Some studies (e.g., Arbib & Seba, 2017) predict that both driverless cars and ridesourcing will become ubiquitous in the early 2020s, based on a range of assumptions such as very low vehicle costs per mile and a willingness of individuals to give up private ownership of automobiles. This extreme scenario contrasts with more modest estimates—such as that by Deloitte (2015)—of transitions and cost reductions related to driverless offerings. The University of California, Davis (UC Davis) report presenting 3 Revolutions Scenarios to 2050 (Fulton et al., 2017) provides a range of plausible futures and what these might portend for vehicle sales, stocks, energy use, and CO_2 emissions, but it does

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[1] “Ridesourcing services are prearranged and on-demand transportation services for compensation in which drivers and passengers connect via digital applications. Digital applications are typically used for booking, electronic payment, and ratings” (source: SAE, 2018).

not attempt to model the choices and other factors that might be important in determining which scenarios will prevail.

One important factor for individual mobility choices is the relative cost of different current and future transportation options. Our recent article (Compostella et al., 2020) explored the monetary costs of private vehicle and ridesourcing travel. It forms the basis for the monetary cost work presented in the current report and is consistent with that work.

This project focuses on three areas: (1) improving data on the relevant technologies and modes and using this to develop an improved cost model; (2) adding a non-monetary cost analysis and combining it with the monetary cost analysis to create a generalized cost framework; and (3) considering the implications for policy to accelerate transitions as needed or move them in more socially optimal directions. The paper attempts to provide a clearer sense of the conditions that will be needed to achieve certain scenarios, and the design and intensity of policies that may be needed to achieve specific goals.

Relevance to California Policy and Practice

The impacts—both positive and negative—from widespread electrification, high-level automation, and ridesourcing are uncertain. Early research indicates that one of the most important single factors affecting energy, congestion, and pollution is the degree to which automated vehicles are deployed in shared fleets as opposed to being personally owned. A key factor affecting the prevalence of each model is the economic competitiveness of travel. Policies in California (such as high-occupancy–vehicle [HOV] lanes) already directly and indirectly affect the relative economics of transportation modes and occupancy levels, but, in general, transportation policies in California are not well developed to address a highly automated, shared mobility future.

This analysis consists of three primary tasks, which also encompass the methodological approach: a literature review/data gathering effort, development of an economic model of consumer choice among a range of travel options now and in the future, and an analysis of those options using this model and applying simple policy levers to estimate how these might affect choices and travel patterns.

Literature Review / Database Development

There is a well-established literature on travel cost and behavior, including mode choice and vehicle choice in response to pricing and other factors (e.g., Ding et al, 2017, among many). However, little published work to date directly relates to the “3 Revolutions” (electrification, automation, and shared mobility), for example, choice of on-demand services in response to pricing or use of driverless cars. This shortage of published research is largely due to the fact that the 3 Revolutions present new options, and, in the case of automation, a lack of available data. However, it should be possible and reasonable to apply existing literature to these new travel options, since their use is likely to depend on basic cost and travel time factors. And there are now sufficient data and future estimates regarding the costs of such services and technologies to factor these into projections of their use. This project reviews and applies this literature in two ways:

1) We review data and estimates of the costs of on-demand ride-sourcing services, broken down by cost component and situational variability, and of automated vehicles and services provided with such vehicles (i.e., on-demand services and automation combined). We try to improve on existing estimates as needed. For example, the estimated cost per mile (translated into retail price) of on-demand services with driverless vehicles has been estimated to be anywhere between $0.10 and $0.60 per vehicle mile, when such services become available. Such a typical range is shown in Figure 1, including estimates from the previous UC Davis report and other studies. These are reviewed and the UC Davis estimates revised and further elaborated as a key part of this task.
2) We consider the situations in which individuals do (or will) make choices among a range of travel options and how existing literature may apply, and develop ranges of applicable parameters from this literature (such as mode choice elasticities) to see what they suggest about the uptake of these services.

Monetary costs of travel by private vehicle and on-demand services

The approach used here is based on a bottom-up vehicle and fuel cost component analysis, and follows the original version of this analysis recently published as Compostella et al. (2020), allowing estimation of overall cost per mile for light duty vehicles (LDVs), with different combinations of vehicle class, powertrain, automation, time frame, and use case. The costs are calculated on a per vehicle-mile and per passenger-mile basis (assuming specific vehicle occupancy rates), which allows cost comparisons for different travel choices available to consumers. Cost components are organized as fixed and variable costs as shown in Table 1.

Table 1. Fixed and variable costs considered in this study (source: Compostella et al., 2020)

Fixed costs	Variable costs
Vehicle purchase/depreciation cost	Maintenance, repair, and tires
Insurance cost	Fuel (including electricity)
Tax and registration fees	Vehicle cleaning
Automated Vehicle technology additional cost (only in fully automated future scenario)	Ridesourcing service overhead (including profit)
	Ridesourcing driver earnings (only in current scenario where on-demand services need a driver)

Several recent studies have provided estimates of monetary costs of various modes and technologies associated with automated LDV travel, considering at least some of these cost categories. Following the more detailed treatment by Compostella et al. (2020), we summarize the estimates from these studies in Table 2 and briefly discuss them below.

As shown in Table 2, few of the studies included all the vehicle types or the cost categories that we are considering here. Nearly all included private and ridesourced driven vehicles, though only a few also included the future costs associated with driverless LDVs. Most included the costs associated with vehicle purchase and major operational categories such as fuel and maintenance, though few included parking or cleaning costs. Taxes were included in some but may be better excluded in comparisons that are intending to provide a neutral comparison of options. We have not attempted to separate out those tax values from other costs in this review.

All of the papers estimate the cost of a private driven internal combustion engine (ICE) vehicle, with a range of $0.57-0.82 per vehicle mile travelled (some are in units of $/passenger mile travelled, which could imply VMT costs above the given range). Wadud (2017) also included a much higher cost case based on very expensive vehicles that we neglect in the range we are reporting here. Battery electric vehicles (BEV) (from just two studies) show a much narrower range, of $0.61-65 per mile. Private automated vehicles in the future (around 2030) are estimated to be somewhat more expensive, though not much more: typically, these estimates are within 10% of the current (circa 2020) cost of driven vehicles. And one study estimates them to be much cheaper ($0.38 per mile).

In contrast, the cost of operating vehicles in ridesourcing situations is typically estimated to be much higher, mainly due to driver costs. Though not reflected in the table, the fixed costs of operating vehicles (such as the purchase cost) is actually much lower than for private vehicles, since the vehicles are driven and amortized over many more miles. But driver costs and the overhead costs of the ridesourcing companies lead to relatively high per-mile costs. In Table 2, these costs are shown to range from $1.40 to as high as $4.39 per mile (though, as we show later in this paper, the recent average costs of ridesourcing trips in California are most likely below $2 per mile). Of course, this much higher cost per mile helps explain why this mode of travel does not dominate; it is expensive and typically used at most for a few high-value trips per week, for most people.

However, the last column of Table 2 reveals an important potential change in the future: driverless ridesourcing costs could be far lower than today, and even significantly lower than the cost of privately-owned vehicle trips. The range is from an incredibly low of $0.05 per mile to a high of $1.01, with a number of estimates below $0.50. Thus, there is some basis for thinking that by removing the driver, even with the expected higher purchase costs of the vehicle, these high-mileage driverless vehicles will be able to provide ridesourcing services at very low cost. However, the wide range also suggests high levels of uncertainty.

While we cannot eliminate this uncertainty, in this report, we attempt to provide a clearer "base case" set of estimates for a wide range of factors. We also attempt to be transparent in terms of methods and assumptions.

Table 2. Literature cost estimates (per vehicle or passenger miles traveled, $/VMT or $/PMT) for automated light duty vehicles (LDV) (source: Compostella et al., 2020)

Study[1]	Cost					Included in cost?					
	Units	Private LDV		On-demand commercial service LDV		Purchase, Fuel, Mainten-ance, Insurance	Tax	Parking	Cleaning	Driver[2]	Over-head[3]
		Human driver	Automated vehicle	Human driver	Automated vehicle						
Internal Combustion Engine Vehicles (ICEVs)											
Johnson (2016)	$/PMT	0.82		2.04	0.33[4]–0.86	X	X	X		X	X
Arbib (2017)	$/VMT	0.65–0.78				X	X				
Wadud (2017)	$/VMT	0.61–1.68	1.03–1.85	1.46	1.01	X	X	X		X	X
Bösch (2018)	$/PMT	0.78	0.81	4.39	0.66	X	X	X	X	X	X
Sperling (2018)	$/PMT	0.57		1.40-2.30	0.10–0.20	X	X			X	X
Fulton (2017)	$/PMT	0.64		1.61		X				X	X
Electric Vehicles (EVs)											
Bridges (2018)	$/VMT		0.38		0.06–0.24	X	X				X
Arbib (2017)	$/VMT	0.61–0.62			0.05–0.16	X	X				X
Fulton (2017)	$/PMT	0.65	0.68	1.61	0.72	X				X	X

1. Only the first author of multi-authored citations is listed within the table to conserve space for the following references: Johnson & Walker (2016); Arbib & Seba (2017); Fulton et al. (2017); Bosch et al (2018).
2. Only for on-demand commercial service.
3. “overhead” refers to per-ride fees charged by ridesourcing companies such as Uber.
4. $0.33 refers to automated ridesourcing service in electric sedan (source: Johnson & Walker, 2016. Peak car ownership. The market opportunity of electric automated mobility services., p. 28)

Hedonic and Generalized Costs of Travel

In addition to the monetary costs described above, there a range of non-monetary cost factors influencing travel choices. These are sometimes termed “hedonic” factors, typically related to happiness or utility. An important such factor is the value of time, and the time spent associated with traveling. Other hedonic factors include convenience, comfort, security, and safety. Travelling is considered a “disutility” that travelers would like to reduce (Mokhtarian, 2018). The value of travel time (VTT)—or, conversely, travel time cost (TTC)—has been shown to be an important factor in making trip choices. Here we mainly refer to TTC, putting travel time into the cost framework, so that by assigning a dollar value to time, it can be compared to monetary costs. Together, monetary and travel time cost provide something like a “generalized cost” of a trip.

However, many other factors—such as comfort, convenience, and security—could also affect the generalized cost of travel, either by affecting the time cost or a cost measured as something other than time. One example that is not travel-time related is the “pride” value of owning and driving one’s own vehicle (Moody & Zhao, 2019). The convenience of being able to leave personal possessions inside one’s own vehicle between trips would be another hedonic benefit unrelated to travel time. A list of hedonic factors that could affect the preference between trip modes and travel options is provided in Table 3. This is not a comprehensive list, but provides a range of examples that: a) are typically trip-time related, b) are possibly time related or can be thought of as affecting the time cost, and c) are unrelated to or independent of the time spent traveling.

Table 3. Types of non-monetary costs of travel

Travel-time related	Possibly time related	Unrelated to travel time
Travel time (driving)	Driving stress (higher time cost during stressful periods of driving due to traffic, etc.)	Car ownership “hassles” (apart from monetary cost) such as effort to clean, maintain, register, refuel, etc.
Travel time (passenger, conventional vehicle)	Shared space during trip (positive or negative additional cost related to ride sharing, apart from any additional travel time)	Car ownership positives (car pride, guaranteed ride; can leave personal belongings in the car)
Travel time (passenger, automated/redesigned vehicle)	Ridesourcing uncertainty (ride availability, pickup time)	
Parking search time	Pooled ride uncertainty (additional time due to route deviation)	
Walking time	EV range anxiety (hedonic cost of stress from uncertainty in ability to recharge vehicle)	
Waiting time for pickup (indoors, outdoors)	Perceived environmental cost of a travel option	

In the analysis presented here, we only consider cost types in column 1 of Table 3, where a time cost can clearly be associated with the activity, and the literature describes estimates of this time cost. Columns 2 and 3 are more complex to analyze and there is less evidence in the literature to support quantification.

An important aspect of time cost relates to activities that can be undertaken inside a vehicle during the trip, and how this affects this cost, or the "perceived" cost. It is reasonable to assume that the more activities that can be undertaken while traveling, the less the perceived time cost of that travel. If one must give undivided attention to driving, there is little chance to conduct any other useful or enjoyable activities and the cost is typically high (though there is considerable variation – for example, some individuals enjoy driving). If one does not need to drive, one might be able to read, check a phone, or undertake work-related or leisure activities. This presumably lowers the time cost of in-vehicle travel and the literature suggests that this is true.

Changes in technology may be changing the nature of in-vehicle travel and the time costs of this travel. For example, advances in information and communication technology are broadening the range of activities that can be conducted while traveling, and the increasing phenomenon of ''passengerization'' (Mokhtarian, 2018), by which drivers become passengers through ridesourcing, are increasing the effectiveness of travel time usage (e.g., through the use of device-enabled ridesourcing services). In the future, when fully automated vehicles (AVs)—i.e., driverless vehicles—become available, drivers will be relieved of the physical effort and cognitive load of driving and will be able to use their time more productively. Greater perceived productivity of a travel mode adds to its utility (Malokin et al., 2019).

In the following discussion, we address travel time cost (TTC) in the context of the cost of various trip choices for two scenarios: one with trips in the near-term (with a driver, circa 2020) and another with trips in the long-term (driverless, circa 2030-35).

There have been many studies of time cost in the context of travelling and making specific types of trips. These have often focused on how time cost varies depending on the situation and also the underlying willingness to pay for reducing time spent in different situations, which can be a function not just of trip conditions but also of income and the value (e.g., economic benefit) of undertaking the trip. A basic set of TTC estimates is provided by U.S. Department of Transportation (US DOT, 2014), which referred to these as value of travel time savings (VTTS) and approximated them as a ratio to wage or income level. The US DOT estimated these ratios of VTTS (or our TTC) to hourly incomes in the U.S. as follows, on average:

- personal local travel (shorter trip): 50% of hourly income
- business local travel: 100%,
- personal intercity travel: 70%
- business intercity travel: 100%.

These can be converted to dollar values if particular wages are assumed. The mean hourly wage in California in 2018 was about $28 (US BLS, 2018). Given the percentages listed above, the average estimates for local trips are $14/hour for personal purpose and $28/hour for business trips. For intercity travel it is equal to $20/hour for personal purposes and $28/hour for business.

Litman (2019) reported a similar type of relationship between wage and travel cost, and pointed out that this tends to change with traffic level and use-cases. For personal or commuting trips, the perceived cost per hour for *drivers* is around 50% of their wage. However, in congested traffic this can increase to 100% of their wage, as it can during any waiting time. For car *passengers*, cost ranges from 35% to 70% of their wage, according to the traffic conditions, with 70% for waiting time. Litman (2019) also observed that an unreliable arrival time can increase cost per unit time (which can be triggered by congested traffic conditions, so overlaps with that cost).

Beyond the basic time cost of traveling, some studies have estimated the time cost of other aspects of trips. For example, Reck and Axhausen (2019) estimated the cost of the "first and last mile" travel time, to reach a main mode of transport such as a train system, for three areas in the U.S.[2] The authors estimate a travel cost about 50% of hourly household income. The authors also found that the time cost for ridesourcing versus, e.g., walking the first and last mile, depended on the length of that connecting 'mile,' and the time spent on the ridesourcing trip—including waiting for vehicle arrival. The net time cost can make ridesourcing less attractive than walking for shorter first/last mile distances.

Another important travel time stage is time spent searching for parking. Shoup (2006) presented a model of how travelers choose whether to "cruise"—i.e., search for free or cheaper curb parking—or to save time and pay more for off-street parking. This tradeoff was used to estimate a time value of cruising. The perceived cost of cruising varies and no simple, single value is provided.

Cookson and Pishue (2017) also estimated the cost of search time for parking across various cities in the U.S. For two major California cities, Los Angeles and San Francisco, the average of on- and off-street parking search time was estimated to be between 11-12 minutes per trip. This would be a significant addition in time cost to any trip less than 1 hour.

Among many efforts to evaluate travel time related to transit ridership, a study by the National Academies of Sciences (NAS, 2013) reported a method to calculate the value of waiting and walking times for a public transit service as multipliers of the value of time in a reference condition—taken as in-vehicle travel. As an example, the average multiplier for the value of waiting-time during travel is about 2×, meaning that the value of the time waiting for transit is approximately 2 times greater than the time spent riding in a transit vehicle. The multipliers for waiting time range of 1×–5× with a mean of about 2×; walking time was found to be similar. On the other hand, Litman (2019) notes that walking and cycling are sometimes associated with

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[2] Seattle (WA), Pinellas County (FL) and Marin County (CA)

positive time values (negative costs) given their perceived benefits (e.g., enjoyment, health). He suggests using a 1.5x multiplier as an average.

In the context of future automated, driverless vehicles, Fosgerau (2018) considered that the VTT may be related in part to the productivity of the traveler during the trip (as opposed to "hedonic" meaning enjoyment) and has to be expressed as a function of the coefficient of productivity. Traveling with fully automated vehicles may increase in-vehicle productivity since people will not have to drive, and vehicles may be better designed as work environments. The value of such productivity would lower the time cost (TTC).

Mokhtarian (2018) described potential time-use changes caused by "passengerization" that could happen in a fully driverless. "Passengerization" refers to how travel could be increasingly passenger-oriented, with vehicle cabin spaces re-arranged to improve comfort or facilitate activities like watching a video or working on a computer. It might trigger new on-board activities that displace previous on-board activities (for example, working vs. making a phone call), and might free time for new off-travel activities by bringing outside-trip activities into the trip, for example, a (large) moving vehicle becoming the venue for a yoga studio vehicle or a bar for social networking. Any of these types of changes to vehicles, and changes to activities in the vehicle, could increase the VTT.

These studies are speculative. The lack of widespread availability of automated vehicles makes it difficult to empirically estimate the changes in VTT they may engender. In an attempt to provide some early empirical evidence, some surrogate studies have been undertaken. Gao et al. (2019) investigated the magnitude of change in VTT that could result from the advent of AVs. They used ridesourcing as a proxy for AVs, where people choose between driving their personal vehicle or riding in a ride-sourced vehicle. Each mode is characterized by a monetary cost and travel time. A residual effect in choice patterns is captured as the additional value of riding in a ride sourced vehicle. The estimated time cost of using an AV trip (represented by ridesourcing) was half that of driving. This may be a reasonable proxy to use until actual AVs become common.

Methodology: Considering Generalized Cost Across a Range of Travel Situations

The basic approach of this analysis was to calculate *generalized cost,* as the sum of monetary and time costs, for a range of travel situations and defined trips. This provides a rough sense of relative costs under different conditions and may indicate how an average traveler would perceive these costs. However, this method does not permit making estimates of actual choices (or, across the population, mode share) since there is a wide variation of travelers with different utility functions, as well as many different trip situations (at a micro level, each traveler faces a unique trip situation for each trip). These results only provide a general, simplified view, but through some sensitivity analysis we attempt to establish some cost relationships that may be relatively robust, i.e., applicable over a wide range of travelers and trip situations.

The range of situations that we consider include six dimensions, as shown in Table 4. These include different vehicle technologies, travel time factors, income deciles of the population, trip types/lengths, trip mode choices (private or ride-sourced), and epochs (near and long term). We only consider LDV travel in this study, we do not consider public transit or micro-mobility modes. The specific assumptions and particular trip comparisons made are presented further below. Though many assumptions are universal or at least universal to the U.S. context, we make some assumptions on a California-specific basis and the trips are considered to be specific to the SF Bay Area.

Table 4. Dimensions of trip types and situations considered in this analysis

Vehicle technologies	Travel time factors	Income deciles	Trip types/ lengths	Trip mode choices	Time frames
Internal combustion engine (ICEV) including hybrids (HEV) Electric vehicles (EV) include battery-electric and plug-in hybrid (BEVs and PHEVs)	"Main trip" (in-vehicle, in-route); congested vs. uncongested Waiting time when not in vehicle Parking search time Walking to and from vehicle	10th percentile Median income (50th percentile) 90th percentile	Short urban trip Long suburban-to-urban trip Long suburb-to-suburb trip	Private vehicle Solo ridesourced trip Pooled ridesourced trip	Near term (2020) Long term (2030-2035)

A core focus is a comparison of trips in privately owned vehicles vs. ridesourced vehicles; for both situations, the vehicle types considered include ICEVs, EVs, and, in the long-term scenario, automated/electric vehicles. We consider a wide range of monetary costs associated with these modes for specific trip types. The primary difference between near- and long-term analysis is that for the near-term, no automated vehicles are included whereas in the long term, only automated vehicles are considered. This affects the purchase and operating costs of vehicles, though incomes, values of time, trip characteristics, etc. are kept fixed for ease of comparison of cases.

The technology types and vehicle cost information is taken from our recently published paper Compostella et al., (2020). In that paper, we estimate the fixed and variable costs for a range of LDV technologies (gasoline ICEV, HEV, PHEV40 [40-mile electric range], BEV200 [200-mile range], and BEV300), across a range of vehicle classes (typical midsize car, small sports utility vehicle [SUV], and midsize SUV). Here we focus on an ICEV and a BEV200 for a medium sized car. We also refer the reader to Compostella et al. (2020) for a full discussion of the vehicle-related cost details we estimate for each vehicle type in the near and long-term context. Here we provide selected figures showing key results from that analysis.

Vehicle Monetary Cost Assumptions

As reported in Compostella et al. (2020), many of our vehicle technology cost factors are derived from Moawad et al. (2016), which provides a detailed analysis of technology cost. We also use their estimates for vehicle fuel economy. Their work is based on simulations using the Argonne National Lab's *Autonomie* software. While these estimates from Moawad et al. (2016) provide an important foundation for our own estimates, they are only a starting point. For example, their work does not consider costs for ridesourcing vehicles that travel many tens of thousands of miles per year, nor costs for automated (driverless) technology. The following is a list of our additional assumptions and estimates.

Vehicle depreciation

From vehicle purchase cost, we apply a fixed rate of depreciation over 5 years of ownership, leaving a residual value that is recovered upon vehicle resale. Following Elgowainy et al. (2016), we use 5 years to provide a typical first owner perspective. The depreciation expense is divided by the miles driven over the 5 years to compute a capital cost per mile. For ridesourcing vehicles, we assume no residual value at the end of 5 years of use at 80,000 miles per year, or 400,000 total miles.

Maintenance and insurance cost

We use average values estimated by the American Automobile Association (2018) based on vehicle powertrain and class. For ridesourcing vehicles, we assume drivers are the owners of their vehicle, and we assume a ridesourcing premium is added to their regular vehicle insurance premium (Glover, 2019). In the long term, we treat AV insurance cost in a similar way in our base case but consider the possibility that this insurance cost is much lower in a sensitivity case undertaken in the original paper.

Vehicle energy costs

Energy costs vary as a function of driving distance, efficiency, fuel type, and fuel price. We use fuel economy values for the range of vehicle types as per Moawad et al. (2016) for near and long term, and current and projected energy prices for gasoline and electricity from the Energy Information Administration (EIA, 2017). Fuel cost is discounted over the five years of vehicle ownership.

Ridesourcing driver cost

Ridesourcing driver cost is estimated based on recent data on average national gross revenue[3] minus expenses. We assume that driver earnings are independent of vehicle class and

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[3] Average calculated between the fares of a 6-mile trip in San Francisco, New York, Chicago, Atlanta, Austin, Minneapolis, using Uber fare estimator (Uber, 2018).

powertrain. We estimated the net revenue by subtracting from revenue (based on average service price per mile) the overhead cost charged by the service company (such as Uber) and all vehicle-related expenses. To put this another way, the final cost per mile is a sum of all vehicle related expenses, company overhead cost, and driver income.

Non-per-mile costs

Some costs, such as for parking and vehicle-cleaning, are not paid per mile and do not easily translate to per-mile costs. Parking cost is linked to a given trip so that if allocated on a per-mile basis, it results in a higher contribution for shorter trips and lower for longer trips. For our monetary cost estimates per mile, we capture parking costs for example trip lengths. We capture cleaning cost by dividing the cost of cleanings per year by the miles traveled.

Vehicle automation

AV technology is in its infancy and thus it is difficult to estimate future costs. We do not consider vehicle automation for our near-term (2020) estimates, but we focus on AVs for our long term (2030-35) analysis. Mosquet et al. (2015) and Sperling (2018) both estimate a long-term, high volume production cost of $10,000 per vehicle for AV technology.[4] We use that value as our base estimate, though in Compostella et al. (2020) we consider alternative values in our sensitivity analysis. Regarding AV efficiency, we assume the two key impacts to be offsetting: that AVs require additional energy use to power the extensive on-board electronics and computing power, but are likely to be more efficient given their highly calibrated operation, improvements in traffic flow that they generate, etc. Thus, we assume they have the same efficiency as a driven vehicle of the same technology and size. This assumption is consistent with other studies, such as that by Bridges (2018).

We use the range of monetary cost assumptions outlined above to estimate an overall per-mile cost for each vehicle powertrain, vehicle class, use (private or ridesourcing), for human driven and automated vehicles, in the near- and long-term. This approach also allows a comparison of the passenger mile cost for private driving and ridesourcing trips.

Monetary Costs: Results

The results of our analyses are presented as a series of side-by-side comparisons of the travel fixed and variable costs specific to the different operating modes and vehicle powertrains.

The results of the vehicle costing analysis for near and long term are shown in the following figures, all taken from Compostella et al. (2020). Figure 1 provides detailed results on the cost of vehicle components in the near- and long-term (though without automation). The largest reduction in cost from near- to long-term is due to the expected decline in battery cost, and thus electric vehicle, costs. While the ICEV remains the cheapest over time the cost of plug-in

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[4] Mosquet et al. (2015) refers to 2025, while Sperling (2018), to 2040.

hybrids (with 40-mile electric range) and BEVs (with 300-mile range) are reduced significantly and become much closer to the cost of the ICEV.

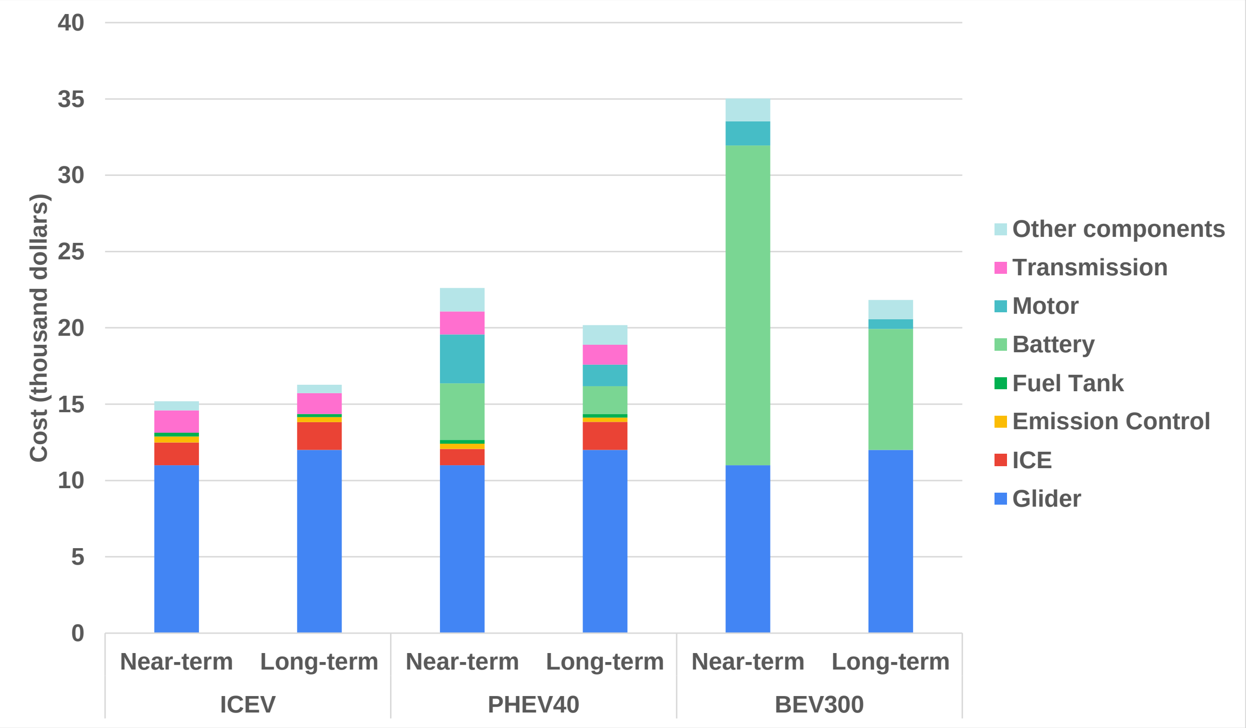

Figure 1. Near-term and long-term costs of midsize car components (source: Compostella et al., 2020). (Abbreviations: ICE, internal combustion engine; ICEV, internal combustion engine vehicle; PHEV40, plug-in hybrid electric vehicle with 40-mile electric range; BEV300, battery electric vehicle with 300-mile range.)

Figure 2 adds operating costs and shows the estimated costs (in $/VMT) of private vehicles and ridesource vehicles, for mid-size sedan ICEV, HEV, PHEV, and BEVs in circa 2020. The dominant cost contributor for private vehicles is vehicle depreciation. The dominant cost contributors for ridesourcing are driver cost and provider overhead. The height of the ridesourcing bars are roughly consistent with estimates of average per-mile fares of Uber and Lyft services, though these can vary considerably with geography, time-of-day, demand, etc. Electrification of private vehicles increases overall operating costs, particularly for longer-range BEVs, though the energy savings does help to offset the higher capital costs. For ridesourcing vehicles, the purchase and other fixed costs of vehicle operation are far lower per mile than for private vehicles, since these costs are amortized over many more miles in the 5-year period. For these vehicles, BEV energy cost savings fully offset the capital cost, but it is hard to detect this given the overall lower levels of these costs relative to the driver and overhead costs of operation. The height of these bars is identical, as we assume the driver absorbs any additional operating costs of these vehicles, and the price to the consumer is fixed across technologies. But they are so close that this is not a particularly important assumption.

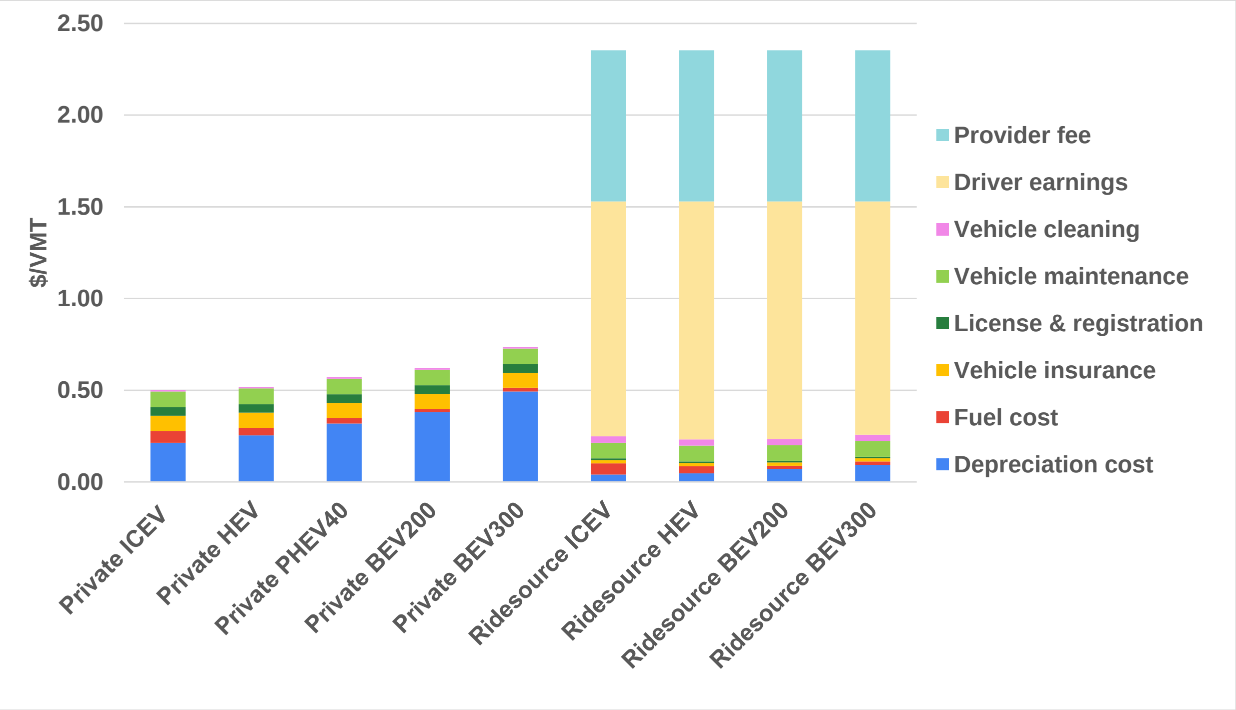

Figure 2. Cost ($/VMT) for private and ridesourcing midsize cars in the near-term. (source: Compostella et al., 2020)

Figure 3 converts the cost basis of the estimates from vehicle miles to passenger miles traveled (VMT to PMT), taking into account the average occupancy of vehicles and typical fares paid for pooled ridesourcing services. This allows pooled services to be included in the comparison—which, as shown, provide much reduced costs relative to solo trips. However, their cost per passenger mile is still much higher than for a private car.

These results suggest that the current use of pooled and especially solo ridesourcing services must typically reflect high benefits, given their higher costs. These benefits would tend to be largely in the form of time savings or convenience. The value of these time savings (lower time costs) are considered further below.

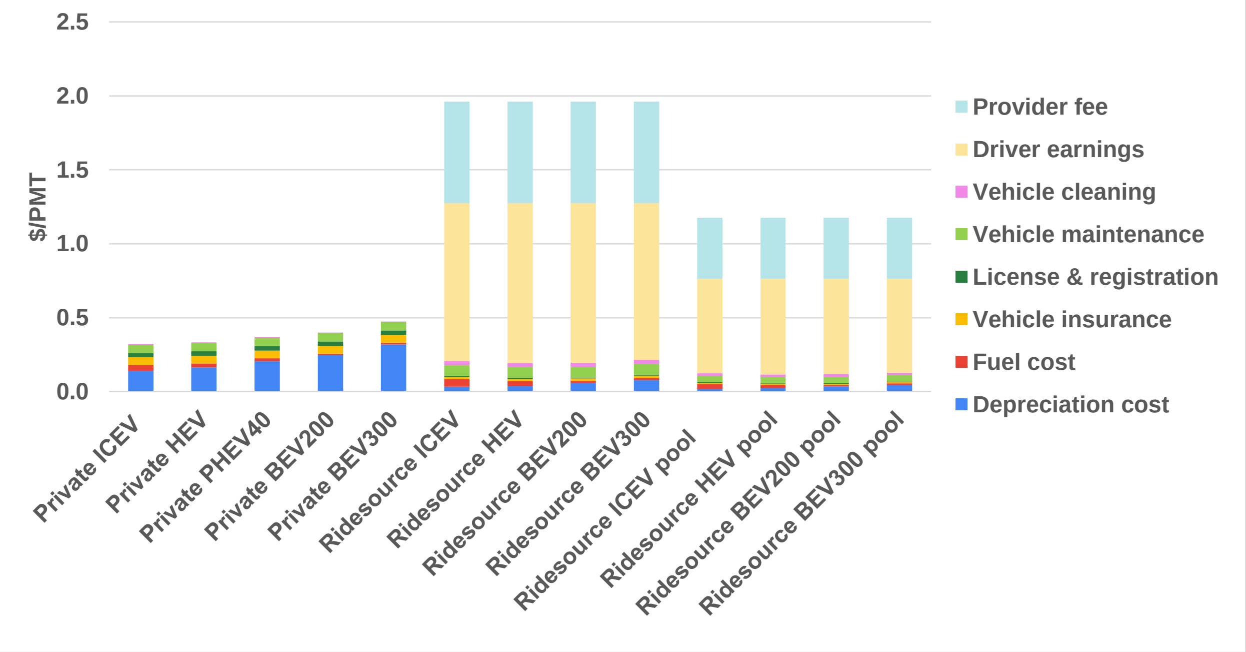

Figure 3. Near-term costs ($/PMT) for private and ridesourcing midsize vehicles. (Source: Compostella et al., 2020)

Long-term (circa 2030-2035) Vehicle Cost Assumptions

In the long term, the cost of batteries and thus electric vehicles is expected to drop, and AVs are introduced into the analysis. Figure 4 shows the travel costs (in $/VMT) for private driving and ridesourcing in a future automated scenario in ca. 2030-2035. There is a negligible impact of the automated technology cost and the recouped cost of the driver on the overall cost that make traveling with ridesourcing cheaper than traveling with private vehicles. Traveling with a BEV costs about the same as an ICEV for private driving, yet, BEVs travel costs far less in the case of ridesourcing. The cost of automation is inconsequential for ridesourcing given amortization over so many miles. This all suggests that at some point in the future, driverless BEV ridesourced vehicles could compete with private vehicles of any type. It should be noted, however, that the cost effectiveness of future ridesourcing options is dependent on the overhead cost charged by provider companies. Here we assume it retains a similar share of total per-mile cost as in the near term (Compostella et al., 2020).

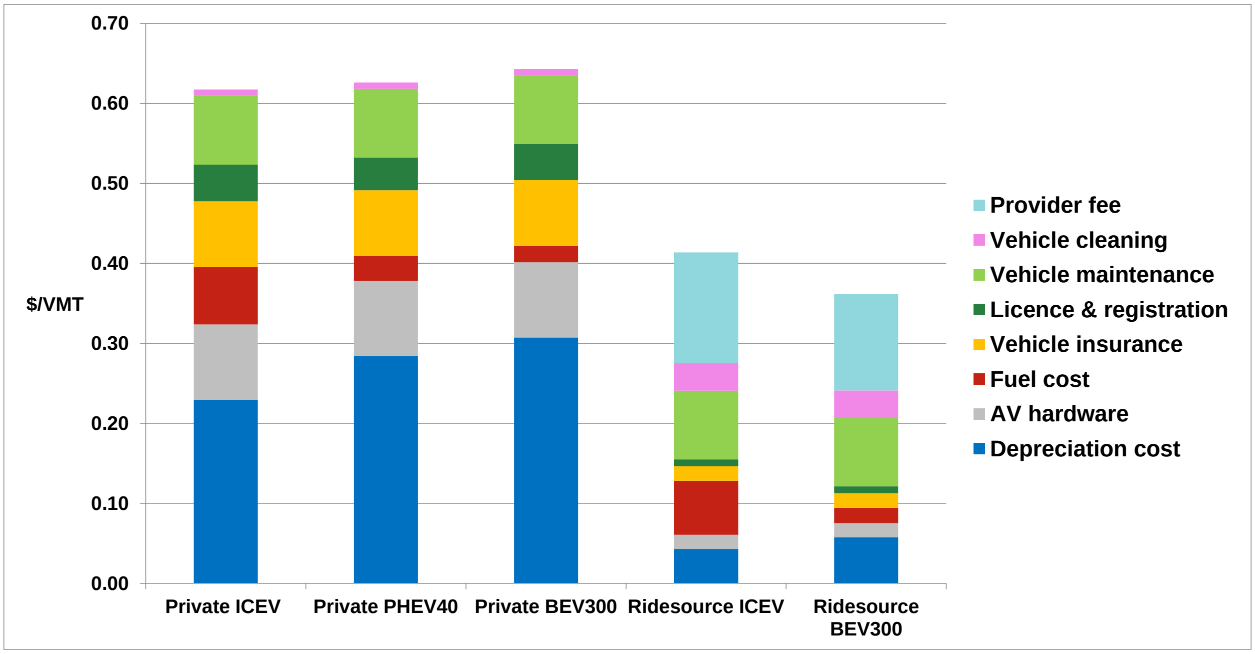

Figure 4. Long-term costs per vehicle mile ($/VMT) for driverless automated midsize cars(Source: Compostella et al., 2020)

Figure 5 shows the costs (as $/PMT) in the long-term of pooled ride-sourcing with 2+ passengers. Pooled rides will continue to have a cost advantage, though in absolute terms this advantage is much less than in the near term (around $0.10 per passenger mile compared to over $0.60 in the near term case shown in Figure 3) (Compostella et al., 2020).

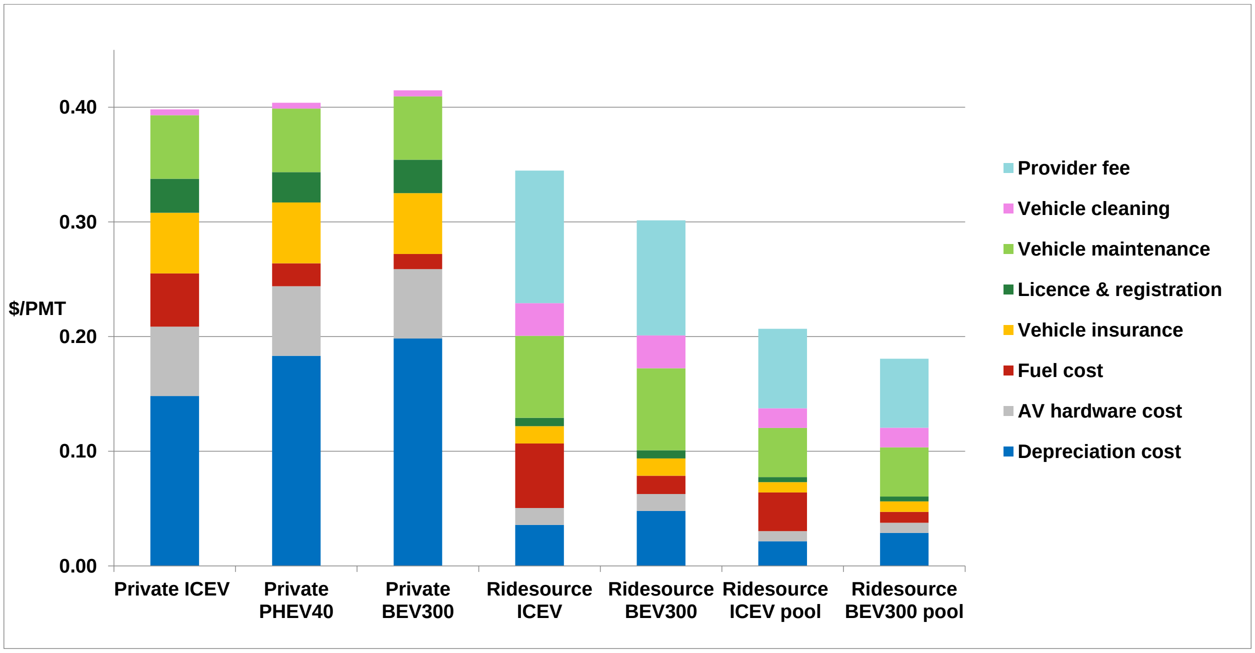

Figure 5. Long-term costs ($/PMT) of driverless midsize cars. (Source: Compostella et al., 2020)

Generalized Cost Analysis

For estimating the travel time cost (TTC), we consider four specific aspects of trips, and estimate these amounts over the same range of trip types as described above for monetary cost. We then compare the total cost of trips by mode, vehicle type, etc., in different situations.

As indicated in the literature review above, we include the value of time from various components of vehicle trips. These include "main trip" time, time spent searching for parking, waiting time, and time walking to and from the vehicle. Based on the literature review and other assumptions outlined here, our base estimates of the values or costs of various trip components are shown in Table 5.

Table 5. Base case time costs used in this analysis

Main trip time		**Other activities**	
Driving own vehicle	70% of wage	Waiting	100% of wage
Passenger in today's vehicles	50% of wage	Searching for parking ("Cruising")	125% of wage
Passenger in future automated vehicle	35% of wage	Walking	125% of wage

- **Main trip time.** Based on the reviewed studies, particularly US Department of Transportation (2014), we assume that driving one's own vehicle has a time cost, on average, of 70% of a person's wage. We further assume this drops to 50% for passengers in conventional vehicles who can do some other activities, and to 35% (half that of today's drivers) for people in a future automated vehicle that have an even greater range of possible activities.
- **Other activities:** As discussed above, a range of values are reported in the literature for the value of travel time outside of the main-trip time (Litman, 2019; NAS, 2013). The values we use, shown in Table 5 (under "Other time uses"), reflect the earlier discussion of estimates from the literature. These costs are higher than main-trip time costs, although we use somewhat lower time costs for waiting and walking than are estimated by the National Academy of Sciences (NAS, 2013) for mass transit compared to driving. Our rationale is that with ridesourcing, rather than transit, such times can be spent waiting indoors or with more confidence in the length of the predicted waiting time. As found by Litman (2019), walking may be a positive for many travelers, so we keep the average just 25% higher than for main trip travel.

Due to the variability and uncertainty in estimating these time costs, we conducted a sensitivity analysis and compared results to our base case.

The actual California wage estimates used here come from the Bureau of Labor Statistics (US BLS, 2018), with a median value of about \$28 per hour. We also consider the 10th and 90th percentiles, which are $11 and $57 respectively. Much higher incomes (and effective wage rates) exist, of course, such as for some professionals and executives, which can reach hundreds of dollars per hour, but these are relatively few people.

Trip-related Assumptions for Scenarios

We consider the above time value factors in a range of scenarios, with main trip length, duration, and speed summarized in Table 6. We characterized trips in the San Francisco Bay area, extracted in November 2019 with Google Directions API:

1. The "Urban-urban" trip: from San Francisco city area to San Francisco Central Business District (CBD),
2. The "Suburban-Urban" trip: from the Bay Area to San Francisco CBD, and
3. The "Suburb-Suburb" trip: a trip where origin and destination are both in the Bay Area.

Table 6 reports the averages of 92 origin-destination (OD) pairs for the "Urban" trip, 580 OD pairs for the "Suburban-Urban", and 580 pairs for the "Suburb-Suburb" trip case. We simulated morning rush hours (7:15 AM) of November 2019.

Table 6. Average length, duration, and speed for different trip types.

Type of Trip	Trip distance (miles)	Trip duration (minutes)	Speed (mph)
"Urban-urban" (n = 92)	5	19	15
"Suburban-Urban" (n = 580)	25	39	38
"Suburb-Suburb" (n = 580)	40	51	48

We performed sensitivity analyses to examine how the generalized cost is affected by varying the estimates of the following parameters (independent variables):

- **Waiting and walking time:** Based on the average of 50 queries to ridesourcing apps (i.e., Uber and Lyft), the waiting time for a ride is 5 minutes. We also assumed 3 minutes to walk to and from one's personal parked vehicle.
- **Pooled ride time:** Based on 50 queries to ridesourcing apps, we found that the estimated time from the trip request to the arrival of the vehicle at the origin is between 5 and 20 minutes with some correlation to trip distance. Assuming the travel time for a solo ride is between 15 and 60 minutes, we assumed a pooled ride would require 33% longer than the solo ride, though this is a rough approximation. This percentage of additional time for pooling could be higher for shorter trips, as proportionally more time is devoted to picking-up and dropping-off of other passengers, or it could be higher for longer trips, where the deviation from the direct route is greater. A detailed analysis of this tradeoff was outside the scope of this study.

Generalized Costs: Results

Figures 6-10 show the results for *generalized costs* under different scenarios. The generalized cost is the sum of estimated vehicle costs and travel time cost (TTC). The different scenarios are based on various combinations of each of the following variables:

1. Type of trip: urban-urban vs. suburban-to-urban vs. suburb-to-suburb; each characterized by a given sample distance
2. Traffic: uncongested (base case) vs. congested; these are reflected in different speeds of travel
3. Value of travel time (determining TTC), in terms of wage: low (10th percentile) vs. median (50th percentile; base case) vs. high (90th percentile)
4. Year: 2020 (base case) vs. 2030–35.

Briefly, Figures 6 and 7 present different types of trips (variable 1) under base case conditions for the other variables; Figure 8 varies the TTC (by varying the assumed wage); Figure 9 increases traffic and other time factors (waiting for ridesourcing, longer time to park and to walk to and from the vehicle); Figure 10 varies the year from 2020 to 2030–2035 and assumes automated vehicles.

Figure 6 shows the base case results for the suburban-to-urban trip, with an intermediate trip distance and speed. This figure (as with Figures 7-10) includes all monetary and non-monetary costs included in the analysis. It reflects a median wage (and thus median value of time) and assumes free flow traffic conditions with an average speed of 38 miles per hour. It also reflects relatively modest amounts of time spent waiting for a ride sourced vehicle (5 minutes), cruising for parking (3 minutes) and walking to and from the vehicle (6 minutes to-and-from combined). The private vehicle options reflect time cost from the driver's point of view; time spent as a passenger in the ridesourcing vehicle has a time cost 70% as high per mile. In this particular case, the cost of solo ridesourcing is more than double the cost of driving either a private ICEV or BEV; the cost of pooled ridesourcing is roughly intermediate. The main determinant of the generalized cost differences is the monetary cost, although for privately driven vehicles, more than half of the total generalized cost are made-up of time costs.

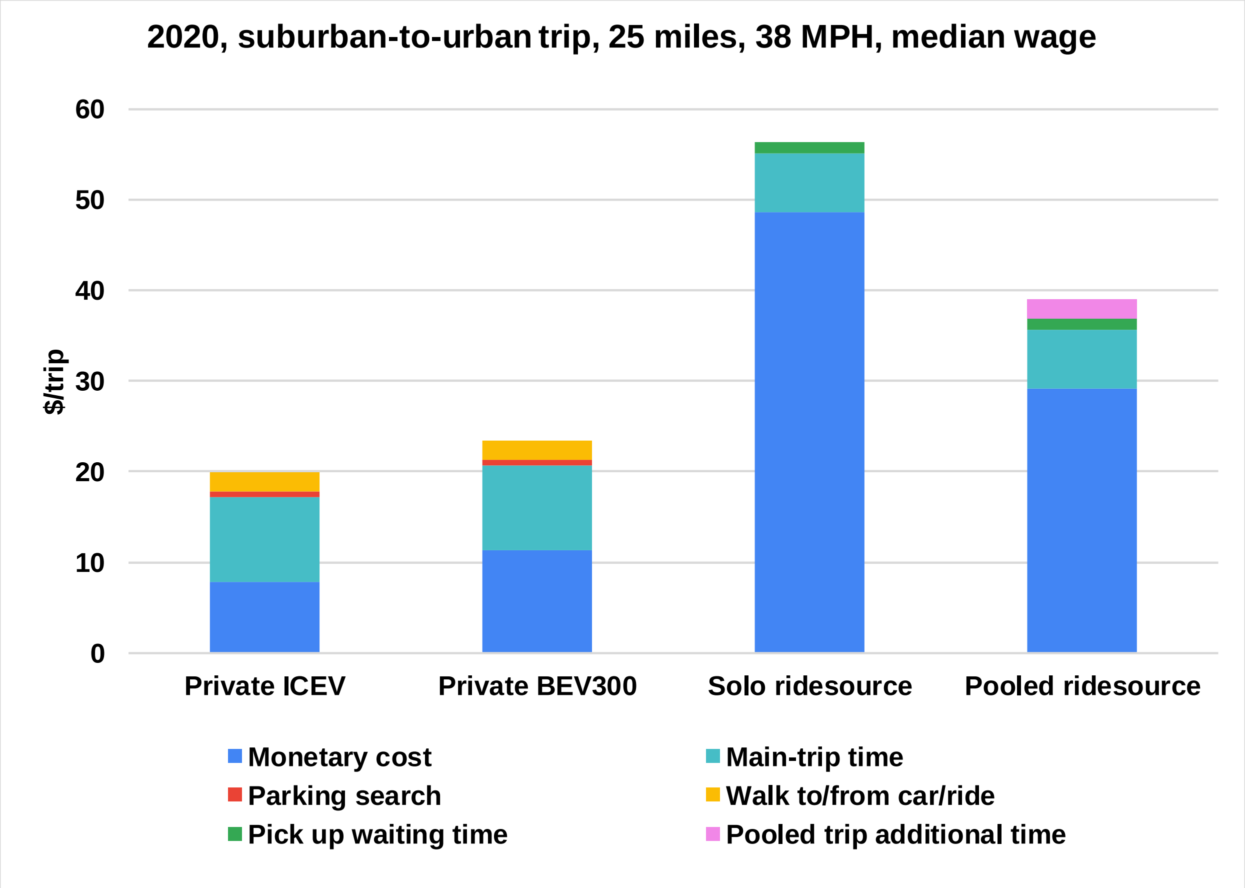

Figure 6. Generalized costs for a base case suburban-urban trip results for four travel options

Figure 7 shows the base case results for the other two trip types: a 5-mile urban trip and a 40-mile suburb-to-suburb trip. The urban trip occurs on city streets at low average speeds; in our data for San Francisco this is 15 mph. The suburb-to-suburb trip occurs on roads and highways at far higher speeds, in the San Francisco Bay area we found this to average 48 mph. In the urban case, the time costs are much more important than in the intermediate speed/distance case shown in Figure 6, while they are even less important for the suburb-to-suburb case than they were in Figure 6. (Note that the y-axis in each of these figures is adjusted so that all bars fits on the plot, thus, the y-axes scales differ between plots.)

These figures show that the slower the average speed, the longer the duration of the trip, and, thus, the more the TTC impacts the relative cost of trips. The time cost of waiting, walking, and parking also emerge as important costs with shorter duration trips, since they do not vary with trip length. All of these time-related effects lead to a far more cost-competitive situation for ridesourcing, including pooled ridesourcing, compared to privately driven vehicles, though the latter are still more expensive, given our assumptions.

Overall it could be concluded that, on average, a person with all of these travel options, these trip characteristics, and the median value of time will opt to drive a private ICEV.

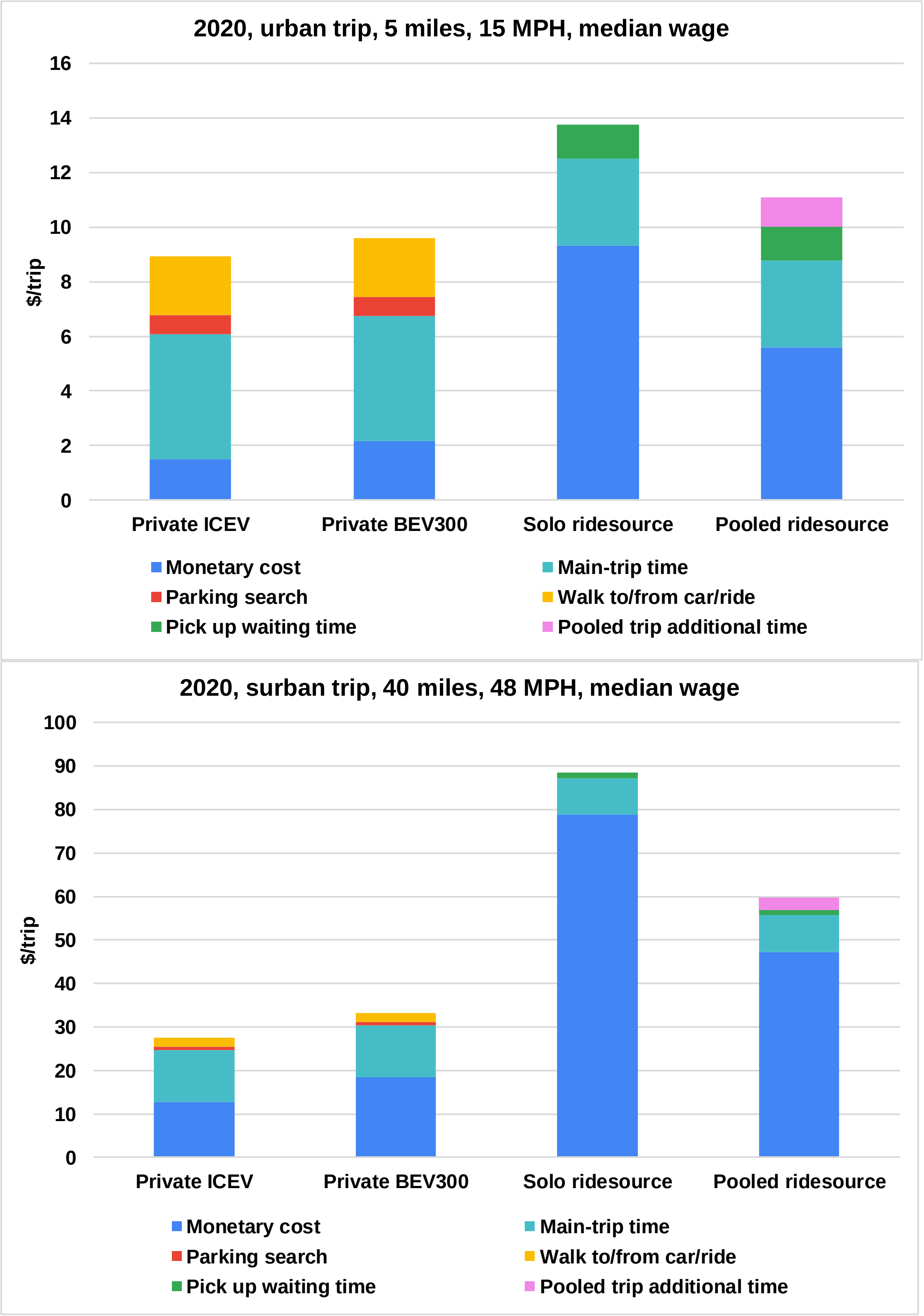

Figure 7. Generalized costs for a base case urban and suburban trip. (Note: The y axis scale differs between panels here and in the following figures.)

In Figure 8, we present the urban 5-mile urban trip case but with more extreme values of time assumptions: the 10th and 90th wage percentiles are used to determine time value. These cases show that with a high value of time, time costs dominate over monetary costs for the use of private vehicles and are even around 50% for solo ridesourcing. As a result, the generalized costs of all four trip choices are similar. This suggests that pooled and even solo ridesourcing may be the most attractive options for those with high time values, in an urban setting with a relatively short trip length and the need for parking and walking if they drive themselves. A traveler might find solo ridesourcing far less expensive than other options when the TTC is especially high—due to the traveler's income or a situation that increases her/his perceived value of travel time. However, for those with very low wages (and thus a presumed very low value of time), time costs are low, and the monetary costs of solo ridesourcing are prohibitive. Even pooled ridesourcing in these circumstances is considerably more expensive than driving one's own vehicle.

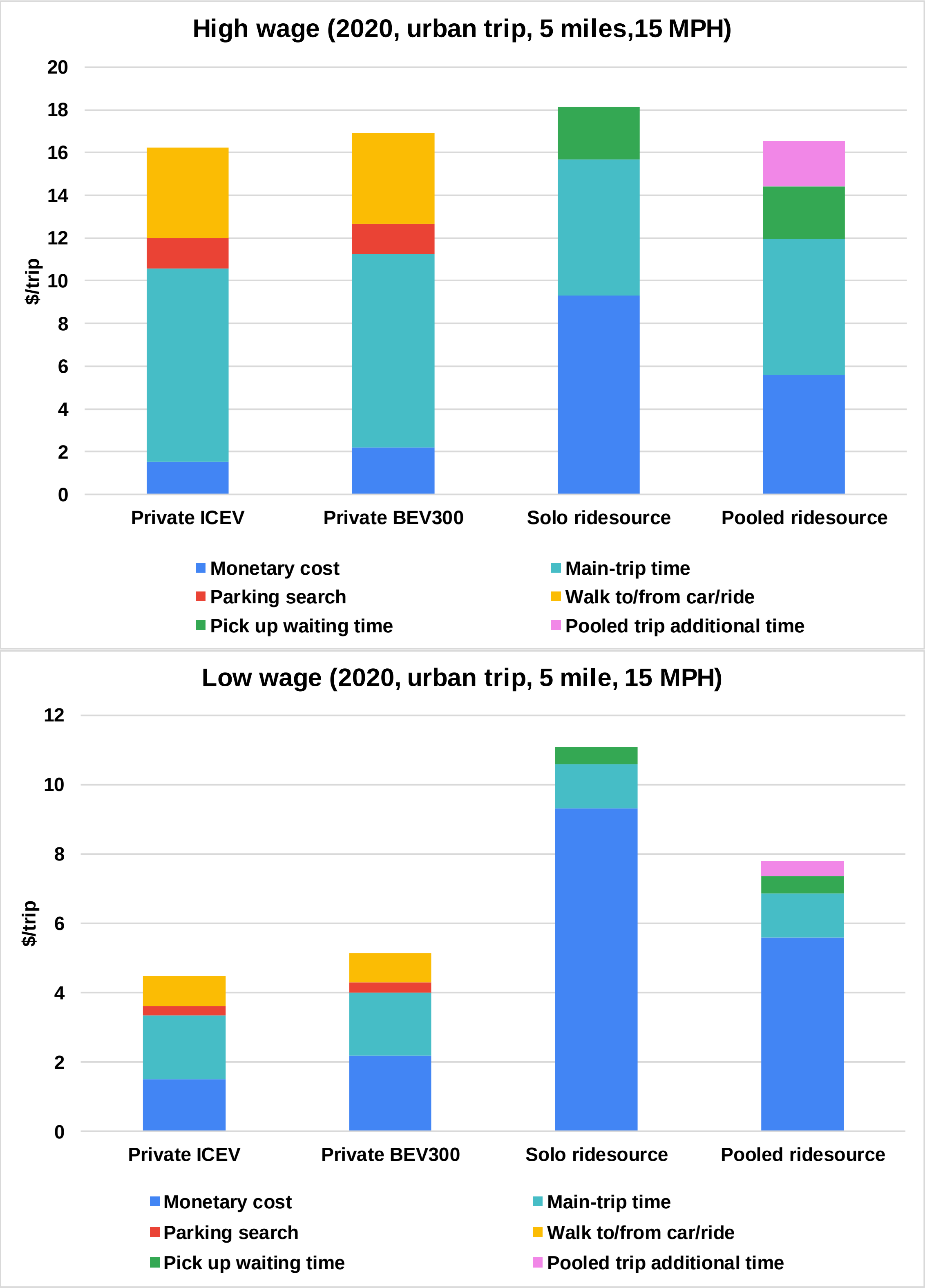

Figure 8. Generalized cost for an urban trip assuming a high (*top*) and low (*bottom*) wage and value of travel time, with other assumptions as in the base case. (Note: y-axis labels differ between panels.)

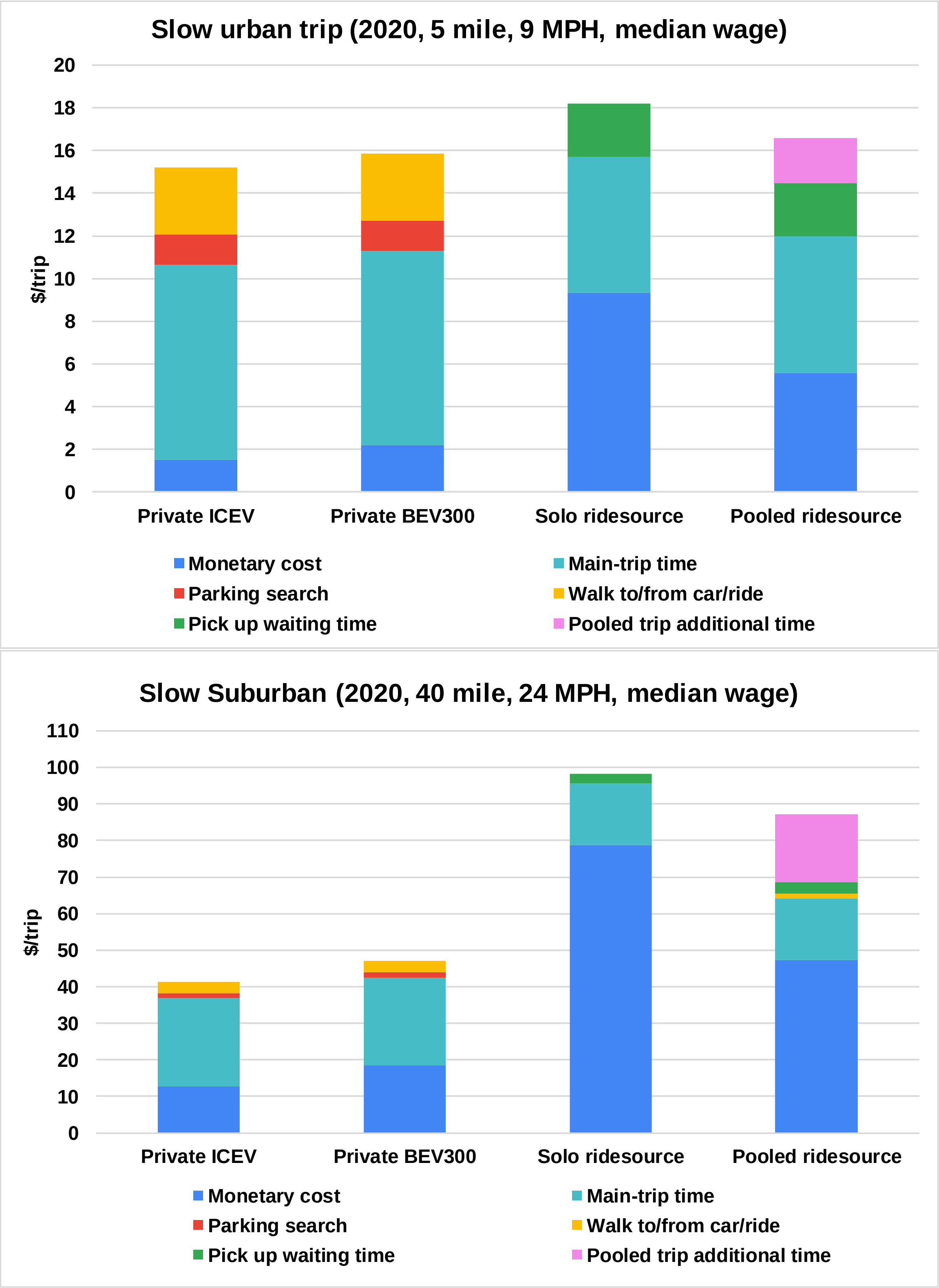

Figure 9. Generalized cost for urban (*top*) and suburb-to-suburb (*bottom*) trips with slower speeds, longer parking/walking/waiting times

Figure 9 replaces the base case time factors with “high case” factors—congested traffic, slower trips, and with 50% higher time value costs for waiting and for walking. This makes things worse for every kind of trip so the total generalized costs of the trips in these figures are higher than they are with the base speed and time cost assumptions. The changes in generalized cost also change the comparative costs of the options.

For short urban trips, these time-related penalties push the cost of private driving up close to the level of pooled and even solo ridesourcing. Thus, with time penalties (due to congestion, waiting, walking, and parking), ridesourcing becomes competitive with private vehicle use at the 50th percentile (median) value of time. In contrast, without time penalties, ridesourcing becomes competitive only for the 90th percentile value of time. However, even with much higher time-related costs, the long suburb-to-suburb trip is still far cheaper in a private vehicle, given the high cost of ridesourcing.

The final set of results focuses on future technologies, in particular, vehicle automation. Figure 10 provides results for a circa 2030-2035 type future where all vehicles are driverless and passengers have better configurations for doing work and/or engaging in enjoyable activities during the main trip time. This can be expected to reduce the time cost of travel. The efficiencies generated by automated vehicles could also cut traffic congestion and reduce travel times for a given distance. There could also be rebound effects resulting in greater travel distances and overall increases in traffic, but we do not consider those effects here.

The specific assumptions reflected in Figure 10 include:

- Future automated vehicle costs reflect driverless systems (averaging $10,000 per vehicle). Further details on future vehicle costs are discussed in the monetary cost section above and in Compostella et al. (2020).
- We assume an even lower time cost for being a passenger in an automated vehicle than in a regular vehicle (whether private or ride-sourced). Instead of 70% of the cost of being a driver, this cost is set at 50%.
- Waiting times for ridesourcing pickup (given a more efficient system and many more ridesourcing vehicles operating) are cut in half, from 6 to 3 minutes.
- The walk to meet pooled rides is cut in half, as is the waiting time, given better matching possibilities from the many more pooled ridesourcing vehicles in operation.
- Parking search time and walking to final destination are eliminated, as private vehicles provide door-to-door service and then seek parking as an empty vehicle.

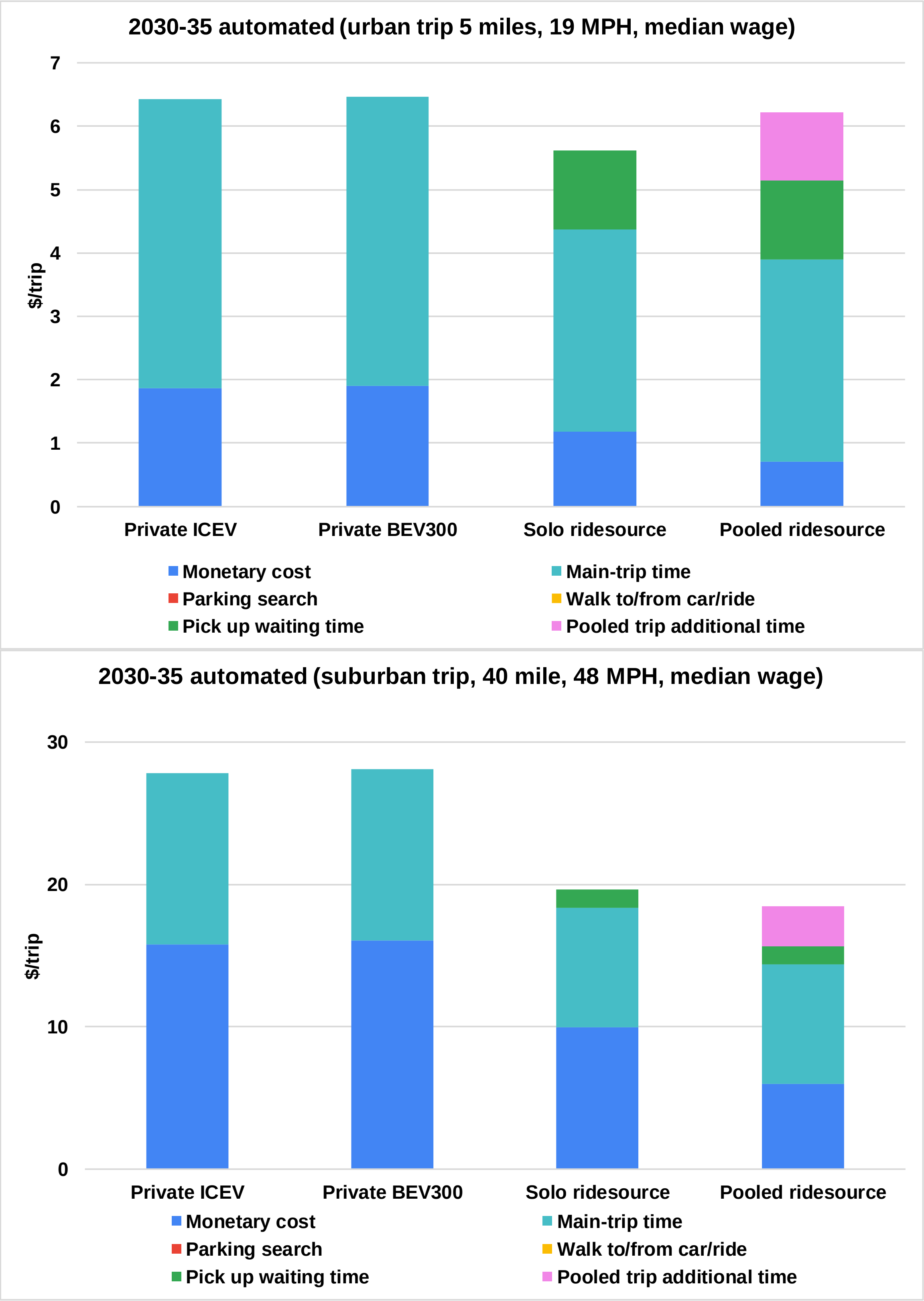

Figure 10. Generalized cost for urban and suburban trips, future scenario (2030-35) with automated, driverless vehicles

The biggest effect of the advent of automation is that ridesourced AVs will have much lower monetary costs than privately owned AVs. This is because ridesourced vehicles operate up to 10 times longer per day than private ones, and costs are amortized over perhaps twice as many miles (even though these vehicles are assumed to be depreciated much faster, lasting 3-4 years instead of 15-20). For shorter urban trips, with automation, solo ridesourcing becomes slightly less expensive (as a generalized cost) than the other options. For the longest, fastest trips (suburb-to-suburb), solo ridesourcing becomes much cheaper than traveling in one's own car but pooled ridesourcing trips retain a slight cost advantage.

These results suggest a future where driverless vehicles could make solo ridesourcing very competitive and reduce the incentive for private ownership (although the general cost of privately owning and using a car also decreases significantly with automation). It is important to remember that this analysis does not take into account many other factors, such as car ownership "pride" or the flexibility private vehicles offer, such as leaving personal belongings in them over multiple trips, taking long trips over many days, etc. Such factors could significantly affect the comparative costs of these choices but are beyond the scope of this paper.

Analysis of Policy Options and Potential Impacts

The initial findings from this research have significant policy implications. These include:

- Currently personal vehicle travel is generally much cheaper than ridesourcing, yet ridesourcing has grown dramatically. Based on this analysis, much of that growth can be attributed to a variety of situations where the value of travel time savings makes these modes appealing even though they are much more expensive (by approximately a factor of 5) than driving one's own vehicle.
- If ridesourced travel is automated, we may see a dramatic growth in these modes and in total miles. Policymakers may then want to consider applying fees (such as VMT fees) to the modes that are associated with higher emissions and more congestion.
- Pooled travel is expected to be cheaper in monetary costs, but these advantages largely disappear for many wage (i.e., TTC) groups when additional time is included. This implies that to encourage widespread pooling, policy would need to differentiate the modes and make the generalized cost of pooling much lower than solo travel. However, policies that incentivize pooling should be carefully developed so as not to draw travelers away from other modes considered beneficial to society, such as public transit, walking, and bicycling.
- EVs have a monetary cost similar to ICEVs in private ownership and, even more so, in ridesourcing (see Figures 2-5). However, higher purchase cost, perceived inconvenience and other barriers may slow the deployment of EVs in ridesourced modes. Policymakers may consider options that lead to a similar price or even significant price advantage for EVs.

This analysis implies that a comprehensive pricing approach, which reflects the wide variety of monetary and hedonic costs from transportation, as well as “external costs” (including at least pollution and effect on congestion) may be most effective in aligning the apparent overall ‘cost’ of travel choices with their real-world impact on others.

Future research should expand the analysis for a range of policies to evaluate under what conditions demand would likely shift in a major way (i.e., reach tipping points) with the advent of different modes of travel, such as driverless mobility services.

Examples of potential future policies to include in models:

- Pricing by impact: inclusion of an externality-based fee for all modes
- Pricing of empty miles: inclusion of estimated costs for empty miles for all modes
- Pooling incentives: reduction of cost for shared modes based on occupancy
- Equity-based user-side incentives: reduction of cost for low-income users of shared services
- Electrification incentives: reduction of cost of EV shared and personal modes

Conclusions

This report has focused on developing generalized cost estimates for a limited range of modes, in California for different origin/destination pairings, congestion conditions, and wage of traveler. For these conditions we compared travel in privately owned vehicles vs. ridesourced vehicles, also varying electric vs internal combustion engine, automation, and pooling.

The results indicate that in the near term, even when based on a range of time-related costs, the overall cost of ridesourcing is likely to be higher than privately driven vehicles except for travelers with a very high value of time, and mostly in urban conditions. Also, even for travelers with average values of time, trips with long periods of time needed for parking and/or walking to and from the vehicle may provide ridesourcing with an advantage.

In the future, with automated driverless vehicles, the monetary costs of ridesourcing could drop to the point where this option is cheaper in many situations than private vehicle trips.

As the costs of private ownership and pooling decrease, especially with the anticipated advent of automated vehicles, increased congestion and passenger miles traveled could be a concern. Policies that encourage more choices of more sustainable modes (walking, bicycling, public transit, pooling) may be required to reduce congestion, greenhouse gas emissions, and societal costs. However, more research is needed regarding costs, especially hedonic costs, and their effects on mode choice to more precisely determine policy implications.

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