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Can sharing a ride make for less traffic? Evidence from Uber and Lyft and implications for cities

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ABSTRACT

The popularity of Uber and Lyft and advances in autonomous vehicle technology have spurred public interest in the potential of shared ride services to reduce traffic congestion, vehicle emissions and space devoted to parking. However, research has shown that long waiting times, circuitous routes and privacy concerns might lead most patrons to choose exclusive-ride services over shared services (ride-hail or autonomous), thus increasing rather than decreasing vehicle mileage.

This paper uses Uber and Lyft experience from 2014 to 2020 to examine the effectiveness of shared (or "pooled") services in reducing vehicle miles traveled (VMT) in four cities with large concentrations of ride-hail trips and suburban areas of California. Taking into account three key inputs – pooling rates, modal shifts and deadhead miles – results show that pre-pandemic levels of pooling led to at least a doubling of VMT when comparing ride-hail trips with patrons' previous mode, with increases of 97% in Chicago, 114% in New York City, 118% in San Francisco, 157% in Boston and 118% in California suburbs.

These large VMT increases are driven by the addition of dead-head miles before each pick-up and the absence of offsetting VMT reductions among travelers who switch to ride-hail from public transportation, biking and walking. VMT increases are only modestly mitigated by the use of ride-hail for "first mile/last mile" trips to connect to public transportation or by reduced cruising for parking by drivers in their personal vehicles.

In sum, ride-hail adds to vehicle mileage for trips associated with ride-hail even taking into account pooling. This pattern is likely to endure in a world of autonomous vehicles given that auto users tend to switch to solo services due to considerations of travel time, reliability, comfort and privacy, while pooled options mainly draw patrons from sustainable modes like public transportation. The implication for public policy is that in dense urban areas, it remains important for policy-makers to prioritize space-efficient modes of public transportation, walking and biking. At the same time, ride-hail can clearly be valuable to meet specific needs such as providing paratransit services to people with disabilities, providing first and last mile connections to transit services and connecting late-night workers to jobs.

These results will be important as cities emerge from the coronavirus pandemic and navigate a path to economic recovery, social equity, and environmental sustainability.

1. Introduction

When a company named Sidecar launched the first "rideshare" service in San Francisco in 2012, it set out to reinvigorate traditional carpooling which had been steadily declining for decades (Ferguson 1997; McKen 2015). Sidecar anticipated that it could combine smartphone apps, GPS and computer algorithms to match prospective passengers with drivers in real time. Rideshare would fill empty seats in cars where both driver and passengers wanted to go from A and B, but without the cumbersome planning of traditional carpool programs. Rideshare would thus reduce vehicle mileage and emissions. Both passengers and drivers would save money, and both would enjoy the social interaction fostered in a community of drivers sharing rides (Stone 2017).

Many of these same goals live on with carpool apps offered by Waze and Scoop today. In 2012, however, drivers quickly turned Sidecar into a taxi-like service. Drivers took passengers to where the passenger wanted to go, not where the driver was already going. Both drivers and passengers flocked to this new service, which was quickly copied by Lyft and Uber. But because these were not trips that drivers were already making, rideshare did not reduce vehicle miles traveled (VMT), but at

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best only replaced personal auto mileage with for-hire mileage.

The companies still intended to "fill the empty seats in our cars and on our roads," and thus reduce traffic (Steinmetz 2014). In 2014, they began offering UberPool and Lyft Line, true shared-ride (or "pooled") services in which strangers are picked up and dropped off while other passengers are in the vehicle.

Sidecar went out of business in 2015, but Uber and Lyft attracted customers frustrated with taxicab and public transportation services, or wanting to avoid high parking costs or driving home after the bars close (Rayle et al., 2016; New York City Office of the Mayor 2016). Ridership boomed, particularly among young, well-educated professionals increasingly populating resurgent cities. By 2019, a Pew Research Center survey found that 70% of urban college graduates had used ride-hailing services like Uber or Lyft (Jiang 2019). In 2018, ride-hail companies transported an estimated 3.2 billion passengers, several orders of magnitude more than other new mobility services such as car share, bike share or scooters and approaching the ridership of urban bus and rail systems (Schaller 2019; Circella 2018; NACTO 2019).

Ride-hail also caught the attention of transportation planners who hoped it could serve as a complement to public transportation, walking, biking and other non-auto modes. They were joined by tech firms and auto makers developing autonomous vehicle technology who looked to the day that autonomous vehicles could be integrated into ride-hail services to offer shared autonomous vehicle (SAV) services.

The travel behavior shifts underlying this vision are shown schematically in Fig. 1. Auto users would shift mostly to pooled ride-hail in the immediate term and later to SAVs. Pooling and SAVs would combine the convenience of the auto and taxi with the lower cost and greater efficiency of strangers sharing their rides. A host of societal benefits were predicted: less traffic, lower vehicle emissions, fewer motor vehicle crashes, and more productive use of land now devoted to parking (Bosch et al., 2018; Loeb and Kockelman 2019; Sperling et al. 2018; Shaheen 2018).

A substantial literature has found that widespread adoption of SAVs could reduce VMT as well as vehicle and parking requirements. Travel models for the Austin, Texas area found that each SAV within a geofenced area could potentially replace between 10 and 13 privately owned vehicles, with one study finding that 49% of rides would be shared (Fagnant and Kockelman 2018; Farhan and Chen 2018) A study using New York City taxi trips found that switching from traditional taxis to shared autonomous taxis could reduce fleet size by 59% and decrease total travel distance by 55%, with commensurate reductions in carbon emissions (Lokhandwala and Cai 2018). Another study using taxi data found that 2,000 to 3,000 vehicles, with a capacity of 10 or four passengers, respectively, could substitute for the existing 13,000-vehicle taxi fleet in New York City (Alonso-Mora et al., 2017). A simulation of shared autonomous vehicles using taxi booking data in Singapore found that sharing could enable the taxi fleet to serve 20–25% more booking requests while also reducing waiting times during peak hours (Wang 2018).

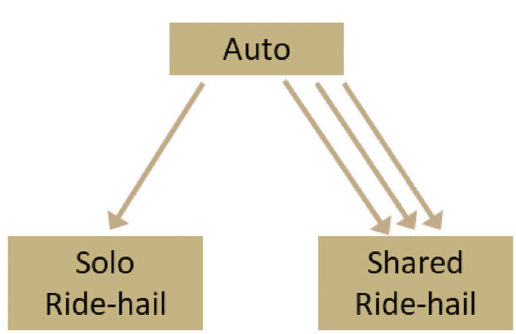

Fig. 1. Schematic Depiction of Traveler Shifts from Auto to Ride-Hail (Early 2010s expectation).

Based on the popularity of Uber and Lyft and the modeling results for SAVs, many planners and researchers expected that autonomous vehicle technology will speed the shift away from personal autos, most significantly toward shared autonomous vehicles (SAV) that would be cost-competitive with personal vehicles, with transformative implications for urban mobility (Bosch et al., 2018; Loeb and Kockelman 2019; Sperling et al. 2018; Shaheen 2018).

At the same time, researchers identified factors that might deter people from using SAVs. One important factor was waiting times. Travel models for mid-sized cities estimated wait times ranging from slightly less than 4.5 min at peak periods (Fagnant and Kockelman 2018) to 7.4 min (Farhan and Chen 2018) and as much as 13–15 min (Vosooghi et al., 2019). Even with the high trip densities of New York City, waiting times would average 2.8 min with a mean trip delay of 3.5 min in one study (Alonso-Mora et al., 2017). Another study using New York City data found patrons would wait 2–3.5 min for pick-up and experience approximately 12–22 min in additional travel time (Lokhandwala and Cai 2018).

Privacy concerns, such as the desire to have one's own space, an aversion to being close to strangers, and concerns with personal safety, may also deter SAV use. A survey of Austin-area workers found that these privacy concerns discouraged respondents from sharing rides currently and led to a significant aversion to future shared autonomous services (Lavieri and Bhat 2019). A survey in Boston found that "sharing a ride is not the preferred travel mode for most Bostonians." (World Economic Forum and Boston Consulting Group 2018).

The end result of these concerns may lead travelers to prefer exclusive-ride services over pooled options despite lower pooled fares. A stated choice survey of residents in major metropolitan areas of Australia found that users switching from their personal vehicle would be more likely to choose an exclusive-ride autonomous option over the shared-ride option, which would preclude ride-hail from reducing VMT for a given trip (Krueger et al. 2016).

As Uber and Lyft ridership rose rapidly, concerns were also raised about the new services' effects on public transportation. Do ride-hail users now (and SAV users in the future) leave their cars at home or do they switch from public transportation and other non-auto modes like biking and walking? Shifting from non-auto modes would inevitably increase VMT since the ride-hail mileage would not be offset by reduced personal vehicular mileage.

Vosooghi et al. (2019) found that adoption of shared autonomous vehicles would come primarily at the expense of public transportation and lead to an overall VMT increase over current travel. A conjoint model using 4 to 16 passenger shared autonomous vehicles in the Boston metro area found that within downtown Boston, people would shift to a shared autonomous service from public transit more than from personal motor vehicles. The result would be increased traffic volumes and more congestion. However, in suburban areas travelers would shift from personal cars in favor of a combination of shared autonomous vehicles and solo taxi and ride-hail trips, leading to reductions in VMT (World Economic Forum and Boston Consulting Group 2018).

Another factor affecting VMT is "deadhead" miles between passenger trips, e.g., from the drop-off of one passenger to the pick-up of the next. Modeling estimates of deadhead mileage vary widely, from less than 10% of total mileage (Farhan and Chen 2018), to 24–26% (Vosooghi et al., 2019) and 41% during peak times and 43% at off-peak times (Bosch et al., 2018). The higher levels of deadheading would work to offset VMT reductions from less mileage in personal vehicles.

In the midst of research and discussion of these issues, public health measures to combat the global coronavirus pandemic brought unprecedented disruption across the globe, with huge reductions in travel across all modes. Ride-hail ridership in the U.S. decreased by 75%–80% with public transportation and urban auto driving experiencing similar declines (Conger and Griffith 2020). For safety reasons, Uber and Lyft shut down their pooled services in March 2020 (Lee 2020).

As the pandemic is brought under control and states and cities begin to chart a path to a post-pandemic future, it is timely to assess what can be learned from the 2010s experience with ride-hail and specifically pooled trips. Policy makers will need to consider – or possibly reconsider – policies for integrating public transportation and ride-hail services, charging lower trip fees on pooled ride-hail trips, reserving curb space for pick-up and drop-off of passengers, and substituting ride-hail for ADA paratransit and traditional fixed-route bus service.

Although the pandemic has made planning for AVs take a back seat, it is also worthwhile to consider the experience with pooled ride-hail for an AV future. Much of the discussion about AVs has anticipated that large-scale SAV services would be widely popular and offer potentially deep and wide-ranging benefits in VMT, emissions, traffic safety and parking requirements. To the extent that these expectations are off track, planning for an autonomous world may need to change gears, perhaps with more focus on autonomous shuttles that serve first and last mile connections to transit, or for public transportation vehicles themselves.

This paper focuses on the specific issue of ride-hail and VMT, which underlies much of the debate over the benefits of both solo and pooled rides currently and in an SAV future. The paper examines ride-hail companies' door-to-door exclusive-ride services like UberX and Lyft and shared ride offerings which include UberPool, UberPool Express, Lyft Line and Lyft Shared Rides. Since introducing pooled options in 2014, the companies have devoted considerable effort and resources to enticing drivers and passengers to these services. Their experience offers a unique opportunity to examine how travel behavior is affected by both quantifiable factors such as travel time and fares, and less tangible but clearly important factors like service reliability, personal privacy, comfort and convenience, across a range of urban and suburban contexts. The paper focuses on the question of how the growth of ride-hail affects vehicle mileage in major urban centers where trips are most concentrated and thus VMT and other impacts are likely to be greatest, and in suburban areas more typical of the U.S. population. Using three key inputs – pooling rates, modal shifts and deadhead miles – the paper estimates VMT increases for each of the five urban and suburban locales. The paper then assesses the sensitivity of VMT increases to model inputs, considers additional factors that might offset a part of calculated increases in VMT, and discusses the implications of the findings.

2. Data and analysis

Ride-hail service is available in a wide variety of communities across the United States, but trips are heavily concentrated in large U.S. cities with large public transportation systems. Overall, nine large metropolitan areas account for an estimated 70% of ride-hail trips (Schaller 2018). New York City has by far the largest trip volumes (298 million trips in 2019); Chicago has about one-third this volume (100 million trips in 2018), and Boston, much smaller in population, about one-half that number, with 42 million ride-hail trips in 2019 (NYC TLC 2020; City of Chicago 2019; MDPU 2020).

Because of the high trip volumes in these large, dense, transit-oriented cities, VMT impacts of ride-hail are of most concern in these cities, and in particular in their downtown business districts and close-in residential neighborhoods where there is the greatest concentration of trips. Trip densities drop rapidly away from the center by as much as a factor of 10 (MAPC 2018; McLaughlin 2019; SFCTA 2017; Gutman 2018; City of Toronto 2019; Brown 2020; Schaller 2017a).

This paper draws on published studies and publicly-available data sources to calculate VMT impacts in four representative large, dense, transit-oriented U.S. cities and for suburban areas of California for which sufficient data is available for this analysis. A literature review was undertaken for this purpose that identified relevant published papers, reports, regulatory filings and news reports as well as publicly available datasets of ride-hail trips. Each source was evaluated for methodological and analytic rigor with a particular emphasis on identifying the most robust and recent data available. Results were also compared across sources to identify potential issues. Results tended to be similar across major cities, with differences noted below. The suburban case shows differences that would be expected for a lower density, auto-oriented context.

VMT impacts of ride-hail growth depends primarily on three factors: the percentage of trips that are pooled; modal shifts; and deadhead miles. VMT impacts will tend to be lower where trips are pooled, ride-hail users shifted from taxis and autos and thus non-ride-hail VMT is removed from the street network; and where deadheading is minimized. Conversely, VMT impacts tend to be greater where trips are not pooled; patrons move from public transportation, biking and walking; and there are more deadhead miles between fare-paying trips.

Data on pooling rates, mode shift, and deadhead mileage used in this paper are based on ride-hail trip and mileage data and statistically valid user surveys undertaken by researchers from government and academia. Inquiries were also made to ride-hail company staff to clarify certain issues that arose in this process, as noted below.

2.1. Pooling rates

Pooled trips account for between one-eighth and one-third of ride-hail trips where pooling is offered. Among major cities, pooled trips have accounted for between 13% and 27% of all trips in recent years in New York, Chicago, Boston and the Denver area. The figure is higher for San Francisco, where ride-hail originated, with about 36% of trips pooled. Time-series data for New York and Chicago indicate that pooling rates declined in 2019, apparently in concert with reduced fare discounts after Uber and Lyft's 2019 IPOs (NYC TLC 2020; McLaughlin 2019; MAPC 2018; Henao 2017; Rana 2020a; Rana 2020b). A recent but relatively small sample in California based on driver trip logs found that 12% of Uber and Lyft rides were pooled statewide (CARB 2019).

In the last several years, both Uber and Lyft introduced variations on pooled services aimed at increasing overall adoption. Company staff indicated that by 2019 most pooled trips involved patrons meeting drivers at a designated location rather than being picked up at their point of origin. These "walk to a stop" services are branded as UberPool Express and Lyft Shared Rides. These services reduce if not eliminate the need for drivers to go around the block to make a pick-up or drop-off and thus reduce delays for passengers already in the vehicle. The effect is to make ride-share more like bus and other transit services that operate along predetermined routes. However, unlike a bus, pick-up locations and routing are determined by algorithms making calculations on the fly.

Geographically detailed trip data from Chicago, New York City, Washington DC and Toronto show pooling is most popular in outlying city neighborhoods such as the South Side of Chicago, eastern Brooklyn and the South Bronx in New York, and northwestern Toronto. Residents in these areas have relatively low incomes and a substantial number do not own a vehicle. However, the public transportation network is less robust as compared with neighborhoods closer to downtown. Pooling can thus be an attractive option for those without a car, being cheaper than solo rides but faster and more reliable than the bus or train. ((City of Chicago 2019; NYC TLC 2019; Moored and Wilkins 2017; City of Toronto 2019; Schwieterman 2016).

Changes in VMT calculated below are based on the following pooling rates:

- Boston: 20% of rides are pooled, based on an in-vehicle survey of 944 Boston-area ride-hail patrons conducted in the fall of 2017 by the Boston regional planning agency (MAPC 2018).
- Chicago: 18.5% pooled, based on trip data submitted by the companies and made public by the City of Chicago for 1,031,294 Uber and Lyft trips from January to September 2019 (Bellon 2019).
- New York: 16% pooled, based on trip data submitted by the companies and made public by the City of New York for 298,057,337 ride-hail trips from March 2019 to February 2020 (NYC TLC 2020)

- San Francisco: 36% pooled, based on data provided by Lyft and Uber to the website Quartz in 2018 (Griswold 2018) and match rates (percentage of pooled trip requests that were matched with other passengers) reported in Hou et al. (2020). It is possible that the pre-pandemic pooling rate for Uber and Lyft trips was somewhat lower than this figure given statewide pooling rates of 12% based on CARB (2019), a rate of 22% for all urban areas of California based on data provided the author from a statewide survey (Circella 2019), and declines in pooling rates in Chicago and New York City cited above. Even if this is the case, results for San Francisco are useful in showing VMT impacts with relatively high use of pooled services.
- California suburbs: no pooling, based on ride-hail company statements that they do not offer pooling outside of major markets and consistent with a California on-line survey that found little if any pooling in suburban areas (Circella et al., 2019).

Since customers are typically picked up and dropped off in sequence during a pooled trip and not all at the same time, only a portion of each trip involves strangers riding together. It can be estimated that about one-half of mileage on pooled trips involve overlap between passengers, based on data for New York City trips and information from the industry (Schaller 2018; personal correspondence with Uber staff July 2019).

2.2. Modal shifts

Ride-hail services attract patrons to shift from other transport options including their personal vehicle, taxi, and public transportation, as well as non-motorized modes such as walking and biking. In addition, trips otherwise difficult to make may be induced by the availability of ride-hail service. The resulting modal shifts are very context-dependent, reflecting what modes are frequently used in a given geographic area and the relative attractiveness of ride-hail and competing modes based on travel and wait times, reliability, cost and comfort.

For calculating VMT impacts of ride-hail, the key figure involves shifts from personal auto to ride-hail and from taxi to ride-hail. In both cases, the new ride-hail mileage is at least partially offset by reduction in the use of personal autos and taxis. The two are somewhat different since the reduction in taxi mileage comes from both the fare-paying trip and from deadheading before the trip, the latter not being relevant for personal auto trips.

User surveys in major cities show that the shift to ride-hail from auto/taxi ranges from 39% to 50%, the lower figure coming from an online survey for the Boston, Chicago, Los Angeles, New York, San Francisco, Seattle and Washington DC metro areas and the latter figure from a passenger survey in New York City (Clewlow and Mishra 2017; NYC DOT 2018). Most of the remainder would have used public transportation as the alternate mode, consistent with transit agency analyses that show a significant portion of their ridership declines in recent years are associated with transit riders moving to ride-hail (MBTA2017, DC Metro 2018; NYCT 2018; Feigon and Murphy 2018).

City-specific survey results are available for two of the four large cities in the analysis:

- Boston: 18% of ride-hail users would have used a personal vehicle and 23% would have used a taxi if ride-hail was not available for that trip, based on the survey of 944 Boston-area ride-hail patrons, for a total of 41% by auto/taxi (MAPC 2018).
- New York: 15% would have used a personal vehicle and 35% would have used a yellow or green taxi, car service or black car, based on a telephone and online survey of 3,602 New York City residents conducted in mid-2017, for a total of 50% by auto/taxi (NYC DOT 2018).

Data are not available for citywide modal shifts in Chicago or San Francisco. However, it seems reasonable to assume that modal shifts in San Francisco are similar to those in Boston, and that Chicago's figure is similar to New York City's, based on similarities between these city pairs in geography, the extent of their public transportation networks, and availability and trip volumes of taxis pre-2012.

(It should be noted that a 2014 intercept survey in San Francisco showed 6% of ride-hail users would have used a personal vehicle and 39% would have used a taxi (Rayle et al., 2016). The authors note that the study was exploratory in nature and omitted or underrepresented daytime and airport trips and trips in outlying geographic areas of the city. I.e., interviewing was limited to late afternoon and evening hours (5:30 p.m. to 10:30 p.m.), four selected days (Wednesdays to Saturdays), and three entertainment and restaurant districts (Mission District, the Marina and North Beach). It seems more reasonable to use the Boston figures which do not have these limitations than the San Francisco exploratory survey. The combined auto/taxi mode switch is similar in the two surveys (45% in Rayle and 41% in the Boston data), but Rayle shows a much higher proportion by taxi, as would be expected in the late afternoon/evening in entertainment and restaurant districts.)

For California suburbs, mode shift of 90% from personal auto is used based on a 2015 online survey of 928 suburban dwellers in California (Circella 2018). This figure is averaged from a latent class analysis showing 99.9% of a "car user" group of suburban residents would have used a personal auto and 48.8% of a "transit and TNC" group would have used an auto.

2.3. Deadhead miles

A report utilizing mileage data provided by Uber and Lyft showed that deadhead miles comprise 40%–48% of vehicle mileage for drivers working for these companies in six large metro areas (Balding et al., 2019). At these deadheading rates, an average ride-hail trip of 5 miles generates 3.3 to 4.6 miles of deadheading. As will be seen in the VMT calculation, deadheading is a major source of additional VMT from ride-hailing.

There are generally lower rates of deadheading within central cities than for metro areas as a whole due to efficiencies produced by higher trip densities in central cities. Deadhead miles comprise 43% of total in-service miles in Seattle, compared with 48% in the Seattle metro area, for example (Hyman et al., 2020; Balding et al., 2019). However, reductions in deadheading associated with increased trip densities appears to level off at a certain point. In Manhattan, which has by far the highest densities of ride-hail trips in the country, deadheading accounted for 35% of trip mileage on weekdays from 4 p.m. to 7 p.m. and 39% from 7 p.m. to midnight in June 2017 (Schaller 2017b). This leveling-off effect is also seen in Uber (2020) data that show very substantial decreases in deadheading per trip in the San Francisco area from 2013 to 2016 as trip volumes ramped up rapidly but much smaller reductions from 2016 to 2019.

Changes in VMT calculated below are based on the following deadheading rates:

- Boston: 40% deadhead miles as a portion of all miles. This figure is based on 45% deadheading for 51,265,000 ride-hail miles in the Boston metro area in September 2018 (Balding et al., 2019) and reduced by five percentage points to account for denser trip volumes within the city based on the difference cited above between metro area and city deadhead rates in Seattle.
- Chicago: 40% deadheading, based on 45% deadheading for 98,930,000 ride-hail miles in the Chicago metro area in September 2018 (Balding et al., 2019) and reduced by five percentage points to account for denser trip volumes within the city.
- New York: 40% deadheading based on trip data submitted by the companies and made public by the City of New York for 3,565,525 ride-hail trips in Manhattan in June 2017 (Schaller 2017b). Deadheading was slightly higher in the boroughs outside of Manhattan in June 2017, but large increases in outerborough trip volumes are likely to have reduced deadheading per trip since 2017. Thus the 40% Manhattan figure is used in this analysis for the city as a whole.

- San Francisco: 35% deadheading, based on 40% deadheading for 126,130,000 ride-hail miles in the San Francisco metro area in September 2018 (Balding et al., 2019) and reduced by five percentage points to account for denser trip volumes within the city.
- California suburbs: 49% deadheading is assumed, based on the lower trip volumes and the more dispersed trip patterns in suburban areas.

Finally, an average ride-hail trip of 5 miles in major cities and 9 miles in suburban areas is used, based on a national travel survey with 2,286 ride-hail trips conducted in 2016-17 by the Federal Highway Administration (Schaller 2018). These distances are used in calculating reductions in mileage that occur as people replace auto/taxi trips with ride-hail trips.

2.4. VMT changes due to ride-hailing

The VMT change for each city is calculated by comparing vehicle mileage generated by the previous mode (personal auto or taxi) and VMT generated by the ride-hail trip. The formula for calculating baseline VMT (without ride-hailing) is:

Auto occupied miles + taxi occupied miles + taxi deadhead miles

Where

Auto occupied miles = Passenger trip length X Percent using auto in previous mode
Taxi occupied miles = Passenger trip length X Percent using taxi in previous mode
Taxi deadhead miles = (Passenger trip length/Taxi occupied percentage – Passenger trip length) X Percent using taxi in previous mode

The formula for calculating VMT with-ride-hailing is:

*(VMT for non-pooled trips * Percent of trips not pooled) + (VMT for pooled 2-passenger trips * Percent of pooled 2-passenger trips) + (VMT for pooled trips * Percent of pooled 3-passenger trips)*

Where

Ride-hail deadhead miles = (Passenger trip length/Ride-hail occupied percentage – Passenger trip length)
VMT for non-pooled trips = Passenger trip length + Ride-hail deadhead miles
*VMT for pooled 2-passenger trips = Passenger trip length + (Passenger trip length * Second passenger non-shared miles for 2-passenger pooled trips) + Add'l miles to reach 2nd/3rd passenger + Ride-hail deadhead miles*
*VMT for pooled 3-passenger trips = Passenger trip length + (Passenger trip length * Second passenger non-shared miles for 3-passenger pooled trips) + (Passenger trip length * Third passenger non-shared miles for 3-passenger pooled trips) + (Add'l miles to reach 2nd/3rd passenger *2) + Ride-hail deadhead miles*

To illustrate with a simple example, suppose one person replaced a personal auto trip of 5 miles with a ride-hail trip of equal distance that included 4 miles of deadheading. VMT would increase from 5 miles to 9 miles, or 80%. If two people switch, one from personal auto and the other from public transportation, VMT increases from 5 miles (the single auto trip) to 18 miles (two solo ride-hail trips), an increase of 260%. If, however, these two people shared a ride (and assuming they are in the vehicle together for one-half of the ride), VMT increases from 5 miles (the single auto trip) to 11.5 miles (4 miles deadheading and 7.5 miles with one or both passengers), an increase of 130%. The actual calculation takes into account the factors mentioned here, and also deadheading by taxis and small route diversions to pick up pooled passengers.

As shown in Table 1, in Boston per-passenger VMT prior to ride-hail averages 2.99 miles, taking account of trip length (5 miles for auto/taxi), taxi deadheading and previous mode. Adding dead-head mileage and adjusting for mileage reductions from pooling, the average ride-hail trip generates 7.69 miles of VMT. The result is that the average ride-hail trip in Boston more than doubles VMT per passenger, from 2.99 miles to 7.69 miles, an increase of 157%. The large VMT growth is due to a combination of many users switching from non-auto modes and the addition of deadhead miles.

VMT increases are lower in Chicago (97%) and New York (114%) than in Boston. This is due to greater shifting from taxis in those cities and thus fewer additional deadhead miles with ride-hail. San Francisco is somewhat lower than Boston, with a 134% increase in VMT, due to less deadheading. VMT increases by 118% in suburban California where there is a high rate of mode shift from personal auto but no pooled trips.

In sum, looking across the five scenarios, ride-hail at least doubles VMT over what would be the case without ride-hail service, based on pooling rates, modal shifts and deadheading. The increases range from 157% in Boston to 97% in Chicago.

Table 1
VMT change from growth of ride-hail in Boston, Chicago, New York, San Francisco and suburban California.

	Boston	Chicago	New York	San Francisco	Suburban Calif.
Model inputs					
Mode if not use ride-hail					
Auto	18%	15%	15%	18%	90%
Taxi	23%	35%	35%	23%	0%
Public transit, walk, bike, not make trip	59%	50%	50%	59%	10%
Ride-hail					
Occupied miles as pct of occupied + deadhead	60%	60%	60%	65%	51%
Pct of trips that are pooled (2 or 3 pax)	20%	19%	16%	36%	0%
Pct of trips that are pooled with 3 passengers	4%	3%	3%	13%	0%
Pct. of miles that pooled pax ride together	52%	52%	52%	52%	52%
Results[a]					
VMT without ride-hail (using auto, taxi, PT, etc.)	2.99	3.93	3.67	2.82	8.10
VMT with ride-hail	7.69	7.74	7.83	6.58	17.65
# of ride-hail miles that replace 1 pre-RH mile	2.57	1.97	2.14	2.34	2.18
Percent change in VMT	157%	97%	114%	134%	118%

VMT without ride-hail includes taxi deadheading. Boston and Chicago use figure of 45% deadhead miles for taxis; New York City 40% and California suburbs 60% (Schaller 2015, 2017b). All cases assume 0.2 additional occupied miles to pick up pooled passengers.
Calculations assume that chance of adding a third passenger mirrors the overall rate of pooling. Using Boston as an example, the overall pooling rate of 20% yields 4% pooling with three passengers (20% of 20%).
[a] VMT figures are shown per passenger, based on 5 mile average trip (9 miles for suburban California). Note that changing the average trip distance does not affect percentage changes.

2.5. Sensitivity analysis

Assumptions made in specifying model inputs might significantly affect the results of these calculations and thus it is important to assess how large the effect might be. One major assumption involved modal shifts; results in Table 1 are based on applying known modal shifts in New York and Boston to Chicago and San Francisco respectively. If we reverse the pairing and apply the higher New York auto/taxi shift to San Francisco, the 134% VMT increase in San Francisco shown in Table 1 would fall to 79%. Conversely, if the lower Boston auto/taxi shift is applied to Chicago, the 97% increase in VMT in Chicago would rise to 159%.

Deadheading figures for three cities were reduced by five percentage points to account for differences between known deadheading levels in metro areas and the denser center city. If the adjustment is doubled to ten percentage points, the VMT increases would be lessened, from 157% to 138% in Boston; 97%–82% in Chicago; and 134%–118% in San Francisco. Conversely, if no adjustment were made from the metro-level deadheading figures, VMT increases would be larger: 180% in Boston; 114% in Chicago and 152% in San Francisco.

Given the downward trendline in pooling rates in Chicago and New York in 2019, the 36% pooling rate in San Francisco might also have fallen from the 2018 level used in Table 1. If we assume a nine percentage point drop as happened in Chicago and New York, then the San Francisco VMT increase would be 144% instead of 134%.

Finally, VMT calculations use results from New York City showing that 52% of pooled mileage has multiple passengers in the vehicle (e.g., after the second pick-up). If we assume a higher figure of 75%, indicating much greater efficiency in matching passenger origins and destinations perhaps due to the walk to a stop service model, VMT increases are two to five percentage points lower in each city (154% in Boston, 95% in Chicago, 111% in New York and 129% in San Francisco.)

Finally, the California suburban case assumed a deadheading rate of 49%, a figure that arguably might be either higher or lower. If deadheading in California suburbs were 40% like most major cities, the suburban California VMT increase would drop from 118% to 85%. If deadheading were 60% similar to the historic rate for taxicabs (Schaller 2015), the VMT increase would rise to 178%.

Table 1 shows VMT increases from the introduction of ride-hail ranging from 97% to 157%; the sensitivity testing widens the potential range to 79%–180%. Thus, it is possible that the increase in VMT for trips moving to ride-hail is slightly less than originally calculated (79% instead of 97%) or somewhat more (180% instead of 157%). All results, however, show very substantial increases in mileage from travelers shifting to ride-hail from their own vehicle, taxis, public transportation and other modes.

2.6. Potential effects of first-mile/last-mile trips, cruising for parking, changes in household vehicle ownership and vehicle electrification

Another set of considerations that might affect the results shown in Table 1 involve the role of "first mile/last mile" connections, reductions in cruising of personal vehicles, potential effects if the availability of ride-hail leads to reduced car ownership, and reductions in vehicle emissions from conversion to electric vehicles. These are assessed in turn.

First, regarding "first mile/last mile" connections, ride-hail might make it possible for travelers to replace auto trips with a combination of ride-hail and public transportation, taking ride-hail for a short part of their journey and public transportation the rest of the way. This scenario could produce a reduction in VMT as ride-hail is used for only a portion of the journey.

User surveys show very little use of ride-hail to connect to public transportation, however. A survey in the Boston area found that 9% of home-based ride-hail trips were used to reach a transit connection and 4% of trips returning home were from a transit connection (MAPC 2017). A New York City survey found that 0.4% of transit trips used a for-hire vehicle to connect to transit and 0.9% used a for-hire service to connect from transit (NYC DOT 2018). A national survey found that only 7% of ride-hail users combine ride-hail trips with public transit on at least a weekly basis, while 35% do so at least occasionally (Masabi 2018).

Table 2 shows VMT estimates adjusted to take account of ride-hail trips that connect to public transportation. The estimate is based on the midpoint from the Boston survey (7%), and assumes an average transit trip of 8 miles. The result is a 4 to 13 percentage point reduction in VMT increases from Table 1, resulting in overall VMT increases of 93%–149% depending on location.

Another factor to consider is that drivers who switch to ride-hail have no need to cruise for a parking space. Cruising mileage can be substantial in the type of urban environment of many ride-hail trips. A compilation of field surveys by Hampshire and Shoup (2018) found that drivers cruise for an average of 8 min when searching for a space along retail and commercial corridors. Based on an average speed of 7 miles per hour, as shown in one study cited, the average cruising distance is 0.93 miles. These cruising miles would be eliminated as auto users shift to ride-hail. However, not all auto trips involve cruising given the widespread availability of off-street parking. Assuming for purposes of analysis that one-half of personal vehicle trips that shift to ride-hail involve cruising, then 0.47 miles of cruising are eliminated for every trip shifted from autos. As shown in Table 2, this adjustment shaves 3 to 11 percentage points off VMT increases, resulting in an overall increase in VMT that ranges from 93% to 150%.

Incorporating the adjustments for both first and last mile trips and cruising for parking, VMT increases from ride-hail fall into a revised range of 90%–142%, also shown in Table 2. These are still quite large VMT increases.

Another factor to consider is whether the availability of ride-hail contributes to reduced VMT through lower car ownership. Conway, Salon and King (2018) note that the availability of ride-hail might allow urban residents to reduce their car ownership and replace many auto trips with public transportation, walking or biking. This would seem particularly likely in urban neighborhoods rich with bus, rail, walking and biking opportunities. Ride-hail along with other new mobility options such as bike share and shared electric scooters might be the last piece of the puzzle to move some urban households toward having fewer or no personal vehicles.

Several studies point to small but potentially significant reductions in car-owning as a result of ride-hail. Three surveys found that 7–9% of ride-hail users reported reducing their car ownership as a result of using ride services (Henderson 2017; Clewlow and Mishra 2017; Hampshire et al., 2017). These findings support the idea that ride-hail can create a chain-reaction of less car ownership and less driving.

However, this "car shedding" might simply be part of normal

Table 2
VMT growth adjusted for first/last mile connections and cruising for parking.

	Percentage change in VMT				
	Boston	Chicago	New York	San Francisco	Suburban Calif.
Base case	157%	97%	114%	134%	118%
Adjustment for first/last mile connections	149%	93%	109%	126%	105%
Adjustment for reduction in cruising	150%	93%	110%	127%	107%
Adjustment combining first/last mile connections and reduction in cruising	142%	90%	105%	119%	96%

changes in household car ownership. Klein and Smart (2017) found that 21% of households decreased and 17% increased their car ownership in a two-year span. "Car shedding" by some households might be offset by car purchases by other households. Circella et al. (2019) found that more people increased than reduced their car ownership after starting to use ride-hail services. The prospect that ride-hail users are not making an overall shift away from motor vehicle use is further supported by survey research showing that few ride-hail users increased their use of public transportation after starting to use ride-hail (Alemi et al., 2018; Henao 2017; MBTA 2017).

Another potential factor affecting car ownership is that household-specific changes may not translate to overall car ownership in a given neighborhood or city. Manville, Taylor and Blumenberg (2018) and Mills and Steele (2017) found that displacement of lower-income residents in transit-rich neighborhoods in Los Angeles and Portland, Oregon, corresponded with more vehicle ownership and less transit ridership at the neighborhood level. It may be that people moving into these areas reduced their personal car ownership but their arrival in the neighborhood raised car ownership and auto use in the neighborhood as a whole.

A recent study by Ward et al. (2019), using difference-in-difference statistical techniques for the period 2005 to 2015, found no statistically significant relationship between statewide vehicle registrations and the entry of ride-hail service in urbanized states including California, Illinois, Massachusetts and New York. (The model did show ride-hail leading to reduced vehicle registrations in predominantly rural states and states with middling levels of urbanization.) Modeling also showed no statistically significant impact on VMT from ride-hail entry.

In addition, Census data for the eight major cities with the heaviest ride-hail use (Boston, Chicago, Los Angeles, New York, Philadelphia, San Francisco, Seattle and Washington DC) show that car ownership rates are either unchanged or have grown over the past decade. The trendline for urban neighborhoods with the greatest concentration of ride-hail trips mirrors trendlines for each city as a whole, suggesting little or no relationship between ride-hail use and auto ownership trends (Schaller 2020). While these data are simply descriptive, they tend to suggest that the influx of ride-hail and other new mobility options has not translated to lower vehicle ownership rates.

In sum, while more research is needed in this area, it appears unlikely based on available evidence that ride-hail has reduced vehicle ownership.

A final issue concerns emissions and vehicle electrification. Uber and Lyft have announced plans to transition to electric vehicles by 2030, and SAVs could be electric when introduced (Hawkins 2020). Jones and Leibowicz (2019) and Narayanan et al. (2020) found that shared electric vehicles could reduce greenhouse gas (GHG) emissions to a level below that of private cars. UCS (2020) estimates that an electrically powered ride-hail vehicle would have 72% lower GHG emissions per mile than personal vehicles and 68% lower emissions per mile than taxis (128 gCO2e per mile for electric ride-hail versus 464 gCO2e for auto and 397 gCO2e for conventionally powered taxis). Applying these GHG emission rates to VMT yields GHG emission reductions ranging from 21% to 40% for the four major cities and California suburbs. Thus, it appears that electrification of the ride-hail fleet would offset VMT increases discussed earlier, leading to lower GHG emissions for an electric ride-hail fleet as compared with emissions of users' prior mode. There are several important caveats to this result, however. First, emissions reductions are contingent on electrification, which is a decade or more in the future under current ride-hail company plans. Second, far greater reductions in vehicle emissions are essential to address climate change than the 21–40% estimated here. Finally, electrification does not address the impacts of increased VMT on traffic congestion, injuries and fatalities, or quality of life and the attractiveness of urban living. These are no less important considerations in a discussion of ride-hail and VMT.

3. Discussion

Early expectations were that ride-hail service generally and pooling in particular would attract large numbers of auto users, as shown schematically in Fig. 1. In reality, only a minority of ride-hail users took ride-hail instead of their own motor vehicle. Many of those using ride-hail would have used public transportation, walked or biked had ride-hail not been available. Moreover, the large majority of auto users moving to ride-hail chose solo rides over pooled rides. These observed shifts in travel choices are shown schematically in Fig. 2.

The experience with pooling has underscored the difficulty in persuading travelers to cross over from the left side solo options that offer convenience and fast travel to the right-side options that offer the efficiency and lower costs of strangers sharing their rides. Ride-hail company efforts to encourage this shift illustrates the trade-offs involved.

UberPool and Lyft Line originally maintained the convenience of door-to-door service provided by autos and taxis. But that produced zig-zag routes and longer and less certain travel times. In response, the companies replaced door-to-door service with walking to a nearby pick-up location. This change reduced or eliminated the problem of zig-zag routing, but it also eliminated the convenience of door-to-door service that fueled Uber and Lyft's popularity. Being more like public transportation in this respect, the new pooling services predominately attracted people who would otherwise have used public transportation.

The experience with ride-hail thus underscores how the long-standing appeal of non-shared travel over shared service models has carried through to solo versus pooled ride-hail options. As shown schematically in Fig. 2, solo ride-hail travel is most like other non-shared modes of auto, taxi, walking and biking, all of which provide door-to-door service and minimize travel time. Pooled ride-hail is most like public transportation as a shared mode that likely takes longer, introduces uncertainty about waiting and travel times, and reduces personal privacy.

Travelers predominantly shift between non-shared services or between shared services. Availability, cost, travel time and travel time reliability play major roles in the choice. There is less shifting from non-shared to shared services due to the advantages of non-shared modes as being faster, more reliable, and offering greater privacy and comfort. However, significant numbers of public transportation customers shift to solo ride-hail to the extent they can afford the fare.

Given this picture, it is important for policy-makers in dense urban centers where street space is in high demand to prioritize public transportation, walking and biking, which are far more space-efficient than auto-based modes (NACTO 2020). Policies like ride-hail fees can serve to both support public transportation and discourage ride-hail use. There is little reason in these areas to encourage pooled trips over solo trips since

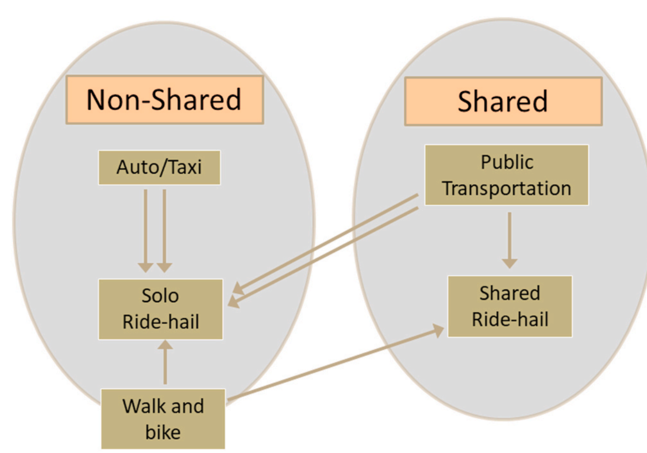

Fig. 2. Shared and non-shared market segments.

pooling also adds to VMT while drawing heavily from public transportation.

In considering whether to prioritize ride-hail over the personal auto, there are conflicting considerations. On the one hand, personal auto generates less VMT than ride-hail. However, ride-hail does not require valuable space for parking. Ride-hail also provides the opportunity for travelers to combine auto with other modes over the course of the day, taking public transportation to get to work during the morning peak period, for example, and ride-hail for a late-night trip home. Ride-hail may also, in the future, be more readily electrified than personal vehicles, reducing carbon and other emissions. Policies to accommodate ride-hail, such as curbside pick-up and drop-off zones, thus have the most compelling rationale at times and places where traffic is less of a concern and public transportation service is relatively sparse. Examples are late at night and in outlying city neighborhoods.

Outside dense urban centers, ride-hail can provide much-needed transportation for people who have limited public transportation options. Ride-hail has proven valuable in providing paratransit services to people with disabilities, first and last mile connections under contract to transit agencies, and filling gaps in public transportation services such as for workers on midnight shifts (NASEM, 2019). It makes sense for trip fees to be lower or waived in these areas, as illustrated in Chicago and New York City, and for curb space to be provided where there are large volumes of pick-ups and drop-offs.

It has been argued that SAVs will be able to attract more people from personal vehicles due to a lower cost structure and thus lower fares. This has been the $64,000 question for planning for an SAV future. Results from this research counsel caution on this issue. If they offer door-to-door service, SAVs will likely encounter the customer resistance to zig-zag routes that pooled services experienced. If SAVs ask patrons to walk to a stop, they are likely to attract an outsize number of public transportation users rather than auto users.

If SAVs can offer money savings, auto users have shown a preference to pocket the somewhat smaller savings of solo ride-hail over pooled trips. This is consistent with past consumer response to the trade-off between money savings and level of service. In recent years, auto sales have strongly trended toward higher-priced SUVs over lower-cost sedans (Colias and Naughton, 2020). Over many decades, as real household incomes increased, consumer expenditures on transportation rose with the result that there has been little change in the proportion of household spending that goes to transportation. (By contrast, the proportion of household spending going toward consumer staples like clothing and food has declined.) (U.S. Bureau of Labor Statistics, 2006 and 2019).

It has also been argued that pooling is "at the earliest stages of this whole shift" toward shared mobility and that given the right public policies, sharing will grow sufficiently to offset VMT increases observed to date (Chase 2018). Numerous researchers have counseled intensifying the search for ways to increase pooling (Alemi et al., 2019; Alemi et al., 2018; Brown 2020; Narayanan et al., 2020; Shaheen 2018; Sperling et al. 2018; UCS 2020). This raises an important question: what level of pooling would lead to reductions in VMT?

Table 3 shows a highly hypothetical scenario that leads to no change in VMT from ride-hail growth. The scenario assumes that:

a) 85% of trips are pooled (versus zero percent in suburbs and 16–20% in most cities pre-pandemic).
b) Most pooled trips are primarily with three passengers (versus most with two passengers pre-pandemic).
c) 70% of ride-hail patrons shift from auto or taxi (versus one-half or less pre-pandemic).
d) Deadheading drops to 20% of all mileage (versus 35–49% pre-pandemic).
e) Non-shared mileage of pooled trips (e.g., before the second passenger is picked up) is reduced to 20% of pooled passenger miles (versus 48% pre-pandemic).

It is difficult to see how these benchmarks could be attained, and particularly daunting to envision them in combination. Achieving a high pooling rate is most likely in dense urban settings, but would almost certainly draw large numbers of public transportation users rather than predominantly auto users.

Conversely, in suburban contexts where there is little public transportation, ride-hail draws primarily auto users, but low trip densities would make for very circuitous routes or long walks to a pick up location. In both urban and suburban contexts, reducing deadhead mileage would lead to longer wait times, making pooling less attractive to auto users.

This hypothetical scenario illustrates that travelers' desire for fast and reliable transportation as well as considerations of comfort and privacy are likely to perpetuate the current bifurcated shared/non-shared character of the market for urban transport. So long as that is the case, neither pooled ride-hail nor shared autonomous vehicle service models seem promising avenues toward reduced VMT.

Autonomous technology can be quite helpful even within a bifurcated market structure, however. Autonomy has the potential to change the cost structure of providing shared services, not just in sedans or SUVs as envisioned by SAVs, but also in larger transit vehicles. By reducing cost per mile, autonomy could open the door to replacing standard buses with smaller vehicles at higher frequency. Higher frequency is a key to improving the attractiveness of transit services and attracting patrons from other modes. Services could operate on fixed routes as most buses do today, or in various on-demand models pioneered by microtransit companies like Via and the now-defunct Chariot, where schedules, routing and stops may be either pre-set or determined in real time.

Table 3
Hypothetical scenario that produces No change in VMT.

Model inputs	
Mode if not use ride-hail	
Auto	70%
Taxi	0%
Public transit, walk, bike, not make trip	30%
Total	100%
Ride-hail	
Occupied miles as pct of occupied + deadhead	80%
Pct of trips that are pooled (2 or 3 pax)	86%
Pct of trips that are pooled with 3 passengers	74%
Pct. of miles that pooled pax ride together	80%
Results	
VMT without ride-hail (using auto, taxi, PT, etc.)	3.50
VMT with ride-hail	3.50
# of ride-hail miles that replace 1 pre-RH mile	1.00
Percent change in VMT	0%

4. Conclusion

In the early 2010s, ride-share companies embraced a vision of harnessing sophisticated computer algorithms to combine the speed and convenience of personal cars with the efficiency and lower costs that are traditionally the province of public transportation. Shared, door-to-door transport could thus provide both individual benefits in saving costs and perhaps encouraging social contact, with societal benefits of reduced traffic, vehicle emissions and parking demand.

But even with substantial fare discounts and driver subsidies to promote pooled trip-making, ride-hail users overwhelmingly opted for solo-ride services like UberX and Lyft over pooled services like UberPool, UberPool Express, Lyft Line, and Lyft Shared Rides. Travelers shifting from auto to solo ride-hail clearly increased VMT simply due to the addition of deadhead miles. VMT increases from patrons moving to ride-hail were quite large, on the order of doubling or more for trips associated with ride-hail in both big cities and suburbia. This happened because most passengers shifted from public transportation or other non-auto modes, which added mileage not only from deadheading but also the ride-hail trip itself.

Hopes that widespread pooling would mitigate if not erase VMT increases have not borne fruit, even when Uber and Lyft discounted fares. Nor has VMT growth been significantly mitigated by the use of ride-hail to connect to public transportation, or by reduced cruising for parking by drivers in their personal vehicles. Nor is there evidence of an overall shift away from personal vehicle ownership and use in areas with high ride-hail usage.

These findings have important implications for hopes that autonomous ride-hail services will lead to VMT reductions. For one thing, door-to-door SAVs will also encounter customer resistance to zig-zag routes. Moreover, the walk-to-a-stop service model used for UberPool Express and Lyft Shared Rides mainly attracts public transportation users, not personal auto users, and thus adds to VMT no matter how many people share a ride. Autonomy might lead to more migration from public transportation to ride-hail, producing further large increases in VMT.

Much of the public embraced ride-hail as offering a convenient, reliable and quick means of transportation. These strong individual benefits make it a valuable component of the overall transportation system. But public policy must balance individual benefits against societal costs in traffic congestion, vehicle emissions, and undermining public transportation ridership. Particularly in dense urban areas, space-efficient modes like public transportation, walking and biking must take the front seat in policy-making, with space for ride-hail and personal autos of lower priority.

These considerations become even more important as cities emerge from the coronavirus pandemic and navigate difficult decisions to keep their citizens safe while also forging a path to economic recovery, social equity and environmental sustainability.

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