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Sustaining Uber: Opportunities for Electric Vehicle Integration

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In partial fulfillment of a Bachelor of Arts Degree in Environmental Analysis,
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Reader:
Bowman Cutter

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Abstract

Uber and Lyft, the “unregulated taxis” that are putting traditional taxi companies out of business, are expanding quickly and changing the landscape of urban transportation as they go. This thesis analyzes the environmental impacts of Transportation Network Companies, particularly in California, with respect to travel behavior, congestion, and fuel efficiency. The analysis suggests that fuel efficient taxis are being replaced by less fuel efficient Uber and Lyft vehicles. Linear regressions were run on data from the Clean Vehicle Rebate Project’s Electric Vehicle Consumer Survey of electric vehicle owners in California. The findings indicate that Uber drivers are more reliant upon the state rebate than the general population of electric vehicle owners in California.

Introduction

Shared mobility services are changing the landscape of urban transportation. Growing especially quickly are Transportation Network Companies, also called ridesharing services, which use mobile apps to connect paying riders to paid drivers driving their own non-commercial vehicles. The largest TNC, Uber, is worth tens of billions of dollars, more than the United States taxi and limo industry and 80 percent of companies in the S&P 500 (Verhage 2016, Watanabe 2016). App-based taxis are transforming urban transportation, from the travel behaviors of individuals to the business models of the industry's largest companies. Most automakers are partnering with shared mobility companies or creating their own; Toyota has partnered with Uber, GM with Lyft, the second biggest TNC in the US, Daimler has added RideScout, and Tesla is working on their own ridesharing technology (Bond Jr. 2015, PwC 2015).¹ As these new transit services emerge, older ones struggle, especially taxis. The "mobility revolution" is thought by some to be a solution to rising urban congestion and pollution (Bouton 2015), but it may have the opposite effect if it continues outcompete fuel efficient taxis. With a focus on California, this paper will analyze the impacts of Transportation Network Companies on the sustainability of urban transportation and in particular the number of low and zero emission vehicles in urban car fleets.

While the private sector is quickly adjusting to the proliferation of TNCs, the public sector has been hesitant to adapt to the existence of Uber and its competitors. Compared to taxis, TNCs operate virtually unregulated, avoiding licensing costs, driver insurance requirements, standard employee training and background checks, state-controlled fares, and fleet size caps (Wang 2015). This has raised several legitimate concerns about TNCs regarding passenger safety, labor rights and fairness of competition. There have been multiple driver strikes in response to decreasing fares and increasing per-ride commission (Lazzaro 2015). Uber's claims about its driver wages have been widely disputed and allegations abound that its drivers make less than minimum wage, when accounting for vehicle operation costs (Bogage 2016). Uber drivers are technically "contractors" rather than employees of the company, and thus pay out of pocket for all incurred costs, including gas and maintenance, and do not receive traditional employee benefits. Although the company publicly denies that it takes advantage of its drivers, Uber's treatment of its "contractors" is such that a former corporate staffer said the following about using Uber himself: "You get in the habit of not identifying yourself as an Uber employee when you're a passenger, that's for sure. A lot of people say they work at another company in the building when getting picked up or dropped off at Headquarters" (Cushing 2014). Uber and Lyft are also adversarial towards each other; both have admitted to sabotaging the other service by paying people to request and then cancel rides on the other's app. For all of these reasons, Uber has been called "the closest thing we've got today to the living,

¹ Automaker-carshare partnerships include: GM with Enterprise CarShare, Honda with Zipcar, Daimler with Car2Go, one of the largest carshare operations in the world, and BMW has created its own service DriveNow.

breathing essence of unrestrained capitalism” (Leonard 2014). Uber defends its treatment of its “driver-partners” by emphasizing how many of them work other jobs and use Uber as just a temporary source of income (Hall and Krueger 2015). Yet, the fact remains that 38 percent of Uber drivers have no other job. These issues deserve attention, but this thesis will focus on them only insofar as they relate to the environmental impacts of TNCs.

Due to the myriad controversies surrounding Uber and Lyft, most policies related to TNCs have aimed to restrict them. Uber and Lyft were banned from Austin for not having proper driver background checks (Hartmans 2016). Uber left Auburn, Alabama after the city began regulating TNCs the same as regular taxis and it left Eugene, Oregon after the city sued the ridesharing service over safety concerns (TLPA 2015). New York City Mayor de Blasio tried to cap Uber’s growth at 1 percent while his administration studied the company’s effects on traffic congestion, but Uber quickly unleashed a campaign that forced him to abandon the policy (Hawkins 2015). The governments that are not trying to restrict TNCs are not doing much else on the matter either. A 2015 report by the National League of Cities found that only three percent of city transportation plans consider the effects of the proliferation of ridesourcing technology, despite the presence of TNCs in 60 of 68 cities reviewed (NLC 2015).

Legislators have embraced other shared mobility services, including carsharing. Carsharing services, essentially short-term car rental, do not employ or contract drivers and so do not have the labor rights or rider safety concerns that TNCs do. Carsharing also is not disrupting an industry as TNCs are with taxis. And environmentally, there is much more of a consensus that carsharing reduces traffic congestion; studies show that every carshare vehicle removes anywhere from five to 13 personal vehicles from the road (Martin et al. 2010, Shaheen 2015). Policymakers have encouraged and even partnered with companies like Zipcar. In California, carshare companies receive rebates for purchasing electric vehicles (CVRP 2016) and in Los Angeles and San Francisco they receive discounted or free city parking spaces (Shaheen 2010). While lawmakers have seized opportunities to promote sustainability through carsharing, ridesharing has been left out.

The effect of Transportation Network Companies on congestion is not as clear as it is for carsharing services. The term “ridesharing” is misleading, especially from an environmental perspective. Traditional ridesharing, also called carpooling, is when one car simultaneously executes multiple trips for which the driver and rider(s) share a common destination. TNC drivers do not share a destination with their riders; like taxis, they drop off one passenger then drive to their next passenger’s location. TNCs do reduce congestion in some ways, for example through the efficient transport of passengers, and but they increase congestion through the displacement of more sustainable modes of transportation like walking and public transit (Rayle et al. 2016).

One of the most straight forward effects of TNCs is that they are diminishing American taxi fleets, fleets which have become quite fuel efficient since 2006. From 2006 to 2016, due in part to the efforts of local governments around the country and in part to better technology and prices, urban taxi fleets have transitioned to hybrid electric vehicles on a large scale. If policymakers do not focus as much on the fuel economy of TNC vehicles as they did on taxi vehicles, this progress will be lost and the transition to ridesharing services is likely to bring more emissions. The fuel efficiency of TNC vehicles is not currently public information but it is crucial in determining the environmental impact of Uber and Lyft and how to regulate them.

Given that fuel efficient taxis are being replaced by Transportation Network Company vehicles, the integration of electric vehicles into TNC fleets should be of interest to policymakers and is the focus of this thesis. California's electric grid is the third cleanest in the country for electric vehicle use, due to its high share of renewable energy (Anair and Mahmassani 2012) (Holland 2016).²³ The California Air and Resources Board has committed to reaching 15.4 percent PEV (plug-in electric vehicle) deployment in its new light-duty vehicle fleet by 2030 (Cal ETC). As of June 2016, only 3.3 percent of California's car market is plug-in vehicles (both plug-in hybrid and battery electric vehicles), which is slightly up from 3.2 percent in 2014, so there is a long way to go to reach that goal (CA Outlook 2016). The NRDC projects that at the rate California is adopting PEVs now, the state will come quite short of its goal, with PEV deployment reaching just six percent (Shulock 2016). The rapid expansion of TNC fleets is an opportunity for California to quickly get electric vehicles on the road.

There are two unique environmental benefits of integrating electric vehicles into TNC fleets as opposed to the general fleet of personal vehicles. First and foremost, Uber and Lyft vehicles are driven more than the average personal car and thus will reduce more emissions per vehicle. In a 2013 survey, over 3,000 PEV owners in California urban and suburban areas were found to drive an average 12,118 miles per year, including 42 percent of owners who reported driving less than every day (Tal and Nicholas 2013). In 2015, 5,800 PEV drivers tracked by the US government drove an average 10,486 miles per year (Idaho 2015). According to the NYC Taxi and Limo Commission, the average New York City taxi drives 70,000 miles per year and the average personal car in the city 8,900 miles per year, which means one electric taxi would reduce same amount of emissions as about eight electric personal vehicles (Miller 2013). If Uber vehicles drive the same distance per hour as a median NYC taxi, about 9.5 miles, then the 17 percent of Uber drivers who work more than 35 hours each week (Hall and Krueger 2016) are driving at least 17,290 miles per year, not including commuting and non-work related driving. In January 2016, 17 percent

² Whereas in Beijing, researchers think that traditional hybrids would provide better environmental impacts than plug-in electric vehicles because of the region's reliance on coal (Cai et al. 2016).

³ The time of day which electricity is used is also a big influence on environmental impact, as will be discussed later.

of Uber's active US fleet was about 78,000 drivers. Converting one third of the New York City taxi fleet to electric vehicles would decrease the taxi emissions by 18 percent (Miller 2013). Integrating electric vehicles into TNC fleets would have significant environmental benefits.

The second advantage of electrifying rideshare is the potential to influence consumer adoption of electric vehicles. The effect of riding in an electric Uber on likelihood of buying electric vehicles has not been studied directly; however, Shaheen et al. (2015) tested the effect with respect to carsharing. After people had driven or ridden in an electric vehicle through carsharing, they were more likely to buy an electric car and less likely to buy a non-hybrid. Shaheen highlights that carshare users are younger than the population of electric vehicle owners as proof that carshare exposes its users to EVs who might not have been exposed otherwise. This is true of ridesharing too; 92 percent of rideshare users are 44 years old or younger (Rayle et al. 2016), compared to 38 percent of electric vehicle owners in California (CSE 2016). Critically, these two groups have quite similar educational backgrounds; 81 percent of rideshare users – and 83 percent of EV owners – have a Bachelor's or Post-graduate degree. Ridesharing and electric vehicle-owning populations therefore may be quite similar, which may make ridesharing populations more predisposed to buying an EV than the general population. Although ridesharing users have low car ownership rates – in two different surveys, only 57 percent (Rayle et al.) and 64 percent (Smith 2016) of TNC riders reported having a car at home – but most young, educated students living in cities plan to own a car in the future (Circella 2016). Ridesharing can expose a group of educated, non-car-owning young people to electric vehicles before they buy their first cars.

TNCs are too big for policymakers to ignore their environmental impacts. As can be seen in Figures 1 and 2, Uber added over 400,000 active drivers to its US fleet from January 2013 to January 2016, and in San Francisco and Los Angeles it added over 30,000 and 50,000 drivers respectively between April 2013 and October 2015 (Hall and Krueger 2016). This presents a unique opportunity to influence the car acquisitions of these new drivers, many of whom are purchasing or leasing vehicles for the job – Lyft's Director of Operations and Strategy reported that in Los Angeles, San Francisco and Denver more than 130,000 people who expressed interest in driving for Lyft did not have a suitable car (LA Times 2016). Fifty seven percent of Uber drivers have bought, leased, or made substantial investments in vehicles to drive for Uber (PwC 2015). While Uber and Lyft are still young and growing is the best time to influence the future of ridesharing and its environmental impact.⁴

⁴ This analysis would be a lot more accurate if there were more data available to the public about TNCs. But Uber and Lyft are very private with their data. In early 2015, Uber announced it would provide the City of Boston with quarterly data reports of the duration and general location of its trips (Benedict 2016). Few other governments have since enacted similar agreements (including the state of California). Yet it is difficult to know the exact contents of the reports since the agreements also shield its data from Freedom of Information Act requests. Uber surely has so much of the data that

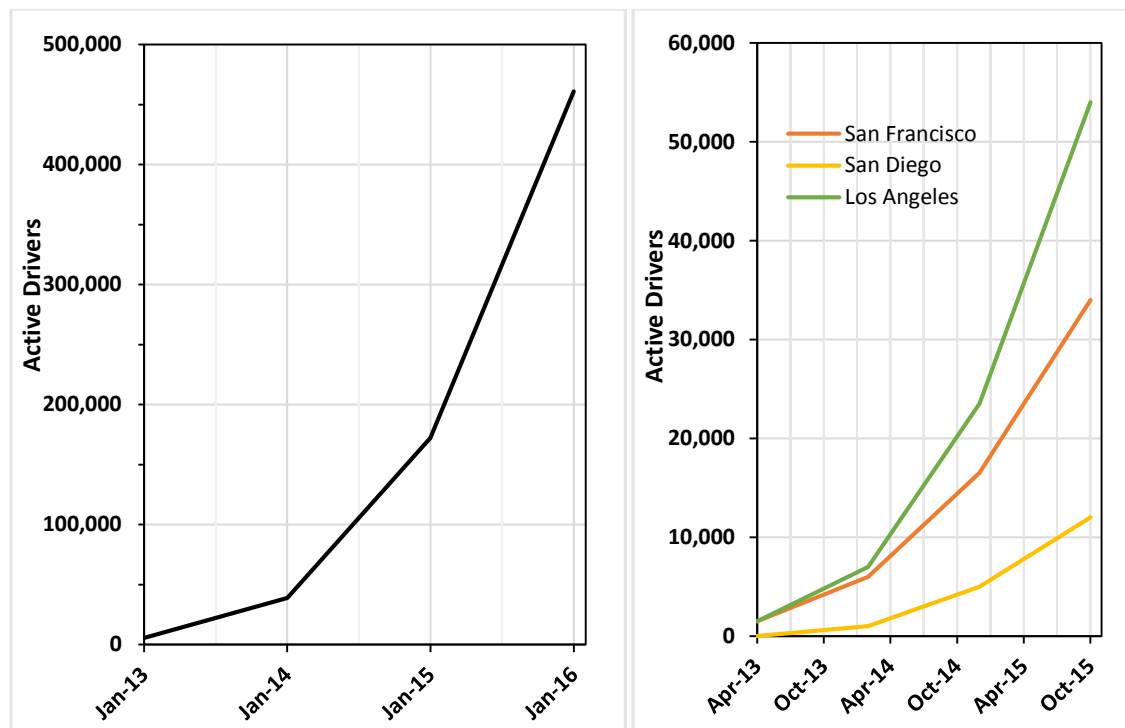


Figure 1: Number of Active Uber Drivers in the US

Figure 2: Number of Active Uber Drivers in Select California Cities

Ridesharing vs. Taxis

Transportation Network Companies have flourished outside of and in the market areas traditionally dominated by taxicabs. For example, in New York City, TNCs thrive during the 4-6 pm timeslot, which is typically when taxis are switching drivers between shifts, and in the newly gentrified boroughs that taxis do not serve as much as others – 92 percent of taxi trips in New York start in Manhattan (TLC 2016, NYDN 2015). As a result of this expansion of the taxi market, the total number of taxi and TNC rides in New York City increased by three million from 2014 to 2015 (Fischer-Baum 2015). TNCs have also done well in areas of the market where they directly compete with taxis. In a survey of TNC users that asked how they would have made their trip if not by a ridesharing app, 39 percent (the most common response) answered that they would have taken a taxi (Rayle et al. 2016). Where Uber competes most directly with taxis, 87 percent of Uber rides would have been taxi rides (Economist 2015).

That TNC rides are replacing taxi rides on a large scale is demonstrated by public data of all Uber rides in Manhattan during two two-month periods, April through June in 2014 and 2015. In April-June of 2015, the combined number of taxi and Uber rides was only 10,000 less than in April-June 2014, but Uber provided 3.82

this paper will be forced to estimate and sometime guess at, including vehicle miles driven by each driver, the type of cars being driven (and thus the amount of pollution being emitted), etc.

million more trips than it did in 2014 while taxis provided 3.83 million fewer trips (Fischer-Baum 2015). In each one of the 51 taxi zones tracked, taxis lost pickups and Uber gained pickups at almost exactly a one-to-one rate. This trend is represented in the below graph. The New York City taxi medallion, historically known as a stable investment, has dropped in value by 40% in the last five years (Hawkins 2016). Figure 3 shows demonstrates Uber’s replacement of taxis in the Manhattan. This graph does not mean that one taxi disappears from the roads for every Uber car added. It is important in understanding the environmental impacts of Uber that the combined number of Uber and taxi rides have increased in New York City.

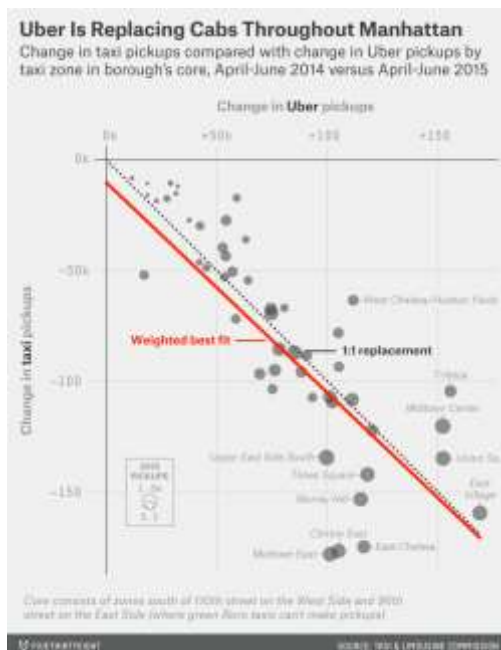


Figure 3: Source: FiveThirtyEight

In Los Angeles, too, taxi trips have decreased while Uber has grown. In the middle of 2013 the number of monthly taxi trips was 723,274 and there were about 1,500 active Uber drivers in the city (Brands 2015, Hall and Krueger 2016). In the next 20 months Uber grew to over 20,000 active drivers and the number of taxi trips at the end of 2014 decreased by 26 percent from the year earlier, to 535,225. The LA Department of Transportation Taxi Report does not try to explain the drop in taxi rides but suggests briefly that “Uber, Lyft and other types of TNC services would have the greatest impact” (Brands, pg. 88). Tim Conlon, president of California Yellow Cab, more straightforwardly said of his company’s 35-40 percent decline in business, “It’s the ride-hailing effect” (Knight 2015). The number of Orange County taxicab drivers, which had increased each year since 2008, dropped 14 percent from 2014 to 2015.

From the beginning of 2012 to the end of 2014, active San Francisco Uber drivers increased from close to zero to around 16,500 (Hall and Krueger 2016). At the same time, between January 2012 and July 2014, the number of monthly trips per

taxi cab fell from 1,424 to 504, a 65 percent loss of business (Cushing 2014). The proliferation of ridesharing services in San Francisco is thought to be the driving factor that pushed the city's largest, albeit already struggling, cab company into bankruptcy (Hawkins 2016). The San Francisco Municipal Transportation Industry, among others, has attributed this recent deterioration of the cab industry to the rise of TNCs.

A similar pattern can be seen in Seattle, where fare revenue for the taxicab industry fell by 28 percent from 2012-13 to 2013-14 (Soper 2015). Revenues had been rising consistently for four years from \$72 million in 2009 to \$100 million in 2012, but plummeted back down to \$72 million upon the proliferation of Uber, Lyft, and other TNCs.

The metrics used in this section are number of paid trips and total revenue. These are good representations of business success but are not directly indicative of environmental impact. The most important metrics for considering environmental impacts are typically vehicle miles traveled (VMT) and vehicle fuel economy, as will be discussed in the following sections.

How TNCs affect Rider Travel Behavior

Convenience and speed are the two main qualities that riders value in taxi services. In a survey of 323 rideshare users, five of the top six answers to "What are the top two reasons you used Uber/Lyft/Sidecar for this trip?" were the convenience of ride-hailing and paying through the mobile app and of not parking, and the speed of the waiting time and overall trip time (Rayle et al. 2016). Dawes (2016) and Nicoll and Armstrong (2016) report survey responses along the same lines; convenience and speed are the most common reasons that riders choose ridesourcing apps over other modes of transportation. Taxi rider surveys yield similar results; in a 2011 survey of New York City cab passengers, the top three answers to what riders liked most about cabs were (1) the convenience of hailing and (2) paying for a ride, and (3) the speed relative to other travel options (NYC TLC 2011).⁵

Measured by convenience and speed, Transportation Network Companies are superior to taxis. Ninety one percent of those surveyed by Rayle et al. (2016) reported that their TNC ride took 10 minutes or less to arrive and 8 percent said it took 10 to

⁵ The number one feature taxi drivers desired in the future taxi was "environmentally friendly" (TLC 2011). It seems that riders may be willing to pay for this future to some extent. For example, in a survey of 2,982 New York City taxi passengers conducted between July 23 and July 30, 2013, 50% of passengers said they would be willing to pay 25 cents extra to ride in a taxi that has zero tailpipe emissions. 37% of passengers said they would be willing to pay 50 cents extra and 24% said they would be willing to pay \$1.00 extra (TLC 2015). A 2007 poll by the Bay Area's Metropolitan Transportation Commission, 46% of respondents said they would support a 25 cent/gallon increase gas prices if the money "would be used to limit or reduce global warming," and another 23% said they would possibly support such a price increase (Agrawal 2010).

20 minutes. Of those who took taxis, 27 percent reported waiting 10 minutes or less, 37 percent 10 to 20 minutes, and 36 percent 20 minutes or more. TNC ride matching technology has made wait times for ridesharing shorter than ever, especially relative to taxis. In terms of convenience, riders can hail and pay for a TNC from their phones. Riders can track the location of their car using their smartphone GPS and follow it along its most efficient route towards the destination. Given that taxi and Uber riders value virtually identical traits in their rides, it makes sense that ridesource services are being chosen over taxis.

The number one thing New York City taxi riders dislike about cabs is the high prices (NYC TLC 2011). Of the 270 TNC riders surveyed by Dawes (2016), the third most common motivation for choosing rideshare, behind convenience and speed, was price. In a report of millions of receipts of TNC and taxi rides, the average Uber and Lyft trip fares were around \$22 while the average taxi fare was \$36 (Certify 2016). This price disparity is not entirely indicative of costs; it is due in part to TNC rides' shorter average distance, 0.6 miles shorter than taxi rides (Rayle). In an interview with an Ontario Airport cab driver, he said that 12 of his coworkers switched to Uber but three have come back, in part because the rides are shorter and thus the commissions lower (W. Saeed, personal communication, November 2016). Through economies of scale and freedom from state-controlled fares, Uber and Lyft have lowered prices to be consistently lower than taxi prices especially for short and medium length rides (Salnikov et al. 2015).

TNCs are such an attractive option that they are stealing riders from other cleaner modes of transit, which results in a net increase in TNC riders' total vehicle miles traveled. In fact, Rayle's survey of TNC users found that eight percent would not have made their trip at all if they could not have taken a TNC (2016). This eight percent could include young people – 16 percent of TNC users are ages 15-24 – that did not previously have an accessible mode of transportation, it could be old people – Wadud et al. (2016) estimates that, if everyone 62 years old⁶ or older were to drive up to as much as 62 year olds, overall personal vehicle travel would increase by 2-10 percent – who are not able to drive for health reasons, as well as the general population of people who are inspired by the convenience of TNCs to travel more. Of the Rayle survey respondents who answered how they would have traveled if not by TNC, 33 percent said transit (rail or bus), eight percent said walk and two percent bike⁷. That is an extra 43 percent of TNC users who, by taking TNCs, are increasing their vehicle miles traveled and pollution emitted.

TNCs both substitute for and complement public transit use. The Rayle survey found that 33 percent of TNC users would have taken transit instead – 14 percent of

⁶ Travel behavior up until retirement age is assumed to be “natural” whereas travel decline after retirement age is assumed to be health-related.

⁷ A different survey of ridesourcing users' alternative transportation choices shows different results; 34 percent would have driven alone or carpoled, 24 percent would have used carshare, 14 percent would have used transit, and 8 percent would have taken taxis (Murphy 2016). The Rayle survey is the more widely cited one.

respondents in another survey (Murphy 2016) – but also that five percent took TNCs to or from public transit (Rayle et al. 2016). In another survey of ridesource users, the most favorable trait of TNCs (answered by 74 percent of respondents) is that they are available where transit sometimes is not (Dawes 2016).

Some local governments have partnered with Uber to encourage the use of public transit. Altamonte Springs, Florida is a characteristically sprawled-out suburb. Its largest mall, hospital, and college campus are all more than a mile away from commuter train stations, which makes public transit unappealing compared to driving (Comas 2016). To address this, the city funded a 25 percent discount of Uber rides that start or end at transit stations. The city also offers an additional 20 percent discount of all Uber rides that start and end within city limits. The program was chosen because it cost two thirds less than the city’s original plan to build additional bus lines and, according to City Manager Frank Martz, the city hoped the Uber subsidy would “make transit convenient” (Altamonte Springs 2016). The Pinellas Suncoast Transit Authority also subsidizes Uber rides to and from transit stations, at 50 percent discounted prices. Pilot projects like these are testing the prospects of TNCs as a solution to the “first-last mile” problem, the unaccounted-for last leg of riders’ trips from transit stations to their final destinations. When the program was announced, Florida State Senator Brandes said that “transit options are being developed that may pull ridership away from PSTA,” evidence that regulators thought Uber was reducing transit use (PSTA).

The early results of these private-public partnerships indicate that TNCs substitute, more than complement, public transit. Although Uber ridership increased tenfold weeks after the Altamonte Springs program began, City Manager Martz reported that “the monstrous majority” of subsidized rides have been intra-community rides not involving transit (Woodman 2016). The project may have made transit more convenient but it seems to have also made taking transit in conjunction with Uber seem less convenient than using Uber only. The PSTA program which subsidizes Uber rides starting or ending at public transit “has not been a huge success in terms of ridership numbers,” according to city planner Chris Cochran. Even the cities themselves are choosing TNCs over transit; both cities abandoned bus lines, instead partnering with Uber (Woodman).

TNC ridership is correlated with lower rates of personal driving and personal car ownership, and may directly reduce car ownership. 43 percent of TNC users surveyed by Rayle et al. (2016) did not own any vehicles, which is more than the 23 percent of taxi riders. Of TNC users who own cars, 40 percent report driving less often as a result of TNCs. The rate of car ownership was not proven to be directly influenced by using app-based taxis; the 10 percent of TNC users who changed their level of car ownership since riding TNCs were equally likely to increase and decrease their ownership levels. However, a 2015 CNBC survey of 2,400 people revealed that 22 percent of Uber users in the US were delaying a car purchase specifically because they had access to Uber (Newberg 2015).

Shared rides are more common in TNC vehicles than taxis. The average number of passengers in Rayle's survey were 2.1 for TNCs and 1.1 for taxis. This is due in part to the carpooling features UberPool and Lyft Line that offer the option to share rides with strangers at a discounted price. In San Francisco, half of Uber rides and more than half of Lyft rides are shared (Deamicis 2015). Carpooling regularly is something only 10 percent of Americans report doing, primarily because of lack of flexibility of drivers and personal safety concerns (Strong 2015). Thus, carpooling has always suffered from a "critical mass" barrier, with too few users to consistently pair riders and drivers (Strong 2015). The ridership that government carpooling programs in the 1990s and early 2000s attracted were almost all people who would have carpooled or taken public transit anyway. TNC carpooling has finally connected a big enough group, that of smartphone users, to make carpooling a reliable, safe, and popular alternative mode of transportation.

The timing of rideshare travel is slightly different than traditional taxi travel, peaking on weekends and during the evenings on weeknights. Both services provide about one third of their rides during the work day. Taxis peak between 6 pm and 8 pm on weekdays, when around 9 percent of weekly trips occurs (TLC 2016). TNC rides peak after that, between 9 pm and 10 pm (NYDN 2015). Twenty four percent of app-based taxi trips in New York City occur between 8 PM and midnight (TLC 2016). About one half of TNC travel came between 6 pm and 4 am on weekdays, during which time one third of taxi rides occurred. These night time rides are where TNCs have both expanded the market and really outcompeted taxis; taxi rides between 11pm and 5am have fallen by 22 percent since June 2013, whereas trips at all other times are only off by 12 percent (Economist 2015). Ridesharing services likely bear most responsibility for the drop in late-night cab hails because it is when passengers place the greatest value on rideshare's advantages in convenience and comfort. Finally, nearly half of TNC riders surveyed by Rayle et al. had ridden on Friday and Saturday, compared to about one third of taxi rides. For the most part, the peaks in TNC travel occur outside of peak-congestion rush hour times.

Ridesourcing services are used mostly for recreational purposes. Socializing was the main reason for those surveyed by Rayle (2016) and Murphy (2016). This fits in with the trend of TNC rides peaking during evenings and on weekends. Yet, TNCs are also increasingly the chosen means of business travelers; in January 2014, the ratio of corporate ground transportation done by ridesharing versus taxis was 18 to 82, but less than two years later it has changed drastically to 81:19 (Certify 2016).

TNCs are used virtually the same as taxis but with important differences, including the displacement of public transit, the increase in total car travel, and the mass participation in shared rides. TNC drivers also drive similarly to taxi drivers yet differ in significant ways, as the next section explores.

How TNCs affect Driver Behavior

The composition of TNC driver fleets changes more quickly than that of taxi fleets. This is due in part to the rapid expansion of Uber and Lyft in their incipient years of existence. It is also due to the convenient and hardly-regulated labor model of TNCs. Anyone with a license, an eligible car, and a smartphone can start driving for Uber or Lyft tomorrow, at little to no cost to the company. At the same time, TNCs experience a very high driver turnover rate; 11 percent of Uber drivers become inactive one month after starting, 30 percent became inactive after six months and just under 50 percent stopped driving after a year (Hall and Krueger 2015). Local governments regulate the composition of taxi fleets, through medallion sales, typically so that the fleet size does not change drastically. A couple taxi drivers I spoke with had bought Priuses solely because the airport where they work, Ontario, required it (W. Saeed and John, personal communication, November 2016).

TNC drivers create their own schedules, which makes their driving patterns inconsistent. Out of a sample of 25 million UberX trips over the course of nine months, five percent of drivers' work sessions were twice as long as their average session and 18 percent were less than half of their average (Chen and Sheldon, 2015). Some TNC drivers take advantage of the flexible schedule by working long hours; in various interviews with Uber and Lyft drivers, I have spoken with people who work on average 12, 14, and (two drivers) 16 hours per day. These consistently long working drivers should be most relevant to policymakers, on account of their predictability and their large share of total miles driven. In an online survey of 453 rideshare drivers, 27 percent of the respondents accounted for 50 percent of the total hours driven (Campbell 2015).

TNC driver hours are on average more fragmented than those of taxi drivers. Most taxi drivers work shifts of at least 10-14 hours, taking at least one half hour or 45 minute break, usually at 12 pm or 9 pm (Miller 2013, Saeed, personal communication 2016). It is common for taxi companies to have their cars in use 24 hours per day, working back-to-back 12 hour shifts. TNC drivers, on the other hand, tend to drive multiple short sessions, mostly between two and five hours, with a median driver averaging a 3.47 hour driving session (Chen and Sheldon). Rideshare app vehicles are very rarely or never traded off between drivers, meaning that TNC cars are only in use when their owners are working. This is especially relevant to the conversation about electric vehicle taxis because taxis that are in use 24 hours per day cannot be charged for multiple hours at a time. Many Ontario Airport taxi drivers want to drive an electric vehicle cannot due to time constraints (Saeed). Meanwhile, TNC cars can feasibly be charged whenever they are not in use.

TNC drivers have more fragmented schedules because their driving behavior is more dictated by ride demand than taxi drivers. The literature on taxi behavior indicates that taxis likely drive for a pre-determined number of hours, or usually until they reach a pre-determined revenue goal (Camerer et al. 1997). Even if ride demand is peaking, they will stop driving once they reach their daily goal. The reverse also

appears to be true, that taxi drivers will drive even while ride demand is low; the Ontario Airport taxi drivers who I interviewed said they almost always drive 12-14 hours per day, even if they go hours without a passenger (W. Saeed and John, personal communication, November 2016). In fact, a coupe reported that they would stop early if it had been a busy and productive day. TNC drivers are most influenced by ride demand. Hall and Krueger's annual reports show that Uber driver revenues, measured per hour, are essentially uncorrelated with hours worked. This means that the hourly wage of an Uber driver who works less than ten hours a week is nearly identical to that of a driver who works more than 50 hours per week. That Uber drivers are uniformly making paid trips at the same rate no matter how much they work, suggests that they only drive when there is demand for it.

Uber and Lyft drivers work when there is adequate ride demand largely because ridesharing apps incentivize them to. The surge price multiplier is the mechanism by which TNCs raises prices within a certain geographic area when demand is greater than supply. This would be illegal for traditional taxis. Uber drivers and riders can see on their GPS map whether surge pricing is in effect and by how much (i.e. prices are 1.2x the regular level in a certain area of the city). Chen and Sheldon (2015) found that the surge multiplier is the most explanatory determinant of when drivers decide to when and for how long to work. As a result, Uber and Lyft's flexible labor supply model matches with ride demand throughout the day much closer than taxi schedules (Cramer and Krueger 2015). This is especially true in regards to sharp rises in ride demand; it is not uncommon for surge pricing to last just several minutes. The below graph from Chen et al. (2015) shows that Uber's surge pricing is quite responsive, since the correlation is strongest when the change in time difference is zero.

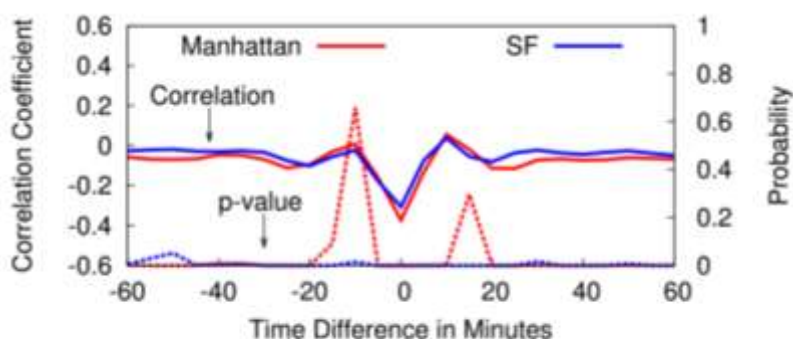


Figure 20: (Supply - Demand) vs. Surge for UberX.

Figure 4: Source: Chen et al. 2015

That TNC drivers are more influenced by demand than taxi drivers is the primary reason why the average capacity utilization rate, the fraction of time a driver has a fare-paying passenger in the car while working, is higher in TNCs than taxis. The utilization rate in UberX cars is on average 50 percent higher than taxis when measured by miles driven, and 30 percent higher when measured by time (Cramer

and Krueger 2015). This means, for example, that for every mile they drive with a passenger, taxi drivers in Los Angeles drive 1.46 miles and UberX drivers drive 0.56 miles without a passenger. It also means that taxis drive more miles without passengers than with them. Data from San Francisco and Los Angeles are displayed in the Table 1. The data comes from a couple years ago when Uber and Lyft had not grown as much as they have today, so Uber's capacity rate is probably even higher now taxis' capacity rate is likely lower.

Capacity Utilization Rate: UberX vs. Taxis

	Taxis	UberX
San Francisco (hours driven)	38.4%	54.9%
Los Angeles (miles driven)	40.7%	64.2%

Table 1: Source: Cramer and Krueger 2015

In addition to the surge price explanation, there are a few other reasons why TNCs have higher capacity utilization rates than taxis. First, while taxis have begun to develop apps, they mainly rely on sight-based street hailing, radio dispatch communication, and call-in ride hailing (Cramer and Krueger 2015). TNC drivers are able to see on their smartphones how many rides are being requested and where. Salz et al. (2015) created a model that simulated taxi fleets in which taxi drivers knew the location of the closest passenger. This change, which simulates current taxi fleets that are equipped with TNC ride-matching technology, was found to reduce the time taxis spent driving looking for passengers by 9.3 percent. Second, in most US cities there are now more Uber vehicles than taxis of the cities' largest taxi company (Cramer and Krueger). By chance, an Uber or Lyft vehicle is probably closer to the customer than a taxi. While the number of TNC drivers is never the actual number of TNC vehicles on the road – even during the peak of Uber rides for the month July 2015, only about one third of the over 20,000 registered Uber vehicles were in use (NY Daily News 2015) – the ride-matching technology and surge pricing mechanism ensure that Uber and Lyft cars that are on the roads are probably driving where there is the most ride demand. As mentioned earlier, city taxi fleets are regulated with the intention of maintaining a stable fleet size, which prevents taxi companies from growing within cities as quickly as TNCs. Third, taxi regulations limit taxi drivers to certain jurisdictions whereas TNC vehicles can drive wherever they want without limitations, financial or otherwise. If a taxi drops off a passenger in a region they do not have a taxi permit for or in a region they are not allowed to pick up riders, they must drive back out of the region before earning their next fare. All of these reasons for Uber's advantages over taxis regarding efficiency, the surge pricing, better technology, and freedom from fleet size caps and permit restrictions, can be attributed to its disproportionately lower levels of regulation.

As previously mentioned, taxi drivers tend to “income-target,” largely irrespective to ride demand. When Seattle taxicab trip revenue dropped by 28 percent from 2012-13 to 2013-14, the number of miles driven by taxis in that time actually increased from 65.8 million to 67.3 million (Soper 2015). The share of the total number of miles driven with a passenger in the cab decreased from 46 percent to 33

percent. Since taxis were making less money per mile, they drove for more miles. Thus, while TNCs drive less than taxis to accommodate the same number of passengers, they may also cause taxis to drive more than they otherwise would have.

There is also evidence to suggest that TNC drivers, in ways that are harder to measure, have driving habits that cause them to drive more. In a survey of Uber drivers conducted by Anderson et al. (2014), part-time and full-time drivers were more likely to drive long distances to work in locations where they can maximize earnings and to remain in their cars. This finding was confirmed in the several interviews I conducted with Uber and Lyft drivers; one driver reported commuting from her home in Moreno Valley to Hollywood, Los Angeles every morning, which is a 152 mile round trip commute (Saeed and Zoe, personal communication, November 2016).⁸ 80 percent of the drivers in Anderson's survey live outside of San Francisco and bring their car into the city every day to drive for a TNC. This trend should be expected to occur among taxi drivers as well, but more so in TNCs due to the pull of surge pricing and the fact that most TNC drivers drive their cars home at the end of driving sessions. It is important to note that the capacity utilization rate only measures the miles traveled while vehicles are officially working, and excludes these extra miles driven to and from home. Another trend Anderson and I found is that TNC drivers often work for multiple rideshare companies, so that while rider demand is low on one app they can switch to a different one. Finally, Anderson et al. (2014) found that a select population of Uber drivers use their income from Uber to financially support a private car that they otherwise would not have bought (Anderson 2014).

TNCs' advantages in efficiency, compared to taxis, are largely due to their freedom from regulations that govern the taxi industry. However, as the next section explores in depth, the disparity in regulation of TNCs and taxis is also why TNCs are less fuel efficient than taxis.

The Electrification of US Taxi Fleets

Looking only at the fuel economy of rideshare and taxi fleets, the transition currently underway in the United States from taxis to rideshare appears to be a dirty one. Though there is scant data available about the types of vehicles being driven in rideshare, the data on taxi fleet vehicles reveals a recent transition to high mileage, low-polluting taxi fleets over the last 10 years. This can be attributed to, among other factors, volatile gas prices, increasingly economical alternative fuel vehicles, and government regulations. In addition to general green vehicle incentives and fuel economy mandates, governments have created policies to encourage the adoption of alternative fuel vehicles particularly in fleets. Between 2007 and 2009, New York City, San Francisco, Boston and Seattle all issued local mandates requiring taxicab

⁸ Even with the extra gas money, Zoe (who drives a Prius) says it is worth it since she averages \$100 per day in Moreno Valley and \$300 per day in Hollywood.

fleets to achieve certain city driving mileage per gallon requirements in the near future (TLPA 2009). Furthermore, municipal government and private fleets have accounted for 89 percent of 57,000 plug-in electric vehicles in 2010 (Market Insights 2012). Table 2 displays the share of “clean vehicles,” which are mostly hybrids but also compressed natural gas vehicles and ultra-low emission vehicle (ULEV) gas cars, in taxi fleets in five of the 10 most populated cities in the United States. Data was collected from various government and news websites.

Percent of Clean Vehicles in US Taxi Fleets

	Los Angeles	San Francisco	New York City	Boston	Chicago
2006			2% (283)		
2007			11% (1,500)	2% (32)	
2008		16%			
2009	<1% (2)				
2010		55%	~28%		
2011		77%			~12%
2012	16% (363)	92%	~59% (~6,000)		
2013	39% (926)	97%		70%	
2014	61% (1,450)		67% (9,105)		
2015	75% (1,775)				82%
2016	77% (1,806)		73% (9,920)		

Table 2: Percent of Clean Vehicles in US Taxi Fleets, 2006-2016

New York City’s taxi fleet became much greener under Mayor Bloomberg, who set a goal in 2013 for the fleet to be one third fully electric by 2020 (NYC TLC 2016). Under his leadership, the Taxi and Limousine Commission tried, eventually unsuccessfully, to instate a minimum 30 mpg fuel economy for all taxi vehicles (Voelcker 2010). The greening of NYC’s taxi fleet was set back considerably by the decision to make the city’s NV200 Taxi of Tomorrow a non-hybrid van. But it is a sign of how economical the hybrid taxis are for taxi drivers that the Greater New York Taxi Association sued to ban the NV200 because it is not a hybrid (Ingram 2013).

Boston also tried to mandate the greening of its taxi fleet but the courts thwarted its initiative (TLPA 2009). In response, Boston has employed several incentives to encourage the shift to hybrids, including granting hybrid taxi drivers the right to skip the line twice for every airport shift, which allows for two additional trips daily, and allowing taxi fleet owners to charge taxi drivers \$15 more per shift to lease out a hybrid. The city also allows hybrid taxis to be used twice as long as the traditional Crown Victorias before being replaced. Chicago has only recently tried to improve the fuel economy of its taxis but it has been very successful. The city currently offers to subsidize taxi driver purchases of fully electric vehicles by up to \$10,000. Other incentives include an unlimited pass for green taxis to move to the front of the passenger line at Chicago airports (for a 12-month period) and a new rate structure to encourage fleet owners to buy more fuel efficient taxis (Sustainable Chicago 2015).

Despite not having any hybrid taxis until 2009, Los Angeles' taxi fleet has become much greener since then. In a South Coast Air Quality Management District (SCAQMD) rule that applies to fleets of at least 15 vehicles in Los Angeles, San Bernardino, Riverside, and Orange counties, government fleets and private contractors under contract with public entities are required to purchase lower emission and alternative fuel vehicles (AFDC 2016). The City of Los Angeles allows hybrid and CNG vehicles to be placed into service five years after the model year, compared to four years for non-green vehicles, and stay in service until 10 years after the model year, compared to eight years for others (Brands 2015). All vehicles must meet Tier 2 SULEV (CARB's rating of a Super-Low Emission Vehicle) pollution emission criteria or better and, in addition to other organization-specific requirements for each year, 80% of each organization's non-wheelchair vehicles are required to be green taxis (note that Table 2 does not coincide with this because it includes wheelchair taxis). Also, all taxis that work at Ontario and LAX Airports must be hybrids or CNGs. In 2013, Toyota CEO Jim Lentz noted that Prius hybrid models were being added to taxi fleets so soon after their release that they must have been bought without incentives (Woodyard 2013). From 2010 to 2014, the greening of LA's taxi fleet reduced smog by 78 percent as compared to 2010, while greenhouse gas emission were cut by approximately 51 percent (Brands 2015).

San Francisco was early and effective at greening its taxi fleet. In 2007, San Francisco's taxi commission required companies to work towards decreasing their 1990 level of emissions by 20 percent by 2012 (La Ganga 2009). Fleets were required to be 100% SULEV by 2012 (TLPA 2009). In 2012, the taxi commission emissions reductions goal was reached despite having twice as many taxis, thus reducing the city fleet's emissions by 10 percent, or 35,139 metric tons of GHG emissions (SFMTA 2012). A total of \$518,670 in grant funds was dispersed by the government to help purchase 251 hybrid vehicles (SFMTA 2012). It is important to note that San Francisco's taxi fleet is smaller than most cities'; in 2014 there were just over 1,400 taxis total while Los Angeles had over 1,400 hybrid taxis. Elsewhere in California taxi fleets are also switching to alternative fuels. San Diego's Regional Airport Authority reduced the permit and trip fees for hybrid taxis (Stewart 2015) and since 2000, San Jose's Airport has only purchased alternative fuel vehicles (Guerra 2014).

Transportation Network Companies do not need to adhere to fleet fuel economy mandates nor do they qualify for fleet vehicle incentive programs. Since Uber and Lyft release little to no data about their vehicles, it is impossible to know their fuel efficiencies. Uber does require its drivers to use relatively new cars, which boosts their fuel economy. A San Francisco police report estimated that 17 of 100 rideshare cars that dropped off rides at the airport were "clean vehicles" (Anderson 2014). Whether or not this is indicative of the fuel economy of Uber vehicles, neither of them are better than the most recent numbers from Los Angeles and San Francisco. Based on the data reviewed in this section, we can assume that a one-for-one taxi-for-rideshare tradeoff is a downgrade in fuel economy and an increase in vehicle emissions per mile.

Environmental Impact Analysis

Congestion

In urban areas, motor vehicles are the dominant source of carbon monoxide, nitrogen dioxide, hydrocarbon, and particulate matter emissions (Currie and Walker 2009). Furthermore, annual congestion delays experienced by the average peak-period driver in the US have increased over 250 percent in the past 30 years. California has some of the worst congestion in the country; measured by hours of delay per auto commuter, Los Angeles and San Francisco are ranked as the second and third-most congested “very large urban areas” in the country, and San Jose and Riverside are the first and second-most congested “large urban areas” (Urban Mobility Scorecard 2015). Congestion reduces driving speeds, which increases travel time and the concentration of vehicle pollutants on the roads. Several studies have calculated the societal costs incurred by traffic congestion; on a national level, these costs come to billions of hours of delays, billions of gallons of wasted fuel (David Schrank and Tim Lomax 2005), and thousands of premature births and premature deaths (Levy et al. 2010). This is why it is so important to determine the effect of TNCs on congestion.

There is not a consensus on TNCs’ contribution to traffic congestion. The Director of the San Francisco Municipal Transportation Agency has linked Uber and Lyft to the city’s recent increase in congestion (Cabanatuan 2015) and New York City officials have done the same (Miller 2015). These claims are weakened by the fact that rideshare travel peaks during non-traditional peak traffic times. And recent studies that use traffic modeling suggest that TNCs reduce urban congestion (Li et al. 2016, Alexander and Gonzalez 2015). There is not overwhelming evidence for either argument. The answer likely lies between them; in some ways ridesharing services reduce congestion and in others they add to it.

One way Uber claims to reduce congestion is by decreasing the use of personal cars (Cushing 2014). If this were true, it would be significant especially given that the share of the world population living in cities is expected to increase 10 percent by 2030 and global automobile sales are projected to nearly double, half of them in cities (Bouton 2015). Some researchers predict that TNCs and public transit, or some combination of the two, will soon be a legitimate alternative for personal car travel, especially with autonomous vehicle technology expected to be ready for such use as early as 2025 (Fagnant 2014). Uber, Lyft, and Tesla are certainly trying to make that a reality, as evidenced by Uber’s \$680 million purchase of an autonomous truck company, GM’s hundreds of millions of dollars spent on similar technology in coordination with Lyft, and similar efforts by Tesla (Bhuiyan 2016). The average car in the US sits idle more than 90 percent of the time (Bouton). If ridesharing does in fact reduce car ownership, the environmental benefits would be enormous; a Life

Cycle Analysis conducted on travel in Los Angeles, based largely on the emissions produced from manufacturing cars, concluded using Uber for all travel would create 93 percent less carbon dioxide emissions than driving a personal car all the time (Carranza et al. 2016).⁹

Users of TNCs do drive their own cars less but they also potentially travel by car more in general. The convenience, speed, and low cost of TNCs are drawing users away from other more sustainable modes of transportation such as walking, biking, and public transit. Additionally, TNC users may be traveling up to eight percent more than they would without the app-based taxis (Rayle et al. 2016). Several recent surveys have illuminated these trends (Rayle, Dawes 2016, Nicole and Armstrong 2016), but more data needs to be gathered about the travel behavior of rideshare users, especially regarding their travel behavior in the absence of TNCs.

Irrespective of rider behavior, rideshare vehicles transport their passengers more efficiently than taxis. Holding constant the number of trips demanded, if TNCs were to replace taxis completely, there would be less congestion. This is based on rideshare's higher number of passengers per ride and higher number of rides per hour (Cramer and Krueger 2015, Hall and Krueger 2016). But with a combination of taxis and TNCs on the road, the effects on rider travel behavior and driver efficiency are much harder to quantify. A way in which Uber's efficiency contributes to congestion is that it is likely individual taxis are driving more than before, in order to make up for business lost to Uber (Soper 2015) (Qian 2016). And regardless of where and by how much TNCs outcompete taxis, the number of combined taxi and TNC rides is increasing in places like New York City and London (Fischer-Baum 2015, Lunden 2016).

If the data were available, one of the most straight forward ways to quantify the environmental impact of TNCs would be the average fuel economy of their vehicles. The next section goes into this subject further, measuring the tradeoff between taxis and TNCs based on fuel economy.

Taxi/TNC Tradeoff

Not regulating the fuel economy of rideshare vehicles means losing the progress made from regulations that have been successfully incorporating alternative fuels into US taxi fleets. From September 2013 to September 2015, Transportation Network Companies drove 612.6 million miles in California (CPUC 2015). Using the Los Angeles taxi fleet as a proxy for taxi fleets in California urban areas (since San Francisco's taxi fleet seems to be an anomaly in terms of its small size and extremely high fuel economy), we will assume that 77 percent of taxis in California are the ARB

⁹ Using Uber half the time and driving a personal car the other half would create 17 percent less tons of carbon dioxide than only driving a car

standard Super Ultra Low Emission Vehicles. For the sake of this calculation, we will assume that those hybrids are made up of about 80 percent Toyota Priuses and about 20 percent Toyota Camry Hybrids, which is about the breakdown of the LA taxis (Brands 2015). For TNCs, because their vehicle fuel efficiencies are not public knowledge, we will use multiple scenarios of different fleet fuel efficiencies. For simplicity's sake, we will assume that all hybrid TNC hybrids are Priuses. The rest of the fleet will be the EPA's "average new vehicle" data for 2016, which emits 440 grams of CO₂ per mile (EPA). We will assume that 30 percent of TNCs are Toyota Priuses and the other 70 percent we will assume has the fuel economy of an average new vehicle. Table 3 shows the amount of combined tailpipe and upstream emissions and smog emitted by the 2016 Toyota Prius, the 2016 Toyota Camry, and the average new vehicle in 2016, Table 4 shows the amount of emissions that can be attributed to the average vehicle of each proxy taxi and TNC fleet. It is important to remember that electric vehicles emit zero tailpipe emissions or smog, although they are responsible for upstream carbon dioxide emissions.

	CO ₂ (grams/ mile)	EPA Smog Rating	NO _x + NMOG (g/m)	CO (g/m)	PM (g/m)	HCHO (g/m)
Toyota Prius	205	LEV-III SULEV30/PZ EV	0.03	1	0.003/0.01	0.004
Toyota Camry Hybrid	260	LEV-III SULEV30/PZ EV	0.03	1	0.003/0.01	0.004
Average New Vehicle	440	LEV-II	0.16	4.2	0.01	0.018

Table 3 - Source: EPA

	CO ₂ (grams/mile)	NO _x + NMOG (g/m)	CO (g/m)	PM (g/m)	HCHO (g/m)
Proxy LA Taxi Fleet	267.5	0.0599	1.736	0.0073	0.0072
TNC Fleet: 45% hybrids	334.3	0.1015	2.76	0.0084	0.0117
TNC Fleet: 30% hybrids	369.5	0.121	3.24	0.0090	0.0138
TNC Fleet: 15% hybrids	404.8	0.1405	3.72	0.0095	0.0159
TNC Fleet: 4.7% hybrids	429.0	0.15389	4.0496	0.0098	0.0173

Table 4: Emissions attributed to an Average Vehicle from Generated Proxy Fleets

The proxy Los Angeles taxi fleet emits 267.5 grams of carbon dioxide per mile. Even a TNC fleet of 45 percent hybrids, which is a high estimation, is responsible for 25 percent more CO₂ emitted per mile driven. A TNC fleet that has the same share of hybrids as the current California vehicle market, 4.7 percent, is responsible for 60 percent more CO₂, in addition to more than twice as many Nitrogen Oxides, Non-methane Organic Gases, Carbon Monoxide, and Formaldehyde, and 26 percent more of the dangerous Particulate Matter (CA Outlook 2016). These are the potential environmental consequences of each taxi that is replaced by an Uber.

The Potential for Electric Vehicles in Rideshare

While urban taxis are, very likely, on average lower-emitting than ridesource vehicles, ridesourcing presents a unique opportunity for the adoption low and zero emission vehicles. 90 percent of taxis in New York City are double-shifted, meaning they are traded off between drivers and are on the road for almost every hour of every day (Miller 2013). There is not information available on how many TNC cars are double-shifted, but the number can be expected to be close to zero. This leaves the operators of ridesource cars much more time for battery charging, whereas taxis would not have much flexibility in when they could charge. Almost all of New York's taxis are not being used for at least an hour between shifts, usually before morning and evening rush hours (Miller). They would be limited to fast-charging chargers that can refuel a 35kWh battery from about 10 to 80 percent in 30 minutes. This is likely part of the reason why Los Angeles did not have any zero emission taxis as of 2015 (Brands 2015). TNCs would have more time to charge and would be more likely to charge during the “cleaner” times of day to use grid electricity. As can be seen in Figure 5, the middle of the day is the cleanest time to charge a PEV (McLaren et al. 2016).

Concerns that the range of electric vehicles is not compatible with taxi and rideshare use are misguided. A study of San Francisco taxi driving patterns found that 80 percent of rides were within a 10 km radius (Carpenter et al. 2015). Especially in densely populated urban areas, vehicle range should not be a problem; a report published by New York City's Taxi and Limousine Commission determined that a fully charged electric taxi would only have to charge once during a 12-hour shift (Miller 2013).

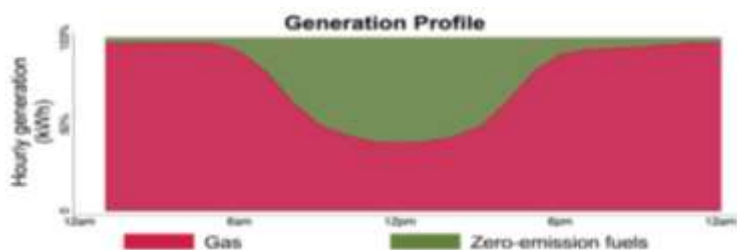


Figure 5: Source: McLaren et al. 2015

Analysis of the Clean Vehicle Rebate Project's EV Consumer Survey

The Center for Sustainable Energy runs the Clean Vehicle Rebate Program (CVRP) for the state of California. It began giving out rebates for electric vehicles in March of 2010 and started surveying subsets of the rebate recipients in September of 2012. The results of the 19,460 surveys taken from then until May 31, 2015 are publicly available. The survey contains an eclectic range of questions, covering topics including demographics, car-buying decision factors, rates of photovoltaic panel ownership, and the information channels through which people learned about electric vehicles. This survey provides profound insight on the characteristics and values of the early adopters of electric vehicles in California.

Tables 2 and 3 were created with data from the CVRP survey. It is important to remember that all survey respondents ended up buying an electric vehicle, so the survey does not inform us about the non-electric vehicle buying population. The table breaks down the 33 month survey period into three subsets of 11-months. Table 5 includes household income, "Saving money on fuel costs" which is the percentage of survey respondents who answered that as their most important decision factor in buying the vehicle, "State Rebates" which is the percentage of respondents who answered that the state electric vehicle rebate was either very important or extremely important in making it possible to acquire the vehicle, and "Photovoltaic at home" which is the percentage of respondents who had a solar photovoltaics system at their residence or were planning to install one.

	September 2012- July 2013	August 2013- June 2014	July 2014- May 2015	9/1/2012- 5/31/2015
<\$100k	19%	25%	24%	18%
\$100k-\$299,99	61%	62%	61%	66%
\$300k-\$499,99	11%	8%	10%	10%
\$500k+	9%	5%	6%	6%
<i>Saving money on fuel costs</i>	31%	42%	35%	38%
<i>State Rebates Very/extremely important</i>	70%	75%	76%	74%
<i>Photovoltaic at Home</i>	43%	38%	39%	40%

Table 5: CVRP Respondents Household Income and Attitude Survey

Table 5 corroborates the existing literature about early adopters of electric vehicles. Looking at the 33-month averages, 82 percent of the respondents come from households with over \$100,000 incomes. Additionally, the earliest adopters, from the first 11-month period, have the highest share of \$300,000-\$499,999 and \$500,000+ income households, and the lowest share of households with incomes less than \$100,000. This first group also cared less than the two other groups about saving money on fuel costs, were the least influenced by the state rebate, and owned solar panels at the highest rate.

The CVRP Consumer Survey also provides information relevant to the integration of electric vehicles into TNC fleets and the need for novel strategies to expose new parts of the market to electric vehicles. Table 6 lists the number of survey respondents who attended electric vehicle “Ride & Drive” events, which are hosted by auto manufacturers. “Initial Interest” is the respondent’s level of interest in buying an electric vehicle at the start of the car-buying process, with 5 meaning they were only interested in EVs and 1 meaning they did not know EVs existed. The respondents who attended Ride & Drive events have a higher average initial interest than those who did not attend. Table 7 shows this trend more clearly; the higher the consumers’ initial interest in buying a PEV, the more likely they were to attend a R&D event. It is possible that attending the event is what spiked people’s initial interest, but much likelier that those who went were already very interested EVs. About one quarter of respondents who were only interested in electric vehicles attended an event. This suggests that the Ride & Drive events are exposing electric vehicles to populations that are likely to buy an EV regardless of attending. Since electric vehicles are still being diffused into the market by early adopters, these lower “Initial Interest” populations are likely representative of the next stage of the diffusion process, the early and late majority adopters.

On a similar note, the CVRP might be biased towards consumers who least need the environmental benefits of electric vehicles where they live. Only 6.3 percent of rebates were given to people living in “Disadvantaged Communities,” so deemed disadvantaged because of exposure to pollution levels (CVRP). A review of one hundred thousand rebates also found that, even controlling for income, rebates are given disproportionately to minorities (Rubin and St-Louis 2016). It is preferable to get as many electric vehicles on the road as possible, but exactly where in California they end up is also an important issue.

Attended Ride & Drive Event	Number of Respondents	Initial Interest	Initial Interest	% Attended R&D
No	14,494	3.97	ONLY interested in a PEV	23.3%
Yes	3,806	4.14	Very interested in PEV	20.6%
			Some interest in a PEV	16%
			No interest in a PEV	12.3%
			Did not know PEVs existed	11.7%

Table 6 (above): Attendees of Ride & Drive Event

Table 7 (right): R&D Attendance by Initial Interest

Cost of Ownership: Electric vs. Non-electric Vehicles

The high initial cost of electric vehicles is the biggest hurdle for taxi owners (TLPA 2009). Purchasing an expensive vehicle requires a larger down payment, sometimes up to three to four times as much, and larger monthly payments, so that financing an EV may not be feasible in the short run even if it is in the long run. Some

insurance companies like Farmers now offer discounts for electric and hybrid vehicles but most companies have higher rates, especially for hybrid and electric taxis which are at risk of crashing more than normal vehicles (Berman 2016).

I gathered the upfront costs for the 2016 model of each electric car, and its non-electric equivalent, owned or leased by the participants in California's CVRP Electric Vehicle Consumer Survey. On average, the electric cars were \$11,201 more expensive to purchase. However, when accounting for federal tax credits and California state rebates, the difference was \$3,660. The federal tax credit is \$2,500 for plug-in hybrids¹⁰ and \$7,500 for battery electric cars, while the state rebate is \$1,500 for PHEVs and \$2,500 for BEVs.

Fuel Costs

Gas prices are more expensive and more volatile than electricity prices (AFDC 2016). Furthermore, California has higher gas prices than the US average. In the past ten years, the average gas price in California has risen above four dollars per gallon several times, once dipping below two dollars (US EIA). The first big wave of taxi companies buying hybrid vehicles happened in the summer of 2008 when average gas prices shot up around the country, to above \$4 in California (TLPA 2009). At the time, most taxis were old, large cars like the Ford Crown Victoria which had a fuel economy of about 16 miles per gallon. The fuel efficiency of hybrid vehicles was twice (Ford Escape Hybrid 34 mpg, Toyota Camry Hybrid 33 mpg) and three times (Toyota Prius 48 mpg) as high (AFDC 2009). In 2008, Denver's Yellow Cab announced a long-term commitment to hybrid vehicles. Company President Brad Whittle said "the fuel savings more than pays for the cost of the vehicle," estimating that the hybrid would save them \$5,000 per vehicle per year (TLPA, pg. 8). At the same time Arlington-based Red Top Cab converted part of its fleet to hybrids, its owner estimating fuel cost savings of \$2,500 per vehicle per year. The volatility of gas prices is also an issue for taxis; in late 2012 when Hurricane Sandy hit, Crown Victorias waited for hours at gas stations while high-mileage hybrids worked back-to-back shifts.

Using the EPA's fuel economy estimator, I calculated the average annual cost of fuel for each of the electric vehicles, and their non-EV equivalents, that are owned by respondents in the CVRP Consumer Survey. For the estimator's gas price, I inputted the average gas prices in California over the past five years (October 31, 2011-October 31, 2016), \$3.56 for regular gas and \$3.78 for premium, as well as the EPA-calculated average electric charging price for California, \$0.15 per kWh. For the annual miles traveled I inputted 45,000 annual miles. For the ratio of city (stop-and-go) to highway driving I inputted 70 city to 30 highway driving, which is the same ratio used to calculate taxi emissions by the Los Angeles Department of Transportation and San Francisco Municipal Transportation Agency (Brands 2015,

¹⁰ Except for the Ford C-max Energi PHEV and Ford Fusion Energi PHEV, for which the federal tax credit is \$4,007.

SFMTA 2008). On average, the cost to fuel electric cars over a five year period were \$16,126 cheaper than to fuel the non-electric equivalents.

Part of the fuel cost for rideshare drivers is the opportunity cost of fueling (and not earning ride fares). The range of a BEV is about a third of a standard vehicle, so battery electric vehicles must be refueled about three times as often (Carpenter 2016). For rideshare drivers, this means refueling more often between fares or turning down more fares, but either way they are losing out on earning fares. However, the opportunity cost of fueling non-EVs can be more, such as in the case of Crown Victorias which need to be refueled multiple times per shift (TLPA 2009). A fully charged 35k W/hour battery can last a full 12-hour shift if it is charged once during the shift (NYC TLC 2015). In the regression analysis part of this thesis, the key independent variable relates to level of importance of fuel costs to consumers' vehicle purchase decisions.

Maintenance and Repair Costs

A concern with hybrids and electric vehicles initially was that they would not be able to withstand the mileage of a taxi. Toyota CEO Jim Lentz said in 2013 that he was surprised that the Prius was so popular among cab companies and he was nervous about it because they were not designed for commercial use (Woodyard 2013). Yet the design has proved to be quite durable and long-lasting; San Francisco retired its first 15 Ford Escape Hybrid taxis after some of them have driven more than 300,000 "trouble-free" miles (Voelcker 2009). Crown Victorias were known to need replacing every 18 months but hybrid taxis commonly last 10 years (TLPA 2009). Hybrid brakes, with their regenerative braking system, need repairs much less frequently and electric cars have hundreds of fewer parts than gas-powered engines and thus need fixing much less frequently.

Hybrid and electric cars need less maintaining and repairing but the parts and repairs are usually more expensive. An HEV battery will need to be replaced once in the vehicle's lifetime, which will cost \$7,000 (TLPA). A fully electric vehicle battery replacement may cost \$9,000 (TLC 2015). The opportunity cost of maintaining and repairing EVs may be higher as well; repairs take longer since HEV and BEV parts are more complex. Furthermore, hybrids and EVs tend to be lighter, which leads to more serious damages in crashes. The average taxi endures three crashes in its lifetime, and based on taxi drivers' higher vehicle miles traveled than average drivers, maintenance costs can be up to 10 times more for taxis than non-taxis (Litman et al. 2009).

Total cost of ownership includes more than what is mentioned in this section. Most notable is the cost of depreciation, which is most relevant to buyers of new vehicles and on Edmunds.com is usually listed as the highest cost besides the upfront purchase. But as mentioned earlier, most relevant to this paper is fuel cost and how much car buyers value it.

Literature Review: Influences on Electric Vehicle Adoption among Taxi Drivers

There is not literature specifically about adoption of electric vehicles among drivers of Transportation Network Companies. The most relevant literature pertains to taxi driver adoption of alternative fuel vehicles and adoption of EVs by the general car-buying population. The literature is survey-intensive, which can be a misleading proxy for actual consumer behavior, especially when the subject is something like electric vehicles which are not very prevalent in society (Rezvani et al. 2013). A random sample of interviewees will likely contain a large percentage of people who have not been directly exposed to EVs and thus might have more arbitrary reasons for their responses. An advantage of surveys is the insight they provide into the decision-making of individual consumers, which is exactly what this paper is trying to do in the context of individuals considering purchasing an EV for driving rideshare. This is why I selected the CVRP Electric Vehicle Consumer Survey for my analysis, because it is of only people who have already bought or leased an electric vehicle. It provides the unique insights of individuals' decision-making with regards to decisions they have actually made.

The average car consumer undervalues fuel economy (Lane 2010), which as previously demonstrated is one of the most valuable aspects of EVs. Because EVs are not prevalent, the majority of respondents of EV-related surveys have incorrect perceptions of EV characteristics and a lack of awareness of EV policies (Krause 2013). A US Department of Energy survey reported that 52 percent of those surveyed could not name an electric vehicle (Singer 2016). Misperception, specifically of EV fuel and maintenance cost savings, affects consumer interest in plug-in electric vehicles; experimenters that informed consumers of five-year fuel costs found saw the probability increased significantly that consumers expressed a preference to acquire a conventional hybrid, plug-in hybrid, or a battery-electric vehicle (Dumortier et al. 2015)¹¹. Another government survey found that US car-buyers only really consider the first three years of fuel costs (Tran et al. 2012).

Not only is the public generally ignorant about EVs, but they also seem to be less influenced by financial incentives than may be expected. Those surveyed by Krupa et al. (2014) who were most likely to consider buying a plug-in electric vehicle reported not being willing to pay more than a few thousand dollars extra upfront, as opposed to a gas vehicle, even knowing about the hundreds of dollars saved in fuel costs per year. Diamond et al. 2009 finds that government-provided monetary incentives have a non-significant effect on hybrid electric vehicle (HEV) sales. EVs may be repeating the trend seen in solar panel sales where cost effectiveness was

¹¹ There is also a mass misperception of the range of electric vehicle batteries; "range anxiety," the fear that electric vehicles do not have big enough ranges to be feasible, are often cited as reasons not to buy. But in fact, based on National Household Travel Data, 95% of Americans' daily trips can be made in an EV (Van Haaren 2011). Ironically, the second largest driver of the electric vehicle charger market is range anxiety (Market Research 2011).

more of be a barrier to entry (when they were more expensive) than they are a driver of adoption now that they are cheaper (Kahn 2007). Jenn et al. (2013) conducted an analysis of car sales and determined that HEV incentives were only effective when the amount provided was above \$1000. However, Baptista et al. (2012) found that “potential buyers of EV and PHEV technologies are extremely sensitive to fuel prices/electricity prices

We can reasonably expect rideshare drivers to be more influenced than regular consumers by EV financial incentives since their relationships with their vehicles are more profit-minded. A small literature on taxi driver adoption of alternative fuels helps shed light on EV adoption in the context of commercial drivers. Financial consideration does seem to be a significant factor in taxi driver adoption of alternative fuels. A London Fuel Cell Vehicle (FCV) adoption pilot program and joint survey of London cab drivers found that the biggest driver of FCV adoption was the opportunity for personal financial gains (Mourato et al. 2004). Gao et al. (2008) found that the two most important factors when New Yorkers buy a vehicle for use as a taxi were vehicle cost and cost of maintenance. Anderson (2014) surveyed rideshare drivers and found that part-time and full-time drivers were more likely to voice economic motivations, consider ridesharing a job equivalent to taxi driving. It is likely that for the 40% of Uber drivers for whom Uber is their only or largest source of income (Hall and Krueger 2015), pay closer attention to fuel costs than the average car consumer.

The fourth and fifth most significant factors found by Gao et al. were engine power and environmental impact (2008). Mourato et al. also found environmental considerations to affect taxi drivers’ longer term purchasing decisions; how willing drivers were to adopt FCVs was correlated with their degree of concern about air pollution and their level of knowledge of fuel cell technology (Mourato et al. 2004). Gao’s survey indicates that taxi owners were relatively uninformed about HEVs and listed consumer awareness as the primary factor in HEV adoption rates (2008). In a survey of 464 Los Angeles taxi drivers, Park et al. (2014) found that perceptions of social responsibility and potential risks to society were more important in the adoption of EVs than perceptions of utility and economic aspects (though all variables were correlated to some extent).

Liu et al. (2012) and Gao et al. found that personal characteristics of taxi drivers correlate with likelihood to adopt electric vehicles. Gao et al. found older age, more working experience, and more education to be associated with higher hybrid adoption, while Liu et al. found the same traits to correlate with likelihood to switch from gasoline taxis to a lower-polluting natural gas vehicle. However, Liu then conducted an updated version of the same experiment in 2015 and determined that most driver characteristics and working patterns have no influence on drivers’ fuel preferences of their next purchase (Wang et al. 2015). They explain the conflicting findings by pointing to the differing stages of clean fuel replacement. In 2005 their test city of study, Nanjing, had only one natural gas station and only four in 2009. These findings indicate that the aforementioned driver characteristics are significant explanatory variables of driver adoption of alternative fuel vehicles only until the

alternative fuel in question has been more thoroughly integrated into a city, in which case they are adopted by a more normal distribution of drivers.

Another, not as well demonstrated, difference between rideshare drivers and the taxi drivers in the reviewed surveys is that many rideshare drivers have never driven commercially before. Wang et al. found that current fuel has a strong influence on the fuel preference for a driver's next taxi (2015). If prospective rideshare drivers do not currently have a car or drive a taxi, then that influence may not be as strong. As Mayhew (2004) proves, change often happens not when old generations change their ways but when they are replaced by new generations with new ways.

This thesis will assume that TNC driver adoption of electric vehicles can be modeled quite similarly to the adoption of EVs among taxi drivers, with variables such as income, education, environmentalism, cost of ownership, and nearby charging infrastructure, with extra weight added to cost of ownership.

Regression Analysis

Data Description

I used this CVRP survey data in order to look more closely at what drives California’s electric vehicle buyers. Unfortunately, the CSE does not allow full access to survey data, only fragments of it. In order to piece together complete survey responses, I only used the responses that had completely unique combinations of several variables. This left me with 306 of the over 19,000 responses. The bias of this selection process resulted in an overrepresented rural population. This is because there were less surveys from rural areas and thus a higher chance that a rural survey response would have a unique combination of variables. Despite being small and rural-heavy, this sample is very representative of the 19,460; and in the ways in which it is not representative it is skewed more towards the typical demographics of TNC drivers, which is convenient in the context of this paper. Table 8 summarizes the differences between the extracted sample and the full survey data. Notably, “State Rebates” is identical and “Saving money on fuel costs” is within three percentage points. The income is significantly lower, but this makes it align more with the income of a TNC driver.

	Extracted Sample	Full Survey
<i><\$100k</i>	43%	18%
<i>\$100k-\$299,99</i>	45%	66%
<i>\$300k-\$499,99</i>	6%	10%
<i>\$500k+</i>	6%	6%
<i>Saving money on fuel costs</i>	41%	38%
<i>State Rebates</i>	74%	74%
<i>Very/extremely important Photovoltaic at Home</i>	54%	40%
<i>Initial Interest(1/2/3/4/5)</i>	(1% 3% 20% 33% 43%)	(1% 4% 22% 40% 32%)

Table 8: From CVRP Survey

In Table 9 are the variables used in my regression analysis. To generate “_income” I took the log of the midpoint of one of 15 income brackets reported by the respondents. The missing income variables are for respondents who did not report their incomes. “MostImportantCost” is a dummy variable for whether the respondent’s most important decision factor in their car purchase was fuel cost. “PVatHome” is a dummy variable for whether they have or are planning to have a solar panel system at their residence. Finally, “InitialInterest” and “StateRebate,” are 1-5 ratings of their initial interest in buying an EV and how important the state rebate was in allowing them to purchase an EV. The actual state rebates at the time were \$2500 for battery electric vehicles, which make up 73 percent of the extracted sample, and \$1500 for plug-in hybrid electric vehicles, the other 27 percent.

<i>Variable</i>	<i>Observations</i>	<i>Mean</i>	<i>Std. Dev.</i>	<i>Min</i>	<i>Max</i>
<i>_income</i>	245	11.69776	0.7314962	10.53208	13.12236
<i>MostImportant_Cost</i>	306	0.4117647	0.4929591	0	1
<i>PVatHome</i>	306	0.5359477	0.499523	0	1
<i>InitialInterest</i>	306	4.140523	0.91429	1	5
<i>StateRebate</i>	304	4.148026	1.075283	1	5

Table 9: Summary of Statistics

Theory of Equations

Since the number of observations is low, only the most important independent variables will be used, so as to not over-control for any effects. The first equation is:

$$\text{InitialInterest} = \beta_0 + \beta_1\text{MostImportant_Cost} + \beta_2\text{PVatHome} + \beta_3_income + \beta_4\text{StateRebate} + \mu$$

Where the initial interest is said to be determined by the respondent's valuation of the state rebate's importance in their purchase, whether they were most motivated by fuel cost, whether they had or planned to have a photovoltaic solar panel at home, and their income. "MostImportant_Cost" is expected to correlate negatively with InitialInterest, since cost-minded people would be initially turned off by the upfront cost of EVs. "StateRebate" is expected to also correlate negatively with InitialInterest. "PVatHome" is expected to positively correlate with InitialInterest, since people who own solar panels are more likely to buy EVs – in California, 42 percent of EV owners also have solar panels, compared to 1 percent of the general population (Tal et al. 2013). This variable is included to control for people who are willing to pay for environmental goods. Finally, "_income" is expected to have a positive coefficient since early EV adopters tend to be wealthy. The "MostImportant_Cost" variable is of particular interest because of taxi drivers' consideration of vehicle cost above all other factors when buying new vehicles (Gao et al. 2008).

The second equation is:

$$\text{StateRebate} = \beta_0 + \beta_1\text{MostImportant_Cost} + \beta_2\text{PVatHome} + \beta_3_income + \beta_4\text{InitialInterest} + \mu$$

Where the importance of the state rebate in allowing respondents to buy an electric vehicle is said to be determined by whether they were most motivated by fuel cost, whether they had or planned to have a photovoltaic solar panel at home, income, and initial interest in buying an EV. "MostImportant_Cost" is expected to correlate positively with StateRebate. The "MostImportant_Cost" variable again is the primary variable being tested. "PVatHome" is expected to negatively correlate with StateRebate, since people who own solar panels have proven a willingness to pay for environmental goods (Tal et al. 2013). Finally, "_income" is expected to have a negative coefficient since wealth would make a small rebate less important.

Results

The first regression supported the hypothesis that `MostImportant_Cost` is negatively correlated with `InitialInterest`. The statistically significant coefficient ($p < 0.05$) implies that if someone's most important decision factor in their car purchase is fuel cost, then their `InitialInterest` is 0.257 lower than it would otherwise be. The other statistically significant result from the first regression was that owning or planning to own a solar panel at home increases `InitialInterest` by 0.233 ($p < 0.05$). The second hypothesis, that `MostImportant_Cost` is positively associated with `StateRebate`, was also confirmed. At a statistically significant level ($p = 0.007$), fuel cost being the most important decision factor increases the respondents' valuations of the importance of the state rebate by 0.374. The full regression tables are in Tables 10 and 11.

From these results we can conclude that compared to the general population of electric vehicle buyers, Uber drivers (whose car-buying decisions are assumed to be most motivated by cost) are significantly less interested in electric vehicles at the start of the car-buying process and significantly more reliant upon the state rebate in making their purchase of an EV possible.

Dependent Variable (Initial Interest)	
Observations	244
R-squared	0.045
Independent Variables	
<code>MostImportant_Cost</code>	-0.257** (0.121)
<code>PVatHome</code>	0.233** (0.117)
<code>_income</code>	-0.129 (0.0812)
<code>StateRebate</code>	-0.0438 (0.0569)
Constant	5.822*** (1.010)
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$	

Dependent Variable (State Rebate)	
Observations	244
R-squared	0.052
Independent Variables	
<code>MostImportant_Cost</code>	0.374*** (0.137)
<code>PVatHome</code>	-0.113 (0.133)
<code>_income</code>	-0.136 (0.0923)
<code>InitialInterest</code>	-0.0564 (0.0733)
Constant	5.920*** (1.162)
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$	

Table 10 (above): Regression: Dependent Variable (`InitialInterest`)

Table 11 (right): Regression: Dependent Variable (`StateRebate`)

Conclusion and Policy Recommendations

Transportation Network Companies like Uber and Lyft are changing the way cities travel. It is important understand the environmental consequences of these changes. TNCs should be encouraged to use fuel efficient and electric vehicles. In light of this, the following policies are recommended:

1. Require that Transportation Network Companies publish the fuel efficiency of their vehicles.

Uber is extremely private about its data. For all of the reduced emissions and miles driven that Uber representatives publicly take credit for (Cushing 2014, Lunden 2016), they do not back it up with solid evidence. I suggest mandating that TNCs publish annual reports on the makeup of their fleets with respect to fuel efficiency.

2. Provide Clean Vehicle Rebates specifically for TNC drivers.

The regressions from this paper prove that cost-minded car buyers (used as a proxy for TNC and taxi drivers) are likely to rely more on the state rebate to purchase an electric vehicle. The Clean Vehicle Rebate Program currently includes 20 rebates per year for carshare services, \$1,000 for fully electric vehicles and \$600 for plug-in hybrids, because they “provide a unique opportunity for introducing eligible vehicles to a large consumer base” (CARB 2016). As this paper has demonstrated, this logic can also apply to ridesharing services. Although I suggest supplying rebates for more than 20 EVs, that would be a good start.

There is the problem of not being able to control if an Uber driver quits Uber after receiving the rebate. To account for this, I recommend employing the strategy used for the electric vehicle federal tax credit; giving the money in fragments, as the driver hits miles driven milestones.

3. Allow taxis to use a price multiplier

The government needs to decide how it will save the taxi industry from TNCs, or if it wants to. It seems like California does want to, given the August 2016 transfer of taxi regulatory jurisdiction from cities to the centralized California Public Utilities Commission (Hawkins 2016). One quick way to help the taxi industry would be to overhaul the traditional taxi price structure which is determined by distance and travel time. This model does not take time of day into consideration, so customers are overcharged when demand is low and undercharged when demand is high (Qian 2016). Given the success of Uber and Lyft’s surge price multiplier, both in business and environmentally (more efficiently allotting drivers by time and place to meet rider demand), it makes sense to create a similar price structure for taxis.

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