APPENDIX H.

CHAPTER 5 SUPPORTING DOCUMENTATION

Elasticity-Based Approach to Emissions Fee Structure Impact Estimation-Technical Appendix

Memo on Additional Results of Fee Structure Impact on Emerging Modes-Technical Appendix

Elasticity-Based Approach to Fee Structure Impact Estimation – Technical Appendix

Date:	Thursday, October 24, 2019
Project:	CDOT Emerging Mobility Impact Study
From:	HDR, Inc.
Subject:	Determination of elasticities for use in Fee Structure Impact Analysis

Based on the level of effort and constraints of the project, it was determined that an elasticity based approach would be used to estimate the impact of fees imposed on emerging modes on vehicle miles traveled (VMT) and emissions in Colorado. This appendix aims to describe in greater detail the process and assumptions that informed the elasticity-based impact analysis.

An elasticity is a measure of the responsiveness of demand to a good or service to an incremental price change, while everything else remains the same. In practice, researchers estimate an approximate value for elasticities using observable data. Own-price elasticities are values that relate the demand for a good or service to the price of that good or service. Cross-price elasticities are values that relate the demand for a good or service to the price of another good or service, a supplement or a complement.

For the purposes of this study, a literature review was performed to gather information on elasticities and the relationships between the demand for emerging modes of interest and the price for these modes. In the time available, the project team exhausted the research available on demand for emerging modes (transportation network companies (TNCs), rideshare services, taxis, car rentals, car shares, and residential delivery services) that included estimation of price elasticities. The report provides a review of the findings. Table 1 provides a high-level summary of all relevant elasticities pulled from the literature.

Table 1. Compiled Emerging Mode Elasticities from the literature

Study	Location	Data	Demand	Elasticity measure	Fare	
Flores-Guri (2003) via Hensher & Rose (2014)	New York, USA	Time series (1990–99)	Taxi services	Kilometer driven		-1.05
Rouwendal et al. (1998) via Hensher & Rose (2014)	The Netherlands	SP (collected in 1997)	Taxi services	Number of trips	All taxi users:	-1.14
					Business:	-0.76
					Going out:	-1.75
					Going to the railway station:	-0.69
Queensland Transport (2000) via Hensher & Rose (2014)	Queensland, Australia	N/A	Taxi services	Number of trips	Brisbane:	-0.36
					Other cities:	-0.5
Booz Allen Hamilton (2003) via Hensher & Rose (2014)	Canberra, Australia	SP (collected in 2002)	Taxi services	Number of trips	All taxi users:	-0.36
					Peak hour:	-0.23
					Off peak:	-0.41
Hensher & Rose (2014)	Melbourne, Australia	SP (collected in 2012)	Taxi services	Number of trips	Tourism	-1.478
					Business	-0.645
					Day to day activity	-0.753
					Night time travel	-1.132
					Weighted average	-1.042
Schaller (1999)	New York, USA	Time series (1990–96)	Taxi services	Number of trips met		-0.22
Toner (2010)	Four UK cities	Stated preference (SP)/transfer price (collected in 1989–91)	Taxi services	Number of trips		-0.8

Study	Location	Data	Demand	Elasticity measure	Fare	
Cohen et al. (2016)	Four US cities	Time series (2015)	Uber (TNC)	Number of trips purchased w.r.t. surge multiplier threshold	1 to 1.2	-0.52
					1.2 to 1.3	-0.34
					1.3 to 1.4	-0.58
					1.4 to 1.5	-0.49
					1.5 to 1.6	-0.50
					1.6 to 1.7	-0.68
					1.7 to 1.8	-0.89
					1.9 - 2.3	-1.01
					2.4 - 3.0	-0.25
					3.1 - 5.0	-0.65
					Evening rush	-0.50
					Morning rush	-0.52
					Slow nighttime	-0.53
					Weekday day	-0.46
					Weekday evening	-0.54
					Weekend day	-0.66
					Weekend evening	-0.54
					Weekend event	-0.55
Menezes & Uzagaliveva (2013)	Azores, Portugal	Survey collected in 2007	Car rental	Duration of car rental		-0.36
Palmer-Tous et al. (2007)	Mallorca, Spain	Survey collected in 2007	Car rental	Duration of car rental		-0.34

Study	Location	Data	Demand	Elasticity measure	Fare	
Anderson et al. (2004)	Denver, Colorado	Industry data from one company at the Denver International Airport	Car rental	Duration of car rental		-0.07
Copenhagen Economics (2015)	n/a	Summary of price elasticity literature	Taxi services/ Rideshare	Number of trips	Single passenger rideshare	-1.4
					Two or more passenger rideshare	-1.0
Carteni et al. (2016)	Southern Italy	SP survey	Car share (park-and-share service)	Number of trips		-0.85
Okrent & Alston (2012)	US	Consumer Expenditure Survey paired with CPIs	Food purchased away from home	Meals	Limited service restaurants	-0.13
					Full service restaurant	-1.96
Andreyeva et al. (2010)	US	Summary of price elasticity literature	Food purchased away from home	Mean Price Elasticity Estimate	(95% CI) Low End	-0.23
					(95% CI) High End	-1.76
Goolsbee & Chevalier (2003)	n/a	Online Amazon and Barnes & Noble book sales collected in 2001	Retail (book sales)	Sales		-0.5

Generally, there is a large spread in the elasticity values, and great variation in the particulars of the studies from which relevant elasticities were available (only a handful of the available specifics for any given study are included in the table above). No single value is obviously applicable for one of the emerging modes of interest. There is also no obvious choice for the Colorado urban or rural markets.

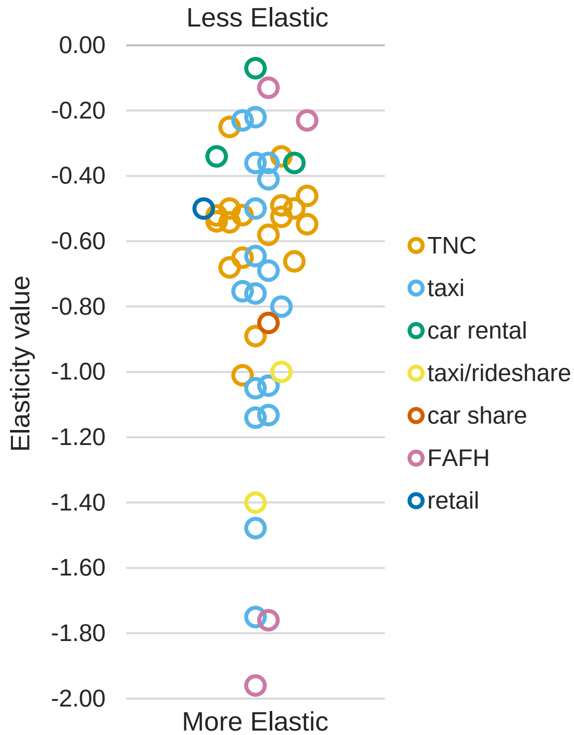
Forty-six elasticity values were extracted from sixteen research papers (34 of the elasticities were sourced from 12 primary research papers). Half the studies are less than 10 years old, the oldest study was published in 1998, accessed as a secondary source through a more recent study. Table 2 describes the number of elasticities found for each emerging mode. Note that for some papers, there was no differentiation between rideshare services, TNCs, and taxi services. For the paper on car shares, it was unclear if the program discussed was a non-peer to peer or peer to peer car share program.

Table 2. Count of elasticities and research papers by mode

	Number of elasticities	Number of papers	Number of papers less than 10 years old
Taxi services	17	7	2
TNC	18	1	1
Car rental	3	3	1
Taxi/rideshare	2	1	1
Car share	1	1	1
Food away from home (FAFH)	4	2	2
Retail	1	1	0
Total	**46**	**16**	**8**

In absolute value, the two largest relevant elasticities found in the literature are intended to represent changes in demand for "food purchased away from home" with price changes. The next largest represents demand for taxi services for "going out" based on data from The Netherlands in the late 1990's. The lowest elasticities are represented by an approximate elasticity from a study on rental cars from one company at the Denver International Airport, the second lowest represents demand for a type of "food away from home", and the third lowest was estimated for taxi services in New York City in the early 1990's. All the elasticities are graphed together in Figure 1, by mode. The elasticities are grouped toward the lower (in absolute value) end of the range. The average is around -0.7; the median about -0.5.

Figure 1. Spread of elasticities from the literature on demand for emerging modes.



The analysis assumes one constant elasticity for all emerging modes, as there is not enough evidence in the literature to assume demand responses are significantly different on average across modes. The constant elasticity-based approach to estimating the impacts of the fee structures on emerging modes will perform fairly well as long as changes in price are relatively small (and this is the case for the fee structures tested).

The project team determined that two elasticities should be tested with the fee structures in the analysis, one high and one low, to represent the range of responsiveness evidenced in the literature. Ideally, the values would be representative of the wide range but not skewed by excessively large values exhibited in a specific sub-market. The project team aimed for the high elasticity (in absolute value, and representing a more elastic demand) to approximate the 85^{th} percentile of the distribution of elasticities. Similarly, the team aimed for the low elasticity (in absolute value, and representing a less elastic demand) to approximate the 15^{th} percentile of the distribution. Based on the spread of elasticities from the literature, a qualitative analysis with these aims in mind and professional judgement resulted in the values of -1.0 for the more elastic demand scenario, and -0.3 for the less elastic demand scenario.

The additional simplifying assumptions are explored in the report, and are briefly reiterated here:

1) Elasticity of demand does not vary across travel mode, trip purpose, vehicle fuel efficiency, or between rural and urban areas, largely due to a lack of research and data on demand behaviors.

2) Travelers/consumers will perceive the price change incurred by the fee, which motivates them to change their travel behavior (thereby decrease VMT and trips).
3) Prices (and attractiveness) of the emerging modes, relative to each other, does not change, such that demand does not shift between emerging modes under the fee structure.
    a. Incentives applied to shared rides and zero emission vehicles (ZEVs) violate this assumption.
    b. Flat fees applied to modes with different magnitudes of fares and prices, or mileage-based fees applied to modes with different price-per-mile costs and fares, violate this assumption.
4) Trip lengths will not change under the fee structure, such that the percent change in trips equals the percent change in vehicle miles.

Further, it should be noted that this analysis does not consider emerging issues in behavioral economics, such as consumer choice or preference, loss aversion, reactions to small versus large financial incentives, and reactions to marketing campaigns. Additionally, the analysis does not account for shifts in demand from emerging modes to personal vehicles or transit under the fee structure.

Bibliography

Anderson. C.K., Davison, M., Rasmussen, H. (2004) Revenue Management: A Real Options Approach. *Cornell University, School of Hotel Administration*.

This team of researchers outline an approach though real options addressing revenue management, particularly geared towards the rental car industry. Data provided in this study originates from Dollar Rent-A-Car in 2001, where economy cars available for weekday pickup at Denver International Airport could be acquired through purchase.) As a function of remaining time and available inventory, their model "produces minimally acceptable prices" and quantities of rental cars that have been released to users at a particular price, also referred to as a "release quantity" (Anderson et al., 2004). They report a price elasticity of demand at -1/15, which may by arithmetically calculated to be -0.067.

Andreyeva, T., Brownell, K.D., Long, M.W. (2010) The Impact of Food Prices on Consumption: A Systematic Review of Research on the Price Elasticity of Demand for Food. *American Journal of Public Health* vol. 100(2): 216-22.

Andreyeva and her cohort produce an article summarizing secondary research on 160 studies that report on the price elasticity of demand for major food categories. This study also pulled data from a variety of sources (e.g. USDA and the U.S. Dept. of Commerce for time series data, Nationwide Food Consumption Survey, National Food Stamp Program Survey for survey data, and ACNielsen for retail scanner data). One major purpose behind this analysis was the intention of assessing average elasticities by food category. The authors find that price elasticities for foods and nonalcoholic beverages range from -0.27 to -0.81. The most sensitive goods with respect to a change in price were food away from home (FAH), soft drinks, juice, and meat (-0.7 to -0.8).

Bento, A.M., Goulder, L.H., Jacobsen, M.R., von Haefen, R.H. (2009) Distributional and Efficiency Impacts of Increased US Gasoline Taxes. *American Economic Review*, 99(3): 667–699.

Bento et al. sought answers regarding the impacts that increased gasoline taxation would ultimately have on markets for various types of vehicles (e.g. new, used, and scrapped). The dataset used is composed of two parts. The first is a random sample of US household's vehicle decision-making in the 2001 National Household Travel Survey (NHTS). Second, data on new and used automobiles' price and non-price characteristics were received from Ward's Automotive Yearbook, The National Automobile Dealers Association (NADA) Used Car Guide, and the Department of Energy (DOE) fueleconomy.org website. The authors estimate the demand elasticity with respect to the "rental" price, which represents the one-year cost of purchasing/leasing a new vehicle. Their results find that for all vehicles (new, used, scrapped), the "rental" price elasticity was −0.88, while new vehicles themselves exclusively faced an elasticity of −1.97 (Bento et al., p.683).

Carteni, A., Cascetta, E., de Luca, S. (2014) A Random Utility Model for Park & Carsharing Services and the Pure Preference for Electric Vehicles. *Transport Policy*. Vol. 48: p.49-49

This study examines and models the choice to switch from private car trip to a carsharing service available in parks within a close proximity of the study's location, as well as the propensity to choose an electric vehicle for such a service. The data used within this study comprises stated preference surveys of the studies explored in the literature review. This study reports an average direct (own-price) elasticity with respect to the fare/cost of carsharing at -0.85, and an average direct (own-price) elasticity with respect to travel time of -0.27.

Cohen, P., Hahn, R., Hall, J., Levitt, S., Metcalfe, R. (2016) Using Big Data to Estimate Consumer Surplus: The Case of Uber. *National Bureau of Economic Research*. Working Paper 22627.

Cohen et al. utilize data on UberX ride requests and transactions—from the first half of 2015—for the sessions of roughly 54 million users in four cities: Chicago, San Francisco, Los Angeles, and New York City. From the available data, the group was able to estimate demand elasticities along a demand curve that was also derived from the data. Their objective of estimating consumer surplus was accomplished, however our interest in this study was the price elasticities that were reported. The authors estimate a number of elasticities within this study, by breakouts of surge price intervals and sub-populations (e.g. city, time of day, and rides in a period), and controlling for wait time. Overall, the own price elasticity of demand (PED) reported for all periods was -0.5463. One limitation of this study was that in order to estimate elasticities, the prevailing method was short-term changes in the surge price, rather than changes in market price over long periods of time. As a result, the reported elasticities may not represent long term reactions to changes in price.

Dans, E. (2018) Why Price Elasticity Doesn't Apply to Amazon. Retrieved from https://medium.com/enrique-dans/why-price-elasticity-doesnt-apply-to-amazon-d3a69d4efd17

In this article, Dans explains why the demand for Amazon services may have a low, possibly zero, sensitivity to price increases. He argues that the company doesn't incur the traditional effects of price elasticity that are observed in markets due to the uniqueness of the services, and uses economic logic (e.g. lack of "practically comparable substitutes") to defend the statement of Amazon Prime's general inelasticity.

Deloitte Access Economics (2016) Economic Effects of Ridesharing in Australia. *Deloitte*.

Deloitte conducted this 2016 study on ridesharing companies (or TNCs) like Uber, Lyft, and DiDi Kuaidi with the intent of assessing the economic effects that ridesharing has in the nation of Australia. A difference-in-difference estimation approach is taken, and the data originates from Uber and the state of California. Their study also addressees the impacts that will be incurred among numerous stakeholders (e.g. regulators, traditional businesses, the Uber platform, and consumers). Deloitte assumes a price elasticity of -2 for this analysis, rooted in an assumption made in a separate analysis conducted by the Centre for International Economics for the ACT Taxi Industry Innovation Reforms (Deloitte, 2016: p.63, Appendix A).

Einav, L., Knoepfle, D., Levin, J., Sundaresan, N. (2014) Sales Taxes and Internet Commerce. *American Economic Review*. 104(1): 1-26 https://web.stanford.edu/~jdlevin/Papers/SalesTaxes.pdf

Einav et al. employ eBay data to test the elasticities of internet retail purchasing to sales taxes. The data utilizes to evaluate this phenomenon originates from eBay's online marketplace. They translate an estimate from their model into a price elasticity and ultimately report a tax-price elasticity of -1.7. Meaning that, for every 1% increase in sales tax, purchases decrease by 1.7%.

Farajallah, M., Hammond, B., Penard, T. (2016) What Drives Pricing Behavior in Peer-to-Peer Markets? Evidence from the Car-Sharing Platform BlaBlaCar.

This team of researchers study the leading car-sharing platform in Europe at the time to explore what determines prices and outcomes on peer-to-peer platforms. They report that traditional peer-to-peer markets (i.e. eBay) are the source of data, and that the fraction of seats sold decreases by 10% for each additional [one] Euro price increase.

Flores-Guri, D. (2003) An Economic Analysis of Regulated Taxicab Markets. *Review of Industrial Organization.* 23, p. 255-266.

Daniel Flores-Guri began his work on the study with the intention of modeling a taxicab market wherein there is an active regulation of entry and taxi fares. He states that for the purposes of conducting this study, that Schaller's dataset (supplemented by additional years) was used in order to estimate the model's parameters and derive data for its endogenous variables. Flores-Guri reports that there is a "positive, inelastic relationship" between the demand for taxicab services and vacant taxicabs. The elasticity is further explained by a quantitative value for the price elasticity of demand, at -1.052 (Flores-Guri, 2003: p. 262).

Fouquet, R. (2012) Trends in Income and Price Elasticities of Transport Demand (1850–2010), *Energy Policy*. 50, issue C, p. 62-71.

Through his study, Fouquet sought not only to estimate trends in income and price elasticities, but to offer a perspective on the future growth use of transportation. The study incorporates a body of sources that provided Fouquet with data on horse-drawn and railway transport, their prices, and total miles traveled between 1840 and 1913. His results delineate that the long run income and price elasticities of aggregate land transport demand were estimated to be -0.8 and -0.6, respectively.

Goolsbee, A. and Chevalier, J. (2002) Measuring Prices and Price Competition Online: Amazon and Barnes and Noble. *Quantitative Marketing and Economics I, 2.*

Goolsbee and Chevalier used publicly available data on over 20,000 books, using their sales ranks to measure price sensitivity. They find that Barnes and Noble had a large own price elasticity (-3.5) while Amazon sales exhibited a much smaller own price elasticity (-0.45).

Hensher, D. and Rose, J. (2014) Demand for Taxi Services: New Elasticity Evidence. *Transportation*. Springer, vol. 41(4), p. 717-743.

Hensher and Rose collaborate for the purpose of investigating the determinants that influence the choice of, and consequently the demand for, taxis services. They used available data from the Victorian Taxi Industry inquiry, and employed a mixed multinomial logit (MMNL) choice model to perform their econometric analysis that lead to the study's estimates and conclusions. As a result of their analysis, Rose and Hensher

come to the conclusion of a number of PEDs with respect to the cost of taxi fare. In the business and tourism market segments, price elasticities were reported at -1.437 and -0.556, respectively. However, the authors also report that trips categorized as "day-to-day" activities and "night time" activities faced elasticities of -0.671 and -1.079, respectively.

Houde, J.F., Newberry, P., Seim, K. (2017) Economies of Density in E-Commerce: A Study of Amazon's Fulfillment Center Network. *National Bureau of Economics Research.* https://www.nber.org/papers/w23361.pdf

Through this study, the trio of authors set out to examine economic phenomena that were related to the expansion of Amazon's distribution center network. Their data on online and offline retail good purchase can be sourced to a combination of comScore Web Behavior database, Forrester Research surveys, and household spending data from Environmental Systems Research Institute (ESRI). They state that per their empirical calculations, a 1% increase in price leads to a decrease in demand of 1.4%.

Litman, T. (2019) Understanding Transport Demands and Elasticities How Prices and Other Factors Affect Travel Behavior. *Victoria Transport Policy Institute*.

Through secondary analysis, Litman expounds upon the concepts related to transport demand in this study. Supplementing this, he also investigates the determinants of travel demand (e.g. price, quality of service) and how elasticity values can be utilized to evaluate and measure these factors. Examples of the findings of Litman's investigation include railway demand with respect to fare (-0.65 in the short run, -1.08 in the long run), bus demand with respect to fare (-0.28 in the short-run, -0.55 in the long-run), and car ownership with respect to general public transport costs (-0.1 to -0.3).

Menezes, A. and Uzagaliveva. A. (2013) The Demand of Car Rentals: a Microeconometric Approach with Count Models and Survey Data. *Review of Economic Analysis* 5: 25-41

Menezes and Uzagaliveva analyze demand in the market for tourism in Azores, Portugal. The data used to evaluate the market for car rental in Azores was gathered from surveys administered to tourists in Azores in the summer of 2007. These 1000 questionnaires were distributed at the primary regional airports and data were captured by the Studies and Consultancy Department of Norma-Acores. Their study employs price elasticities of demand for car rentals for the purpose of supporting policy initiatives that would subsequently internalize congestion costs. This paper reports a price elasticity of demand at -0.36.

Okrent, A.M. and Alston, J.M. (2012) The Demand for Disaggregated Food Away from Home and Food at Home Products in the United States. *United States Department of Agriculture*. *Economic Research Report.* Number 139.

Alston and Okrent studied the role of food away from home (FAFH) purchases and estimated demand for over 40 disaggregated FAFH and food at home (FAH) products. They were able to construct a monthly time series of household expenditures by employing Consumer Expenditure Survey data from the period of 1998-2010. Their results explain that demand for FAFH products is more sensitive to changes in food spending patterns than FAH products. The authors report both own and cross-price elasticities by food product category. Within the scope of reported own-price elasticities are cereals and bakery (-0.58), meat and eggs (-0.31), dairy (-0.05), fruits and vegetables (-0.79), nonalcoholic beverages (-0.65), other FAH (-0.98), FAFH and alcohol (-0.71), and nonfood (-1.00). Unfortunately, aggregated elasticities were not reported, likely due to the focus of the study—demand of disaggregated Food-Away-From-Home and Food-at-Home Products.

Oum, T.H.; Waters II, W.G.; Yong, J.S. (1990) A Survey of Recent Estimates of Price Elasticities of Demand for Transport. *Infrastructure and Urban Development Department*. *The World Bank*.

With this 1990 paper, the authors seek to evaluate a factors related to the demand for transport (e.g. Cost recovery, pricing, efficient resource use) through a review of previous literature (most of the studies reviewed were published in the 1980's). The team reported market demand price elasticities in ranges for a variety of modal choices, in addition to the intent of the modal choice (p. 14-15, Table 2, 3) based on their literature review findings. The elasticity range for intercity rail (leisure, business, not distinct) was -0.11 to -1.54. Elasticities also varied for peak and off-peak hours. Additionally, the range for the freight's elasticity for aggregate commodities was -0.60 to -1.52 by rail and -0.05 to -1.34 by truck.

Palmer-Tous, T., Riera-Font, A., Rosselló-Nadal, J. (2007) Taxing Tourism: The Case of Rental Cars in Mallorca. *Tourism Management* 28: 271–279.

Palmer-Tous et al. study the relationship between increased tourism and the rise in hired rental cars in the Spanish territory of Mallorca. This study employs survey data from a sample of 764 tourists at Mallorca airport during the island's high season (May to September). Their paper suggests that a fixed-rate of taxation on rental hires would result in decreased congestion and an increased overall transport efficiency. Their elasticities vary, depending on the model that is observed. They report a price elasticity of -0.19 in the case of the zero-inflated Poisson model (ZIP), and an elasticity of -0.34 in the case of the simple Poisson model (P) (Palmer-Tous et al., p. 277).

Saksena, M.J., Okrent, A.M., Anekwe, T.D., Cho, C., Dicken, C., Effland, A., Elitzak, H., Guthrie, J., Hamrick, K.S., Hyman, J., Jo, Y., Lin, B.H., Mancino, L., McLaughlin. P.W., Rahkovsky, I., Ralston K., Smith, T.A., Stewart, H., Todd, J., and Tuttle, C. (2018) America's Eating Habits: Food Away From Home. *United States Department of Agriculture*. *Economic Research Report.* Number 196.

Similar to the previous study by Okrent and Alston (2012), Saksena et al. study the demand for FAFH and have found that not only has the demand for these products grown, but the availability of these foods grew as well. However, in the case of this study the writers report elasticities from a secondary perspective. There are several "main data sources" listed in the paper, including the National Health and Nutrition Examination Survey (NHANES), USDA ERS's Food Expenditure Series, the National Household Food Acquisition and Purchase Survey (FoodAPS), the Consumer Expenditure Survey, and the U.S. Census Bureau's Monthly Retail Trade. Referencing Okrent and Alston (2012), it's reported that the demand for limited service restaurants were nearly perfectly inelastic to changes in price (-0.13), while demand for meals from full-service restaurants exhibited price elasticity (-1.96). In additional secondary reporting, it is stated that

Richards and Mancino (2013) found the price elasticity of demand between -0.5 and -0.9 (meals at limited/full-service restaurants).

Schaller, B. (1999) Elasticities for Taxicab Fares and Service Availability. *Transportation.* 26, p. 283.

This study was intended to examine the effects that travel/trip demand incurs (regarding the availability and market for taxi services), as a result of increases to taxi fares. Data on taximeter and odometer readings were provided by the Taxi and Limousine Commission. Schaller used this data to estimate fare revenue and service availability within the study. He also states that the elasticity of trip demand with respect to the price of ridership is estimated to be -0.22, while the elasticity of overall [taxi] service availability with respect to fares is -0.28.

Stefandotter, A., Danielsson, U., Nielson, C.K., Sunesen, E.R. (2015) Economic Benefits of Peer-to-Transport Services. *Copenhagen Economics*.

In 2015, Copenhagen Economics was commissioned by Uber to perform an economics impact analysis of having “a well-functioning peer-to-peer transport service in the Nordics.” Their study compiles findings from academic studies for bus ridership, and peer-to-peer transport service providers like Uber, TaxiKurir (2015), and Topcab (2015). The study ultimately results in a deep dive into the economic benefits that are realized as a result of car-sharing options becoming an “increasingly more viable mode of transportation.” They use a price elasticity of -1.4 for ridesharing with a single passenger and an elasticity of -1.0 for ridesharing with two or more passengers based on a literature review of primary research. Stefandotter et al. also cite Ward (2002) for a price elasticity of -2.67 with respect to the trip demand for taxi services, as a high end of the range of the demand elasticity for such services.

Toner, J.P. (2010) The Welfare Effects of Taxicab Regulation in English Towns. *Institute for Transport Studies*. University of Leeds.

Jeremy Toner conducted this study in order to analyze his model of the taxi industry, which demonstrates that “socially undesirable outcomes” would ultimately be the product of an “infeasible” price competition (i.e. numerous taxis operating at exorbitant prices). For data, Toner included one of his old studies in addition to a series of State Preference and Transfer Price experiments in four English cities (Toner, 2010: p. 306). He reports an aggregate price elasticity of demand (with respect to fare price) at -0.8.

Additional Results of Fee Structure Impact on Emerging Modes – Technical Appendix

Date:	Thursday, October 24, 2019
Project:	CDOT Emerging Mobility Impact Study
From:	HDR, Inc.
Subject:	Additional results on emissions from the Fee Structure Impact Analysis

This appendix contains additional results on emissions from the analysis of fee structures on emerging modes. Vehicle emissions from internal combustion engines (ICEs) are assumed to decrease proportionately with ICE vehicle miles traveled (VMT) under the fee structure. Zero-emission vehicles (ZEVs) are assumed to have zero emissions, so this analysis does not account for the emissions from upstream energy generation required for ZEV operation.

Reduced emissions (short tons of $CO2_e$) in 2030 are monetized based on dollar values for the Social Cost of Carbon (per metric ton of CO_2) from the USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs (2018). Unit values are converted to short tons and inflated to 2019 dollars (using the Gross Domestic Product Price Index from the Office of Management and Budget Historical Tables) which results in a unit value of $0.95 per short ton of $CO2_e$ emissions.

Table 1 presents the dollar value of reduced emissions by mode generated by the various fee structures, together with the level of emissions and the percentage change in emissions for a given emerging mode. As with the results presented in the main report, the high end of estimated impacts is represented by the high fee structure combined with the more responsive demand scenario, and the low end is represented by the low fee structure combined with the less responsive demand scenario.

Table 1. Results on Emissions from the Impact of Fee Packages on Emerging Modes in 2030

	Mileage-Based Fee		Flat Fee		Percentage-Based Fee	
	Low-End Impact	High-End Impact	Low-End Impact	High-End Impact	Low-End Impact	High-End Impact
TNCs - single						
Daily $CO2_e$ emissions (tons)	874	854	874	853	874	853
Value of daily reduced emissions†	$1.92	$21.16	$1.94	$21.69	$1.99	$21.88
Percent change in daily emissions	-0.23%	-2.55%	-0.23%	-2.62%	-0.24%	-2.64%
TNCs - pooled						
Daily $CO2_e$ emissions (tons)	131	128	131	128	131	129
Value of daily reduced emissions†	$0.23	$3.01	$0.21	$2.59	$0.11	$1.36

Additional Results of Fee Structure Impact on Emerging Modes – Technical Appendix

	Mileage-Based Fee		Flat Fee		Percentage-Based Fee	
	Low-End Impact	**High-End Impact**	**Low-End Impact**	**High-End Impact**	**Low-End Impact**	**High-End Impact**
Percent change in daily emissions	-0.18%	-2.43%	-0.17%	-2.09%	-0.09%	-1.10%
Peer-to-Peer Car Share						
Daily $CO2_e$ emissions (tons)	1	1	1	1	1	1
Value of daily reduced emissions†	$0.00	$0.03	$0.00	$0.02	$0.00	$0.02
Percent change in daily emissions	-0.31%	-3.44%	-0.20%	-2.29%	-0.24%	-2.64%
Non Peer-to-Peer Car Share						
Daily $CO2_e$ emissions (tons)	5	5	5	5	5	5
Value of daily reduced emissions†	$0.01	$0.13	$0.02	$0.19	$0.01	$0.13
Percent change in daily emissions	-0.25%	-2.77%	-0.35%	-3.98%	-0.24%	-2.64%
Taxis						
Daily $CO2_e$ emissions (tons)	18	18	18	18	18	18
Value of daily reduced emissions†	$0.02	$0.25	$0.03	$0.31	$0.04	$0.46
Percent change in daily emissions	-0.13%	-1.45%	-0.16%	-1.80%	-0.24%	-2.64%
Car Rentals						
Daily $CO2_e$ emissions (tons)	1,380	1,339	1,383	1,376	1,380	1,347
Value of daily reduced emissions†	$3.85	$42.30	$0.68	$7.66	$3.14	$34.54
Percent change in daily emissions	-0.29%	-3.23%	-0.05%	-0.59%	-0.24%	-2.64%
Residential Delivery						
Daily $CO2_e$ emissions (tons)	n/a	n/a	n/a	n/a	688	672
Value of daily reduced emissions†	n/a	n/a	n/a	n/a	$1.57	$17.22
Percent change in daily emissions	n/a	n/a	n/a	n/a	-0.24%	-2.64%
Total*						
Daily $CO2_e$ emissions (tons)	3,099	3,034	3,102	3,071	3,098	3,025
Value of daily reduced emissions†	$6.04	$66.89	$2.87	$32.46	$6.86	$75.61
Percent change in daily emissions	-0.21%	-2.28%	-0.10%	-1.11%	-0.23%	-2.58%

* Includes residential delivery emissions, for which the analysis does not estimate an impact from the mileage-based and flat fee structures.

† Valued in undiscounted 2019 dollars.

The percentage increase of the fee over the base fare is presented in Table 2 and Table 3 for ICE vehicles and ZEVs, respectively.

Table 2. Results on Emissions from the Impact of Fee Packages on Emerging Modes in 2030

	Mileage based fee		Flat fee	
ICE vehicles	**Low**	**High**	**Low**	**High**
TNCs - single	0.77%	2.32%	0.78%	2.38%
TNCs - pooled	0.61%	2.21%	0.56%	1.90%
Taxis	0.44%	1.31%	0.53%	1.63%
Non-Peer Car Share	0.84%	2.52%	1.18%	3.61%
Peer-to-Peer Car Share	1.04%	3.13%	0.68%	2.09%
Car Rental	0.98%	2.94%	0.17%	0.53%

Table 3. Results on Emissions from the Impact of Fee Packages on Emerging Modes in 2030

	Mileage based fee		Flat fee	
ZEVs	**Low**	**High**	**Low**	**High**
TNCs - single	0.43%	1.55%	0.39%	1.33%
TNCs - pooled	0.00%	1.11%	0.00%	0.14%
Taxis	0.24%	0.88%	0.27%	0.91%
Non-Peer Car Share	0.47%	1.68%	0.59%	2.02%
Peer-to-Peer Car Share	0.58%	2.09%	0.34%	1.17%
Car Rental	0.54%	1.96%	0.09%	0.30%