The Impact of Fuel Costs Improvement on Driving Behaviors of NYC Taxi Drivers

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Abstract

Fuel efficiency has improved because of environmental policies and high gas prices. In most cases, increased vehicle usage is associated with negative outcomes because of potentially increasing emissions. In the New York City (NYC) taxi industry, however, increased vehicle usage corresponds to increased supply, which is meaningful because of limits on the number of permissions and the fixed fare system. I estimate the impact of fuel efficiency improvement on the driving behaviors of NYC taxi drivers by using a fixed effects model. Three types of taxi driver decisions are considered: customer search distance, number of working hours, and shift participation. The results show that fuel efficiency improvement stimulates NYC taxi operators to drive further distances when searching for customers, and drivers of hybrids are more responsive to changes in gas prices. Drivers, however, do not work longer shifts when operating high efficiency vehicles; moreover the probabilities of using high or low efficiency vehicles are similar, although increases in gas prices lead to more use of hybrids.

1 Introduction

Increasing fuel efficiency has been a major trend in the automotive industry, stimulated primarily by several environmental policies and high gas prices. Both private vehicles and commercial transportation vehicles have improved in efficiency. In most cases, increased vehicle usage is considered a problem because it crowds out decreasing emission by fuel efficiency improvement. In the commercial transportation sector, however, increasing vehicle usage is the source of the increasing quantity supplied. Especially in the New York City (NYC) taxi industry, this increased supply is meaningful because of restrictions on taxi permissions and the fixed fare system. In this paper I focus on how drivers' activity in the NYC taxi industry changes in relation to improvements in fuel efficiency. Three factors are considered in this analysis: customer search distance, working hours and shift participation.

I examine the different response to gas price on driving behaviors between vehicles with different efficiency. In particular, the response of hybrid vehicle drivers to the gas price may differ from the choice made by gas-only vehicle drivers. With high efficiency vehicles, taxi operators may drive more. Since the change of gas prices also influences the customers' demand for taxis, the response of taxi usage to gas prices might be biased. Thus, this paper focuses on the difference between hybrid and gas-only vehicle drivers. Fixed effects models are used for estimation of the impact on search distance and working hours. A probit model is used for vehicle usage probability estimation.

Information on all trips made by NYC medallion taxis in 2013 is used. Trip data have been automatically collected by the NYC Taxi & Limousine Commission (TLC). Vehicle model information is provided by the NYC TLC at the daily level. Daily wholesale gas prices at New York harbor are available at the U.S. Energy Information Administration (EIA). By merging three datasets, trip level data are used for estimation of the impact on

search distance. After aggregation at the shift level, I examine decisions about working hours and probability estimation for the choice to operate vehicle is conducted.

This study contributes to the literature that relates to the change of vehicle usage according to changes of fuel cost. Small and van Dender (2005) analyzed the rebound effect for motor vehicles using a pooled cross section of US states for 1966-2001. They found the rebound effect, but it was relatively small. Hymel and Small (2015) found existence of the rebound for drivers using light-duty vehicles. They found that the rebound effect is much greater in magnitude in years when gasoline prices are rising than when they are falling. West et al. (2015) found that the replacement of vehicles by Cash for Clunkers did not increase vehicle usage. Because of lack of identification, the reduction of vehicle usage by lower-performance cars may have cancelled out the rebound effects in their paper. This paper expands the area of research to the commercial transportation sector, especially the taxi industry, in which vehicle usage depends on individual drivers.

This study also contributes to the literature that relates to customer search behavior of taxi drivers. Lagos (2003) calibrates a general equilibrium model including location heterogeneity. Recent studies by Buchholz (2015) and Frechette, Lizzeri and Salz (2016) examine the welfare loss of customer searching friction, which generates spatial mismatch by using a structural model of the NYC taxi industry. The variation of response to taxi fuel efficiency and gas prices are not considered in the literature so far. This paper does not adopt structural estimation to allow for wide variation of gas price fluctuation and time frame.

Finally, this study contributes to the literature that relates to labor participation of taxi drivers. Camerer et al. (1997) found that the daily wage elasticity of labor supply of New York City cabdrivers is negative. However, Farber (2005) found small income effects. Farber (2008) adopted reference-dependent preferences for the daily labor supply model of NYC

drivers. Crawford and Meng (2011) developed reference-dependent preferences models to include targets for hours as well as income. Faber (2015) analyzed the impact of weather conditions on taxi driver's labor supply. These papers all focused on wages and income but did not consider gas prices or fuel efficiency in their model. Thus, the current study adds to the literature on taxis by showing the impact of changes of operation costs on the decisions of taxi drivers.

I found three important empirical results. First, the fuel efficiency improvement stimulates drivers to search further for customers. Second, the fuel efficiency of taxis does not affect the working hours of taxi drivers. Third, the probability of operating high efficiency vehicles tends to reflect gas price fluctuations more than for low efficiency vehicles but the average of vehicle operating probabilities of hybrid and gas-only vehicle are similar. Thus, fuel efficiency improvement does not increase the number of taxis on the road but stimulates drivers of hybrid taxis to search more than drivers of gas-only vehicles.

2 Taxi, Gas Price and Fuel Efficiency

After the introduction of hybrid engine vehicles, fuel efficiency of private and commercial vehicles has improved. With a high efficiency vehicle, people may drive more on average and respond less to changes in gas prices. Similarly, to private vehicle owners, taxi operators may drive with more efficient vehicles. Increased taxi usage will offset the reduction of emissions per mile, but it also implies an enlarged supply of a taxi services. When reduced operation costs of taxis stimulate drivers to operate taxis more, customers may be able to hail taxis more quickly. In this paper, I consider three decisions of taxi drivers: customer searching, working hours and shift participation. Each decision is analyzed by fixed effect regression

models.

Estimation of drivers' responses to gas prices is hard to identify because of responses of demand and traffic. The willingness to pay of customers on taxi services may change when the gas prices fluctuates. To eliminate the impact on demand, I forcus on the difference in the response of gas prices between drivers of hybrid and gas-only vehicles. When preferences of customers between hybrid and gas-only vehicles are not changed by gas price fluctuations, the difference in response to gas prices is caused only by the driver's decision. I assume that preferences of customers for taxi fuel types does not change over time in response to short run changes in gas prices.

3   NYC Yellow Cab

The NYC taxi market is the largest taxi market in the United States, comprising about 34% of all U.S. taxi services. On average, 485,000 trips with 600,000 passengers are taken per day. A typical taxi travels 70,000 miles per year, enough to travel around the world 2.8 times and 5 times more than the average annual driving distance of the typical non-taxi driver.[1]

3.1   Regulation and Monopolistic Competition

NYC taxis are highly regulated. A medallion is required to operate a vehicle as a yellow cab. Only 13,437 medallions were issued for NYC yellow cabs until 2013. The medallion gives permanent permission to operate a taxi in NYC. After purchasing a medallion from the

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[1]The average annual miles per driver is 13,476. TLC factbook 2014, NYC Taxi & Limousine Commission: `http://www.nyc.gov/html/tlc/downloads/pdf/2014_taxicab_fact_book.pdf`, Our nation's highways, Federal Highway Administration: https://www.fhwa.dot.gov/ohim/onh00/bar8.htm

NYC Taxi & Limousine Commission (TLC), the owner can sell the medallion and the price has been very high because the number of medallions has not changed while population expanded, leading to economic profits. The fare system is controlled by the NYC TLC, which determines the flag drop price and payment by time and distance. Medallion cabs face limited competition in Manhattan. Other types of competitors were introduced, but the impact of increasing competition in 2013 was not large. In August 2013 a new type of taxi, the Boro taxi, was introduced. The use of the Boro taxi has been restricted because customers cannot hail them on the street in most parts of Manhattan.[2] E-hail service was not popular in 2013 in NYC. The first e-hail service, Uber, started their business in NYC in 2012. Because of legal issues, TLC ran a year-long pilot program of E-hail service from February 2013. During the pilot program, there was little usage of E-hail service. The number of E-hail vehicles was 5,000 and the number of E-hail trips was 69,000 in January 2014.[3]

3.2 Shift

Taxi drivers participate in day and night shifts. The time frame of the shifts is designed to divide two high demand periods for commutes. The day shift is usually finished between 4PM and 6PM. The behavior of taxi drivers during the day and night shifts could be different because of differences in congestion, demand, and changing shift policy. For this reason, I estimate regressions based on the day and night shifts separately.

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[2]The GPS of Boro taxi will not allow the meter to work if the cab is starting in Manhattan below East 96th or West 110th streets.

[3]TLC factbook 2016, NYC Taxi & Limousine Commission pp 11: `http://www.nyc.gov/html/tlc/downloads/pdf/2016_tlc_factbook.pdf`

3.3 Do NYC Taxi Drivers Need to Worry about Gas Price

Drivers may have their own medallion, rent from a medallion owner, or be hired by a company. The contract is usually based on a shift level with fixed rates, which do not vary with gas prices. The rental rates for one shift were roughly $100, regardless of vehicle models in 2013 and drivers usually pay all fuel costs.[4] Thus, the fluctuation of gas prices and fuel efficiency does not directly affect the medallion owners. The fare system is fixed by the NYC TLC. On September 4, 2012 the NYC yellow cab fare was increased to its current level. The flag drop fare is $3.00 with a TLC tax of $.50. Total fare increases by unit, which is calculated based on travel distance and time. The fare is not adjusted for gas prices or vehicles with different fuel efficiency. Thus, the cost burden of gas price fluctuations belongs to drivers.

3.4 Efficiency Improvement of NYC Yellow Cab

The crown Victoria long had been the main vehicle of the NYC Yellow Cab. Over time this gas-only sedan has been replaced increasingly with hybrid vehicles with better fuel efficiency. In this analysis vehicles are divided into three types: non-hybrid sedans, hybrid sedans, and hybrid SUVs. Table 1 shows the vehicle characteristics of the most common model in each bin. The traditional type, gas-only sedan, is less efficient but has more space and a more powerful engine. The hybrid sedan is more fuel efficient but is smaller with a less powerful engine. The proportion of hybrid taxis increased from 14% in 2008 to 55% in 2013.

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[4]There is no fixed rule but many articles mentioned that drivers usually refuel. I represents an article link in Forbes. https://www.forbes.com/sites/marcwebertobias/2011/11/18/how-taxi-companies-rip-off-their-drivers/#c50b6af796af

Table 1: Most Frequent Model in Each Bin

Type	Gas-Only Sedan	Hybrid SUV	Hybrid Sedan
Model	Crown Victoria	Escape	Prius
MPG	19	34	50
Length (in)	212.0	174.7	175.6
Width (in)	78.3	71.1	68.7
Height (in)	58.3	67.9	58.7
Horse Power	224	177	132
Size (Liter)	4.6	2.5	2.0
Proportion of Bin	44.69%	34.50%	20.81%

* Ward's automotive yearbook

4 Data

4.1 Trip

NYC TLC collects data on each yellow cab's entire trip automatically as a part of the Taxicab Passenger Enhancements Project (TPEP). This rich data set covers the entirety of NYC taxi driver trips and includes vehicle and driver identification numbers. The dataset provides distance, fares, and longitude/latitude of pick-up and drop-off locations per trip. The trip data with vehicle identification number are available for 2013. This identification number can be matched with the medallion number which is unique.

4.2 Vehicle Information

NYC TLC provides the vehicle information number (VIN) of each medallion at the daily level from 2013. By scraping from the VIN information website, vehicle models are collected. Since the overlap period between trip and vehicle information data is 2013, the entire trip data in 2013 are used for analysis. Twelve million trips are observed in each month.

4.3 Gas Price

The actual gas prices that drivers paid are not available. Drivers may choose the best refueling strategy, which includes choice of gas station and frequency. Since this information is hidden, spot gasoline prices at New York Harbor are used for daily gas prices paid by drivers. Although these prices are not retail, variation will be correlated with retail prices. Gas prices in 2013 were relatively lower and more stable than gas prices in 2011 and 2012. However, the prices in 2013 were around $3.5 per gallon and the experiences with high gas prices in 2011 and 2012 may have made drivers more sensitive to gas prices. All gas price data are collected from the U.S. Energy Information Administration (EIA).[5] The fuel cost per mile traveled is calculated as gas price divided by miles per gallon of vehicle.

4.4 Shift Level

Shift level data are calculated by the summation of trip level data. Trip data only include pick-up and drop-off information. The starting time and finishing time of the shift are not observed based on trip data. Thus, most of the analysis defines the shift based on the time difference between the last drop-off and the next pick-up times. In this analysis, a 6 hour difference between fares is used as the criterion for delineating shifts, which is widely accepted in prior papers. Shift time is calculated as the difference between the first pick-up time and the last drop-off time. To eliminate unusual observations, shifts of more than 2 hours and less than 12 hours are used for estimation.

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[5]www.eia.org

4.5 Grid Cells

The demand for taxis varies by location. Many characteristics of demand at a location are constant over time. The location fixed effects can control for locations at subway stations, bus stops, population, and the proportion of residential areas. To set location dummies in estimation, Manhattan is divided into 288 cells based on 2010 census tracts. Figure 1 represents the grid map of 2010 census tracts in Manhattan area.

5 Customer Search Driving Distance

Operating a taxi comprises two types of trips: driving to deliver customers and driving while searching for customers. After dropping customers off, drivers can drive around to find customers or stay and wait for customers. Customer search can increase revenue by increasing the probability of finding customers and finding a better location. Distance while searching for customer is used as a measurement of customer searching. Economic analysis predicts that increased fuel efficiency stimulates drivers to search more by decreasing operating costs.

5.1 Theoretical Approach

I assume that the driver chooses the search driving distance (D^s) before pick-up based on profit maximization. The expected net profit of a trip with customer searching costs is

$$\pi = R(D^s, GP, MPG) - D^s * \frac{GP}{MPG} \ ,$$

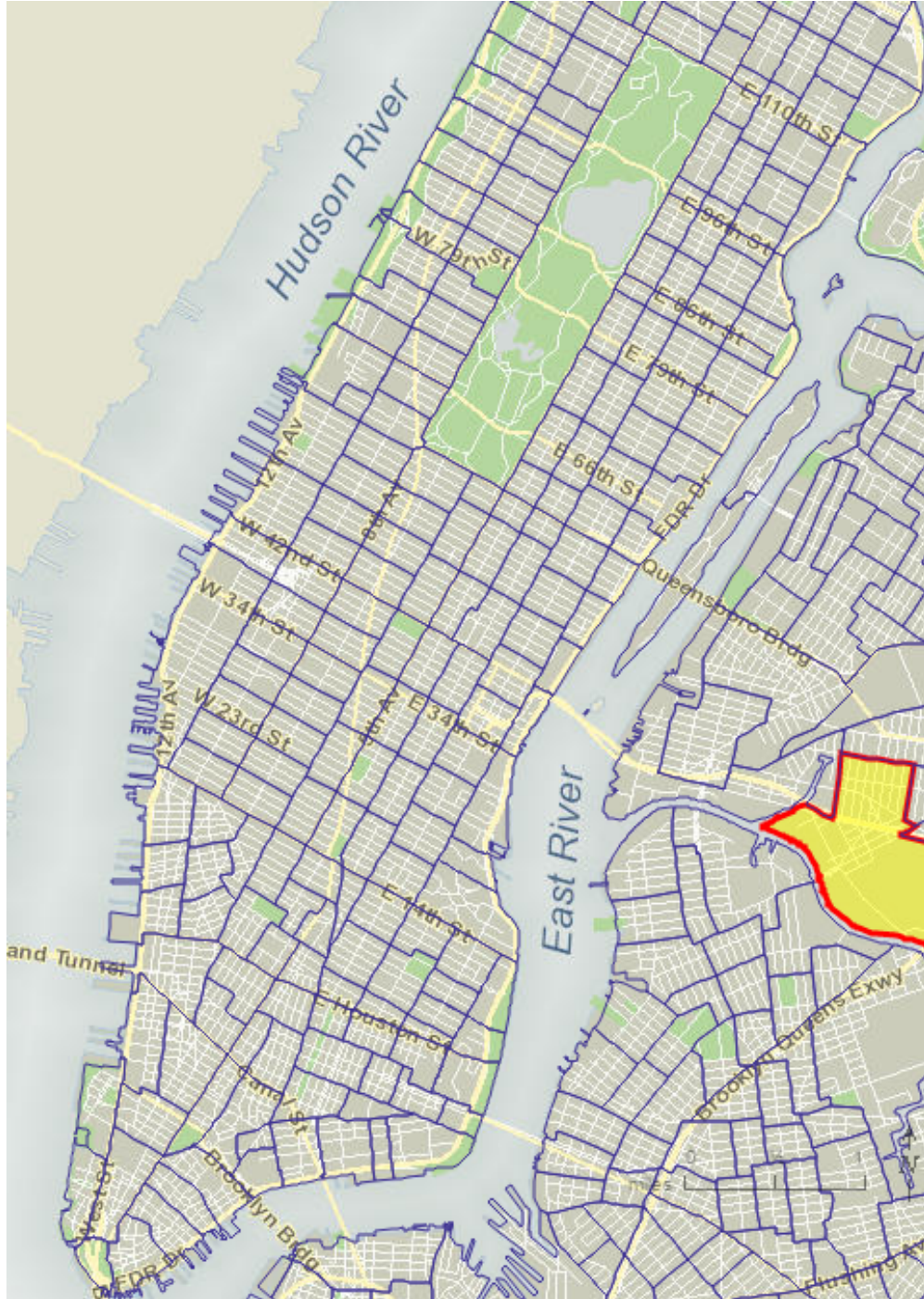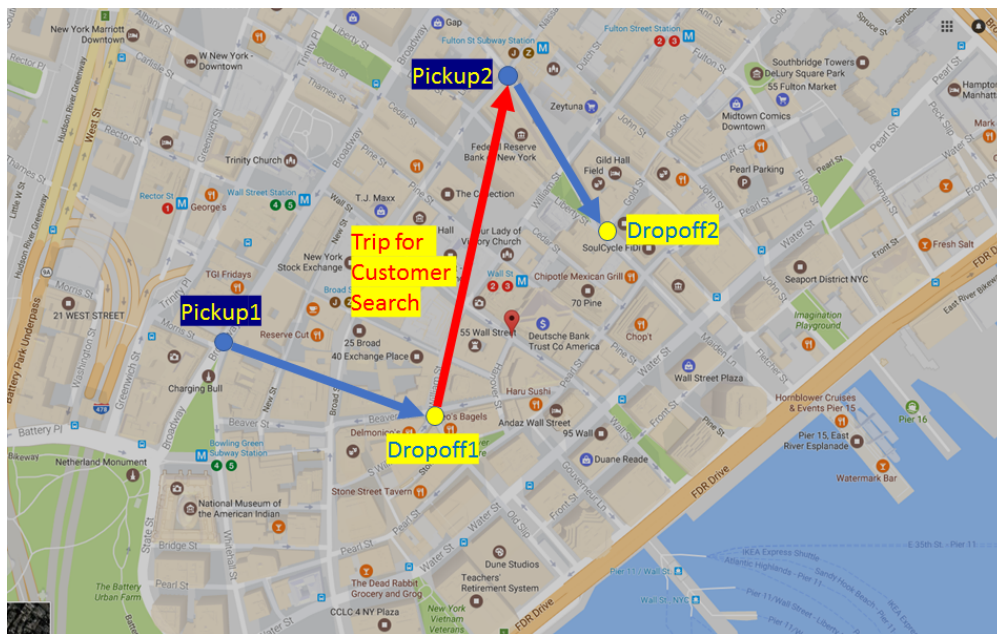Figure 1: Census Block in Manhattan Area

Figure 2: Searching Trip

The blue lines are fare trips. The red line, search trip, is defined as a trip from last dropoff place (Dropoff 1) to next pickup place (Pickup 2).

where $R(D^s, GP, MPG)$ is the average net revenue, D^s is search distance, GP is the gas price, and MPG is the miles per gallon for the operating vehicle.

I assume taxi drivers are not able to distinguish between customers in advance of picking them up. This assumption implies that fare trip distance and time are exogenous to taxi drivers when choosing search distance.

The driver's customer search problem between customers can be distilled to maximizing the following equation.

$$\max_{D^s} R(D^s, GP, MPG) - D^s \frac{GP}{MPG}$$

The first order condition for a maximum is

$$FOC : R_1(D^s, GP, MPG) = \frac{GP}{MPG} \tag{1}$$

From the first order condition, three predictions can be deduced. First, the correlation between search distance and gas prices is negative because the marginal profit decreases when gas prices increase. Second, the correlation between search distance and fuel efficiency is positive because the marginal cost of search distance is lower for more fuel-efficient vehicles. Third, the response of search distance to gas prices for more fuel-efficient taxis is higher because the increases in gas prices cause costs to rise more for gas-only taxis. The derivations of the three predictions in a profit-maximizing model are in Appendix A.

5.2 Regression Model

I developed regression (2) from the choice function for searching distance, which is derived from the first order condition in equation (1).

$$log(D^s_{i\tau}) = \delta_H + \delta_W + \delta_M + \delta_i + \delta_S + \delta_E + \delta_{HC}D_{HC} + \delta_{HS}D_{HS}$$

$$+ \beta log(GP_{i\tau}) + \beta^{HC}log(GP_{i\tau})D_{HC} + \beta^{HS}log(GP_{i\tau})D_{HS} + \epsilon_{i\tau} \qquad (2)$$

where i indexes taxi drivers, τ indexes search trip, $D^s_{i\tau}$ is search distance, δs are dummy vectors for hour (H), day of week (W), month (M), individual driver (i), last drop-off location (S), and pick-up location (E), D_{HC} is a dummy variable for hybrid sedans, D_{HS} is a dummy variable for hybrid SUVs, and $GP_{i\tau}$ is a gas price. The δ_{HC} and δ_{HS} coefficients show the baseline search distance for hybrid drivers relative to gas-only drivers when gas prices don't change, and $\epsilon_{i\tau}$ is a random error term.

The search distance, $D^s_{i\tau}$, is calculated as the linear distance between the last drop-off location and the next pick-up location. The spot price of gasoline at New York City Harbor is used for the gas prices. The coefficient of the gasoline price, β, captures the baseline response to gas price fluctuation for gas-only taxi drivers. The coefficient of the interaction term of the gasoline price and the hybrid sedan dummy, β^{HC}, shows the difference in responses to gas prices between gas-only drivers and hybrid sedan drivers. The coefficient of the interaction term of the gasoline price and the hybrid SUV dummy, β^{HS}, shows the difference in responses to gas prices between gas-only drivers and hybrid SUV drivers.

The impact of gas prices on the taxi industry could differ by day and night shift because of different congestion levels between the day and night shifts. Since the gas price influences

congestion level, the impact of fuel cost likely is not constant between day and night shifts. Thus, separate regressions are estimated for day and night shifts.

5.3 Dealing with Demand-Side Heterogeneity in Measuring the Effects of Gas Prices

In measuring the impact of gasoline prices search distance decisions, there is a potential demand-side endogeneity problem. Increases in gas prices will lead to greater demand for taxi rides because the costs of driving have risen for the customer, but the cost of the cab ride has not. As a result, the level of the coefficient for gas prices for each type of vehicle might be biased by these demand side effects. These levels would be β for the gas-only vehicles, $\beta + \beta^{HC}$ for the hybrid sedan and $\beta + \beta^{HS}$ for the hybrid SUV.

There is likely no demand-side endogeniety problem for coefficients that capture the difference in response to gasoline prices: β^{HC} for the hybrid sedan and β^{HS} for the hybrid SUV. There is no reason to expect that taxi customers would respond to a change in gas prices by demanding a specific fuel efficiency for the taxi hire. In this argument, the preference difference between low and high efficiency vehicles still exists even if this difference does not change according to gas price fluctuation. There is no monetary gain from seeking a specific fuel efficiency of vehicle because the customer is charged the same regulated fare for all taxi rides. When hailing a cab, customers tend to take the first one that comes to save on time and avoid the uncertainty about wait time for the next taxi. There may be settings where people ask for a hybrid in response when phoning for one. Even then, it is unlikely that they will alter their preference for a hybrid in response to daily fluctuations in gasoline prices over the range studied. Therefore, in analyzing the impact of gas prices on search distance, I focus the analysis on β^{HC} for the hybrid sedan and β^{HS} for the hybrid SUV.

In examining the impact of the type of vehicle on the search distance, the δ^{HC} and δ^{HS} fixed effects for hybrid sedans and hybrid SUVs might include some demand-side effects. If people with environmental interests seek to use hybrid taxis, then we would see the density of hybrid taxi seekers rise, which would reduce the search distance. This would then lead to a negative bias that works against the sign that we expect to see for δ^{HC} and δ^{HS} from supply-side decisions by the taxi drivers.

5.4 Search Distance Results

Table 2: Search Distance Coefficients and Standard Errors from Fixed Effects Regressions

Shift	All Trips	Day	Night
$log(GP_{i\tau})$*Hybrid Sedan	0.0765***	0.0519**	0.0266
	(0.019)	(0.020)	(0.029)
$log(GP_{i\tau})$*Hybrid SUV	0.1712***	0.0737**	0.1792***
	(0.032)	(0.035)	(0.043)
Hybrid Sedan	-.0205	-.0061	0.0386
	(0.020)	(0.021)	(0.030)
Hybrid SUV	-.1015***	-.0031	-.1058**
	(0.033)	(0.037)	(0.045)
$log(GP_{i\tau})$	0.3528	0.5089*	0.2407
	(0.280)	(0.287)	(0.291)
N	139,189,234	51,286,095	87,865,475

All robust standard errors are clustered at daily level.
***Significant at the 1% level; **Significant at 5% level; *Significant at 10% level.

Table 2 presents the results of estimation for search distance. The first column represents the impact of gas prices for trips in all shifts. The second column represents the impact of gas prices during day shifts. The third column represents the impact of of gas prices during night shifts.

In all estimation results, the β coefficients for $log(GP)$ are positive: 0.3528 in all trips,

0.5089 in day shift, and 0.2407 in night shift data regression results. The results imply that drivers of gas-only taxis will increase their search distance by 0.3528 percent in response to a one percent rise in gas prices in all trip regression results. These surprising results may come from the demand side bias. Increased gas prices will lead to greater demand of taxi ride because of increased customers' driving costs. This increased demand is varied by fare trip distance. Given that the taxi rates do not change with gas prices, the mix of trips taken by customers might lead them to travel increased distances by taxi. If so, taxis might end up farther from the congested areas in midtown and thus end up facing longer driving distances to search for their next customers.

In the all trip data results, the coefficient of 0.0765 for the $log(GP) * HybridSedan$ measures the difference in the effect of gas prices on search driving distance between drivers with hybrid sedans and drivers of gas-driven sedans. This coefficient implies that drivers of hybrid sedans travel 0.07 percent more miles while searching for customers than drivers of gas-only taxis when the gas prices rise by one percent. The overall difference in the search distance driven by drivers with hybrid sedans and gas-only vehicles can be shown using the combination of the coefficients of the hybrid sedan dummy of -0.0205 and the $log(GP)*HybridSedan$ variable of 0.0765. The formula is $0.0765*log(GP)-0.0205$. The gas prices varied from \$2.56 to \$3.15 over the course of the year. The natural log of the gas prices for the hybrid sedans ranged from 0.94 when the gas price was \$2.56 to 1.14 when the gas price was \$3.15. When the $log(GP)$ was 0.94, the difference is $0.0765 * 0.94 - 0.0205 = 0.0514$, which implies that the drivers of hybrids tended to drive about 5 percent more in search distance between trips than the drivers of gas-only vehicles. The calculation at the other extreme of $0.0765 * 1.14 - 0.0205 = 0.0672$ implies that the drivers of hybrids were driving about 7 percent more distance in search of customers than the drivers of all-gas vehicles.

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The coefficient of 0.1712 for $log(GP) * HybridSUV$ implies that drivers of hybrid SUVs drive 0.17 percent more while searching for customers than drivers of gas-only taxis when gas prices rise by one percent. Following a similar process as in the calculation above, the hybrid SUVs drove $0.1712 * 0.94 - 0.1015 = 0.0594$ percent more than gas taxi drivers, when the gas price was \$2.56 and $0.1712 * 1.14 - 0.1015 = 0.0949$ percent more when the gas price was \$3.15. These calculations imply that a driver of a hybrid SUV tends to drive search distance per trip from 6 percent more to 9 percent more than drivers of gas-only taxis. Each of these comparisons of search by drivers of hybrid taxis relative to search by drivers of gas-only taxis makes sense by themselves. It is somewhat surprising that the effect of the gas prices on hybrid SUV drivers is greater than the effect on hybrid sedan drivers because the miles per gallon of vehicles are lower for hybrid SUV drivers.

In the day shift results, the coefficient of 0.0519 for the $log(GP) * HybridSedan$ implies that drivers of hybrid sedans drive 0.05 percent more while searching for customers than drivers of gas-only taxis when gas prices rise by one percent. The overall difference in the search distance driven by drivers with hybrid sedans and gas-only vehicles is calculated. When the gas price was \$2.56, the difference is $0.0519 * 0.94 - 0.0061 = 0.0426$, which implies that the drivers of hybrids tended to drive about 4 percent more in search distance between trips than the drivers of gas-only vehicles. The calculation at the other extreme of $0.519 * 1.14 - 0.0061 = 0.0534$ implies that the drivers of hybrids sedan were driving about 3 percent more distance in search of customers than the drivers of gas-only vehicles. The coefficient of 0.0737 for the $log(GP) * HybridSUV$ implies that drivers of hybrid SUVs drive 0.07 percent more while searching for customers than drivers of gas-only taxis when gas prices rise by one percent. Following a similar process, the calculation for hybrid SUVs are $0.0737 * 0.94 - 0.0031 = 0.0661$ when the gas price was \$2.56 and $0.0737 * 1.14 - 0.0031 = 0.0814$

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when gas price was \$3.15. These calculations imply that a driver of a hybrid SUV tends to drive search distance per trip from 6 percent more to 8 percent more than drivers of gas-only vehicles.

In the night shift data results, the coefficient of 0.0266 for the $log(GP) * HybridSedan$ implies that drivers of hybrid sedans drive 0.03 percent more while searching for customers than drivers of gas-only taxis when gas prices rise by one percent. The overall difference between the search distance driven by drivers with hybrid sedans and gas-only vehicles is calculated. When the gas price was \$2.56, the difference is $0.0266 * 0.94 + 0.0386 = 0.0636$, which implies that the drivers of hybrids tended to drive about 0.06 percent more in search distance between trips than the drivers of gas-only vehicles. The calculation at the other extreme of $0.266 * 1.14 + 0.0386 = 0.0691$ implies that the drivers of hybrid sedans were driving about 0.07 percent more distance in search of customers than the drivers of gas-only vehicles. The coefficient of 0.1792 for the $log(GP) * HybridSUV$ implies that drivers of hybrid SUVs drive 0.18 percent more while searching for customers than drivers of gas-only taxis when gas prices rise by one percent. Following a similar process, the calculations show that the drivers of hybrid SUVs drive $0.1792 * 0.94 - 0.1058 = 0.0624$ more than drivers of gas-only vehicles when the gas price was \$2.56 and $0.1792 * 1.14 - 0.1058 = 0.0998$ more when the gas price was \$3.15. These calculations imply that a driver of a hybrid SUV tends to drive search distances per trip from 6 percent more to 10 percent more than the drivers of gas-only vehicles.

Table 3: Change of Search Distance at Day Shift by Gas Price

Gas Prices	\$ 2.56	\$ 3.15	Difference
Gas-Only Search Distance	1.61 Mile	1.79 Mile	0.18 Mile
Hybrid Sedan Search Distance	1.69 Mile	1.90 Mile	0.21 Mile
Hybrid SUV Search Distance	1.73 Mile	1.95 Mile	0.22 Mile

In summary, replacement of only-gas with hybrid vehicles stimulates drivers to travel more when searching for customers. Replacing the gas vehicle with a hybrid SUV increases search distance more than replacing it with a hybrid sedan. The overall response of gas price is higher during the night shift, but the calculated difference between distance from gas-only and hybrid is similar between day and the night shifts. The calculated difference is from 0.04 to 0.10. Table 3 shows how the search distance driven differs between drivers of hybrid sedans and of gas-only vehicles over the range of gas prices in the data set.

Increased search distances imply that fuel efficiency improvement does not decrease emissions as much as increased miles per gallon. The actual increase in miles is hard to calculate based on the current results. Here I provide a very rough calculation using strong assumptions. From the 2014 TLC factbook, the average annual driving distance per vehicle is 70,000 miles. For calculation, I assume that half of total usage, 35,000 miles, is searching distance of a gas-only taxi. The results of all trips regression represent that hybrid SUV drivers travel longer distance by 8% and hybrid sedan drivers travel longer distance by 4%. By increased searching distance, SUV operator drives 2,800 miles more, and sedan operator drives 1,400 miles more. In comparison with the private sector annual vehicle usage of 13,476 miles, these increased amounts of driving are not substantial.

6   Shift Time

For taxi drivers, fuel costs are the most important variable costs. As in other industries, increased variable costs cause producers to decrease quantity or increase price. Since the fare system is fixed by the NYC TLC, drivers only can respond to changes in fuel cost by changing working hours. The theoretical prediction of the impact of fuel improvement can

be positive or negative. The impact of decreased fuel costs decreases shift time when the substitution effect is larger than the income effect. Drivers might respond to increased fuel costs by reducing the length of shifts because some periods are not beneficial for working. In the opposite situation, decreased fuel costs increase shift time when drivers try to reach their daily income level. Two theoretical approaches about extreme cases are represented.

6.1 Theoretical Model with Only Substitution Effects

A simple theoretical model without the income effect can be used to predict how workers will decrease shift time in response to changing fuel costs. Assume the utility function of a driver is quasi-linear in wealth. The utility equation is

$$U(w, T) = w + u(T)$$

where, w is wealth level, T is working hours, and $u(T)$ is utility of working hours. The driver's utility of working hours is assumed to be a negative convex function of working hours with $u'(T) > 0$ and $u''(T) < 0$. The assumption of a quasi-linear wealth function implies that the income effect is eliminated.

The driver's working hour problem is

$$\max_{T} E + F(T, GP, MPG) + u(T)$$

When utility maximizing, the first order condition is

$$FOC : F_1(T, GP, MPG) + u'(T) = 0 \tag{3}$$

From the first order condition, three predictions of correlation can be made. First, the correlation between shift time and gas prices is negative because marginal profit decreases when gas prices increase. Second, the correlation between shift time and fuel efficiency is positive because marginal profit increases when the taxi has higher miles per gallon. Third, shift time responds more positively to gas prices when fuel efficiency is higher because increases in gas prices cause profits to decrease more for gas-only taxis. Mathematical derivations of each predictions are included in appendix B.

6.2   Theoretical Model with Target Income Level

A simple theoretical model without the target income level can be used to predict how workers will increase shift time in response to changing fuel costs. Assume the utility function of a driver is quasi-linear in wealth with an income target. The utility equation with an income target $\bar{w}$ is

$$
U(w,T) = \begin{cases} \bar{w} + u(T) & , w \geq \bar{w} \\ 0 & , w < \bar{w} \end{cases}
$$

In addition, the profit function is assumed to be equal to the function in the previous section. i.e., $w = E + F(T, GP, MPG)$.

At the above income target level $\bar{w}$, the driver's working hour problem is

$$
\max_T \bar{w} + u(T)
$$

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When utility maximizing, the first order condition is

$$FOC : \bar{w} = E + F(T, GP, MPG) \tag{4}$$

From the first order condition, three predictions come from the comparative statistics. First the correlation between shift time and gas prices is positive because profit decreases when gas prices increase. Second, the correlation between shift time and fuel efficiency is negative because profit decreases when miles per gallon increase. Third, shift time does not rise as much when gas prices rise when the taxi is more fuel efficient because more time worked leads to higher profits. The derivation of each prediction is in appendix C.

6.3   Regression Model

As with search distance, the regression equation is derived from the shift time choice function in either equation (3) and (4).

$$
\begin{aligned}
log(T_{it}) = {} & \delta_{SH} + \delta_W + \delta_M + \delta_i + \gamma^{HC} D_{HC} + \gamma^{HS} D_{HS} \\
& + \beta log(GP_{it}) + \beta^{HC} log(GP_{it}) D_{HC} + \beta^{HS} log(GP_{it}) D_{HS} + \epsilon_{it} \ ,
\end{aligned}
\tag{5}
$$

where i indexes taxi drivers, t indexes shift, T is total shift time, δs are dummy vectors for starting hour (SH), day of week (W), month (M), and individual driver (i), D_{HC} is a dummy variable of the hybrid sedan bin, γs are parameters of dummy variables for hybrid vehicles, D_{HC} is a dummy variable for the hybrid sedan, D_{HS} is a dummy variable for the hybrid SUV, and GP_{it} is the gas price. Most variables are equivalent to the ones in the search distance model, equation (2). The location dummies are eliminated.

As before, I estimate the shift time model separately for the day and night shifts. The night shift usually starts from 4PM to 6PM. Day shift drivers need to deliver the taxi to night shift drivers and the location tends to be in the middle of Manhattan. In addition, the demand around noon is higher than around midnight. For this reason, the night shift driver has more flexible shift times than day shift drivers. Thus, estimations are separately conducted for day and night shifts.

6.4 Shift Time Results

Table 4: Shift Time Coefficients and Standard Errors from Fixed Effects Regressions

Shift	All Shift	Day	Night
$log(GP_{it})$*Hybrid Sedan	-.0027	-.0067	0.0168
	(0.011)	(0.012)	(0.012)
$log(GP_{it})$*Hybrid SUV	-.0280*	0.0094	-.0095
	(0.017)	(0.019)	(0.022)
Hybrid Sedan	0.0006	0.0046	$-.0155$
	(0.010)	(0.012)	(0.012)
Hybrid SUV	0.0221	0.0044	0.0081
	(0.017)	(0.019)	(0.022)
$log(GP_{it})$	-.0213	-.0194	-.0306
	(0.053)	(0.034)	(0.077)
N	5,550,513	2,697,724	2,852,789

All robust standard errors are clustered at daily level.
***Significant at the 1% level; **Significant at 5% level; *Significant at 10% level.

Table 4 represents the results of estimation for shift times. The first column represents the impact of gas prices for shift time in all shifts. The second column represents the impact of gas prices during day shifts. The third column represents the impact of gas prices during night shifts. Similar to the results in the search distance regression, the coefficient of logged gas prices ($log(GP)$) is potentially biased because of a demand side response to a changing

gas price. If the logic about controlling for demand-side endogeneity discussed earlier is used, the coefficients β^{HC} and β^{HS} for the difference in response to gas prices will not be affected by the demand side changes. With the time-invariant preferences between gas-only and hybrid taxi, the bias is captured at the coefficient of $log(GP)$ and other variables are unbiased.

All parameters, except one, are small and statistically insignificant. Only the parameter of the interaction term of the logged gas price and hybrid SUV dummy in the all shift regression is statistically significant. Not much emphasis should be given to this coefficient because the coefficients of the interaction term of logged gas price and hybrid SUV dummy in the night and day shift regressions are statistically insignificant.

In summary, the results show that drivers do not change shift times in response to gas prices or fuel efficiency of their taxi. The results do not support income effects or target income behavior.

7 Vehicle Usage Decision

The two estimations above deal with the drivers' decisions during shifts. Before these two decisions, drivers decide whether to participate in a shift or not. The medallion owner might decide not to use or rent her cab for maintenance or other reasons when the gas price is high. Fuel efficiency improvements may increase the probability of operation. To estimate the impact of fuel efficiency improvements on vehicle usage decisions, a probit regression model is conducted. When the gas price is high, the average profit decreases and drivers are less likely to operate taxis. Even if the expected profit is positive, owners may choose to check or repair their vehicles when gas prices are higher. The impact of gas price on gas-only

vehicles is higher than hybrid vehicle.

7.1 Latent Variable Equation

I estimate the model for choice to drive using a profit regression.

$$
\begin{aligned}
y_{it} = {} & \delta_W + \delta_M + \delta_{Night} + \gamma^{HC} D_{HC} + \gamma^{HS} D_{HS} \\
& + \beta log(GP_{it}) + \beta^{HC} log(GP_{it}) D_{HC} + \beta^{HS} log(GP_{it}) D_{HS} + \epsilon_{it} \ ,
\end{aligned}
\tag{6}
$$

where i indexes taxi drivers, t indexes shift, y_{it} is a latent variable that captures whether the driver operates the vehicle, δs are dummy vectors for day of week (W), month (M), and night shift (Night), γs are the parameters of dummy variable for hybrid vehicles, D_{HC} is a dummy variable for hybrid sedans, D_{HS} is a dummy variable of hybrid SUVs, and GP_{it} is a gas price. The individual driver dummies are eliminated because potential drivers are unknown.

7.2 Vehicle Usage Decision Results

Table 5 shows the coefficients from probit estimations. Table 6 shows the marginal effects. The first columns in both tables represent the impact of gas prices for vehicle usage probability in all shifts. The second columns represent the impact of gas prices on vehicle operation during day shifts. The third columns represent the impact of of gas prices on vehicle operations during night shifts.

In the results for all shifts, the coefficients of the hybrid SUV are statistically significant but the hybrid sedan coefficients are not statistically significant. From here, I focus on the marginal effects in table 6. The marginal effect of 0.0633 for the $log(GP) * HybridSUV$

Table 5: Vehicle Usage Decision Coefficients and Standard Errors from Probit Regressions

Shift	All Shift	Day	Night
$log(GP_{it})$*Hybrid Sedan	0.1588	0.3130***	-.0925
	(0.099)	(0.103)	(0.124)
$log(GP_{it})$*Hybrid SUV	0.2605**	0.4466***	-.0505
	(0.129)	(0.121)	(0.183)
Hybrid Sedan	-.1560	-.3369***	0.1378
	(0.099)	(0.104)	(0.125)
Hybrid SUV	-.3308**	-.5633***	0.0534
	(0.130)	(0.122)	(0.185)
$log(GP_{it})$	-.1985	-.4149	0.1322
	(0.433)	(0.389)	(0.556)
Night	0.5461***		
	(0.015)		
N	7,778,375	3,889,187	3,889,187

All robust standard errors are clustered at daily level.
***Significant at the 1% level; **Significant at 5% level; *Significant at 10% level.

shows that hybrid SUVs are chosen more than gas vehicles when gas price rise.

The overall difference in the vehicle usage probability of hybrid SUV and gas-only vehicles can be shown using the combination of the marginal effects of the hybrid SUV dummy of -0.0804 and the $log(GP) * HybridSUV$ variable of 0.0633. The formula is $0.0633 * log(GP) - 0.0804$. When the log(GP) was 0.94 at a gas price of \$2.56, the difference is $0.0633 * 0.94 - 0.0804 = -0.0209$, which implies that the taxi drivers tend to drive hybrid SUVs 2 % less than gas-only vehicles. When gas prices are at the maximum in the sample, the calculation, $0.0633 * 1.14 - 0.0804 = -0.008$, implies that the hybrid SUV tends to be used 0.8 percent less than gas-only vehicles.

In the day shift results, all coefficients are statistically significant. The marginal effect of -0.1273 for the $log(GP)$ table 6 suggests that gas-only vehicle are less likely to be used in a shift when gas prices rise. The marginal effect of 0.0960 for the $log(GP) * HybridSedan$

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Table 6: Marginal Effect of Vehicle Usage Decision Coefficients and Standard Errors from Probit Regressions

Shift	All Shift	Day	Night
$log(GP_{it})$*Hybrid Sedan	0.0386	0.0960***	-.0164
	(0.024)	(0.031)	(0.022)
$log(GP_{it})$*Hybrid SUV	0.0633**	0.1370***	-.0089
	(0.031)	(0.037)	(0.032)
Hybrid Sedan	-.0379	-.1033***	0.0244
	(0.031)	(0.032)	(0.022)
Hybrid SUV	-.0804**	-.1728***	0.0094
	(0.031)	(0.037)	(0.032)
$log(GP_{it})$	-.0482	-.1273	0.0234
	(0.105)	(0.119)	(0.098)
Night	0.1328***		
	(0.003)		
N	7,778,375	3,889,187	3,889,187

All robust standard errors are clustered at daily level.
***Significant at the 1% level; **Significant at 5% level; *Significant at 10% level.

measures the difference in the effect of gas prices on vehicle usage probability between drivers with hybrid SUV and drivers of gas-driven impact. This shows that drivers are more likely to respond to higher gas prices by driving a shift with a hybrid sedan than by driving a shift with a gas-only vehicle.

The overall difference in the vehicle usage probability of hybrid Sedan and gas-only vehicles can be shown using the combination of the marginal effects of the hybrid Sedan dummy of -0.1033 and the $log(GP) * HybridSedan$ variable of 0.0960. The formula is $0.0960 * log(GP) - 0.1033$. When the $log(GP)$ was 0.94 at a low gas price of \$2.56, the difference is $0.0960 * 0.94 - 0.1033 = -0.0131$, which implies that the drivers tended to use the hybrid sedan one percent less than gas-only vehicles. The calculation at the highest gas price of $0.0960 * 1.14 - 0.1033 = 0.006$ implies that the drivers tended to use or rent the hybrid sedan 0.6 percent more often than gas-only vehicles.

The marginal effect of 0.1370 for the $log(GP) * HybridSUV$ shows that gas price rise of one percent raised the probability of using hybrid SUV by 0.1370 more than the use of a gas-only vehicle. The overall difference in the vehicle usage probability of hybrid SUV and gas-only vehicles can be shown using the combination of the marginal effects of the hybrid SUV dummy of -0.1728 and the $log(GP) * HybridSUV$ variable of 0.1370. The formula is $0.1370 * log(GP) - 0.1728$. When the log(GP) was 0.94 at a low gas price of \$2.56, the difference is 0.1370 * 0.94 - 0.1728 = -0.0440, which implies that the hybrid SUV was used or rented 4 percent less more than gas-only vehicles. When the gas price was at the maximum, the calculation, 0.1370 * 1.14 - 0.1728 = -0.0166, implies that the hybrid SUV owners tend to use or rent 1.6 percent less than gas-only vehicles.

In contrast to the day shift, all coefficients are not statistically significant in the night shift results. This implies that the probability of using hybrids and gas-only vehicles is no

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different during the night shift. The different results between day and night regression may come from the average of revenue and congestion. After rush hours, the congestion level is not nearly as large during the shift. In addition, the impact of requested maintenance might influence only the day shift decisions because the auto shops are typically open only during the day.

In summary, the impact of fuel efficiency improvement affects only the probability of vehicle usage in day shifts. Higher gas prices tend to lead to the use of more efficient vehicles during the day shift.

Table 7: Change of Taxi Industry at Day Shift by Gas Price

Gas Prices	$ 2.56	$ 3.15
Gas-Only Participation	77.46%	74.80%
Hybrid Sedan Participation	81.39%	80.82%
Hybrid SUV Participation	72.93%	73.15%
Average Operating Taxi	10124	9950
Average MPG	26.38	26.53

In addition, I compare how the average number of vehicles and fuel efficiency are changed by gas price. Table 7 shows how the probability of driving each type of taxi changes between the low and the high gas price. The parameters from the day shift are used for the calculations during Monday in January. As the gas price rises from the minimum to the maximum, the participation probability for hybrid SUVs rises. Meanwhile, the participation probabilities for hybrid sedans and gas-only taxis fall. However, the probability falls only 0.5 percentage points for the hybrid sedan, compared with 2.5 percentage points for the gas-only vehicle. The reduced participation rate of taxi causes the total number of operating taxi to fall from 10124 to 9950. Meanwhile, the average fuel efficiency is increased because of different responses between vehicle types. In summary, when the gas price is high, average fuel efficiency of taxi increases but the total number of active taxi falls.

8   Conclusion

In this paper, I estimate the impact of improved fuel efficiency on the driving behaviors of NYC taxi drivers by using fixed effect models. Three types of taxi driver decisions are considered: customer search, working hours, and shift participation.

The regression results show that drivers of hybrid taxis drive more in search for customers than drivers of gas-only taxis when the gas price is high. In addition, hybrid drivers search relatively more than gas-only taxi drivers in response to an increase in gas prices. Similarly, the probability of operating using high efficiency vehicles rises when gas prices rise. Within the range of gas prices studied, however, the average probability of operation is similar between low and high efficiency vehicles. In summary, fuel efficiency improvement only increases NYC taxi drivers' trip distances when they are searching for customers. Drivers do not work longer shifts with high efficiency vehicles, and the probability of using both hybrid and gas-only vehicles is similar.

9 Reference

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Appendices

A   Summary Statistics

Table 8: Summary Statistics

	Min	Mean	Max	S.D
Search Distance (Mile)	0.000	0.8864	62.300	1.63
Fare Distance (Mile)	0.002	2.1087	60.603	2.25
Shift Duration (Minute)	120.02	501.52	719.98	124.77
Gas Price (Dollar)	2.56	2.82	3.16	0.14
Operating Probability	0	0.7861	1	0.41
Obs Search Trip		139,392,953		
Obs Shift		5,550,513		
Obs Operation Decision		7,778,375		
Number of drivers		43,191		
Number of vehicles		13,303		

B   Derivation of Comparative Statistics for Searching Distance

Revisit the expected net profit of a trip with customer searching costs.

$$\pi = R(D^s, GP, MPG) - D^s * \frac{GP}{MPG} \ ,$$

where $R(D^s, GP, MPG)$ is the average net revenue, D^s is search distance, GP is the gas price and MPG is the miles per gallon for the operating vehicle.

I assume taxi drivers are not able to distinguish between customers in advance of picking them up. This assumption implies that fare trip distance and time are exogenous to

taxi drivers when choosing search distance. The revenue function is assumed to be a positive and increasing concave function of search distance. Therefore, $R(D^s, GP, MPG) > 0$ for all D^s, $\frac{dR}{dD^s}(D^s, GP, MPG) = R_1(D^s, GP, MPG) > 0$ and $\frac{d^2R}{(dD^s)^2}(D^s, GP, MPG) = R_{11}(D^s, GP, MPG) < 0$. In addition, the concavity of R is assumed as constant over the miles per gallon. Thus, $R_{11}(D^s, GP, MPG) = R_{11}(D^s, GP)$ for all MPG. Revenue is also assumed to fall at a diminishing rate with gas prices. Thus,

$\frac{dR}{dGP}(D^s, GP, MPG) = R_2(D^s, GP, MPG) < 0$ and

$\frac{d^2R}{(dGP)^2}(D^s, GP, MPG) = R_{22}(D^s, GP, MPG) \leq 0$

The driver's customer search problem between customers can be distilled to maximizing the following equation.

$$\max_{D^s} R(D^s, GP, MPG) - D^s\frac{GP}{MPG}$$

The first order condition for a maximum is

$$FOC: R_1(D^s, GP, MPG) = \frac{GP}{MPG} \tag{7}$$

B.1   The Correlation between Search Distance and Gas Prices is Negative.

Let $D^{s*}(GP, MPG)$ be the solution of the first order condition, equation (1). After plugging $D^{s*}(GP, MPG)$ into equation (1), the derivative of both sides of equation (1) with respect to gas prices is

$$R_{11}(D^s, GP, MPG)D^{s*}_1(GP, MPG) + R_{12}(D^s, GP, MPG) = \frac{1}{MPG}$$

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, where $D^{s*}_1(GP, MPG) = \dfrac{dD^{s*}}{dGP}(GP, MPG)$

The derivative of search distance with respect to gas prices is negative.

$$D^{s*}_1(GP, MPG) = \frac{\dfrac{1}{MPG} - R_{12}(D^s, GP, MPG)}{R_{11}(D^s, GP, MPG)} < 0 \tag{8}$$

The denominator $R_{11}(D^s, GP, MPG)$ is negative under the second order condition of maximization. $R_{12}(D^s, GP, MPG) < 0$ because marginal revenue decreases when gas prices increase. Thus, the numerator, $\dfrac{1}{MPG} - R_{12}(D^s, GP, MPG)$, is positive. The division of a positive numerator by a negative denominator implies that the correlation between search distance and gas prices is negative.

B.2 The Correlation between Search Distance and Fuel Efficiency is Positive.

This argument is similar to the above argument. After plugging $D^{s*}(GP, MPG)$ into equation (1), the derivative of both sides of equation (1) with respect to miles per gallon is

$$R_{11}(D^s, GP, MPG)D^{s*}_2(GP, MPG) + R_{13}(D^s, GP, MPG) + GP = 0$$

, where $D^{s*}_2(GP, MPG) = \dfrac{dD^{s*}}{dMPG}(GP, MPG)$

The derivative of search distance with respect to the taxi's miles per gallon is positive.

$$D^{s*}_2(GP, MPG) = \frac{-GP - R_{13}(D^s, GP, MPG)}{R_{11}(D^s, GP, MPG)} > 0 \tag{9}$$

The denominator $R_{11}(D^s, GP, MPG)$ is negative under the second order condition of

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maximization. $R_{13}(D^s, GP, MPG) > 0$ because marginal revenue of search distance increases when taxi's miles per gallon. Thus, the numerator, $-GP - R_{13}(D^s, GP, MPG)$, is negative. The division of a negative numerator by a negative denominator implies that the correlation between search distance and gas prices is positive.

B.3 The Response of Search Distance to Gas Prices in Creases When Miles per Gallon is Higher.

I am seeking the sign of the coefficient of the interaction term between gas prices and miles per gallon in the regression equation. The interaction terms of gas prices and hybrid vehicle dummies show how the response of search distance varies when the fuel efficiency of taxi changes.

Let MPG_{Hyb} and MPG_{Gas} such that $MPG_{Hyb} > MPG_{Gas}$ and set up two equations, one plugging MPG_{Hyb} into equation (2) and another plugging MPG_{Gas} into equation (2).

$$D^{s*}_1(GP, MPG_{Hyb}) = \frac{\dfrac{1}{MPG_{Hyb}} - R_{12}(D^s, GP, MPG_{Hyb})}{R_{11}(D^s, GP, MPG_{Hyb})} \tag{10}$$

$$D^{s*}_1(GP, MPG_{Gas}) = \frac{\dfrac{1}{MPG_{Gas}} - R_{12}(D^s, GP, MPG_{Gas})}{R_{11}(D^s, GP, MPG_{Gas})} \tag{11}$$

The different response on gas price is the difference between the correlation between search distance and gas prices with high efficiency vehicle and low efficiency vehicles. This difference is calculated by subtracting equation (5) from equation (4).

$$D^{s*}_1(D^s, GP, MPG_{Hyb}) - D^{s*}_1(D^s, GP, MPG_{Gas})$$

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If I assume that $R_{113} = 0$, i.e. the second derivative of revenue function with respect to search distance (R_{11}) is unaffected by changes in the miles per gallon. Thus, $R_{11}(D^s, GP, MPG_{Hyb}) = R_{11}(D^s, GP, MPG_{Gas}) = R_{11}(D^s, GP)$.

The difference in equation is positive.

$$
D^{s*}_1(D^s, GP, MPG_{Hyb}) - D^{s*}_1(D^s, GP, MPG_{Gas})
$$
$$
= \frac{\dfrac{1}{MPG_{Hyb}} - \dfrac{1}{MPG_{Gas}} - R_{12}(D^s, GP, MPG_{Hyb}) + R_{12}(D^s, GP, MPG_{Gas})}{R_{11}(D^s, GP)} > 0 \tag{12}
$$

Increases in gas prices cause revenue to decrease more for gas-only taxis. Thus, $0 > R_{12}(D^s, GP, MPG_{Hyb}) > R_{12}(D^s, GP, MPG_{Gas})$. which implies that the numerator is negative.

The denominator $R_{11}(D^s, GP, MPG)$ is negative under the second order condition of maximization. The first part of the numerator, $\dfrac{1}{MPG_{Hyb}} - \dfrac{1}{MPG_{Gas}}$, is negative because $MPG_{Hyb} > MPG_{Gas}$. The second term, $-R_{12}(D^s, GP, MPG_{Hyb}) + R_{12}(D^s, GP, MPG_{Gas})$, is negative by the assumption that $R_{12}(D^s, GP, MPG_{Hyb}) > R_{12}(D^s, GP, MPG_{Gas})$. The division of a negative numerator by a negative denominator implies that the difference in response to gas price on search distance by fuel efficiency improvement is positive.

C Derivation of Comparative Statics for Shift Time with Only the Substitution Effect

Revisit the utility equation without income effect in the body of the paper.

$$
U(w, T) = w + u(T)
$$

where, w is wealth level, T is working hours, and $u(T)$ is utility of working hours. The driver's utility of working hours is assumed to be a negative convex function of working hours with $u'(T) > 0$ and $u''(T) < 0$. The assumption of a quasi-linear wealth function implies that the income effect is eliminated.

The wealth level is determined by an endowment (E) and the profit of driving which depends on working hours, gas prices and fuel efficiency $w = E + F(T, GP, MPG)$. The profit function is assumed to be greater than or equal to zero at all times, $F(T, GP, MPG) \geq 0$ for all T. The marginal profit of time $(f(T, GP, MPG))$ is positive $\frac{dF}{dT}(T, GP, MPG) = F_1(T, GP, MPG) > 0$ for all T. The second derivative of the profit function with respect to time is negative $\frac{d^2F}{dT^2}(T, GP, MPG) = F_{11}(T, GP, MPG) < 0$. In addition, I assume that F_{11} is not changed by the miles per gallon of the taxi drivers. Thus, $F_{11}(T, GP, MPG) = F_{11}(T, GP)$.

The driver's working hour problem is

$$\max_T E + F(T, GP, MPG) + u(T)$$

When utility maximizing, the first order condition is

$$FOC : F_1(T, GP, MPG) + u'(T) = 0 \tag{13}$$

From here, I present three theoretical predictions of correlations for regression models. First the correlation between shift time and gas prices is negative. Second, the correlation between shift time and fuel efficiency is positive. Third, shift time responds more positively to gas price when fuel efficiency is higher.

C.1 The Correlation between Shift Time and Gas Prices is Negative.

Let $T^*(GP, MPG)$ be the solution of the first order condition, equation (8). After plugging $T^*(GP, MPG)$ into equation (8), the derivative of both sides of equation (8) with respect to gas prices is

$$F_{11}(T, GP, MPG) \, T_1^*(GP, MPG) + F_{12}(T, GP, MPG) = -u''(T^*)T_1^*(GP, MPG) \, ,$$

where $T_1^*(GP, MPG) = \dfrac{dT^*}{dGP}(GP, MPG)$

The derivative of shift hours with respect to gas prices is negative

$$T_1^*(GP, MPG) = \frac{-F_{12}(T, GP, MPG)}{F_{11}(T, GP, MPG) + u''(T^*)} < 0 \tag{14}$$

The denominator $F_{11}(T, GP, MPG) + u''(T)$ is negative under the second order condition of maximization. $F_{12}(T, GP, MPG) < 0$ because marginal profit decreases when gas prices increase. Thus, the numerator, $-F_{12}(T, GP, MPG)$ is positive. The division of a positive numerator by a negative denominator implies that the correlation between shift time and gas prices is negative.

C.2   The Correlation between Shift Time and Fuel Efficiency is Positive.

This argument is similar to the above argument. After plugging $T^*(GP, MPG)$ into equation (8), the derivative of both sides of equation (8) with respect to miles per gallon is

$$F_{11}(T, GP, MPG)\, T_2^*(GP, MPG) + F_{13}(T, GP, MPG) = -u''(T^*)T_2^*(GP, MPG) \,,$$

where $T_2^*(GP, MPG) = \dfrac{dT^*}{dMPG}(GP, MPG)$

The derivative of search distance with respect to miles per gallon is positive.

$$T_2^*(GP, MPG) = \frac{-F_{13}(T, GP, MPG)}{F_{11}(T, GP, MPG) + u''(T^*)} > 0 \tag{15}$$

The denominator $F_{11}(T, GP, MPG) + u''(T)$ is negative under the second order condition of maximization. $F_{13}(T, GP, MPG) > 0$ because marginal profit increases when the taxi has higher miles per gallon. Thus, the numerator, $-F_{13}(T, GP, MPG)$, is negative. The division of a negative numerator by a negative denominator implies that the correlation between shift time and gas prices is positive.

C.3   The Response of Shift Time to Gas Prices increases When Miles per Gallon is Higher.

As in the search distance regression, I also am seeking the sign of the coefficient of the interaction term between gas prices and miles per gallon in the regression equation. The interaction terms of gas prices and hybrid vehicle dummies show how the response of search distance varies when the fuel efficiency of taxi changes.

Let $MPG_{Hyb} > MPG_{Gas}$ and set up two equations, one plugging MPG_{Hyb} into equation (9) and another plugging MPG_{Gas} into equation (9).

$$T_1^*(T, GP, MPG_{Hyb}) = \frac{-F_{12}(T, GP, MPG_{Hyb})}{F_{11}(T, GP) + u''(T)} \tag{16}$$

$$T_1^*(T, GP, MPG_{Gas}) = \frac{-F_{12}(T, GP, MPG_{Gas})}{F_{11}(T, GP) + u''(T)} \tag{17}$$

The different response on gas price is the difference between the correlation between shift time and gas prices with high efficiency vehicle and low efficiency vehicles. This difference is calculated by subtracting equation (12) from equation (11).

$$T_1^*(T, GP, MPG_{Hyb}) - T_1^*(T, GP, MPG_{Gas})$$

If I can assume that $F_{113} = 0$, i.e. the second derivative of the profit function with respect to working hours F_{11} is unaffected by changes in the mils per gallon. Thus, $F_{11}(T, GP, MPG_{Hyb}) = F_{11}(T, GP, MPG_{Gas}) = F_{11}(T, GP)$.

The difference in equation is positive.

$$T_1^*(T, GP, MPG_{Hyb}) - T_1^*(T, GP, MPG_{Gas})$$
$$= \frac{-F_{12}(T, GP, MPG_{Hyb}) + F_{12}(T, GP, MPG_{Gas})}{F_{11}(T, GP) + u''(T)} > 0 \tag{18}$$

Increases in gas prices cause profits to decreases more for gas-only taxis. Thus, $0 > F_{12}(T, GP, MPG_{Hyb}) > F_{12}(T, GP, MPG_{Gas})$, which implies that the numerator is negative. The denominator $F_{11}(T, GP) + u''(T)$ is negative under the second order condition of maximization. The division of a negative numerator by a negative denominator implies that the difference in response to gas price on shift time by fuel efficiency improvement is positive.

D   Derivation of Comparative Statistics for Shift time with Target Income Level

Revisit the utility equation with income target $\bar{w}$.

$$U(w,T) = \begin{cases} \bar{w} + u(T) & , w \geq \bar{w} \\ 0 & , w < \bar{w} \end{cases}$$

In addition, the profit function is assumed to be equal to the function in the previous section. i.e., $w = E + F(T, GP, MPG)$.

At the income target level $\bar{w}$, the driver's working hour problem is

$$\max_{T} \bar{w} + u(T)$$

When utility maximizing, the first order condition is

$$FOC : \bar{w} = E + F(T, GP, MPG) \tag{19}$$

From here, I present three theoretical predictions of correlations for the regression model. First the correlation between shift time and gas prices is positive. Second, the correlation between shift time and fuel efficiency is negative. Third, shift time does not rise as much when gas prices rise when the taxi is more fuel efficient.

D.1 The Correlation between Shift Time and Gas Prices is Positive.

Let $T^*(GP, MPG)$ be the solution of the first order condition, equation (14). After plugging $T^*(GP, MPG)$ into equation (14), the derivative of both sides of equation (14) with respect to gas prices is

$$F_1(T, GP, MPG) \ T_1^*(GP, MPG) + F_2(T, GP, MPG) = 0 \ ,$$

where $T_1^*(GP, MPG) = \dfrac{dT^*}{dGP}(GP, MPG)$

The derivative of shift hours with respect to gas prices is positive.

$$T_1^*(GP, MPG) = \frac{-F_2(T, GP, MPG)}{F_1(T, GP, MPG)} > 0 \qquad (20)$$

The denominator $F_1(T, GP, MPG))$ is positive when drivers gain more profit with more working hours. The numerator $-F_2(T, GP, MPG)$ is positive because profit decreases when gas prices increase. The division of a positive numerator by a positive denominator implies that the correlation between shift time and gas prices is positive.

D.2 The Correlation between Shift Time and Fuel Efficiency is Negative.

After plugging $T^*(GP, MPG)$ into equation (14), the derivative of both sides of equation (14) with respect to miles per gallon is

$$F_1(T, GP, MPG)T_2^*(GP, MPG) + F_3(T, GP, MPG) = 0$$

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, where $T_2^*(GP, MPG) = \dfrac{dT^*}{dMPG}(GP, MPG)$

The derivative search distance by miles per gallon is negative.

$$T_2^*(GP, MPG) = \frac{-F_3(T, GP, MPG)}{F_1(T, GP, MPG)} < 0 \tag{21}$$

The denominator $F_1(T, GP, MPG)$ is positive when drivers gain more profit with more working hours. The numerator $-F_3(T, GP, MPG)$ is negative because profit decreases when miles per gallon increase. The division of a positive numerator by a negative denominator implies that the correlation between shift time and gas prices is negative.

D.3 The Impact of Changing Miles per Gallon on the Response of Shift Time to Gas Price is Negative.

I am seeking the sign of the coefficient of the interaction term between gas prices and miles per gallon in the regression equation. The interaction terms of gas prices and hybrid vehicle dummies show how the response of search distance varies when the fuel efficiency of taxi changes.

Let $MPG_{Hyb} > MPG_{Gas}$ and set up two equations, one plugging MPG_{Hyb} into equation (15) and another plugging MPG_{Gas} into equation (15).

$$T_1^*(T, GP, MPG_{Hyb}) = \frac{-F_2(T, GP, MPG_{Hyb})}{F_1(T, GP)} \tag{22}$$

$$T_1^*(T, GP, MPG_{Gas}) = \frac{-F_2(T, GP, MPG_{Gas})}{F_1(T, GP)} \tag{23}$$

The different response on gas price is the difference between the correlation between shift

time and gas prices with high efficiency vehicle and low efficiency vehicles. This difference is a subtraction equation (18) from equation (17).

$$T_1^*(T, GP, MPG_{Hyb}) - T_1^*(T, GP, MPG_{Gas})$$

The difference in the response to gas prices between the hybrid and the gas-only vehicle is negative.

$$
\begin{aligned}
T_1^*(T, GP, MPG_{Hyb}) - T_1^*(T, GP, MPG_{Gas}) \\
= \frac{-F_2(T, GP, MPG_{Hyb}) + F_2(T, GP, MPG_{Gas})}{F_1(T, GP)} < 0
\end{aligned}
\tag{24}
$$

Profits decrease more in response to for gas-only vehicle than for hybrid vehicle. Thus, $0 > F_2(T, GP, MPG_{Hyb}) > F_2(T, GP, MPG_{Gas})$.

The denominator $F_1(T, GP)$ is positive because more time worked leads to higher profits. The numerator, $-F_2(T, GP, MPG_{Hyb}) + F_2(T, GP, MPG_{Gas})$, is negative because $F_2(T, GP, MPG_{Hyb}) > F_2(T, GP, MPG_{Gas})$. The division of a negative numerator by a positive denominator implies that the difference in response to gas price on shift time by fuel efficiency improvement is negative.

All of these predictions are opposite to the predictions without income effects.