Hailing in the Rain: Temporal and Weather-Related Variations in Taxi Ridership and Taxi Demand-Supply Equilibrium

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Word count: 6230 + 6 Figures + 1 Tables = 7980
Abstract: 238

Paper Submitted for Presentation and Publication at the
Transportation Research Board's 92nd Annual Meeting, Washington, D.C., 2013

ABSTRACT

The current study investigates temporal and weather-related variation in taxi ridership patterns in New York City (NYC) from the perspective of demand-supply equilibrium. For this purpose, the study conducted a computationally heavy analysis of a taxi GPS data set with more than 147 million records covering 10 months of activity. It found that there were variations in ridership and trip distances for different day-of-week (DOW), time-of-day (TOD), and weather condition periods. Drivers determine taxi supply, and they respond to this variation in a way that maintains their incomes above approximately $20 per hour. The impact of weather is also investigated. Snow conditions do not affect the hourly revenues but when there is rainfall, drivers make more frequent and slightly shorter trips that increase their income. After reaching their income target, drivers may end their shift early, a finding that may explain the perceived taxi shortage during prolonged rain conditions. It was also shown that within existing trip-frequency and trip-distance patterns, the impact of a recently instituted taxi fare increase in NYC on hourly revenues will vary among different TOD periods. This suggests that a fare increase has the potential to alter the temporal taxi supply as well as the taxi lease rents (which vary by shift) for certain periods. Based on these findings, the paper provides insights into the temporal and weather-related variation in taxi demand-supply equilibrium. Its findings can assist policymakers who regulate the taxi industry.

INTRODUCTION

There are more than 13,000 licensed taxicabs in New York City (NYC) that transport an estimated average of between 680,000 and 895,000 people every day.[1] NYC subway and bus weekday average ridership are about 5.2 million and 2.5 million *(2)*, respectively, hence taxis can be considered as one the major transportation modes used in NYC. More, NYC taxi ridership level is higher than the total transportation systems of most U.S. cities. Despite the high ridership, research on taxis is relatively scarce. The majority of existing studies focus on taxi-industry economics and policy issues, such as the market structure of the taxicab operating licenses, taxi regulations, operational concerns and similar issues. Indirectly, these studies also investigate the passenger demand-and-supply equilibrium, since the (im)balance between demand and supply is the main factor determining taxi revenue and medallion price as well as the quality of service for city residents. Since the taxi industry is heavily regulated, taxi supply statistics are well documented, but passenger demand statistics are difficult to obtain. Researchers mostly use daily or long-term demand estimates which fall short of fully representing existing temporal (i.e., day-of-week, or DOW, and time-of-day, or TOD) variations in supply-demand (im)balance. Abrams et. al. (3) discuss the temporal and spatial imbalances in supply and demand, and point to the need for measures to help maintain equilibrium within the existing taxi supply. Considering that a transportation system's overall efficiency and level of service depend on the critical peak-load periods, the temporal variations can be crucial to understanding the overall dynamics of this transportation sector.

As a result of technological innovations, taxis around the world are being equipped with global positioning systems (GPS) and similar devices that help track routes, fares, occupancy and other vehicle activity. Such devices also transform taxis into vehicles that can probe the transportation network and help researchers understand time-dependent origin and destination patterns in cities *(4,5)* as well as city travel-time variability and reliability *(6)*. In 2006, the New York City Taxi and Limousine Commission (TLC) mandated that by the end of 2007 all taxis in New York City had to be equipped with GPS devices and information screens for passengers.

In the current study, data collected by the TLC are used to investigate taxi ridership, occupancy per trip, passenger pick-up rate per driver and average hourly revenue per driver across different DOW and TOD periods. Weather conditions are found to affect ridership in public transportation and may also affect taxi ridership. New Yorkers tend to think that it is especially difficult to find a cab in Manhattan when it rains. Yet, at the same time, there is a common yet unsubstantiated belief that taxi drivers choose to stay in Manhattan during rainy weather to take advantage of frequent short-distance passenger trips rather than to drive out to make pick-ups from area airports, a phenomenon that results in a taxi supply shortage at JFK airport *(7)*. To investigate possible weather impacts on driver behavior and taxi supply, the present study merges TLC data with historical weather data extracted from

[1] A 2004 study found a total average estimated daily ridership of 660,000 people (1). Our more recent analysis estimated the number in 2012 to be between 680,000 and 895,000.

www.wunderground.com, a weather information website, and from ridership, pick-up rate and revenue variation data under a variety of weather conditions (clear, rain, snow).

The purpose of the study is to address the following research questions:

1. How do ridership and taxi-supply levels change for different time periods and under various weather conditions?
2. Does weather have an impact on the passenger pick-up rate and on hourly revenues for taxi drivers?
3. What are the likely impacts of the recent New York City taxi-fare increase on taxi demand and supply equilibrium?

LITERATURE REVIEW

Travel by taxi is an overlooked field in recent transportation research. While the 1970s and 1980s were more productive decades for such research, there has subsequently been less attention given to the issue. The topic has been undergoing revitalization, and can now benefit from the availability of new taxi-trip data from GPS and similar devices.

Growing awareness of taxis' role in transportation dates back to the mid-1970s *(8,9)*. The role of taxis as a transportation mode for elderly and disabled populations has long been recognized *(10,11)*. Some studies view taxis as feeders to public transportation and other transit modes, while others see them as a transportation mode unto itself *(12,13)*. The literature also examines taxi pooling and sharing rides as a way to increase taxi utility *(14,15,16)*. Some researchers look to taxi pooling as a model for ways to design better public transportation feeder systems *(17)*, especially focusing on the benefits of shared rides from airports *(18)*. Taxis are fundamental components of airport ground transportation, and several studies have been conducted solely on taxi operations at airports *(7,19,20)*. The taxi industry is heavily regulated and studies that focus on these regulations (e.g., taxi operating permits and licenses) have been the most common subjects of taxi research *(13,21,22,23,24)*. Once the taxi supply is regulated and a market is formed through taxi licenses, a taxi fleet becomes an economic entity whose units can be traded. The decision to issue new licenses (or to reduce their number) or to permit fare changes requires extensive research on taxi demand and revenues. Studies on taxi demand and rider characteristics mainly base their findings on macro indicators such as real income, population density, number of workers, household car ownership levels, and number of airport taxi trips for a given population *(25,26,27)*. In last few years, researchers have made use of data from taxi GPS and other similar tracking devices to extract temporal and spatial trip patterns that allows for a more precise portrayal of the dynamics of taxi demand and supply *(28,29,30)*. These studies can offer guidelines for riders and for taxi drivers to locate the "hot-spots" or "hot-periods" indicating where and when taxi riders and drivers are more likely to be found. Such temporal and spatial analyses also provide valuable input for regulatory studies since these studies allow taxi demand-supply dynamics to be captured in a more detailed way.

Acknowledging that taxis are an integral part of the public transportation system makes it possible to compare their characteristics with other transit modes. For example, the impact of weather on public transportation has been widely examined *(31,32,33,34)*. It follows, then, that weather also affects taxi supply and demand. Although the public presumes that weather affects taxi availability, few studies have quantified this problem. The present study helps to fill this gap by integrating taxi GPS data with historical weather conditions and assessing the impacts of DOW/TOD on ridership levels and taxi supply patterns for New York City .

DATA

In this paper, taxi GPS data provided by the TLC are used to determine taxi ridership and supply patterns. The TLC dataset includes more than 147 million taxi trips covering the period from January 15, 2010 to November 28, 2010. Each trip record includes information on trip origin and destination, time of pick-up and drop-off, number of passengers, trip fare and trip distance. For the purposes of this study, trips from JFK International Airport are excluded. The dynamics of JFK airport pickups involve aircraft arrivals, controlled taxi access to terminals and other location-specific factors (e.g. flat fare to Manhattan), that make them different from the dynamics of taxi pick-ups elsewhere.

Information on the weather conditions for each trip is gathered from the www.wunderground.com website. Wunderground classifies weather conditions based on precipitation, clouds, visibility, and other factors. In the current paper, wunderground's weather categories are converted into categories defined by the presence and amount of precipitation:

Existing Categories → Assigned Categories

$$\left.\begin{array}{c}\text{Clear}\\ \text{Partly Cloudy}\\ \text{Scattered Clouds}\\ \text{Mostly Cloudy}\\ \text{Overcast}\\ \text{Fog}\\ \text{Haze}\end{array}\right\}\text{Clear}$$

$$\left.\begin{array}{c}\text{Light Rain}\\ \text{Light Freezing Rain}\end{array}\right\}\text{Light Rain}$$

Rain → Rain
Heavy Rain → Heavy Rain
Light Snow → Light Snow
Snow → Snow
Heavy Snow → Heavy Snow
Unknown→N/A

For historical weather data, weather conditions are updated every hour, unless there is a change in the existing conditions. For each trip, the weather at the time of pick-up is treated as the weather for the entirety of that particular trip. For the main analysis, the data is aggregated based on the corresponding DOW, TOD and weather category for each trip.

Estimation of Taxi Supply

In the taxi industry, a "shift" refers to a 8–12 hour taxi operation period. In NYC, taxicab license owners have to operate their taxi at least 210 shifts per year to keep their license. Taxi owners may lease their vehicle to one or more drivers for each shift. In the TLC data, there is a "shift number" field for each record, but this field represents the "driver shift" rather than the 8-12 hour "taxi industry shift." The shift number changes each time a different driver starts driving the taxi. As long as a driver makes one trip, her/his shift number is recorded in the data. Assuming that a driver makes at least one trip in an hour and drivers do not change shift for the same taxi frequently, the number of unique shifts is almost equal to the number of drivers on duty. This provides a very good estimate of the number of taxis available in traffic for any one-hour period. On the demand side, taxi customers who cannot find a vacant taxi are not recorded in the database and ridership numbers do not reflect actual demand. Although the rider demand number is not as reliable an indicator as the shift number to assess taxi supply, the recorded ridership data may still function as an indicator of the *magnitude* of actual demand.

Taxi Fee Structure in NYC

Taxi drivers or operators work under various cost conditions. Leasing costs, for example, affect drivers who do not own a taxi and they vary for different days and shift periods. Regardless of ownership, one common cost for drivers is fuel. Drivers are aware that long-distance trips bring more revenue, but they also cost more in fuel. As of September 2012, New York City taxis charge passengers $2.50 upon entry plus a $0.50 New York State surcharge. Depending on the time of day or the state of traffic, taxis may also charge a $0.50 night surcharge (between 8PM and 6AM), a $1.00 weekday peak hour-surcharge (between 4PM and 8PM Monday through Friday), or a $0.40 per each additional unit charge. An additional unit is defined as one-fifth of a mile, and/or 60 seconds not in motion or traveling at a speed of less than six miles per hour (36)**.** Due to the fee structure, a driver who makes a four-mile trip on Sunday at midday receives $2.50 + $0.50 + 4 x $NF, where NF is the net fare per mile after deducting the fuel costs. Another driver making two back-to-back two-mile trips at the same time period receives 2 x $2.50 + 2 x $0.50 + 4 x $NF. In other words, the driver making the same distance in the same amount of time but in two separate trips receives $3 more. Similarly, two drivers making the same revenue may have different net earning depending on their trip frequency. As a result, drivers may prefer making shorter, more frequent trips instead of making fewer trips of greater length.

ANALYSIS AND FINDINGS

TABLE 1 shows the daily averages for ridership (total number of passengers), number of trips and occupancy (number of passengers per trip). Ridership is low at the beginning of the week (with Monday having the lowest ridership), reaches its peak on Saturday, and decreases again on Sunday. The lower ridership levels earlier in the week are known as an industry fact *(35)*, and this is reflected in taxi lease prices (to be discussed later). Our findings also support this claim. Average occupancy on subsequent weekdays stays more or less the same, increasing slightly on Friday and becoming generally higher on weekends. Due to this higher occupancy, Saturday ridership is the highest, while the highest number of daily trips is on Friday. Similarly, the lowest number of trips is observed on Sunday, although Monday has the lowest ridership. It is important, therefore, to distinguish among occupancy rates, ridership rates and number of trips for a given time period. Please also note that taxi ridership does not show the sharp (about 40-50%) decline as observed for NYC subway and bus ridership during weekends.

TABLE 1 Daily Taxi Ridership, Number of Trips and Occupancy

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Average Ridership	679209	762550	787112	838973	864911	895725	734566
Average Number of Trips	420267	473511	487500	516363	519846	505790	419598
Average Occupancy (passengers/taxi)	1.62	1.61	1.61	1.62	1.66	1.77	1.75

FIGURE 1 provides greater temporal detail by showing the average hourly ridership and the average number of drivers on duty during each hour. Weekends (assumed to start on Friday evening and end on Sunday evening) have distinct hourly ridership patterns. The highest 1AM and 5AM ridership levels occur on Saturday and Sunday mornings, following the rising trend on Friday and Saturday nights, respectively. By 5AM, weekday and weekend ridership levels become more similar but after 6AM the average weekday ridership exhibits a sharp increase and surpasses weekend ridership. Evening hours (6PM to midnight) have the highest ridership for the week except on Sunday evening when ridership is lower than the rest of the week. Similarly, Monday has the second lowest ridership during the evening period. If one assumes that the high ridership levels are associated with social activities on weekends and after-work hours, Sunday and Monday evenings are the low periods for social activities, at least for people who are frequent taxi riders.

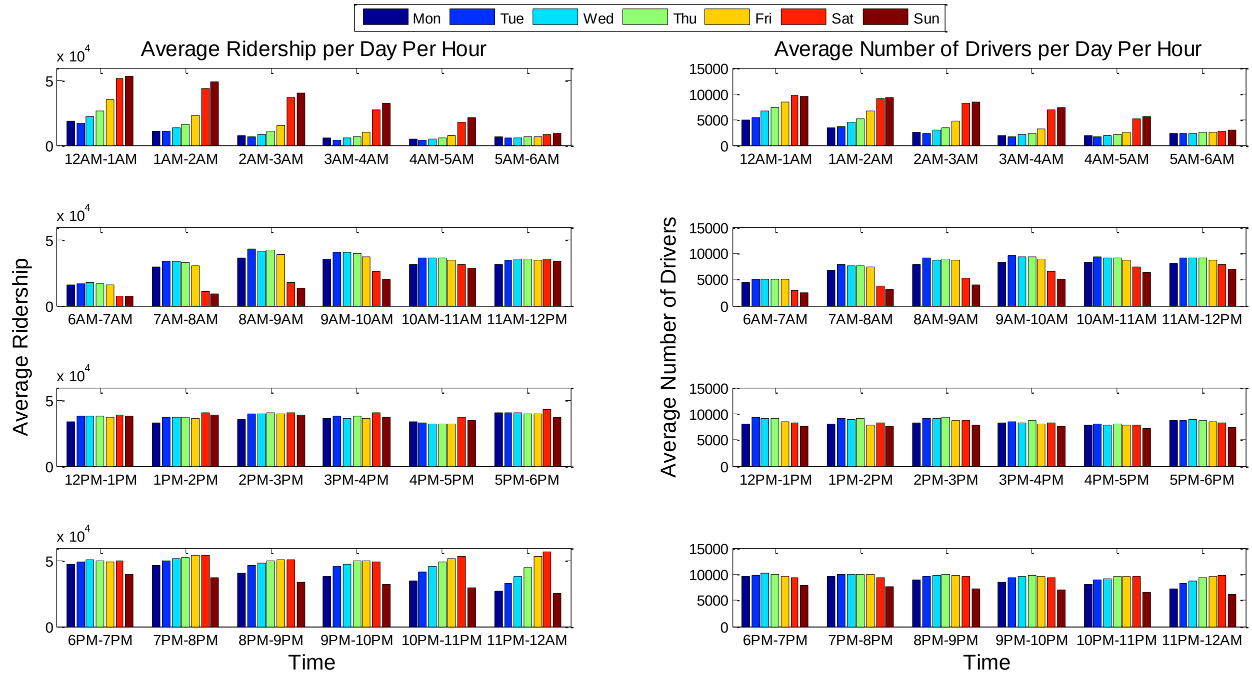

FIGURE 1 Average Ridership and Average Number of Drivers on Duty Per Hour

Taxi drivers/operators are more interested in the overall fare than in the number of passengers they carry per ride because their revenue does not depend on occupancy (ridership) but rather on distance and on the number of trips. For instance, higher taxi occupancy (and therefore ridership) during weekends does not result in proportionally higher income for drivers/operators. In this respect, FIGURE 2, which shows the average number of trips per driver and the average distance per trip, provides some valuable information regarding the demand-supply equilibrium:

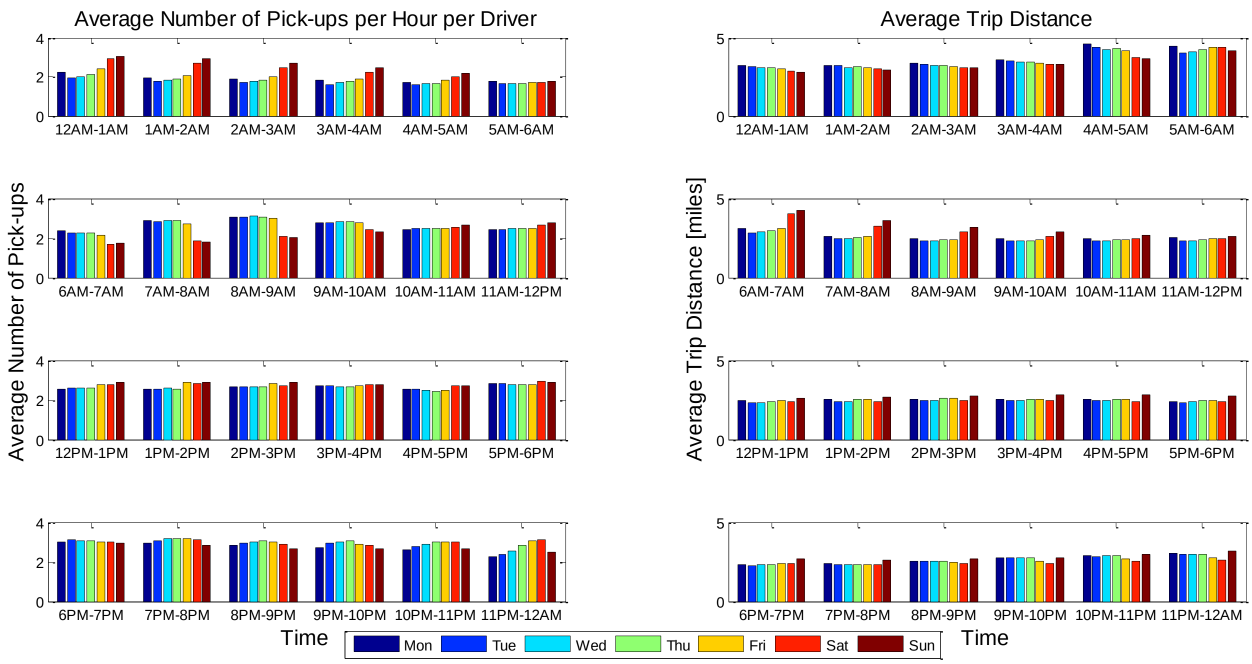

FIGURE 2 Average Distance per Trip and Number of Trips Per Hour per Driver

As shown in FIGURE 2, drivers make the lowest number of trips between 5AM and 6AM, but the average trip distance is the highest for this period. Early morning (4AM-7AM) trip distances are in general higher than for the rest of the day and compensate the possible revenue loss due to the lower number of trips for these hours. Similarly, the higher trip pick-up rates in the evening period (6PM to 12AM) make up for the shorter average trip distances. Based on data provided by a private taxi fleet *(3)*, the average distance for the 5AM-6AM period is 5.3 miles, which is even longer than the value represented in FIGURE 2. For selected hours in a day, FIGURE 3 shows that the ridership, trips per driver and trip distances vary between TOD and DOW. As a result, the hourly revenue per driver also fluctuates. FIGURE 3 shows that drivers earn a minimum of ~20$ per hour (excluding tips) even at the lowest demand periods (e.g. 5AM-6AM). Weekend morning (7AM-8AM) and weekend night (7PM-8PM) exhibits relatively higher ridership levels compared to the 5AM-6AM period. However, the average hourly revenue is again ~$20 for these hours, because the taxi supply also increases in response to increased demand. In contrast, despite almost a 250% increase in ridership during Friday and Saturday midnight compared to Monday and Tuesday midnight, the average revenue per driver only increases around 1.5 times due to the high taxis supply values recorded for Friday and Saturday nights. Close to 10,000 taxis out of over 13,000 licensed medallions are recorded as active on Friday and Saturday nights. This shows that even during the busiest period of the week not all the available taxi supply is on the streets. Taxi drivers are free to choose the periods they operate, or whether to operate at all, and their decision is driven by economic gain rather than the total number of passengers they can transport. Interviews with NYC taxi drivers reveal that they have a keen collective understanding of their expected income levels with respect to varying traffic, demand, and weather conditions as well as their competition with other taxi drivers (7). It may be that the ~$20 hourly income level functions as a composite measure of demand, trip frequency and trip distances, and serves as the minimum equilibrium point in taxi supply-demand dynamics.

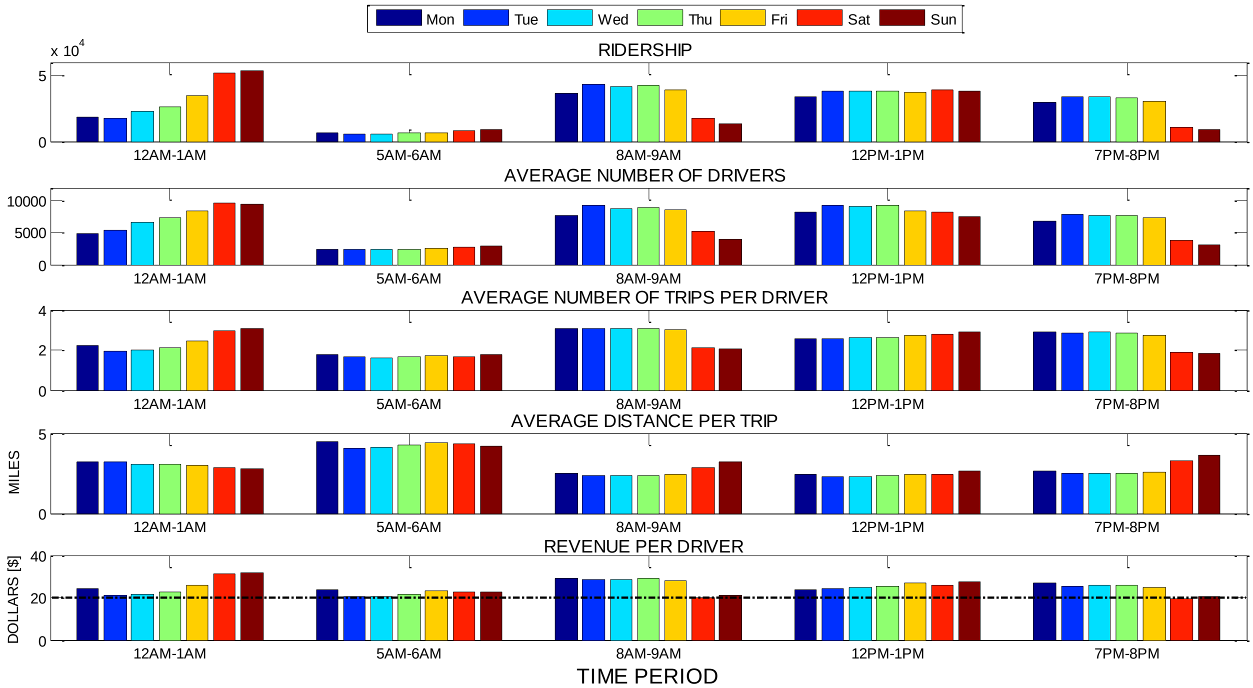

FIGURE 3 Ridership, Number of Drivers on Duty, Trips per Driver and Trip Distance for Selected Time Periods

The variation in number of trips and hourly revenues by DOW and TOD are well recognized in the industry and are reflected in taxi lease price variations. In 1996, the TLC introduced lease-caps, that is, a maximum an owner can charge a driver to lease a vehicle, to ensure minimum driver income for the various shifts. The lease-cap is $105 for all days shifts, $115 for night shifts from Sunday through Tuesday, $120 for the Wednesday evening shift, and $129 for night shifts on Thursday through Saturday. The median lease rates match the lease-cap values except on Monday night ($108), Tuesday night ($113), Saturday and Sunday day shifts ($90) and on the Sunday evening shift ($104). A report prepared for the New York Taxi Workers Alliance in 2003 *(35)* estimated that the gross income for a shift below $160, whose average gross was approximately $137, resulted in an average take home pay as low as $22.14 per shift. Based on the TLC taxi fact book *(1)* fleet drivers' average take-home income per shift in 2005 was $158 after paying the lease fee and gasoline costs. Another study *(3)* in 2007 (following the most recent previous fare increase in 2006) reported the average driver income per shift (8-12 hours) as $220 for owner-drivers and $153 for vehicle owners who lease their medallions. Based on the findings of the current study (which is before the 2012 fare increase), average hourly revenue is around $25, excluding tips, so that a driver's total revenue for a 12-hour shift is about $300 before paying for the lease, gasoline and other costs. Therefore, a $24 difference in a Saturday AM and PM shift lease price is almost equal to 1-hour of revenue for a driver. Hence the lease price is another factor that is likely to affect and to be affected by the demand-supply equilibrium.

The Effect of Weather Conditions

Among NYC residents, rain (or adverse weather in general) is mentioned as an important factor that increases the demand for short trips (especially in Manhattan) and as a reason why it becomes hard to find a vacant taxi. Adverse weather is also cited as a reason for the taxi shortage at JFK airport: drivers choose to stay in Manhattan to make the higher fares that comes from short frequent trips *(7)*. As shown in FIGURE 4 and FIGURE 5, inclement weather causes slightly shorter trip lengths for daytime hours (8AM-8PM). These higher pickup rates for short trips result in higher average hourly incomes for drivers. Before making any further inferences, the calculation method for the pickup rate and hourly income values should be clarified.

If, without considering weather conditions, a particular DOW-TOD category (not distinguishing any weather conditions) occurs *N*-times in the data, then the total duration of the DOW-TOD category adds up to *N*-hours (since each period is 1 hour long). Hence, average revenue per hour for a specific DOW-TOD category is found by dividing total revenue by *N*-hours. Meanwhile, the total number of unique shifts in a category divided by a category count *N* gives the average number of drivers on duty for that particular DOW-TOD period. Average revenue per hour per driver can be found by further dividing average revenue per hour by the average number of drivers on duty. Pick-up rates are calculated in a similar manner. Weather conditions, on the other hand, occur with random frequency and duration for any given DOW-TOD period, and some TOD-weather categories include no cases of certain types of weather conditions. For instance, no moderate snow conditions are observed in the dataset between 7AM and 8AM, hence no statistics can be calculated. For other rare extreme weather conditions, total duration can be very short especially after broken down into temporal categories. For example, heavy rain conditions are observed at four different times in the whole data set for the 12AM-1AM period, and only for 47 minutes in total. The hourly rates in such cases are estimated by adjusting the calculated category average by the category duration (e.g., 2 trips per half hour = 4 trips per hour). This adjustment inherently assumes that the pickup rates recorded for short periods of inclement weather will prevail for the whole hour. In some cases, very high hourly rates can be calculated. However, if the average trip time for a period is 10 minutes, a driver can make 6 pick-ups in an hour on average. If the average trip fare is $10 for the same period, then the maximum hourly average fare a driver receives for pick-ups in a certain period cannot exceed $60. Hence, when the average hourly revenue calculated for any category exceeds the calculated maximum, the maximum hourly average is assigned as the average hourly revenue. So in general, the calculation of revenues and pick-up rates with respect to weather conditions involve assumptions and they may include assumption-related errors.

FIGURE 4 and FIGURE 5 show weather-related pick-ups per hour, average trip distance, and average revenue per hour per driver.

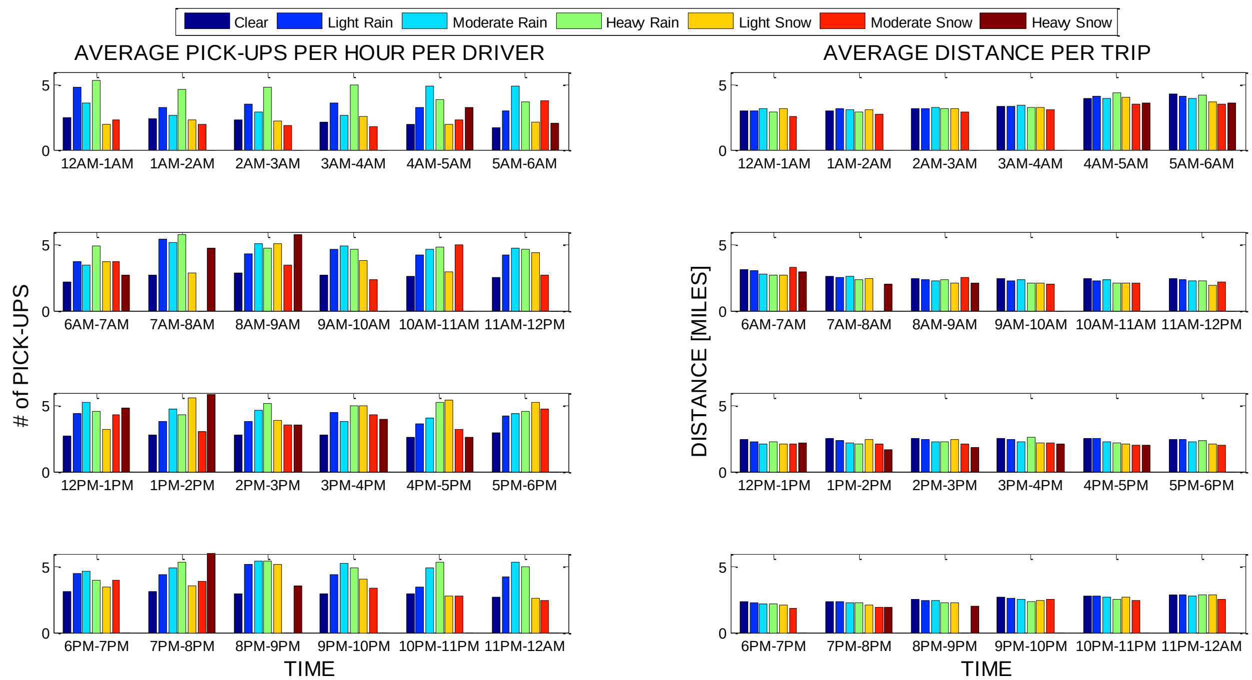

FIGURE 4 Average Trip Distance and Pick-up Rate per Driver per Hour for Different Weather Conditions

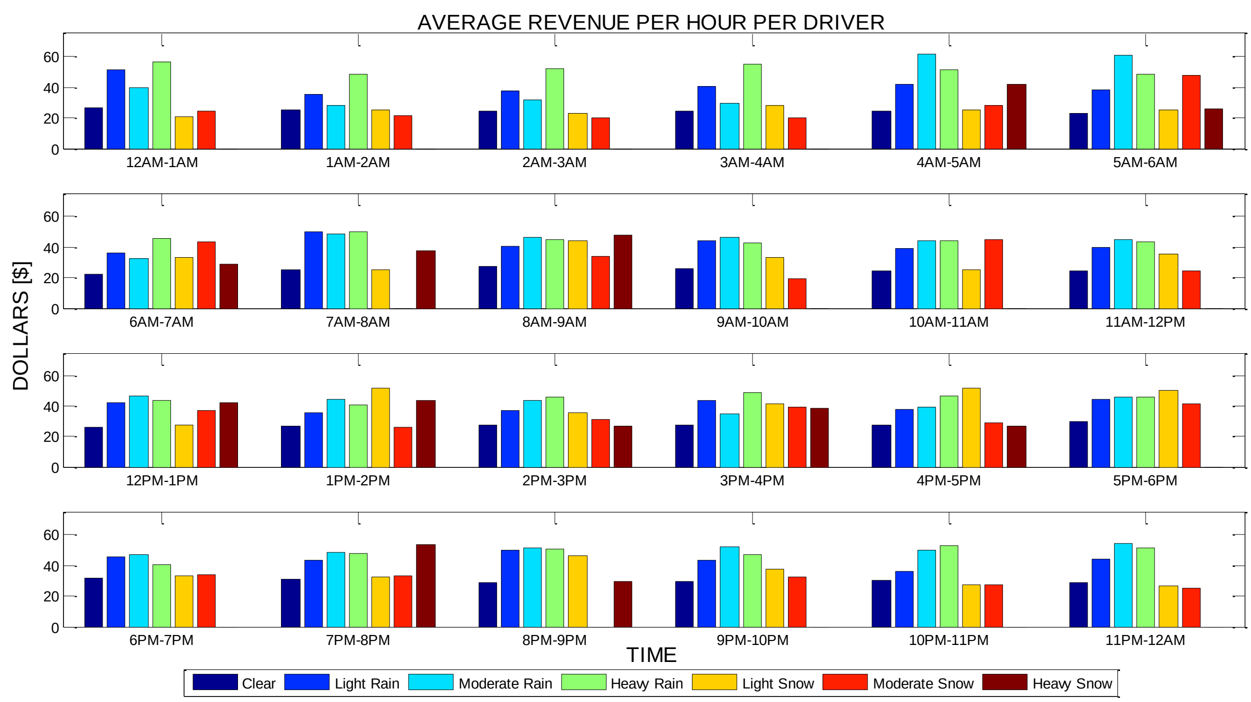

FIGURE 5 Revenue per Hour per Driver for Different Weather Conditions

FIGURE 5 shows that weather conditions do affect drivers' income but that there is no consistent pattern of increase or decrease. Hourly income increases for all rain conditions, but the revenue does not always increase as the rains' severity (light-moderate-heavy) increases. Snow conditions, in contrast, do not necessarily increase the hourly revenues compared to clear weather condition. FIGURE 4 shows that the pick-up rates when snow is falling are generally lower than for rainy conditions. This suggests that taxis are a more popular transportation mode during rain than during snow. It is important to note that the dataset does not fully include the winter months with the heaviest snowfall, and other snow data is limited. Therefore, snow-related estimates should be interpreted with caution.

Weather conditions cannot be forecast far in advance; accordingly, one would not expect that the weather would significantly affect the daily taxi supply. Schaller *(37)* points out that individual taxi operators are income-target oriented and often reduce the amount of service as the demand increases. As a result, adverse weather may not change the total taxi supply for a particular day. However, parallel to Schaller's discussion *(37)*, after prolonged periods of inclement weather conditions, drivers may reach their income target sooner and end their shift before the usual time. Hence, a taxi shortage after long periods of rain *could be* a result of such early shift ends rather than an overall taxi supply problem. The current study did not investigate the validity of Schaller's argument; however some interviewed taxi drivers do not reject the possibility of early shift ends.

The Effect of a Proposed Fare Increase on Drivers' Hourly Revenues and Net Incomes

On July 12th 2012, the NYC TLC approved a fare increase for taxis that went into effect September 4, 2012. The increase does not affect the base fare of $2.50, but the additional unit (one-fifth of a mile, and/or 60 seconds not in motion or traveling less than 6 miles per hour) rate is increased from 40 to 50 cents. The press and other media have stated that the rate of increase is 17%. FIGURE 6 shows the shares of the base fare and metered fare in drivers' hourly income for two selected TOD periods based on the average hourly pick-up rate and average trip distance. For each period, the bar at the left shows the current hourly revenue and the bar at the right hand side shows the estimated hourly revenue after the proposed fare increase.

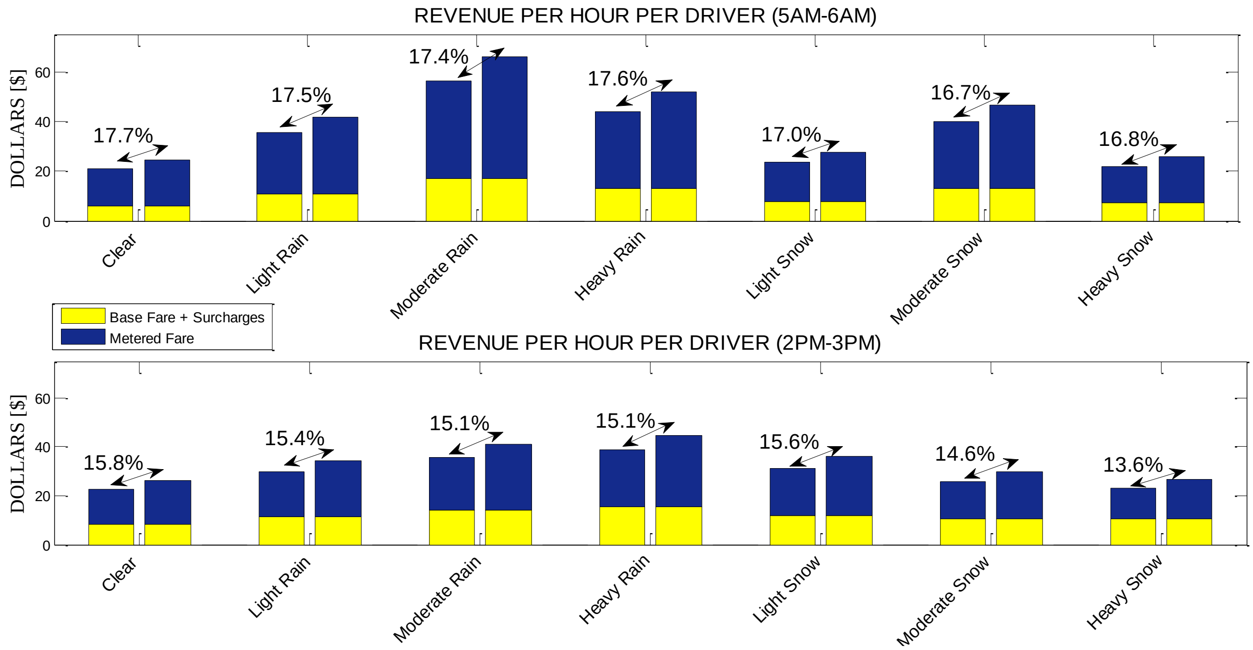

FIGURE 6 Average Hourly Revenues across Weather Conditions Before and After the Proposed Fare Increase

FIGURE 6 provides data to suggest that the fare increase may result in less than an overall rise of 17% because of the TOD variance. It shows that the base fare and surcharges constitute approximately 29% to 34% of a driver's hourly revenue for different weather conditions between 5AM and 6AM within the current fare structure (which includes an additional $0.50 night surcharge because it falls within the 8PM to 6AM period). In contrast, the share of base fare and surcharges ranges from about 37% to approximately 46% for the 2PM-3PM period because there are more frequent and relatively shorter trips at that time. After the fare increase, the share of the base fare + surcharges is reduced and estimated to vary between 25% to 29% of the total revenue for the 5AM-6AM period, and 32% to 40% for the 2PM-3PM period.

The share of base fare and surcharges is important because there are no driver costs associated with this portion of the income (excluding the NY State surcharge of $0.50). Despite the decrease in the share of the *no-cost* part of the total revenue, the total hourly revenue will increase as a result of the fare increase. However, revenue increases are not the same for all TOD periods. The hourly revenue increases by 17% to 18% for the 5AM-6AM period, and by 14% to 16% for 2PM-3PM. In other words, the new fare structure will result in different levels of revenue increase for different TOD periods. On the question of taxi supply, drivers may respond to this revenue increase variation by altering both medium- and short-term taxi supply. It is also possible that the "popular shifts" rankings may change, resulting in altered lease prices for certain shifts. Of course, any negative response from passengers to the fare increase may influence these scenarios. Overall, the fare increase has the potential to affect the TOD taxi supply variation, and/or the lease prices for specific driver shift periods.

CONCLUSIONS

The current study investigates how temporal and weather-related variations in taxi ridership patterns in NYC affect the demand-supply equilibrium. For this purpose, a computationally heavy analysis of a taxi GPS data set with more than 147 million records covering 10 months is performed. It is shown that there are substantial variations in ridership and trip distances for different DOW-TOD weather-condition periods. Taxi supply also exhibits variations due to the decisions of taxi drivers, who are under no obligation to work at any given time, about when to offer service. It is shown that the taxi supply is not solely driven by ridership levels but also depends on trip characteristics such as trip distance because of its effect on received fare. The analysis reveals that the minimum taxi supply is maintained at the level at which drivers receive a minimum of approximately $20 per hour (excluding tips). This balance has mixed effects on taxi availability for riders and income levels for drivers. On the one hand, high hourly revenue does not necessarily cause all the licensed taxis to be in service. Around 10,000 taxis (over 13,000 licensed medallions) are recorded making trips on weekend nights when ridership is highest and average revenue is highest, about $30 per hour (excluding tips). On the other hand, lease rates are set based on revenue levels, and drivers pay higher lease rates for periods with higher income levels. It is also shown that weather can have a high impact on taxi revenue. Relatively shorter-distance trips and, more importantly, higher pick-up rates and eventually higher hourly revenues, are recorded when there is rain. Snow conditions, on the other hand, do not necessarily increase the hourly revenue per driver.

Implications of Findings for the Taxi Demand-Supply Balance

As discussed earlier, the data do not capture actual rider demand; there is no data on the number of people who were unable to hail a taxi when they wanted one. Thus the temporal and weather related variations in the level of service from the perspective of riders cannot be assessed. The data does shed light, however, on the number of taxis on the streets at a given time. Taxi activity in New York City is mainly confined to certain neighborhoods of Manhattan *(1,3)*, and the problem of too few taxis in the other boroughs is one the city has sought to address. The present analysis shows that the whole available taxi inventory is not on the streets even at peak taxi demand periods. Therefore, increasing the available number of taxis would not automatically increase the level of service for areas beyond Manhattan, unless there is a guarantee for drivers of certain minimum revenue (e.g. $20 per hour) from such areas or other incentives are offered.

Yet even taxi-rich Manhattan residents and workers question the adequacy of the taxi supply, especially when it rains. The present analysis shows that rainy conditions lead to higher levels of ridership. More importantly, pick-up rates increase, which allow drivers to make more revenue for the same traveled distance due to multiple base-fare charges. Schaller *(37)* suggests that individual taxi operators are income-target oriented and often reduce the amount of service as demand increases. From the supply perspective, it is unlikely that weather conditions change the taxi supply at the beginning of the day or shift. Parallel to Schaller's discussion, when there is prolonged inclement weather conditions, drivers who reach their income targets may end their shifts early, leading to temporary taxi shortages.

Further analysis of the recent fare increase also reveals that revenue increases are not experienced equally for all DOW-TOD periods. This finding can direct future research. On the one hand, the uneven revenue increases among different shift periods may eventually alter the corresponding lease prices. On the other hand, the increase in revenues may affect taxi drivers' choice of shift. An updated analysis of taxi trips subsequent to the fare increase can shed light into these impacts and other questions.

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