Stuck in Traffic: Measuring Congestion Externalities with Negative Supply Shocks

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May 2024

Abstract

Congestion is one of the most challenging issues of urban agglomeration. Congestion costs are higher than socially optimal levels, and more information is needed about the key parameters required to design optimal policies. This paper exploits an exogenous reduction in for-hire vehicle supply in New York City to estimate their effect on travel speed and document substitution patterns to other transportation modes. A 9.1 percent decrease in taxis is associated with increased travel speed by 0.45 minutes per mile, a 7.2 percent increase. Consumer surplus gains from increased speed fade as waiting times increase and people switch to other transportation modes.

Keywords: Congestion, travel speed, for-hire vehicles, welfare trade-offs
JEL codes: D62, R41, R48

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1. Introduction

Traffic congestion is one of the most challenging issues of urban agglomeration. People residing in large, medium, and small cities report that congestion is a major concern (Bloomberg, 2018). Traffic causes substantial costs. For example, in 2018, across the 25 most congested cities in the United States, the average driver spent 106 more hours traveling than they would have in free-flow conditions, at a total cost of $72.6 billion (Reed and Kidd, 2019). These costs are unavoidable as they result from the concentration of economic activity in urban areas. They reduce one of the most important benefits of cities: the ability to easily connect with others (Glaeser, 2011). The problem is that congestion costs are often higher than their socially optimal levels because roads are generally not priced. Thus, individuals favor private and for-hire vehicles that offer on-demand and personalized travel experiences without internalizing the negative externalities associated with using these vehicles.

Designing congestion policies that approximate the optimal level of a Pigovian tax on road usage requires quantifying how an additional vehicle affects travel speed in a city grid and identifying substitution patterns across other transportation modes. Measuring these parameters presents an identification challenge. Vehicle density in a city is determined endogenously by interactions across the demand for different transportation modes (including private vehicles), supply of for-hire vehicles, and supply and demand of other commercial vehicles. For example, if an individual faces congestion due to an accident or road closures for an event, they might reschedule a trip or change the route. This would affect traffic density, which in turn affects travel speed. The simultaneity between vehicle density and speed implies that travel speed cannot be estimated with deterministic flow functions (Small and Chu, 2003; Yang et al., 2020). Thus, identifying how an additional vehicle affects speed and other transportation modes requires varying the number of vehicles while holding demand constant.

This paper estimates the effect of taxis and other for-hire vehicles on travel speed and documents the substitution patterns to other transportation modes caused by changes in the number of on-demand vehicles in a city. I study these effects in New York City during the period 2009-2017. Because the number of these vehicles in a city is endogenous, the ideal setup for identifying effects on congestion would be randomly taking cars off the streets in a way that is unanticipated by demand. I exploit a natural experiment that mimics this ideal intervention. According to the Taxi and Limousine Commission (TLC, 2018), 57.5 percent of taxi drivers and 33.1 percent of other for-hire drivers in New York City come from countries with large Muslim populations. This suggests that Islam is the main religion of for-hire drivers, while only three percent of the city's population is Muslim (PEW Center, 2014). Islam has two major holidays; their dates change yearly following the lunar calendar. For example, one of these holidays occurred on Sunday, November 6, 2011, Friday, October 26, 2012, and Tuesday, October 15, 2013. This fact makes it difficult for non-Muslims to anticipate these holidays. Thus, we can expect that the number of taxis and other for-hire vehicles on the road in the city will decrease during Muslim holidays because many drivers do not work on those days, while most of the city's population is oblivious to them. This identifying assumption implies that demand for for-hire vehicles and other transportation modes does not change during Muslim holidays, and I show evidence supporting it. Thus, any change in travel speed in the city should correspond to the reduction in the number of for-hire vehicles these days.

The results show that taking for-hire vehicles off the streets significantly increases travel speed in the city. The estimates indicate that during Muslim holidays from 2009 to 2013, the number of active taxis decreased by 1,000 (9.1 percent of the total), and time per mile traveled (the inverse of speed) decreased by 0.45 minutes (7.2 percent of a baseline of 6.5 minutes per mile). This result held in the later period of 2014-2017 and the complete 2009-2017 period, but it is important to acknowledge that the effect in the later period also includes responses from other for-hire vehicles like Uber and Lyft. The results are robust to accounting for noise in the data generation process using randomization inference. Also, the composition of the for-hire driver workforce during Muslim holidays does not explain these results. The results are robust to the entry of Uber and other ride-sharing companies.

Fewer for-hire vehicles on the streets imply that people will substitute across transportation modes. The unpredictability of the shock suggests that private vehicles are not an option, leaving other, less attractive, transportation alternatives. The results show that taxi and other for-hire trips decrease between 1.6 percent and 16.4 percent during Muslim holidays. Moreover, the estimates indicate that the number of passengers per taxi trip decreases by 1.2 percent, suggesting that some people are unwilling to wait because of increased waiting time. People who cannot find a taxi or for-hire vehicle must switch to other transportation modes. During Muslim holidays, taxi travel distance increases between 2.1 and 3.4 percent. Since 25 percent of all trips travel up to one mile and 50 percent up to 1.7 miles, these estimates suggest that people who want to go somewhere reasonably near switch to walking when facing increased waiting times. Any effect on subway rides is within the normal daily variation of these trips. From the supply side, the remaining driver's income increases during these holidays.

While limiting on-demand vehicles increases travel speed, it also implies a welfare loss because waiting times increase as for-hire vehicles leave the streets (Arnott, 1996). Some people cannot use their preferred transportation mode and have to switch to a second-best alternative, like walking or public transportation. Moreover, in some cities, public transportation operates close to its total capacity, and taking a large influx of new passengers would lower its quality (Moss et al., 2018). This would translate into further welfare losses. Thus, to define an optimal traffic regulation policy, it is important to quantify and balance the welfare trade-offs between increased speed, waiting times, and substitution of transportation modes (Stopher, 2004). Understanding these trade-offs is also essential to assess the political acceptability of congestion-managing policies, which tends to be limited (Small et al., 2007).

I quantify how the consumer surplus gains from increased travel speed during Muslim holidays stand against consumer surplus losses from increased waiting times and switching to less preferred transportation modes. I calibrate Anderson's (2014) transportation demand model, which allows matching the parameters that define consumer surplus changes to the reduced form estimate of the speed change. Depending on how much waiting times increase, increased travel speed during Muslim holidays increases consumer surplus in the city between $2.1 and $2.8 million per day. These welfare changes correspond to a short-term, unanticipated reduction in active vehicles. A long-lasting reduction could magnify substitution effects that lead to further reductions of consumer surplus. In this sense, these calibrations represent an upper bound of potential consumer surplus changes from policies that aim to improve travel speed.

Previous research on traffic congestion and its externalities focuses on the effects of policies that restrict the number of vehicles on pollution (Small and Gomez-Ibanez, 1999; Small et al., 2007; Davis, 2008; Gallego et al., 2013; Chen et al., 2013; Viard and Fu, 2015; Carrillo et al., 2016). A second group of papers studies the effects of public transportation on ridership, travel speed and related outcomes (Baum-Snow et al., 2005; Anderson, 2014; Bauernschuster et al., 2017). These studies find that public transit helps reduce driving times in major freeways and decreases total car hours. A third group studies the effect of congestion policies and other determinants of travel speed (Couture et al., 2018; Mangrum and Molnar, 2018; Hughes and Kaffine, 2019; Yang et al., 2020; Kreindler, 2020; Tarduno, 2021; Herzog, 2022). Only a small subset explicitly addresses the simultaneity between traffic density and speed, exploiting policy shocks that affect travel density through both supply and demand for vehicles. Yang et al. (2020) exploit a driving restriction in Beijing by combining variation from plate numbers and the fact that the number four is perceived as unlucky in China. Mangrum and Molnar (2018) study the effect of new taxis on congestion. The authors estimate the local effect of introducing the green taxi program in the outer boroughs of New York City, focusing on the boundary of this program in northern Manhattan. They find lower travel speeds in the vicinity of the boundary due to these new taxis and use aerial photographs to quantify taxi supply and extrapolate this effect to lower Manhattan. Tarduno (2021) estimates the effect of Uber and Lyft on travel time in Austin, Texas, exploiting the exit of these companies from that city.

This study's findings contribute to understanding how traffic congestion affects travel speed. This paper introduces a new identification strategy to quantify the effect of vehicles on speed. In contrast with policy shocks, variation from Muslim holidays affects the supply of for-hire vehicles while demand remains constant. This allows identifying the effect of an additional for-hire vehicle on total travel time per mile without the effects on traffic density that come from changes in demand. Also, most studies that measure the external costs of congestion concentrate on highways due to the simplicity of analyzing the highway network and better data availability. In this paper, I can estimate the marginal external cost of congestion on city streets by using a measure of trip travel speed and exploiting a city-wide shock to identify the effect on speed. Thus, the estimates can be used to bound welfare calculations in different settings. Policymakers can directly use it to design Pigovian taxes for roads that reduce congestion externalities to their optimal levels. The estimates can be informative in other contexts, insomuch as the general characteristics of traffic in New York City by borough and daytime extend to many metropolises in the world. I estimate the change in total travel speed for different sections of the city and day times to capture how it varies when overall vehicle density changes. This can help match the estimated changes in travel speed to other locations by vehicle densities, expanding the external validity of the results. Finally, the consumer surplus trade-offs of reducing vehicles during Muslim holidays suggest that the primary beneficiaries of taking taxis off the streets are people who drive their private vehicles, while individuals who use taxis face gains from travel speed that fade with increased waiting times and substitution to second-best alternatives. These trade-offs potentially explain why congestion-managing policies restricting for-hire vehicles have low political acceptability.

The results on travel speed are also consistent with the existence of hypercongestion (Hall, 2018, 2020). Defining the miles vehicles can travel in one hour in a city as the number of vehicles traveling times speed and considering a total of 1,525,205 vehicles traveling in the city (Moss et al., 2012; NYC Department of Transportation, 2018), the increase in travel speed during Muslim holidays implies a 7.7 percent increase in the number of miles the remaining vehicles could travel in one hour. Consistent with higher vehicle flow in the city, the number of trips for the remaining taxi drivers also increased. Finally, I find suggestive evidence of increased traffic flow during Muslim Holidays.

Additionally, this study contributes to the nascent literature on taxis and other for-hire vehicles. Research on taxis has focused on understanding supply behavior, market frictions, and moral hazard.[1] More recent research has focused on Uber and other ride-sharing companies, evaluating their effects on drunk driving and fatalities, their interrelation with taxis and public transportation, labor supply, and consumer surplus.[2] This paper adds to this literature by quantifying how for-hire vehicles affect travel speeds in a dense city.

2. Driver Ethnicity and the Supply of For-Hire Drivers

According to TLC (2018), taxi and other for-hire vehicle drivers are predominantly men (97 percent) with an average age of 46.[3] The TLC reports that these drivers have diverse ethnic backgrounds. Only nine percent of all drivers were born in the United States, and 57.5 percent of taxi drivers and 33.1 percent of other for-hire drivers come from countries with large Muslim populations like Bangladesh, Pakistan, India, and Egypt. This suggests that while Muslims represent only three percent of New York City's population (PEW Center, 2014), Islam may well be the main religion of for-hire drivers in the city. Thus, we can reasonably expect that many drivers respond to Muslim holidays, while the majority of the population in the city is oblivious to them.

Eid al-Fitr and Eid al-Adha are the two most important holidays in Islam. While specific traditions vary by country; Muslims in the United States celebrate and observe these holidays even though neither Eid al-Fitr nor Eid al-Adha are recognized as federal holidays.[4] Muslims celebrate by gathering with family and friends, similar to Christians celebrating Christmas. In the United States, celebrations of Eid al-Fitr start in the evening, breaking fasting with feasts with family and friends and continue with morning congregational prayers (Al-Islam, 2019;

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[1] See Camerer et al. (1997); Farber (2005, 2008, 2015); Jackson and Schneider (2011); Haggag et al. (2017); Buchholz (2017); Frechette et al. (2019); Thakral and Tô (2021).

[2] See Moskatel et al. (2017); Peck (2017); Dills and Mulholland (2018); Barrios et al. (2018); Cramer and Krueger (2016); Hall et al. (2018); Brodeur and Nield (2018); Hall and Krueger (2017); Cook et al. (2018); Cohen et al. (2016).

[3] Appendix A presents a description of taxis and other for-hire vehicles in New York City, and the regulations the TLC enforces for each type of for-hire vehicle.

[4] New York Public Schools included Eid al-Fitr and Eid al-Adha as holidays starting in the 2015-2016 school year. This implies that non-Muslims' awareness of these holidays may have increased, affecting the later years in the sample, while the rest of the study period is unaffected.

Khan, 2017; Post, 2017; Rojas, 2018). The celebration of Eid al-Adha in the United States involves going to the mosque for prayers in the morning, followed by a feast of meals throughout the day, visiting family and friends, and exchanging gifts (Pervez, 2015; Peyton, 2018). The dates of Eid al-Fitr and Eid al-Adha are determined by the lunar calendar and change every year (Appendix Table B1). In 2009-2017, Eid al-Fitr was mainly during the summer, and Eid al-Adha was between September and November.

Given the significance of these two holidays, Muslim taxi and for-hire drivers may either not work or reduce the length of their shifts. If Islam is the main religion of taxi and other for-hire drivers, this should reduce the number of for-hire vehicles in the city, reducing vehicle density on those dates. Since Muslims are only three percent of the total population in New York City but potentially more than a third of the drivers, the drop in the number of vehicles due to these holidays would correspond to an exogenous shift in supply and not in demand of for-hire vehicles. Moreover, the date of the Muslim holidays changes every year, making it difficult for non-Muslims to anticipate these shocks to supply. This makes these holidays as good as random for potential passengers. In the rest of the paper, I exploit this variation in the supply of for-hire vehicles to estimate how an additional for-hire vehicle affects travel speed, the substitution patterns that arise, and the welfare implications of these changes.

3. Empirical Approach to Study Effects of Changes in the Supply of For-Hire Vehicles

3.1. Data

To estimate the effect of changes in the supply of taxis and other for-hire vehicles on congestion and its welfare implications, I use data provided by the TLC, the Metro Transit Authority (MTA), and the City of New York from 2009—2017.[5]

The TLC reports data for every city trip in a for-hire vehicle. The details and period vary depending on the vehicle type. For yellow taxis, the TLC reports pick-up and drop-off dates and times, pick-up and drop-off locations, trip distances, itemized fares, payment types, and driver-reported passenger counts for each ride in 2009-2017. Data is collected by the taximeters and reported by the technology providers that supply them in New York City. For 2010, 2012,

[5] These data can be downloaded from https://opendata.cityofnewyork.us/, https://www1.nyc.gov/site/tlc/about/tlc-trip-record-data.page, and http://web.mta.info/developers/turnstile.html

and 2013, I also have anonymized driver and vehicle identifiers.[6] One limitation is that the identifiers change every year. For 2009-2013, I also have daily tabulations of the number of yellow taxis that made at least one trip and the number of drivers who made at least one trip. For green taxis, the TLC reports the same information on rides as for yellow taxis for 2013-2017. For other for-hire vehicles, including ride-sharing companies, the TLC reports the dispatching base license number (which identifies the firm that provided the ride), the pick-up date and time, and the pick-up location for each ride in 2015-2017. With these data, I calculate the daily number of rides for each type of for-hire vehicle and the average income a yellow taxi driver makes daily.

I also use the TLC data to define a measure of travel speed in New York City. Measuring how an additional vehicle affects travel speed requires capturing speed changes across the city. Due to the complexities of traffic as a dynamic and nonlinear phenomenon, engineering models and traditional speed measures focus only on small subsets of streets (Bando et al.,1995; Wen, 2008). This approach does not capture vehicle density externalities propagating throughout the city grid. A jammed street can increase or decrease travel speeds in different city sections, making the average speed of a trip that crosses multiple sections uncertain. Focusing on speed on a particular road will not capture how it changes on other streets, which is important from a welfare perspective because individuals care about total travel time. To address this issue, I calculate the duration of each yellow taxi trip and combine it with the trip's distance to obtain the inverse of the average speed of the trip (minutes per mile).[7] Since taxis travel across the entire city, the average speed of the taxi trips will capture the effect of all changes in speed in the grid. Also, the destinations are unknown to the driver before the trip starts, which prevents selection.[8]

The City of New York also reports data on motor collisions in the city from 2012-2017, including date, time, location, number of people injured or killed, and type of vehicles involved. I use these data for robustness analyses.

To study substitution effects triggered by changes in the number of active vehicles, I use MTA data on the number of entries and exits from subway stations in the city from 2010-2017.

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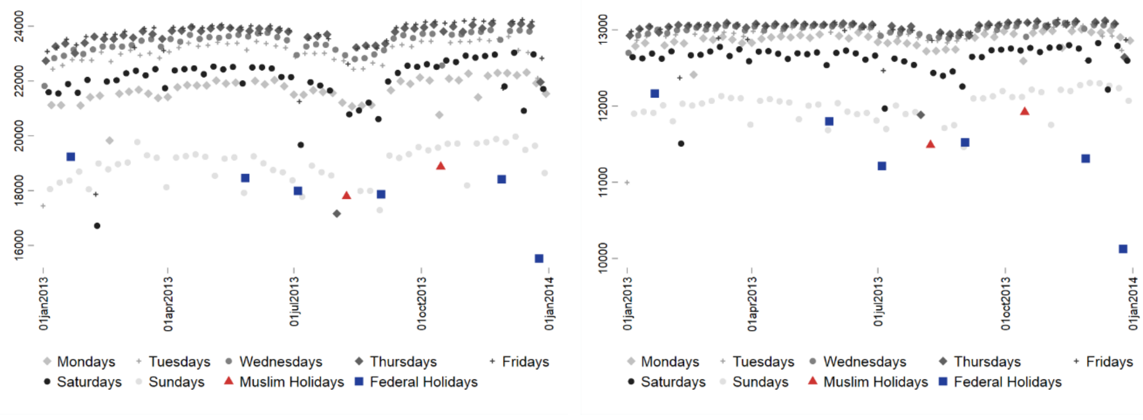
[6] Until 2013, the trip data also included anonymized medallion and driver identifiers that are not public anymore. The data for 2010, 2012, and 2013 comes from Donovan and Work (2016). Downloaded data for 2011 was corrupted and could not be recovered.

[7] See Appendix C for details.

[8] There are more than 800 million yellow taxi trips in the data. Such a large number of observations presents computational issues. For this reason, I use only data from yellow taxis to calculate travel speed and do not include green taxis

These data are aggregated in four-hour intervals per turnstile and include the station name, date, time, cumulative entries, and exits. With this information, I calculate the daily number of subway rides. Also, the City of New York reports every trip of the bike-sharing system in Manhattan. These data report pick-up and drop-off dates, times, and locations, which I use to calculate the daily number of bike trips.

3.2. Driver and Vehicle Patterns over Time



(a) Taxi Drivers (b) Taxis

Notes: This figure presents the number of taxi drivers who had at least one trip per day and the number of yellow taxis that had at least one ride per day in 2013. Federal holidays include Martin Luther King Jr. Day, Memorial Day, 4th of July, Labor Day, Thanksgiving, and Christmas Day

Figure 1: Taxi Drivers and Taxis in 2013

In this section, I describe the evolution of the daily number of for-hire drivers and vehicles over a year. I focus on 2013 as a case study, although I will use the entire sample in my main analysis.[9] Figure 1 panel (a) shows the daily number of drivers who made at least one trip. We can observe seasonal trends across the year. The number of drivers decreases during the summer, from June to August, and increases in September-December and January-May. These changes could reflect underlying patterns of demand for rides over time. Also, there is substantial variation within the week. Sundays have the lowest number of drivers, followed by Saturdays. During the workweek, the number of drivers increases from Monday to Friday. Federal holidays are among the days with the fewest number of active drivers. This drop could merely reflect the lower demand for rides on those days. However, during Eid al-Fitr and Eid al-Adha, there is a drop of similar magnitude to federal holidays in the number of drivers. Only

[9] The same patterns appear in every year available in the data. See Appendix Figures D1 and D2.

Muslims participate in these holidays, and Muslims are a small minority of the city's population. Thus, the decrease in drivers in those days is mainly supply shock because many drivers are potentially Muslim. Figure 1 panel (b) shows the same patterns as in panel (a) in terms of the number of active taxis.

3.3. Identification Strategy

The identifying assumption to estimate the effect of changes in the supply of for-hire vehicles is that the drop in supply during Muslim holidays is not correlated with the demand for for-hire vehicles, the number of private vehicles circulating, the number of other commercial vehicles, and other determinants of outcomes. Under this assumption, a first approach to estimate the effects of this supply shock could be to compare outcomes on the day of the Muslim holiday to the same day in the weeks surrounding it.[10] This approach would address within-week trends, but it would not account for changes in the number of drivers and vehicles from one week to the next because of seasonal patterns, especially during the summer. Seasonal trends would bias the estimate upwards or downwards depending on the direction of the trend.

I implement the following empirical strategy to address these issues. First, due to the daily volatility in the data, for each year, I take the period between May and December to capture seasonal trends in traffic (Davis, 2008; Gallego et al., 2013; Anderson, 2014). This way, the period is long enough to capture trend changes during the summer, fall, and December and controls for extreme weather shocks in the winter and early spring that could bias the trends. Then, I flexibly capture seasonal and within-week trends using summer ($\delta_1 summer_t$), week-of-the-year (γ_{2wt}), and day-of-the-week (γ_{1dt}) fixed effects.[11] I allow these fixed effects to vary by year to capture long-term changes in the trends caused by the entry of ride-sharing companies. I also use dummies to control for holidays observed in New York City that affect transportation demand ($\delta_2 holidays_{dt}$).[12] Finally, previous research shows that weather can affect transportation demand and supply (Davis, 2008; Farber, 2015; Brodeur and Nield,2018). I control for the weather including daily temperature, precipitation, and dummies for the days

[10] I use this strategy graphically for every outcome.

[11] The summer fixed effect defines summer as the period between the Monday after Memorial Day weekend and the Friday before Labor Day weekend. Thus, the actual period changes year by year, and the week-of-the-year fixed effects do not absorb its effect. The results are fully robust to excluding the summer fixed effect.

[12] I use dummies for Memorial Day, the Fourth of July week, Labor Day weekend, Columbus Day, Yom Kippur, Thanksgiving week, Christmas week, and Christmas Day. I also control special events like Halloween and a visit from the Pope in 2015.

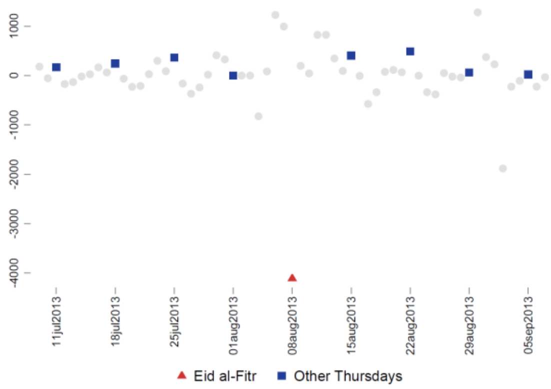
affected by Hurricane Irene in 2011 and Super Storm Sandy in 2012. For trip i in day d, week w, and year t, the estimating equation is

$$y_{idwt} = \alpha_0 + \gamma_{0t} + \gamma_{1dt} + \gamma_{2wt} + \delta_1 summer_t + \delta_2 holidays_{dt} + \delta_3 temp_{dt} + \delta_4 precip_{dt} + \delta_5 Irene_{dt} + \delta_6 Sandy_{dt} + \theta_1 Eid1_t + \theta_2 Eid2_t + u_{idwt} \quad (1)$$

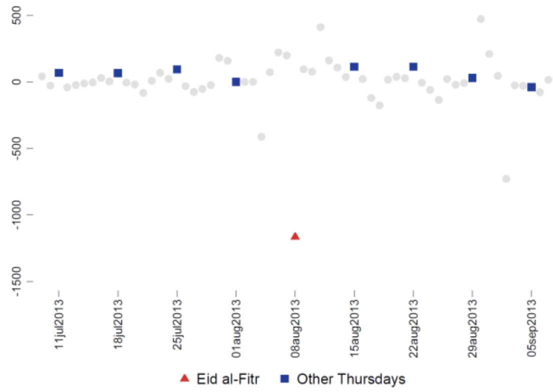
where $Eid1_t$ and $Eid2_t$ are dummy variables that mark Eid al-Fitr and Eid al-Adha every year, respectively. I allow different effects for each holiday because they happen at different times of the year. Eid al-Fitr happened mostly during the summer in the study period, when traffic was lighter because people left the city for vacation. A lower level of congestion at that time of the year would imply that removing the same number of for-hire vehicles has a smaller effect on travel speed. Also, Eid al-Fitr festivities are mainly during the evening of the previous day and morning, while Eid al-Adha is a whole-day event (Section 2). Thus, in Eid al-Fitr, supply decreases when vehicle density, in general, is low in the city.

I study the effect of the for-hire vehicle supply shock caused by the Muslim holidays on two types of outcomes (y_{idwt}). First, outcomes at the individual trip level: speed of a taxi trip, distance traveled, and the number of passengers. Second, outcomes aggregated by day: number of drivers, number of taxis, number of rides in every type of for-hire vehicle, subway rides, bike rides, number of collisions, the number of injuries and deaths in every accident, average driver income, and the average number of rides per driver. The dynamic nature of traffic potentially implies that the error terms are serially correlated within a day. The results of Bertrand et al. (2004) imply that heteroskedastic-robust standard errors are appropriate for the aggregated outcomes. I cluster the standard errors at the day level for the disaggregated outcomes.

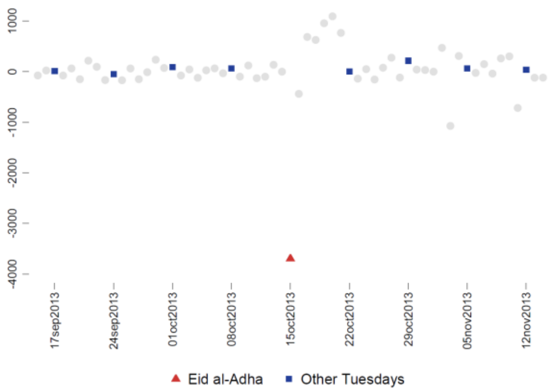
This empirical strategy compares outcomes during the Muslim holidays to other days while controlling for weekly and seasonal trends, holidays, and weather. Given this design, the main concern for identification would be the presence of unobserved shocks that coincide with the Muslim holidays. The fact that the dates of these holidays change every year following the lunar calendar makes a coincidence unlikely. Moreover, as mentioned above, the changing dates imply that it is challenging for non-Muslims to keep track of these holidays. As a placebo check and to account for noise in the data generation processes, including spillovers of shocks across days, I calculate two-sided Fisher p-values by reassigning the date of the Muslim holidays within a range of one month before and one month after the actual dates following the formula derived by Young (2018).



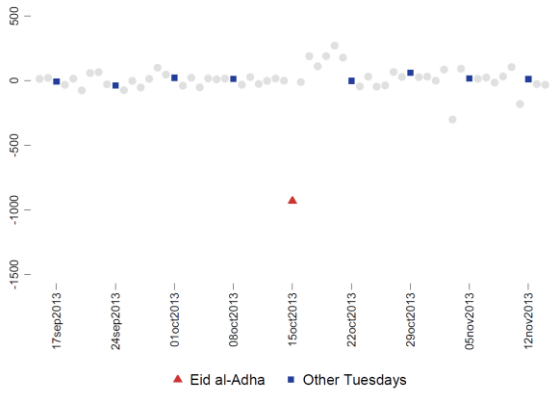
Panel (a) Taxi Drivers - Eid al-Fitr



Panel (b) Taxis - Eid al-Fitr



Panel (c) Taxi Drivers - Eid al-Adha



Panel (d) Taxis - Eid al-Adha

Notes: This figure presents the residualized number of taxi drivers who had at least one trip per day and the residualized number of yellow taxis that had at least one ride per day, after controlling for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions (Equation 1 without Muslim holiday dummies). The graphs present one month before and after each Eid.

Figure 2: Residualized Number of Drivers and Taxis in 2013

The unpredictability of the date of Muslim holidays suggests that the only channel through which Muslim holidays affect vehicle density is the number of active for-hire vehicles. This exclusion restriction depends on the plausibility of two additional channels. New York has a series of food trucks, mainly “Halal carts,” that could also leave the streets during these holidays. It is not clear how the presence or absence of these trucks may affect vehicle density in a city that heavily regulates parking on streets. Second, private vehicles owned by Muslims would also leave the streets on those days. According to the 2019 American Community Survey (ACS), only 22 percent of New Yorkers use their private car to commute (6.3 percent in Manhattan). Also, only 22 percent of households in Manhattan own a vehicle, while more than 90 percent of taxi trips occur in Manhattan. This suggests that private vehicles owned by

Muslims would be a small fraction of the number of vehicles leaving the streets on these holidays. Unfortunately, there is no data on vehicle ownership by religion to assess this concern directly. Data on the number of drivers and vehicles only exists for taxis in 2009-2013. For these reasons, I focus on reduced form estimates in the analyses and only discuss suggestive elasticities in the conclusion.

3.4. Change in the Supply of For-Hire Vehicles

Before presenting model-based estimates, I present a graphical analysis of the identification strategy. Figure 2 plots the residualized number of taxis and drivers in 2013 after controlling for day-of-the-week, week, summer, and holiday fixed effects, and meteorological conditions.[13] Controlling for these fixed effects identifies the variation of Muslim holidays on taxi supply. The number of active taxi drivers and vehicles reaches a minimum on Eid al-Fitr and Eid al-Adha. The reduction in drivers and taxis is similar on both holidays.

	Number of Drivers	Number of Taxis
Eid al-Fitr	-3336.96	-1073.44
	(985.46)	(347.40)
Eid al-Adha	-3975.18	-1126.10
	(271.59)	(162.54)
Baseline	21,046.72	12,379.18
N	1,080	

Notes: Robust standard errors are reported in parentheses. This table presents the effect of the Muslim holidays on the daily number of active taxis and drivers. The regressions control for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions.

Table 1: Effects of Muslim Holidays on Daily Active Taxis and Drivers (2009–2013)

Table 1 presents estimates of the change in supply caused by these holidays in 2009-2013, based on the model described in Equation 1. The number of active drivers decreased by about 3,300 during Eid al-Fitr (15.9 percent of the baseline) and about 3,900 during Eid al-Adha (18.9 percent of the baseline). The difference between both holidays is not statistically significant. Correspondingly, the number of active taxis decreased by about 1,000 during Eid al-Fitr (8.7

[13] See Appendix Figures E1, E2, E3, and E4 for 2009–2012.

percent of the baseline) and about 1,100 during Eid al-Adha (9.1 percent of the baseline). The Fisher p-values are 0.014 for both outcomes.

4. Effects on Travel Speed

	Full Sample		2009-2013		2014-2017	
	Eid al-Fitr	Eid al-Adha	Eid al-Fitr	Eid al-Adha	Eid al-Fitr	Eid al-Adha
Effect	-0.1758	-0.4600	-0.0905	-0.4523	-0.3026	-0.4795
	(0.1038)	(0.0417)	(0.1416)	(0.0443)	(0.1407)	(0.0923)
Baseline	6.21	6.46	6.07	6.26	6.49	6.79
N	799,758,682		490,969,773		308,788,909	

Notes: Standard errors clustered by day are reported in parentheses. This table presents the effect of the Muslim holidays on the inverse of speed (minutes per mile) of taxi trips in the city. Baseline values for Eid al-Fitr correspond to the average time per mile in June, July, and August, while the baseline values for Eid al-Adha correspond to the average time per mile in September, October, and November. The regressions control for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions. As a reference four minutes per mile is the equivalent of a travel speed of 15 miles per hour.

Table 2: Effects of Muslim Holidays on Travel Speed

The results in Section 3.4 show that during Muslim holidays the supply of taxis (and potentially other for-hire vehicles) decreases. As long as this shock in supply is unanticipated by demand, meaning that people do not switch to private cars in those days, I can exploit it to identify how taking taxis and other for-hire vehicles off the streets affects travel speed.

Table 2 shows how travel speed in the city changes during Muslim holidays.[14] For 2009-2017, time per mile (inverse of speed) decreased by 0.18 minutes in Eid al-Fitr (2.8 percent of baseline, Fisher p-value=0.096) and by 0.46 minutes in Eid al-Adha (7.1 percent of baseline, Fisher p-value=0.014). This effect is driven by changes in speed in Manhattan (Appendix Table F1).[15] Couture et al. (2018) show that speed increases with distance. Controlling for distance does not affect these results (Appendix Table F2). The estimated effect is driven by trips that take up to 1.7 miles, while the effect is substantially smaller for trips that take more than 10 miles and potentially use highways (Appendix Table F3). This suggests that trips that use highways are not driving the effect on travel speed. The results are robust to controlling for

[14] Appendix Figures F1, F2, and F3 show the residualized travel times.

[15] Manhattan is defined as the areas south of East 96th Street and West 110th Street.

origin, destination, and hour of the day (Appendix Table F2). The results are also robust to excluding the three days before and three days after the Muslim holidays to account for spillovers due to drivers who take the holiday off working more in the previous and following days to make up for lost income (Appendix Table F2). For Eid al-Fitr, the effect's magnitude decreases from -0.176 to -0.136, which is still insignificant at conventional levels. This is consistent with the nature of the holiday, as celebrations start during the previous day's evening. For Eid al-Adha, the effect's magnitude increases from -0.46 to -0.536, suggesting that spillovers are not biasing the effect on travel speed toward significant findings.[16]

The results are also robust if we collapse the data to the day level. Appendix Table F4 presents these results. For the full sample, I find that during Eid al-Fitr, time per mile decreases by 0.17 minutes, which is insignificant at conventional levels. Conversely, during Eid al-Adha, time per mile decreases by 0.46 minutes, which is significant at the one percent level. These estimates are practically identical to the main results in Table 2 in magnitude and significance. The same holds for the subperiods 2009-2013 and 2014-2017. Appendix Table F4 also presents effects estimated at the 10th, 50th, and 90th percentiles of the daily distribution of travel times. These estimates show that while the entire distribution of travel times shifts to the left during Muslim holidays, indicating shorter travel times, the point estimates are larger for the 90th percentile of the distribution. This indicates that the slowest trips are the most affected, consistent with the effect being driven by trips in Manhattan.

The estimates for the two holidays are statistically different, even when supply decreases by almost the same number of vehicles on both holidays. This difference is consistent with two facts. First, in the sample period, Eid al-Fitr was mainly during the summer months, when people leave the city for vacation and overall vehicle density decreases. Thus, travel speed increases during the summer (see baselines in Table 2), implying that taking out the same number of vehicles during the summer should have a smaller effect on speed than during the rest of the year. Table 2 also presents estimates for 2009-2013 and 2014-2017. In the first period, Eid al-Fitr was mainly in the late summer, when vehicle density was at its lowest, while in the latter period, it was in the early summer with a higher vehicle density. Consistent with the changes in density, for 2009-2013, time per mile (inverse of speed) decreased by 0.09

[16] The results are also robust to excluding coinciding demand shocks, namely Thanksgiving in 2009 (11-26-2009 and 11-27-2099), Rosh Hashanah (09-09-2010), NYC marathon (11-6-2011), and Pride Parade (06-24-2017).

minutes in Eid al-Fitr (1.5 percent of the baseline), while for 2014-2017, time per mile decreased by 0.3 minutes per mile (4.7 percent of the baseline).[17]

Second, the difference in the effect between the two holidays is consistent with the nature of the celebrations. Eid al-Adha is a whole-day event, while Eid al-Fitr festivities are mainly during the evening of the previous day and morning (Section 2). Thus, in Eid al-Fitr, supply decreases when there are generally fewer vehicles in the city and higher average speeds. Appendix Table F5 shows that during Eid al-Fitr, speed gains happened during the early morning, continued during the day, and disappeared in the evening, while during Eid al-Adha, speed gains started at 6 am and continued during the whole day and night, with the largest effects during peak travel hours. It is important to note that even in the early morning, travel speed in New York City is affected by congestion (see Appendix F.2 for details). This implies there is space for speed gains at any time of the day.

	Full 2010, 2012, 2013		Do not take Eid Off		Experienced Drivers		Regular Drivers	
	Eid al-Fitr	Eid al-Adha	Eid al-Fitr	Eid al-Adha	Eid al-Fitr	Eid al-Adha	Eid al-Fitr	Eid al-Adha
Effect	-0.2793	-0.4253	-0.2408	-0.3653	-0.2335	-0.3805	-0.2161	-0.3789
	(0.1117)	(0.0397)	(0.0977)	(0.0405)	(0.0952)	(0.0423)	(0.0957)	(0.0428)
Baseline	5.96	6.17	5.93	6.13	5.92	6.13	5.90	6.10
N	289,909,859		237,850,511		217,547,845		175,849,588	

Notes: Standard errors clustered by day are reported in parentheses. This table presents the effect of the Muslim holidays on the inverse of speed (minutes per mile) of taxi trips in 2010, 2012, and 2013. Baseline values for Eid al-Fitr correspond to the average time per mile in August, while the baseline values for Eid al-Adha correspond to the average time per mile in October and November. The regressions control for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions. As a reference four minutes per mile is the equivalent of a travel speed of 15 miles per hour.

Table 3 Robustness Check: Changes in Driver's Composition

While average time per mile increased from 2009-2013 to 2014-2017, the estimates in Table 2 also indicate that the size of the effect of reducing the supply of for-hire vehicles during Eid al-Adha is stable. During 2009-2013, time per mile in this holiday decreased by 7.2 percent of the baseline, similar to the 7.1 percent decrease for 2014-2017. This similarity suggests that at least the same proportion of for-hire vehicles left the streets in 2014-2017 as in 2009-2013, making estimates in 2009-2013 lower bounds informative for the later period.

[17] Also, shift duration decreased by 5.4 minutes for drivers who take Muslim holidays in the days surrounding Muslim holidays, suggesting that supply is not increasing in the surrounding days.

4.1. Robustness Check: Changes in Driver's Composition

During Muslim holidays, not only does the number of active for-hire vehicles in the streets decrease, but the composition of drivers changes. A competing explanation for the effects on travel speed could be that remaining for-hire drivers are generally faster or take faster routes to take advantage of lower competition in those days. Also, Muslim and non-Muslim drivers could have different propensities for driving in midtown Manhattan or for picking up passengers with different backgrounds implying different destinations and travel speeds. To test these concerns, I exploit the data from 2010, 2012, and 2013. This data includes driver identifiers, which allow testing this concern directly. Using only non-Muslim holiday dates, on average, drivers who do not take Muslim holidays take 6.06 minutes to drive a mile, while drivers who take these holidays, on average, need 6.27 minutes per mile.

To check if this difference biases the estimates, I restrict the sample to drivers who do not take these holidays off and reestimate the effect of Muslim holidays on congestion. Table 3 presents these results. Columns 1 and 2 present the effects on speed using the full sample in 2010, 2012, and 2013 as a benchmark. The point estimates are similar to the ones in Table 2, both in magnitude and significance. Columns 3 and 4 present the results restricting the sample to drivers who do not take Eid off. While the point estimates decrease slightly, there is still a reduction in congestion during Muslim holidays. Time per mile decreased by 0.24 minutes in Eid al-Fitr (4.1 percent of baseline, Fisher p-value=0.131) and by 0.37 minutes in Eid al-Adha (6.0 percent of baseline, Fisher p-value=0.014). The estimates' confidence intervals do not rule out the magnitudes of the effects reported in Table 2. To test if drivers could be using faster routes, I further restricted the sample to drivers who worked for at least 90 days before the first Muslim Holiday (Experienced Drivers) and did not take Muslim holidays off and to drivers who worked more than 240 days in the year and did not take Eid off (Regular Drivers). The idea is that more experienced drivers could know the fastest routes and exploit them during these holidays. However, Columns 5-8 show almost identical results. Thus, driver composition changes are not biasing the estimated effects on congestion.

	# Vehicle Collisions	# Vehicle Collisions with People Injured/Killed		
	Full Sample	Full Sample	No Taxi Present	Taxi Present
	Panel a. All Day			
Eid al-Fitr	7.9773	-1.1935	1.3257	-2.7281
	(17.3972)	(3.9544)	(3.5581)	(1.8155)
Eid al-Adha	8.7038	10.5649	9.8430	0.7180
	(18.0156)	(6.2893)	(5.5193)	(1.2516)
Baseline	602.82	117.19	110.15	7.13
	Panel b. 4 pm to 7 pm			
Eid al-Fitr	-2.1196	2.9565	3.4507	-0.4999
	(8.2522)	(2.3613)	(2.2835)	(0.5514)
Eid al-Adha	10.2950	5.2900	5.4767	-0.1923
	(11.4805)	(3.1036)	(2.6412)	(0.9337)
Baseline	159.97	31.65	30.17	1.54
N	1260	1260	1260	1260

Notes: The first column presents robust standard errors are reported in parentheses. In the other columns standard errors are clustered by day. This table presents the effect of the Muslim holidays on the outcomes detailed by the column headers. The regressions control for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions.

Table 4: Effects of Muslim Holidays on Motor Collisions

4.2. Robustness Check: Effects on Motor Collisions

As a second check if changes in drivers' behavior affect the estimates, I exploit the fact that higher speeds imply higher severity of traffic accidents (Hauer, 2009). If taxi drivers who do not take Eid off change their behavior and drive faster, the severity of accidents involving taxis should increase.[18]

Using data on motor collisions and the same estimation equation, Table 4 panel (a) presents the effect of Muslim holidays on motor collisions in the city. Column 1 shows that during both holidays, there is no significant change in the number of collisions (1.3 percent of baseline with

[18]The results of Dills and Mulholland (2018) suggest that fewer for-hire vehicles may increase alcohol-related crashes. However, this channel would require people to have access to their cars after drinking in bars, which is impossible under the assumption that the shock was unanticipated.

a Fisher p-value=0.752 and 1.4 percent of baseline with a Fisher p-value=0.621). The estimates in Column 2 suggest that the severity of collisions increased by 10.6 injuries or fatalities (nine percent of baseline, Fisher p-value=0.164) during Eid al-Adha when travel speed had the largest increase. This estimate is not significant at conventional levels. There is no significant effect during Eid al-Fitr (-1 percent of baseline, Fisher p-value=0.852) when the increase in speed is lower than during the other holiday. Columns 3 and 4 suggest that any effect, if present, on injuries and fatalities was driven by accidents that did not involve taxis. These results also hold between 4 pm and 7 pm, where demand is high in the city (Table 4 panel b). High demand implies that taxi drivers have an incentive to drive faster. However, the estimates are negative and insignificant for accidents that involve taxis. Overall, these results suggest that the estimated effect on travel speed is not a consequence of remaining taxi drivers driving faster but a result of overall higher travel speed in the city.

4.3. Robustness Check: Effects on Bridge and Tunnel Crossings

	EZPass Toll Crossing	Standard Toll Crossing
Eid al-Fitr	-2814.27	751.08
	(2646.89)	(2646.89)
Eid al-Adha	-7002.29	835.53
	(1710.47)	(1710.47)
Baseline	638,632	116,752
N	1,675	1,675

Notes: Robust standard errors are reported in parentheses. This table presents the effect of the Muslim holidays on the number of daily bridge and tunnel crossings. The regressions control for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions.

Table 5: Effects of Muslim Holidays on Bridge and Tunnel Crossings

I study daily traffic volumes through NYC bridges and tunnels to provide evidence supporting the assumption that the New York City population generally does not observe Muslim holidays. If the assumption is valid, we should not find meaningful effects on bridge and tunnel crossings. Specifically, I estimate the effect of Muslim holidays on bridge and tunnel crossings, distinguishing between E-ZPass crossings and standard toll crossings. Taxis must use E-ZPass, so given that the number of active taxis decreases on these dates, we should observe negative, albeit marginal, effects on crossing with E-ZPass. If the identifying assumption is valid, we should not find a statistically or economically meaningful effect for cabin toll crossings.

	Yellow Taxis 2009-2017	Yellow Taxis 2009-2013	Yellow Taxis 2014-2017	Green Taxis 2013-2017	Uber 2014-2017	Lyft 2015-2017	Other FHV 2015-2017
Eid al-Fitr	-21800.57	-28852.71	-13130.37	-1796.08	-3333.93	-6238.57	-2584.39
	(8619.85)	(13731.66)	(6778.07)	(1010.28)	(3575.43)	(3635.55)	(1773.57)
Eid al-Adha	-29361.76	-37569.30	-15682.88	-3867.19	-8597.48	-734.35	2080.11
	(5938.73)	(6214.05)	(6912.02)	(1118.21)	(4589.68)	(2156.09)	(1789.97)
Baseline Eid al-Fitr	415,386	459,290	360,505	38,746	150,909	37,989	109,821
Baseline Eid al-Adha	429,482	476,915	370,192	34,951	211,525	46,829	137,272
N	1,944	1,080	864	1,012	776	646	648

Notes: Robust standard errors are reported in parentheses. This table presents the effect of the Muslim holidays on the number of daily trips in different types of for-hire vehicles. The regressions control for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions.

Table 6: Effects of Muslim Holidays on For-Hire Vehicle Trips

Table 5 presents these results. For E-ZPass crossings, the estimated effects are negative, insignificant at conventional levels, and small, representing 0.44 percent and 1.1 percent of baseline crossings, respectively. For cabin toll crossings, the effects are positive, insignificant at conventional levels, and only represent 0.64 percent and 0.72 percent of baseline crossings, respectively. Thus, these results are consistent with the assumption that the New York City population generally does not observe Muslim holidays, making the estimated effects on travel speed a consequence of the reduction in active for-hire vehicles.

5. Effects on Ridership, Substitution to Other Transportation Modes, and Supply-Side Responses

Table 6 presents how ridership in for-hire vehicles changes during Muslim holidays.[19] In 2009-2017, on average, daily yellow taxi rides decreased by about 22,000 during Eid al-Fitr (5.2 percent of baseline, Fisher p-value=0.047) and by almost 30,000 trips during Eid al-Adha (6.8 percent of baseline, Fisher p-value=0.014). This is consistent with a reduction in supply. Similarly, in 2013-2017, green taxi rides decreased by around 2,000 during Eid al-Fitr (4.6

[19] Appendix Figures G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, and G11 show trips and the residualized trips.

percent of baseline, Fisher p-value=0.080) and by approximately 3,900 rides during Eid al-Adha (11.1 percent of baseline, Fisher p-value=0.014).

Until 2014, yellow taxis were the dominant type of for-hire vehicle in New York City. Since then, taxi drivers have faced increasing competition from ride-sharing companies. Higher competition may affect how taxi drivers respond to Muslim holidays, but the direction of this effect is uncertain (Brodeur and Nield, 2018). The results show that in 2009-2013, yellow taxi rides decreased by 6.3 percent of the baseline in Eid al-Fitr and by 7.9 percent during Eid al-Adha (Column 2), while they decreased by 3.6 and 4.2 percent of the baseline in 2014-2017 (Column 3). This is consistent with a higher cost of taking a day off.

Trips in ride-sharing companies should also decrease because they potentially have a significant share of Muslim drivers (Section 2). However, we should expect smaller effects than for taxis because as taxis leave the market, increased demand increases a ride's price in ride-sharing companies increasing the driver's opportunity cost of taking a day off. Hence, the estimated effects on trips with these companies are less precise. In 2014-2017, Uber trips decreased by about 3,300 during Eid al-Fitr (2.2 percent of baseline, Fisher p-value=0.539) and by 8,600 trips during Eid al-Adha (4.1 percent of baseline, Fisher p-value=0.260). For Lyft, in 2015-2017, rides decreased by approximately 6,300 in the first holiday (16.4 percent of baseline, Fisher p-value=0.047) and by 700 rides in the second holiday (1.6 percent of baseline, Fisher p-value=0.670). There is no significant effect on other types of for-hire rides. These results speak against the concern that while demand may be unaware of the Muslim holidays, other for-hire drivers could have been aware of the drop in taxi drivers and responded to the shock.

People who cannot find a ride in a taxi or other for-hire vehicle must switch to their second-best mode of transportation to get to their destination. Table 7 explores the substitution patterns triggered by an unanticipated reduction in the supply of for-hire vehicles during Muslim holidays.[20] The number of passengers per taxi trip decreased by 0.01 people (0.8 percent of baseline, Fisher p-value=0.096) on Eid al-Fitr and by 0.02 people (1.2 percent of baseline, Fisher p-value=0.014) on Eid al-Adha.

The magnitudes of the effects are small and suggest that some people are unwilling to share a taxi ride during these holidays. One explanation for this effect is that it is driven by individuals who usually share a taxi but have different final destinations. Suppose we have two individuals traveling in the same direction, but one has to travel a longer distance than the other. In this

[20] Appendix Figures G12, G13, G14, G15, and G16 show residualized subway and bike trips.

case, individuals traveling a short distance may not be willing to wait long for a taxi. This would be consistent with the magnitude of the effects and suggest that individuals traveling short distances generally are more willing to substitute for another transportation mode, implying that, on average, travel distance in taxis should increase during Muslim holidays.

	Number Passengers per Taxi Ride	Taxi Ride Distance	Daily Subway Rides	Bike Rides
Eid al-Fitr	-0.0141	0.0501	-18,517.51	726.88
	(0.0084)	(0.0227)	(118,799.05)	(1,589.77)
Eid al-Adha	-0.0199	0.0989	3,801.25	-859.14
	(0.0025)	(0.0185)	(77,126.48)	(2,355.71)
Baseline	1.68	2.92	4,906,055	34,525
N	822,959,489	799,758,682	1,244	1,044

Notes: Standard errors clustered by day in Columns 1 and 2, and robust standard errors in Columns 3 and 4 are reported in parentheses. This table presents the effect of the Muslim holidays on the number of passengers per taxi trip, the distance of the taxi trip, subway rides, and bike rides. The regressions control for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions.

Table 7: Effects of Muslim Holidays on Other Modes of Transportation

Column 2 shows that the distance traveled in taxis increases during Muslim holidays. In Eid al-Fitr, the distance traveled increased by 0.05 miles (1.7 percent of baseline, Fisher p-value=0.047) and by 0.1 miles in Eid al-Adha (3.4 percent of baseline, Fisher p-value=0.014). Longer trip distances suggest that people who want to go somewhere reasonably near are not willing to wait long (or pay much) for a for-hire trip, while people traveling longer distances are willing to wait longer (or pay more). This effect is driven by the upper quantiles of the distance distribution (Appendix Table G1). Given that 25 percent of all trips travel up to one mile and 50 percent up to 1.7 miles, increased travel distances during Muslim holidays for longer trips suggest that walking is a potential substitute for short for-hire trips. This is also consistent with the shock being unpredictable, implying that individuals did not have access to their private vehicles.

Table 7 also shows how subway trips change on Muslim holidays. For 2010-2017, subway rides decreased by 18,500 in Eid al-Fitr (0.4 percent of baseline, Fisher p-value=0.801) and increased by 3,800 during Eid al-Adha (0.1 percent of baseline, Fisher p-value=0.900). A back-of-the-envelope calculation shows that any increase in subway ridership caused by the reduction in for-hire trips falls within the normal variation of daily subway trips. The estimates in Table 6 suggest that during Eid al-Adha, on average, there were 39,356 fewer trips in 2009-2013 or 26,802 in 2014-2017. Given a mean of 1.68 passengers per trip, the reduction in trips implies that 66,118 passengers in 2009-2013 (45,027 in 2014-2017) had to switch to an alternative transportation mode during Eid al-Adha. Assuming that all these individuals switched to subway rides, it would imply a 1.3 percent increase in subway rides during that holiday (0.9 percent in 2014-2017). This increase is well within the daily variability of subway rides and within the confidence interval of the estimates in Table 7.

Regarding bike trips from the bike-sharing system in Manhattan, there is no significant change during Muslim holidays. In Eid al-Fitr, these rides increased by 700 (2.1 percent of baseline, Fisher p-value=0.736) and decreased by 850 in Eid al-Adha (2.5 percent of baseline, Fisher p-value=0.736). The upper limit of these estimates' 95 percent confidence interval suggests that, at most, bike rides increased by 3,700 during these holidays, representing 5.7 percent of the 66,118 passengers who could not get a for-hire vehicle. These results suggest that bicycles are not a meaningful substitute for for-hire vehicles.

5.1. Supply-Side Responses

During Muslim holidays, Non-Muslim drivers face less competition as some Muslims opt not to work those days. Lower competition should imply more trips per driver; subsequently, daily income per driver should increase. The estimates in Table 8 confirm this intuition. Rides per driver increased by 2.8 trips in Eid al-Fitr (12.6 percent of baseline, Fisher p-value=0.014) and by 3.2 in Eid al-Adha (14.5 percent of baseline, Fisher p-value=0.014). These estimates are not significantly different from each other. As the number of trips increases, the daily income per driver also increases. During Eid al-Fitr, average income per driver increased by $35 (12.7 percent of baseline, Fisher p-value=0.047) and by \$44 in Eid al-Adha (15.6 percent of baseline, Fisher p-value=0.014).

These results, together with previous work on the labor supply of taxi drivers, suggest that the duration of drivers' shifts might also increase during the Muslim holidays (Farber, 2005, 2008, 2015; Thakral and Tô, 2021). Unfortunately, the available data only allows testing this hypothesis in 2010, 2012, and 2013. The estimates in the third column of Table 8 show that shift duration increased by 0.35 hours on Eid al-Fitr (4 percent of baseline) and by 0.08 hours on Eid al-Adha (0.9 percent of baseline). However, the reduced sample does not allow us to control adequately for noise in the data generation process. The estimates lose significance when calculating the p-values with randomization inference (Fisher p-value= 0.033 and Fisher p-value=0.328, respectively). Consequently, it is not possible to draw definite conclusions about changes in shift duration.

	Average Rides per Driver	Average Income per Driver	Shift Duration
Eid al-Fitr	2.80	35.56	0.35
	(0.90)	(11.64)	(0.07)
Eid al-Adha	3.22	43.94	0.08
	(0.75)	(9.08)	(0.03)
Baseline	22.21	280.94	8.71
N	1,080	1,080	14,886,372

Notes: Robust standard errors in Columns 1 and 2 and standard errors clustered by day in Column 3 are reported in parentheses. This table presents the effect of the Muslim holidays on the daily number of trips per taxi driver, the daily income per driver, and the duration of the drivers' shifts. Shift duration is measured in hours. The regressions control for day-of-the-week, week, summer, and holiday fixed effects plus meteorological conditions.

Table 8: Substitution Effects of Muslim Holidays on Supply Outcomes

6. Consumer Surplus Changes of Decreasing the Supply of For-Hire Vehicles

The results in sections 4 and 5 indicate that travel speed increases as for-hire vehicles leave the streets, improving the welfare of riders of for-hire vehicles and people driving private cars (Small et al., 2007; Abrantes and Wardman, 2011). However, as the supply of for-hire vehicles decreases, waiting times increase. Some people may have to switch to another mode of transportation that was not their preferred choice, decreasing welfare.[21] Arnott (1996) argues that reducing waiting times is welfare-increasing to the point that a social planner should consider subsidizing taxis. Thus, the welfare trade-offs between increasing travel speed and waiting times imply that the final effect on consumer surplus is uncertain. It is important to quantify and balance consumer surplus trade-offs between increased speed, waiting times, and substitution of transportation modes to formulate traffic regulation policies. These trade-offs could determine the political viability of congestion policies.

I quantify how consumer surplus gains from increased travel speed during Muslim holidays stand against consumer surplus losses from increased waiting times and switching to less

[21] See Hoffmann et al. (2018) and Saia (2019) for more evidence on substitution patterns.

preferred transportation modes. I calibrate Anderson's (2014) transportation demand model for this exercise. This model allows matching the parameters that define consumer surplus changes to the reduced form estimate of the speed change. Thus, I can quantify welfare gains from increased speed during Muslim holidays without relying on exclusion restrictions. I focus on 2009-2013 when taxis were the dominant for-hire vehicle, to address data limitations on prices for trips in ridesharing for-hire vehicles like Uber. The other critical parameters for this calibration are the value of travel time and average waiting times. I take the New York City-specific value of time estimate of Goldszmidt et al. (2020) of $23.85 per hour and adjust it by the ratio between the average weekly wage in Manhattan and the average weekly wage in New York City's metropolitan area (66 percent increase), yielding a value of time estimate of $39.60.[22] Frechette et al. (2019) used the same taxi data to estimate the distribution of waiting times in 2013. The average of this distribution is 2.57 minutes. I consider three scenarios for increased waiting times by increasing the average waiting time by 25, 50, and 100 percent. Appendix H presents the details of the model and other data-based parameters used in this calibration. The estimated gain in travel speed increases consumer surplus on average by $0.30 per mile traveled. With this input, we can quantify consumer surplus changes by transportation mode choice.

Table 9 presents the calibration results. Panel (a) presents consumer surplus changes by trip associated with reducing the number of active for-hire vehicles during Muslim holidays. People who travel in their private cars only benefit from the speed gain. Multiplying $0.30 times half the average distance traveled on a private car yields a surplus gain of $1.69 per trip. For individuals who chose a taxi and could find one, the change in consumer surplus depends on both the gain in travel speed and potentially higher waiting times. If waiting times do not change, then consumer surplus would increase by $0.25 per trip for individuals whose second best option is walking and by $0.99 per trip for those whose second best is transit (the difference comes from travel distances). These welfare gains fade if waiting time increases due to reducing the number of vehicles. If waiting times double, on average, consumer surplus would decrease by $1.45 per trip for individuals whose second best option is walking and by $0.71 per trip for those whose second best is transit. Finally, for people who chose a taxi and were *not* able to find one, this implies that they waited for a cab up to their maximum and then

[22] I use wage data reported by the BLS (https://www.bls.gov/regions/newyork-new-jersey/ news-release/countyemploymentandwages_newyorkcity.htm)

switched to the second-best option. In this case, consumer surplus would decrease by $1.70 per trip.

	Wait Time			
	No change	25% Increase	50% Increase	100% Increase
	a. Welfare Change Per Trip ($)			
Private cars	1.69	1.69	1.69	1.69
Taxi (walking is second best)				
Found taxi	0.25	-0.18	-0.60	-1.45
Did not find taxi	-1.70	-1.70	-1.70	-1.70
Taxi (transit is second best)				
Found taxi	0.99	0.56	0.14	-0.71
Did not find taxi	-1.70	-1.70	-1.70	-1.70
	b. Daily Welfare Change ($ Millions)			
Private cars	2.559	2.559	2.559	2.559
Taxi (walking is second best)				
Found taxi	0.033	-0.024	-0.080	-0.194
Did not find taxi	-0.020	-0.020	-0.020	-0.020
Taxi (transit is second best)				
Found taxi	0.285	0.163	0.041	-0.204
Did not find taxi	-0.043	-0.043	-0.043	-0.043

Notes: This table presents the results of the consumer surplus calibration. Panel (a) presents results at the trip level, and Panel (b) presents daily changes in welfare. The first column presents the welfare change associated with higher travel assuming no change in waiting times. The following columns incorporate the consequences of increasingly higher waiting times.

Table 9: Consumer Surplus Gains and Losses

Panel (b) scales the previous values by the number of trips that fell in each category in 2013. If there is no change in waiting times, reducing the number of vehicles during Muslim holidays would have increased consumer surplus by $2.8 million per day. However, as waiting times increase, the consumer surplus gain would decrease, reaching $2.1 million per day in the worst scenario in this calibration. Waiting times would have to increase by roughly 6.5 times to cancel the gains in travel speed.

7 Discussion and Conclusion

This paper finds that during Muslim holidays from 2009 to 2013, reducing the number of for-hire vehicles on the streets by approximately 1,000 (9.1 percent of the baseline) reduced the time per mile traveled by 0.45 minutes, representing a 7.2 percent gain in travel speed. This result held in the later period of 2014-2017 and the complete 2009-2017 period, but it is important to acknowledge that the effect in the later period also includes responses from other for-hire vehicles like Uber and Lyft. Fewer for-hire vehicles on the streets imply that people will substitute across transportation modes. Taxi and other for-hire trips decrease between 1.6 percent and 16.4 percent during Muslim holidays. The estimates indicate that during Muslim holidays, the number of passengers per taxi trip decreases by 1.2 percent, and taxi travel distance increases between 2.1 and 3.4 percent. Since 25 percent of all trips travel up to one mile and 50 percent up to 1.7 miles, these estimates suggest that people who want to go somewhere reasonably near switch to walking when facing increased waiting times. Also, there is an income transfer from drivers who take the holidays off to drivers who work. This effect is driven by more trips per active driver during these holidays. From a welfare perspective, taking for-hire vehicles off the streets affects consumer surplus through increased travel speed, waiting times, and substitution for second-best transportation modes. Under three scenarios for increased waiting times, I document daily consumer surplus gains from increased travel speed between $2.1 and $2.8 million.

Under the exclusion restriction that the only channel through which Muslim holidays affect travel speed is the number of active for-hire vehicles, the reduced form estimate on travel speed implies an elasticity of congestion to the supply of for-hire vehicles of 0.79 in 2009-2013 when taxis were the dominant for-hire vehicle. This effect is driven by changes in speed in mid and lower Manhattan, south of East 96th Street and West 110th Street. In the rest of the city, the effects are smaller, which is consistent with the fact that the outer boroughs have lower vehicle density than Manhattan. These smaller values align with the elasticities reported by Mangrum and Molnar (2018), whose estimates are based on speed changes at the boundary of East 96th Street and West 110th Street and do not capture speed changes in mid and lower Manhattan. Kreindler (2020), using within-day city-wide variation in traffic density in Bangalore, finds that an additional 8 km (5 miles) trip increases travel time between 4 and 16 minutes depending on the time of the day. These estimates are substantially larger than the implied change from a back-of-the-envelope calculation using my reduced form estimates ($5 *miles* × 0.46/1000). The difference can be explained by the different nature of the identifying variations in each case. Tarduno (2021) estimates that Uber and Lyft decreased travel speed in Austin, Texas, by 2.3 percent. This magnitude is similar to the effect of Eid al-Adha between 6 and 8 am when traffic density is not so high in New York City. This is consistent with the notion that taking vehicles off the street has smaller effects in locations and times with lower congestion. Tarduno (2021) also estimates congestion costs. This calculation is comparable to the gains in travel speed calibrated in Section 6. The estimates Tarduno (2021) are smaller because the value of travel time in Austin is 47 percent of the value in New York City (Goldszmidt et al., 2020) and the effect on travel speed is also smaller.

The results on travel speed are also consistent with hypercongestion, where as demand for travel increases, travel speed decreases, and the road system's capacity also decreases (Anderson and Davis, 2020). Hypercongestion implies that drivers adapt their routes to avoid the most congested areas in a city, equalizing congestion through the city grid and reducing vehicle flow throughout the city (Hall, 2018, 2020). A back-of-the-envelope calculation illustrates this point. For a fixed location and number of vehicles, the total miles they can travel in one hour equals the number of vehicles traveling times average speed. This is a measure of traffic flow. In 2013, there were 12,379 taxis and 1,512,826 commuting and non-commuting vehicles, totaling 1,525,205 vehicles in New York City. The daily average city-wide speed was 9.58 miles per hour, implying that the available vehicles could travel 14,618,578 miles in one hour. Eid al-Adha had 1,126 fewer taxis than on a regular day, and the average city-wide speed increased to 10.33 miles per hour. This implies that the remaining vehicles in Eid al-Adha could travel 15,745,430 miles in one hour, a 7.7 percent increase compared to regular days. Consistent with higher vehicle flow in the city, the number of trips for the remaining taxi drivers also increased (Table 8). In Appendix I, I find suggestive evidence of increased traffic flow during Muslim Holidays. However, the data available do not allow for a detailed analysis of flows. While these results are consistent with hypercongestion, more research is needed to assess its existence and welfare implications.

The consumer surplus calibration results warrant discussing three additional points. First, this paper's calculations indicate that people driving private cars are the main beneficiaries of increased travel speed. Thus, reducing the supply of for-hire vehicles makes driving a private car more attractive. This could increase demand for private vehicles in the medium term, similar to the effect of other restrictions on vehicles (Davis, 2008). More private vehicles would then cancel the gains in travel speed from removing for-hire vehicles. Second, switching to less preferred transportation modes would only get more substantial for a policy-driven reduction of active vehicles. This would magnify welfare losses for individuals who use for-hire vehicles. Mitigating these losses requires that policymakers ensure that public transportation improves both in terms of capacity and quality of the ride. Finally, these calculations do not include pollution externalities. A back-of-the-envelope calculation suggests that CO_2 emissions decreased between 40.1 and 82.6 tons during Muslim holidays, while NO_x emissions decreased between 0.02 and 0.04 tons (Appendix J). These reductions in emissions imply benefits in terms of health and climate outcomes. Further research is needed to understand if these welfare gains counter losses due to waiting and switching.

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