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Spatial regulation of taxicab services: Measuring empty travel in New York City

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Abstract: Taxicabs are ubiquitous in cities throughout the world, and the industry is going through regulatory change with the growth of app-based services. In the United States, where taxicabs are typically regulated locally, licenses determine where taxis can pick up passengers. This means that for trips that end outside of licensed boundaries taxicabs are prohibited from picking up passengers and are forced to make "deadhead" return trips. This research estimates empty taxi travel associated with spatial restrictions on passenger trip origins in New York City. In 2012, New York introduced a special taxi category intended to improve taxi access in areas of the city considered underserved by taxicabs. The new green taxicabs, as they are called, can drop off passengers anywhere in the city but are restricted from picking up passengers in the central business districts and at any of the region's airports. Using detailed trip data for each taxi ride, we estimate that up to 500,000 kilometers per week of deadhead travel are associated with restrictions on pick up locations, and more than 20 percent of all green taxicab trips end in an area where the driver is prohibited from picking up a new passenger.

1   Introduction

In the United States, as in Canada and the United Kingdom, taxicab services are typically regulated through patchworks of local laws. Licenses are issued by individual cities, counties or airport authorities, all of which impose rules on taxi behaviors. Common rules include metered fares, passenger protections, vehicle standards and limits on where taxi drivers can pick up passengers and where they are required to drop them off when requested. Since many states leave taxi licensing to individual cities, taxi trips within metropolitan regions are frequently made across municipal boundaries and license zones. This prevents more efficient use of available taxi services, and drivers are prohibited from potentially filling empty seats by license restrictions, though the restrictions protect licensee and driver interests. Municipal regulations represent spatial aspects to taxi regulation that are important to the overall operations of taxi services.

Previous studies of taxi regulations across cities have often focused on behavior while cruising for

fares. Flores-Guri (2005) examined the cities of Boston and Cambridge in Massachusetts. He showed that a non-trivial amount of taxi trips began in one city and ended in another. This was a problem of efficiency, where a metropolitan license instead of a city license would fill many of the empty cabs that crossed city boundaries. He also noted, however, that a metropolitan license might lead to inefficient outcomes including regional monopolies of service providers, or concentrations of taxicabs rather than widely available services. These outcomes, if they develop, may harm consumers in the end.

Economic efficiency is only part of the reason taxicabs are widely regulated. Passenger protections are a common justification for taxicab regulation, with clear evidence that some protections are advisable to prevent discrimination (Wohl, 1975; Schaller, Considine, New York City Council, & New York Taxi and Limousine Commission, 1989; Dempsey, 1996; Design Trust for Public Space & New York Taxi and Limousine Commission, 2007). Evidence shows that access to taxi services is affected by race (Ambinder, 1995; Loury, 1998; Siegelman, 1998) and communities with high shares of immigrant and unbanked households (King & Saldarriaga, 2017). With the advent of Geographical Positioning Systems (GPS) data, other literature has explored sorting and trip chaining characteristics in various urban conditions (Li et al., 2011; Yue et al., 2012; Qing, Parfenov, & Kim, 2015). These studies provide evidence that driver and dispatch behavior does influence the supply of taxi services to certain communities.

Current interest in taxicab regulations, driven in part by the growth of commercial interests by private technology firms developing taxi hailing applications for smart phones, is influenced by historical experiences of taxi licensing in and across cities. The primary critique launched against current regulations is that licenses to operate are artificially scarce, which leads to rent seeking by license holders and less than optimal service levels across cities (Moore & Balaker, 2006). It is unclear, however, that license caps are problematic for passenger service as a general principle. Certainly, artificial scarcity has implications for medallion values and investment, and some cities have been historically underserved by taxicabs. However, cities do adjust taxi regulations. Some cities have eliminated taxi license caps altogether, such as Minneapolis in the mid-2000s (Roper, 2012). Yet, since 1970 there is no correlation in U.S. cities between the growth (or decline) of taxi licenses and overall population (King, Peters, & Daus, 2012). This is not to say the license restrictions are harmless; they certainly are problematic in many cities. It is just that license restrictions are best analyzed on a case by case basis.

In addition to changes to conventional taxi regulations, cities and states are responding to the rise of taxi services enabled by smart phones (Cramer & Krueger, 2016; Rayle, Dai, Chan, Cervero, & Shaheen, 2016), though in 2017 the full effect of smart phone technologies on taxi markets should be considered preliminary until data from private taxi firms is available for scholarly use. Renewed interest in taxis has opened policy discussions about how the taxi market should be regulated to maximize public benefits, such as environmental benefits (Strong, 2015). This paper argues that local regulations strongly affect spatial distribution of taxi vehicle travel—not just passenger service—that should also be considered. To develop this argument, we use a natural experiment in New York City to estimate the amount of empty taxicab travel that occurs because drivers are prohibited from picking up new passengers at popular destinations.

The paper is organized as follows. The following section briefly describes typical regulatory schemes for passenger pick up and drop off. Next, the data and methods are described, with a discussion of methodological issues that affect our estimates and are relevant for other studies using the GPS data. This is followed by conclusions and future directions for research.

2   Background on taxicab regulations

As mentioned above, licenses to legally operate taxicabs are usually granted by individual cities (Cooper, Mundy, & Nelson, 2012). These licenses grant rights to pick up and drop off passengers under a specific

set of rules, which typically focus on meter fares, insurance requirements, vehicle standards and other similar concerns. These concerns are related to economic and safety factors associated with taxi services, and to provide access to taxi services to all. Most U.S. cities, for instance, require that all taxi trips are pre-arranged, or dispatched, through a central processor. The advantage of the dispatch model is that taxis can be requested to provide service anywhere in their licensed zone. Requiring dispatch services solves a key access problem with street hail taxi services, which is that under street hail rules drivers will only be available in high traffic areas, such as airports and business hotels (Cooper et. al, 2012).

The New York City taxi market in an example of the complex nature of local regulations. The New York City metropolitan region includes three states and 25 counties, plus all cities therein. New York City, by far the dominant city in the metro area, comprises five of these counties and holds approximately 8.5 million people, which is less than half of the total regional population. New York City regulates its taxi fleet, but the suburban cities and counties surrounding the city license taxi services independently. New York City taxis are prohibited from picking up passengers outside of city limits, and suburban taxis are prohibited from doing so within New York City limits.

New York City has many types of taxi license, each with unique rules and obligations. Traditional taxicabs, which are painted either yellow or green, have licenses that allow drivers to accept street hails—when a passenger stands at the curb and flags down a taxi. Other types of for-hire services must use a dispatch service, whether by phone or through a smart phone app. Limousines and Transportation Network Companies (TNCs) such as Uber, Lyft and Via are licensed this way. By law, all taxi drivers are required to pick up passengers without discrimination of passenger characteristics or trip destination, but this is difficult to enforce and discriminatory practices are well documented, even with e-hail companies (Ambinder, 1995; Ge, Knittel, MacKenzie, & Zoeph, 2016).

Yellow taxicabs and green taxicabs operate under separate rules for specific, well intentioned reasons. Yellow taxis are abundant in certain parts of the city and scarce, at best, in most of it. The central areas of Manhattan are well served to the point that over 40 percent of all traffic south of the midtown business district are taxicabs (Komanoff, 2017). In addition, vast parking lots at the airports are filled with yellow taxis ready to take passengers away. Yet over 95 percent of all yellow taxi trips originate in Manhattan or the airports, which leaves the balance of the city underserved (Schaller et al., 1989; King et al., 2012). To address this, then-Mayor Michael Bloomberg developed the green taxi program, where these special taxis were prohibited from picking up passengers in areas already served by yellow taxicabs (King & Saldarriaga, 2017). The intent was to increase the supply of taxi services in previously underserved areas, and it was largely successful, at least anecdotally.[1] It is difficult to assess total change in taxicabs in the new service areas are these communities were previously served by informal community cars. There may have been substitution from community cars to green taxis, but no data exists to make this evaluation.

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[1] There is study needed about the effect ridesharing companies have has on New York's green taxis. News article suggest that Uber and Lyft have largely supplanted these cabs, but this is speculative at this point.

Figure 1: Taxi service areas and TAZs in New York City

Figure 1 shows the taxi service areas of New York City with Traffic Analysis Zones (TAZ) outlines. The city is comprised of five boroughs: Manhattan, the Bronx, Queens, Brooklyn and Staten Island. Across the Hudson River from New York is the state of New Jersey, where New York licensed taxicabs are prohibited from picking up passengers. New York City taxis licenses allow yellow cabs to pick up street-hail passengers anywhere within the five boroughs, but not in New Jersey. Street-hail refers to the act of standing on the street and signaling for a taxi by raising your arm so the driver sees you. Yellow taxis in New York City are traditionally limited to street-hail hiring, but most cities require dispatch services. Dispatch services protect against taxi services avoiding certain locations that are perceived as undesirable and concentrating taxi activities in the Central Business Districts and airports. Smart phone enabled taxi services are generally called "e-hail" and under ideal circumstances provide wide coverage and avoid spatial discrimination, but this is disputed.

New York taxis can drop off passengers in New Jersey, however, which is common but a very small

share of total taxi trips. Green taxicabs, however, are allowed by their city license to pick up passengers only in the parts of the city that are not shaded in the map. The shaded areas represent the Manhattan Central Business Districts and the three regional airports operated by the Port Authority of New York and New Jersey (PANYNJ). Two of these airports are within New York City (LaGuardia and JFK, both in Queens), where yellow taxicabs can pick up and drop off passengers, but green taxis can only drop off passengers. The third airport, Newark Liberty International, only allows passenger drop offs by New York licensed taxis. There is a $15 surcharge on fares to Newark airport to compensate drivers for the return deadhead trip, but some evidence suggests drivers also deliberately increase fares for these trips (Rajgopal & White, 2015).

Taken together, the yellow and green taxi service area restrictions offer an opportunity to measure the effects of spatial regulations on taxi activities. Green taxis can pick up passengers only outside of restricted areas of Lower Manhattan and local airports—which are known to have high demand for taxi trips— but can drop off passengers anywhere. This potentially creates deadhead trips that, had they not been limited by local service regulations, would have been viable for an additional passenger(s) trip near the destination of the previous traveler. Instead, the taxi driver must travel some distance to a place where they can legally pick up passengers again. In the following section we describe the data used to evaluate the empty travel of taxis caused by returning to areas where they can pick up passengers after dropping off in a restricted area.

3   Data and methods

The analysis presented here uses GPS data from each trip taken by a New York City green or yellow taxi during the week of October 12-19, 2015. These data are logged for each paid trip, and include origin and destination locations, number of passengers, time of trip beginning and end, payment method and total fare. The data were collected through the New York City Taxi and Limousine Commission website and are publicly available (New York City Taxi and Limousine Commission, 2017). A limit to these data are that geographically they only have origin and destination points, as the collected data does not include bread crumb trails of actual taxi trips. Precise routes are unknown and must be estimated. In addition, the data are cleaned of characteristics that may identify drivers, which means that no individual trip can be matched with certainty to any or all subsequent trips. To examine potential excess travel caused by spatial restrictions we then had to make assumptions about where drivers would go after dropping off passengers in restricted areas if they would indeed pick up a new passenger. These assumptions are explained in more detail below.

Estimates for deadhead kilometers traveled were calculated by street network distance from a passenger drop off point in a restricted area to the centroid of U.S. Census Transportation Analysis Zones (TAZs). New York City has 2,243 TAZs with an average size of 540,960 square meters. The distance estimates were derived in two ways: For deadhead trips that ended in Manhattan in areas where green taxicabs are prohibited from picking up passengers (this is the shaded area of Manhattan shown in Figure 1 and represents the area below 110th street on the west side of Central Park and below 96th street on the east side of the park), the distance was calculated to the closest TAZ centroid where a pickup was allowed. This is the shortest distance assumption. It is unlikely that drivers went to the closest possible location, however, as drivers tend to have their own search habits.

For deadhead trips that ended in LaGuardia, JFK or Newark airports, the distance was calculated to TAZ centroids throughout the city where pickups are allowed, and then split proportionately based on observed origins. This is the proportional assumption. This approach assumes that a TAZ that has 15 percent of all green Taxicab origins will also have 15 percent of trip origins after deadheads, a TAZ with five percent of origins will maintain five percent of origins after deadhead trips, as so on. The TAZs

closest to the Manhattan core have the highest share of green taxi origins, and this is reflected in distance estimates. While these assumptions are not perfect, we expect that they allow for reasonable estimates as to the amount of Vehicle Kilometers Traveled (VKT) caused by geographic restrictions in New York.

Technically, these distances were derived using the ArcGIS Network Analyst extension. The LION geographic base file was used as our main network dataset, which is a line representation of New York City's street network and is produced and maintained by New York City's Department of City Planning (New York City Department of City Planning, 2017). Before building the network through the Network Analyst extension, the LION dataset needed to be cleaned, and the street segment elevation values transformed to numerical data. Using the built network, the trips with a destination in a zone where pickups were prohibited (deadhead trips) were added as "incidents", then the TAZ centroids were used as "facilities." We then ran "Closest Facility" analysis, which gave us, for every deadhead destination, the closest TAZ centroid where pickups are allowed, as well as the shortest route to this point and a distance value. Similarly, for the deadhead trips that ended in the airports we ran an "OD Matrix" (origin and destination) analysis, which gave us the distance from all "incidents" (deadhead trip destinations) to all "facilities" (TAZ centroids where pickups are allowed).

As a comparison, we also calculated the distances using two routing APIs (application programing interfaces): Google Maps Directions API (Google, 2017) and Mapzen Turn by Turn API (Mapzen, 2017). Google Maps Directions API uses their proprietary datasets as their base network while Mapzen Turn by Turn API uses Open Street Map data. To calculate distances and the routes from these services we created multiple Python scripts that communicated with the APIs and requested the routes and the distances from the deadhead trip destinations to the TAZ centroids. In both cases, there are factors that affect the information returned. Google Maps returned route information based on the time of day the request was sent, and Mapzen did not have traffic information at the time of request. These issues arise because this process required weeks to complete due to daily limits on requests through the APIs (Google Maps Directions API has a limit of 2,500 requests per day). As in the case of ArcGIS's Network Analyst, these APIs gave us the route and distance from the deadhead trips in Manhattan to the nearest TAZ centroid where pickups are allowed, and the route and distance from the airports deadhead trips to all the TAZ centroids where pickups are allowed. To be clear, the estimates of travel to a TAZ where passenger pick-ups are allowed is based on author assumptions about driver behavior as discussed above. There are no linked trip data that allows exact estimation of subsequent trips.

Comparing the methods there is a discrepancy between the distances derived from ArcGIS Network Analyst and the distances derived from the API services. Overall, the distances estimated from the APIs were much greater than the distances from ArcGIS. However, the APIs returned distances that were similar to each other. The primary reason for this difference in estimates is that the APIs select routes based on distance along with speed limits and traffic conditions to optimize travel time, while ArcGIS (as we set it up) selected routes based solely on distances. While ArcGIS was looking only for the shortest route, the APIs were looking for the shortest travel time and were taking into account not only the street characteristics but also the current traffic conditions. This led to some trips shifting from local streets to higher speed limited access roads which added distance but saved time.

Figure 2 shows, in color, the differences between Google and Mapzen routing for purposes of illustration. Red lines are primarily Google routes and blue is Mapzen, and the differences are most pronounced on the island of Manhattan, which may account for much of the difference. The precise numerical difference is not as important here as the recognition that we returned substantial differences in our estimates based on which approach we used. While we are confident in our results, we present our findings as a range of potential distance traveled rather than a precise point estimate of distance traveled. For all of the following images the taxi data are from the New York City Taxi and Limousine Commis-

sion. The satellite image provided by ESRI, Digitalglobe, Geoeye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, GETmapping, Aerogrid, IGN, IGP and Swisstopo.
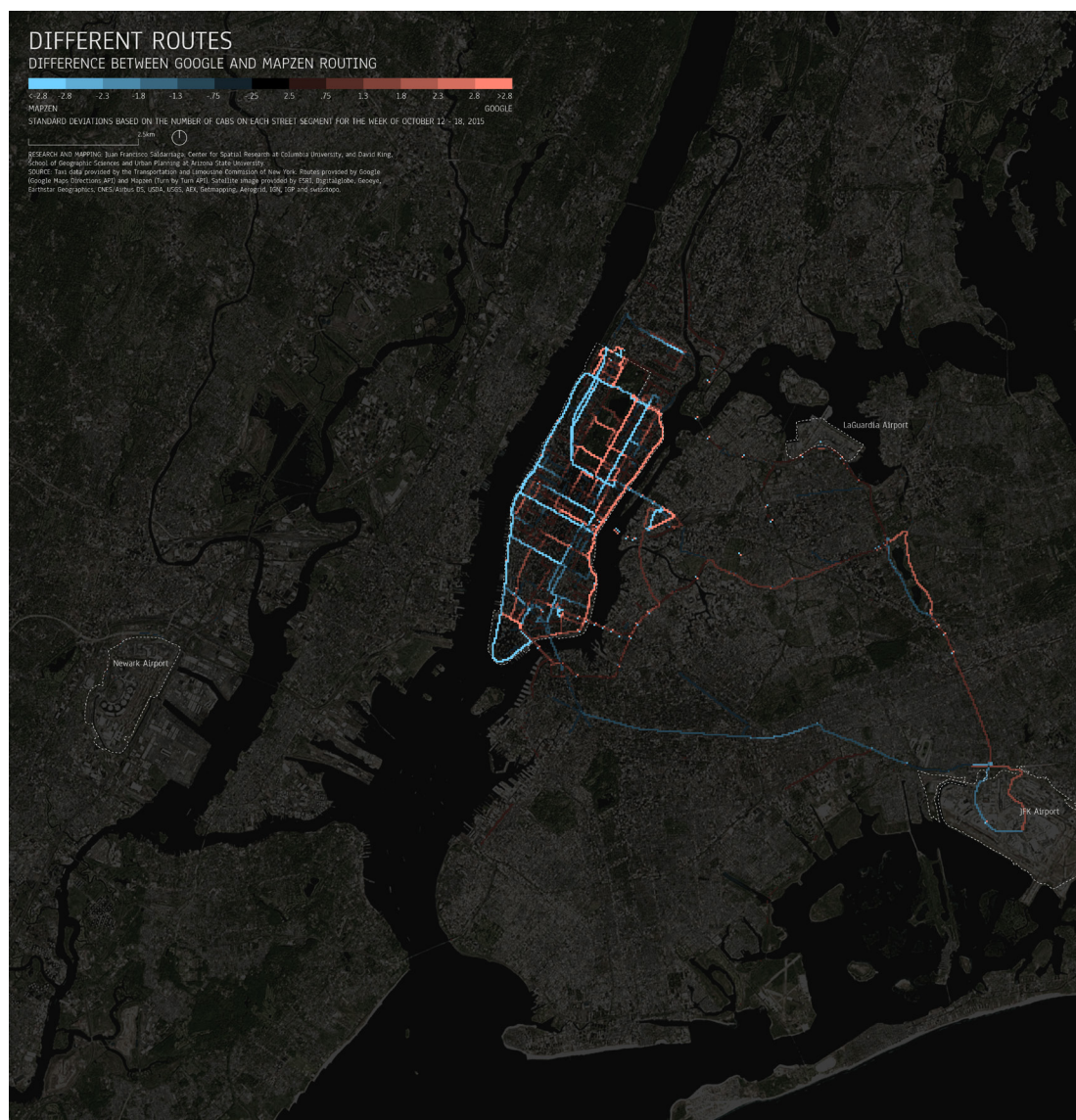

Figure 2: Differences between Google and Mapzen API requests

Figures 3 shows the most common routes likely used by green taxis as they return to areas where they can pick-up passengers. While time of day analysis is not included here, these empty cabs are traveling streets that are already congested many parts of the day. Figures 4 and 5 show the destinations (drop-offs) and origins (pick-ups) for green cabs in our sample. The key point from these maps are that destinations are spread throughout the city but include many drop-offs in restricted areas, and that origins tend to cluster near the central core of Manhattan rather than being broadly spread throughout the city. This suggests that the spatial restrictions may be too crude to achieve the stated social goals of the green taxi program, but such an analysis is beyond the scope of this paper.
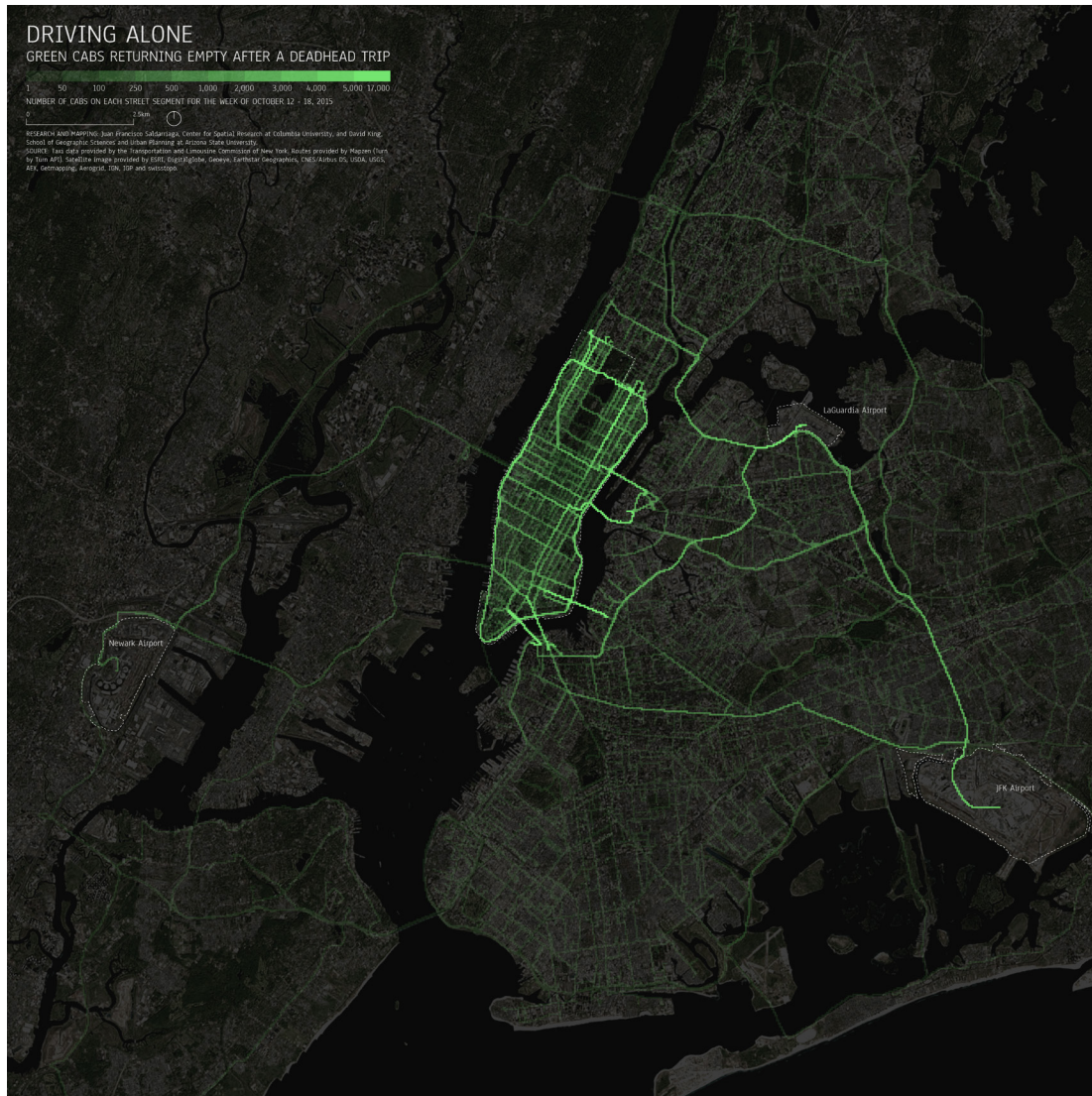
Figure 3: Volume and paths of deadhead green taxi deadhead trips

GREEN DROPOFFS
GREEN CABS DROPOFF LOCATION - OCTOBER 12 - 18

NUMBER OF GREEN CAB DROPOFFS PER CELL (200ft x 200ft) FOR THE WEEK OF OCTOBER 12 - 18, 2015

RESEARCH AND MAPPING: Juan Francisco Saldarriaga, Center for Spatial Research at Columbia University, and David King,
School of Geographic Sciences and Urban Planning at Arizona State University.
SOURCE: Taxi data provided by the Transportation and Limousine Commission of New York. Satellite image provided by
ESRI, DigitalGlobe, Geoeye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP and
swisstopo.

Figure 4: Destinations of all green taxicab trips

Figure 5: Origins of all green taxicab trips

   Summary statistics of the distribution of trips to locations where pick-ups are prohibited are shown in Table 1. As with Figures 2-5, these describe all trips taken for the week being studied. Yellow cabs do not have deadhead trips anywhere in the city as they are allowed to pick up passengers anywhere. Green cabs, in contrast, are subject to restrictions and a non-trivial amount of their total trips are made with passengers. Overall, over 20 percent of all green taxi trips terminate in locations where the drivers are prohibited from picking up passengers. Most of these trips end in Manhattan, but each week thousands of airport trips are made where the drivers must leave the airport empty. Yellow taxicabs feature many deadhead trips from Newark airport, but these are a small share of total trips.

Table 1: Share of deadhead trips by taxi type and destination

	Total Trips	MN Dead-head	MN Deadhead %	JFK Deadhead	JFK Deadhead %	LGA Deadhead	LGA Deadhead %	Newark Deadhead	Newark Deadhead %	Total Deadhead	Total Dead-head %
Taxi Type											
Green	359,929	66,208	18.4	3,163	0.9	5,224	1.5	186	0.1	74,781	20.8
Yellow	2,798,036	0	0	0	0	0	0	4,879	0.2	4,879	0.02

Table 2 shows the results returned from the mapping exercises. We estimate that spatial regulations that restrict passenger pick-ups are responsible for between 333,000 and 500,000 vehicle kilometers of taxi travel without passengers weekly. As described previously, we are more convinced that Google Maps and Mapzen estimates are more accurate as they better reflect driver behavior of minimizing travel time. This suggests that upwards of 26 million km (16 million miles) are driven each year by passenger-free taxicabs just to return to a place where passenger pick-ups are allowed.

Table 2: Estimated vehicle kilometers of travel from deadhead taxi trips by destination

	ArcGIS	Google Maps	Mapzen
MN Total kms (to nearest TAZ)	215,288	343,515	353,674
JFK Total kms (to all TAZ)	62,838	79,584	74,365
LGA Total kms (to all TAZ)	54,894	63,660	63,658
Newark Total kms (to all TAZ)	N/A	7,348	4,949
Total Estimated VKT	333,019	494,106	496,646

The data analyzed here suggests that spatial regulations of taxicab services can lead to large amounts of excess travel in the form of deadhead trips, which are those where taxi drivers are unable to pick up passengers near popular for rider destinations. The analysis presented is limited to the New York City market, but the fact that taxicabs are subject to local regulations in most cities suggest that there are likely generalizable points though of a smaller magnitude. The estimated results do show, however, that even in only the New York market the spatial restrictions on green cab activities have large consequences on wasted fuel, added congestion and excess travel.

The New York taxi fleet uses a mix of engine technologies. Many cabs use conventional internal combustion engines, while hybrid engines have seen a substantial increase in overall share since former Mayor Bloomberg introduced a policy that promoted hybrid technologies. Assuming a conservative 25 miles per gallon for the fleet, 500,000 annual VKT without passengers results in approximately 650,000 gallons of wasted fuel and about 6,500 tons of CO_2 into the atmosphere. These are steep environmental costs to bear for what may be marginal improvements in taxi services in the outer boroughs. In addition to these direct environmental costs, additional traffic and congestion imposes high costs on local communities, though these are not estimated.

4   Conclusion

Taxicab regulations are a fiercely debated policy area in the current era of rapidly growing smart phone enabled taxi applications while entrenched taxi interests fight to save their businesses. Though often regulatory discussions focus on entry to market, driver and passenger safety, or insurance and taxes paid, an underappreciated area of regulatory intervention is the scale at which regulations are enacted. This

research shows that spatial aspects of regulations are potentially large sources of excess travel and associated costs, simply because of a mismatch between pick-up and drop-off regulations.

This research examined the effects of spatial regulations on deadhead trips using a natural experiment in New York City. We found that the well-intentioned green cab program, which was designed to increase taxicab access to the outer boroughs of the city—areas long underserved by the city's yellow taxicabs—led to 20 percent of green cab trips ending in places where the driver was unable to get another fare. This is associated with close to 500,000 VKM weekly by taxis driving around empty.

We caution that there are limitations to the results presented here. Specifically, we are not able to link trips made by any particular taxicab. We have worked to be careful with our interpretation of the results because of this limitation. The estimates derived are not observed effects, rather they are based on reasonable expectations that taxi drivers will seek a new fare when they drop off a passenger. The magnitude of deadhead taxi travel is likely larger in New York City than other cities, spatial restrictions should be considered when designing regulations for taxi-type services.

We are also not arguing that absent spatial aspects of regulation that there would not be any deadheading. Demand for taxis is not uniform across time and space. Drivers who drop a passenger in a residential neighborhood are unlikely to have an easy match to the next passenger simply because of low demand. The example of New York City ameliorates this concern somewhat as green taxis are prohibited from picking up passengers in areas where demand for taxi trips is already high—hence the rational for the green cab initiative. Airport transfers are a particular area of concern as airport pick-ups are often licensed by the airport operator. As airports tend to be located away from taxi-rich downtown areas, airport licenses may cause substantial empty cab kilometers traveled.

There are potential policy interventions that can alleviate some of these problems. For instance, green taxis could be granted a small number of exempt pick-ups in restricted areas. This type of program could be monitored either through high tech ways—such as meter tracking, which already can be done using the GPS system installed, or low tech ways, such as giving drivers pick-up vouchers that they can use at airport taxi stands.

Mostly, however, the results shown here suggest that city by city taxi regulations—or even intracity regulations—are associated with inefficient use of the taxi fleet, even when the regulations were well intentioned to promote taxi coverage. U.S. metropolitan areas that are notoriously fragmented (Feiock, 2009), which suggests that city by city regulations may increase inefficiencies as smart phone enabled taxi services grow. The broader policy discussions about how to regulate taxi services should also include explicit spatial considerations. Regulating taxicabs as a state utility rather than a local concern may improve efficiency, or reciprocal arrangements that allow for more flexible service provision across city or airport borders may reduce empty taxi travel. There is likely no single model that will work everywhere. In regions with many cities, or even regions with large cities with multiple taxi needs, minimizing spatial restrictions while maintaining equitable access to taxi services is critical.

5   Acknowledgments

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