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Does residential parking supply affect household car ownership? The case of New York City

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ABSTRACT

This paper investigates the impact of residential parking supply on private car ownership, the relationship at the heart of the debate on whether residential parking regulations could be used as a demand management strategy to influence travel behavior. However, no empirical studies have sufficiently answered the question. Many believe that parking has little or no effect on car ownership, while others disagree. The paper analyzes 770 households randomly selected from a household travel survey in the New York City region, and measures their complete parking supply, including garage size, driveway spaces, and on-street parking availability, using Google Streetviews and Bing Maps. Results from a nested logit model show that parking supply can significantly determine household car ownership decisions, even after controlling for the endogeneity between the two. Their influence actually outperforms household income and demographic characteristics, the often-assumed dominant determinants of car ownership. Different parking types also behave differently: driveway spaces are more important to car ownership than garages probably because many residents in the study region do not use a garage for car storage. On-street parking is also important to households with off-street parking. Implications for residential parking policies like the maximum off-street parking standard, resident parking permit, and street cleaning are also discussed.

1. Introduction

Conventional parking policies have focused on accommodating travel demand but often overlook their social, economic, and environmental consequences (McShane and Meyer, 1982). With the paradigm shift from supply provision to demand management (Meyer, 1999), such policies have increasingly been criticized as ineffective, inefficient, and unequal, and as contributing to ever-increasing auto dependency and traffic congestion (Shoup, 2005). Many policy solutions have been proposed over the past decade (Litman, 2006), though the future direction of reform is still under heated debate (Barter, 2010; Shoup, 2011; Cato Institute, 2011).

Residential parking has largely remained absent from this discussion (Weinberger, 2012). Compared to the large number of studies on non-residential parking in urban centers, residential parking has attracted minimal attention from both academics and practitioners. Many proposed solutions to parking issues are specific to non-residential parking, and residential parking policy suffers from a dearth of research evidence (Marsden, 2006). For example, Shoup's (2005) market-based approach, based on the effective pricing of on-street parking and the removal of off-street regulations, is less feasible for residential parking due to the difficulty of charging for on-street parking in residential neighborhoods. The maximum off-street parking standard often targets non-residential developments (e.g., in Seattle, WA, and Gladstone, OR), or a small portion of multi-family homes in downtown areas (e.g., Chapel Hill, NC, Burlington, MA, and Bellevue and Redmond, WA). In some cases, the standard is too high (e.g., four spaces per unit in Madison, WI) to be effective. Given the importance of residential parking in the entire parking market, this lack of research is unsatisfactory.

In addition to the political and practical concerns, a major reason why residential parking is neglected is the lack of empirical evidence to support policy interventions, namely how residential parking policy could influence travel behavior. Empirical evidence is needed to address at least three types of questions. First, does residential parking supply have a causal influence on car ownership and usage? If the answer is "yes", is the parking effect large enough, compared to other factors, to justify policy intervention? A statistically significant but relatively minor influence is unlikely to help. Third, what is the relative importance among the different residential parking types, such as garage, driveway, and on-street? The interrelationship matters to parking policy: the rule about minimum off-street parking was adopted to prevent the overcrowding of on-street parking in the early days of motorization

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(Shoup, 2005), and it still permeates the current policy debate, e.g., whether a maximum parking standard will spill over into neighboring streets and whether a maximum standard is required when street parking is priced (Lee, 1987).

However, only a few studies have addressed the first question, much less the other two. One targets car usage (Weinberger et al., 2009), and five focus on car ownership (Wu et al., 1999; HCG, 2000; Kitamura et al., 2001; Guo, 2006; Cho and Baek, 2007; Woldeamanuel et al., 2009). Residential parking is assumed to have little influence on travel decisions, particularly car ownership. One clear example is in New York City, where the Department of City Planning claimed that car ownership is determined primarily by household income and demographic characteristics, not residential parking supply (NYCDCP, 2009). Therefore, residential parking policies can only respond to, instead of intervene in, car ownership demand. This policy stance is supported by many demand management studies that target only car usage, not car ownership (FHWA, 2004), and by car ownership studies that did not consider the parking effect (Prevedouros and Joseph, 1992; Bhat and Guo, 2007).

The effort to provide behavioral evidence of the effects of residential parking policies is hindered by several barriers. Data availability constitutes the first barrier. Residential parking supply is normally not monitored by government agencies. In addition, residential parking supply is affected by multiple regulations, such as the minimum standard, street width requirement, resident permits, and street cleaning, so the data collection process could be time consuming and costly. The second barrier is endogeneity between parking supply and car ownership; a household can choose to live in a residence with a parking supply level that meets its requirements based on preferred car ownership status. Without controlling for this endogeneity, the parking effect on car ownership could be either over- or under-estimated (Mannering, 1986; Chatman, 2009).

The objective of this paper is to provide empirical evidence to support a residential parking policy that goes beyond traffic accommodation. Using 770 households randomly selected from a regional travel survey in New York City, this research addresses all three of the issues described above. It addresses the data problem by using online images, such as those available from Google StreetView and Bing Maps, to measure thoroughly the quantity and types of parking available to individual households. It mitigates the endogeneity problem by dividing the sample into relatively homogeneous groups. It compares the parking effect on car ownership with household income and demographics, the two dominant forces behind car ownership decisions according to the existing literature. Finally, it investigates the relative importance of garage, driveway, and on street parking – and offers specific recommendations for three residential parking regulations: the maximum off-street parking standard, street cleaning, and residential parking permits.

2. Literature

If residential parking were a normal market, the change of supply would affect the parking price—a shortage would increase the price and an abundance of parking would reduce the price. Parking price should affect car ownership cost, and subsequently the car ownership level. However, since residential parking is often bundled with housing, there is usually no price for residential parking on- and off-street no matter how scarce or abundant it is. Correcting this market distortion will certainly affect the car ownership level (Shoup, 2005). However, this paper treats the current price system as given and focuses on the physical relationship between parking and car ownership.

Studies on this perspective come from multiple literatures and so far have produced mixed results. Some could argue that because a car is parked for 95% of its lifetime, the majority of which likely occurs at the home end of travel, residential parking supply should affect car ownership decisions (Kitamura et al., 2001). However, others would argue that because cars have become so important and ubiquitous, car ownership decisions are primarily based on mobility needs and budget constraints (Cao et al. 2007), not policy interventions such as parking regulations (Balcombe and York, 1993; Stubbs, 2002). This section compares two opinions in the literature.

2.1. Parking supply affects car ownership

The relationship between land use patterns and car ownership often suggests a parking effect on car ownership, but only indirectly. Development density and dwelling types are good predictors of residential parking supply (Holtzclaw et al., 2002) and can be used as a proxy to model the parking effect on car ownership. For example, Giuliano and Dargay (2006) used housing type (single family, apartment, row house) to proxy for parking type (garage vs. others) and available spaces in their comparative car ownership models for the US and the UK. Potoglou and Kanaroglou (2008) used a housing-type dummy variable (single family or not) as a proxy to reflect parking cost and availability constraints to model car ownership in Hamilton, Canada. Hess and Ong (2002) and Chu (2002) used the same dummy variable as a proxy for parking availability and cost to model car ownership in Portland, OR, and New York City, respectively. In another study, Ryan and Han (1999) recognized the importance of cost and parking inconvenience at home, but used household and job density as proxies. Most of these studies found statistically significant but minor effects relative to household income and structure.

The same argument can be found in the parking and car usage literature because car usage and car ownership are highly correlated, as shown by many joint models of the two decisions (Golob and Van Wissen, 1989; Hensher et al., 1992). Therefore, if a certain level of parking supply encourages car usage, it is likely to increase the utility of cars and, subsequently, car ownership. This assumption is partially proven by Tam and Lam (2000) in Hong Kong, who show that the availability of parking at workplaces also affects household car ownership. The literature on parking effects on car usage tends to target the non-residential parking supply in urban centers and generally finds that free or subsidized parking in urban centers affects mode choice (Willson and Shoup, 1990; Hess, 2001), and encourages overall car usage (Feeney, 1989; Topp, 1993; McCahill and Garrick, 2010). Again, these results suggest a possible, though indirect, parking effect on car ownership.

To address this drawback, a few other studies have measured residential parking supply directly. Some started with an aggregate measure. For example, Cho and Baek (2007) used the average parking capacity per household within a neighborhood (dong) to measure car ownership in Seoul, South Korea. Guo (2006) created a parking density contour (for both on-street and off-street parking) in London using observations from 7500 zones surveyed by Transport for London. He then used this variable to model household car ownership in London. HCG (2000) specified a parking cost variable at a zone level to model both household and company car ownership in Sydney, Australia.

Other studies have defined a parking variable at the household level. For example, Wu et al. (1999) included a parking dummy variable (taking the value 1 if parking is available in the residence area and 0 otherwise) to model household car ownership in Xi'an, China. Woldeamanuel et al. (2009) included a 4-level rank variable of households' perception of parking difficulty to model car ownership in Germany. To model car ownership in Southern California, Kitamura et al. (2001) defined two dummy variables indicating whether private and other parking spaces are available to a household. Although both aggregate and disaggregate analyses tend to find a statistically significant parking effect on car ownership, the measures are too coarse to offer specific policy recommendations, except for the simple conclusion that parking matters. In many of these studies, parking is only a control variable instead of the question of interest.

2.2. Car ownership independent of parking supply

The majority of car ownership studies actually denounce the parking effect on car ownership, directly or indirectly. Most of them have found dominant effects of household income and demographic characteristics, but marginal effects of other policy-relevant variables, such as density (Li et al., 2010) and transit accessibility (Kitamura, 1989; Deka, 2002). Parking supply is thought to be no exception, even though it is rarely included in car ownership models. For example, the car ownership forecasting literature often assumes that the change in car ownership is primarily based on the change of income or per capita GDP (Button et al., 1993; Dargay and Gately, 1999; Dargay et al., 2007), and follows the well-publicized "S" curve. The implied message is that car ownership is deterministic and is bound to increase when personal income or per capita GDP increases.

The problem with this argument is that it overlooks the fact that passenger cars have nearly always been affordable. For example, the average price of a Ford Model T in the 1920s was approximately $290 (equivalent to $3258 today), less than one quarter of the average household income at that time ($1200–$1500) in the U.S. (Ward, 1974). However, in 2009, the average price of a new car was approximately $28,966 (NADA, 2010), more than half of the median household income ($50,233). In other words, without controlling for differences in quality, cars were actually relatively cheaper in the 1920s than they are now in the US. Increased income and per capita GDP definitely do not explain car ownership completely. Other factors, such as the interstate highway project, federal housing programs, zoning regulations, and parking standards have also played important roles. Car ownership is not deterministic — it has been heavily influenced by public policies, and it could be changed with policy interventions. In Donald Shoup's (2011) words, Americans' relationship with cars is not a love affair, but an arranged marriage.

Another argument against the parking effect on car ownership is that when income is fixed, people's demand for cars remains inelastic because cars are essential for them. Dargay (2001, pp. 807) shows that the income effect on car ownership is not symmetrical: "car ownership responds more strongly to rising than to falling income—there is a stickiness in the downward direction." Weis et al. (2010) studied car ownership changes after the economic crisis in 2008 and found inertia in both mode choice and mobility tool ownership. Price elasticities did not differ much from previous studies.

Because of this inflexibility, residents' car ownership could be insensitive to parking supply, and/or location choice could be sensitive to car ownership demand. Both possibilities receive some support from empirical evidence. For example, in the Netherlands, Coevering and Snellen (2008) found that despite a high level of parking annoyance, residents made very little effort to adjust their level of car ownership to the available parking space in their residential area or vice versa. Even in extremely urbanized areas in major cities, parking pressure plays a slightly more important but still marginal role in residential mobility. Balcombe and York (1993) surveyed eight sites in South England in the early 1990s and found that the convenience of finding an (on-street) parking space may affect the car type, but not necessarily the car ownership decision. Between 22% and 54% of residents surveyed said they did not buy a better vehicle due to fear of vandalism. However, difficulties in finding a parking space might not necessarily deter car ownership or the intention to acquire additional vehicles.

Other studies have described the effect of residential mobility on car ownership levels. Beige and Axhausen (2008) found that residential mobility is influenced by the ownership of different mobility tools and vice versa, which enables households to keep their mobility tool ownership comparably stable over longer periods of time. Cao et al. (2007) found that residential mobility and the associated personal preference largely explain household car ownership. Effects of neighborhood attributes on car ownership become insignificant when personal preferences are included in the model.

In addition to the ideological and political differences behind the two opinions, the disagreement is partly caused by an inability to measure the parking supply and its effect on car ownership explicitly. A household with three cars but a one-car garage is an example of a "small parking effect." However, if driveway and on-street parking spaces are all considered, this could become a story of a "perfect parking effect." Defining and measuring residential parking supply is a key task of this research.

3. New York City case study

Although car dependency is most severe in low-density suburban communities, this paper chooses a dense urban setting, the New York City region, as a case study. This setting presents a diverse array of parking supplies and street regulations, together with a large variation in car ownership, which is able to capture the full spectrum of the parking effect on car ownership. The study region includes three outside boroughs of New York City plus northern Manhattan (north of 110th street) and 10 municipalities across the Hudson River in New Jersey (Fig. 1). South Manhattan is excluded because the data collection approach does not work well with the large buildings that dominate that area.

3.1. Residential parking supply: Definition and measurement

Just as non-residential parking has multiple options (Axhausen and Polak 1991; Hensher and King 2001), residential parking takes different forms, such as enclosed/structured garages, non-enclosed driveways, parking lots, and on-street parking. Each has unique characteristics, is subject to different regulations, and basically forms a distinct sub-market.

The availability of off-street parking is often clearly defined for a household, whereas the overall stock in the market may change dramatically from neighborhood to neighborhood. In contrast, the overall stock of on-street parking is often fixed by the street length, whereas residents may have access to an unlimited number of street parking spaces depending on their acceptable walking distance and searching time. In terms of ease of access, for off-street parking, the available space, location, and time are often guaranteed without uncertainty, whereas neither the space, location, nor time is guaranteed for on-street parking. The intermediate case might be a shared parking lot for an apartment where a tenant may have a guaranteed but not reserved spot. In terms of regulations, off-street parking is generally defined by a minimum or maximum standard and by the set back and impervious area requirements in the local zoning codes. Few regulations govern off-street parking after the lot is built out. In contrast, on-street parking is continually affected by street regulations. Many communities have a 72-h maximum rule to remove abandoned vehicles on public streets. Some ban overnight parking to prevent residents from using public streets for car storage. Some governments limit where a resident or

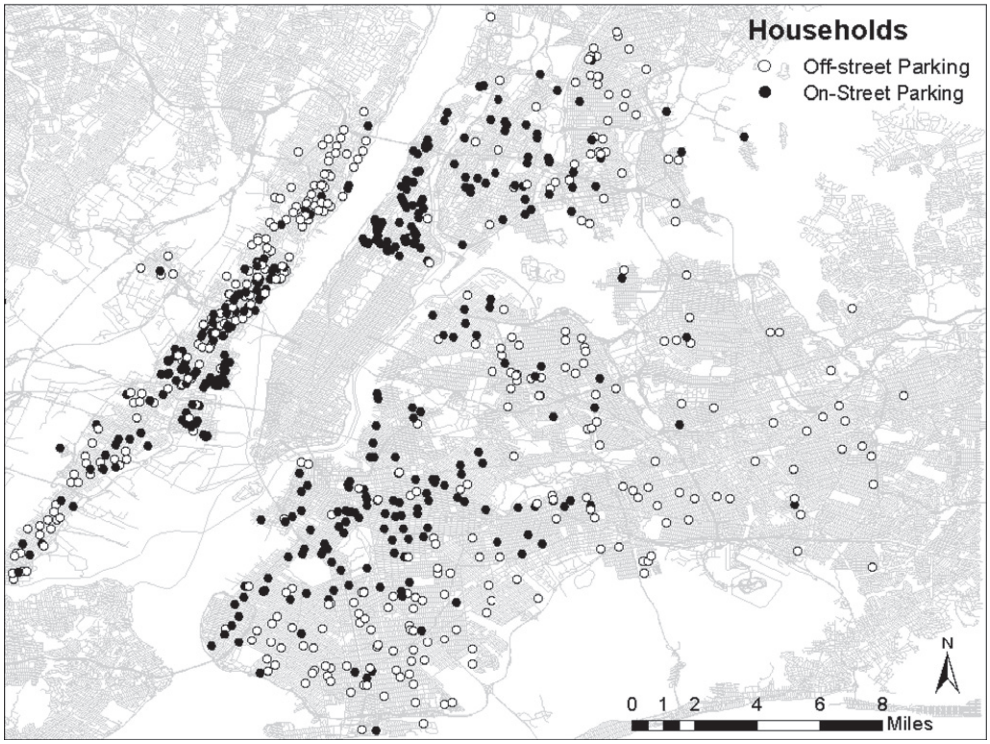

Fig. 1. Targeted households in the Study Region. *Source*: NYMTC (New York Metropolitan Transportation Council) 1998.

visitor can park. Santa Monica, CA, for example, has a two-block rule stating that any resident's or visitor's car parked more than two blocks away from the residence will be towed. In New York City, street cleaning occurs frequently and is often viewed as burdensome by residents who rely on these parking spaces.

Unfortunately, most of these residential parking supplies are not monitored by local governments. Actually, almost nobody knows how many parking spaces are available to a particular household except the household itself. San Francisco comes close: the city completed an on-street and commercial off-street parking inventory for 35% of its neighborhoods (SFPark, 2011). In New York City, the tax lot database (PLUTO) records the square footage of structured parking areas only for buildings with four or more housing units. The Certification of Occupancy database from the Department of Building records structured parking areas for all buildings in New York City, but it is only available in floor plans, making it difficult to extract parking information (McDonnell et al., 2011).

3.2. Measuring parking supply using street images

Street images like Google Streets have proven to be an efficient and reliable data collection instrument; for example, to audit pedestrian environments in Chicago (Clarke et al., 2010), examine the recovery of New Orleans neighborhoods after Katrina (Curtis et al., 2010), count sprawling parking lots in Ohio (Davis et al., 2010), and identify household off-street parking in New York City (Weinberger, 2012).

The limits of this method are as follows: it does not provide the exact time when the photos were taken, and it does not work well for large buildings where parking facilities may not be visible from either street-side or aerial photos. The first limitation affects the measurement of on-street parking because its supply and demand fluctuate at different times of the day. However, this limit may not be critical for the study region because only a few employment clusters (e.g., Brooklyn downtown) exist in the study region and the evasion of commuter parking is likely not prevalent. Therefore, the crowding levels on residential streets in the daytime and evening may change, but the order among these streets is likely to remain[1]. To address the second limit, I targeted single-family homes and small apartments (less than 20 units).

The data were collected according to the following procedure. First, a random sample of 770 households was selected out of the 1995 available households in the study region from the household travel survey conducted by the New York Metropolitan Transportation Council (NYMTC) in 1998. This number is the trade-off between the difficulty of measuring parking supply and the aim to have a relatively large sample size. The NYMTC survey is a stratified sample, including 10,971 households from the entire metropolitan area, but only 1995 households are in the study region. The survey is a bit old, but still the most recent one available. However, the parking effect on car ownership should not have changed much in 13 years, given the slow change of parking stock. Second, the home addresses of the 770 households were obtained from NYMTC after signing a confidentiality agreement. Third, for each of the home addresses, the garage, driveway, and on-street parking supplies were measured using Google Streets or Bing Maps.[2] Be-

[1] Two situations could change such an order: a relative empty residential street at day time is crowded by cars at night after residents drive back from work, and a residential street crowded by non-resident commuters at day time becomes quite empty at night after all commuters drive away. Both are unlikely to occur in the study region. In areas where many residents drive to work, off-street parking is often plenty, and streets are not packed with cars at night. The dominance of non-resident commuters on a residential street is also unlikely due to the lack of major employment centers in the study region. Commuter parking may occur on occasions and at a small scale, but is not sufficient to change the order of street crowding in the sample.

[2] Occasionally, Google Maps may identify a building incorrectly. To solve this problem, the tax lot GIS file in New York City was overlaid in Google Earth to assign exact street addresses to all buildings. For New Jersey households, Bing Maps and MapQuest were used to ensure that the correct location/building was chosen. The two systems tend to produce consistent but different results in cases when Google misidentifies a building.

cause the car ownership rate was collected in 1998 but parking supply was recorded in 2010, some housing units might have been renovated or rebuilt during this period of time. In most situations, a visual check is sufficient to identify this situation. The average year of construction for buildings in New York City is 1941, and buildings built after 1998 only account for a very small portion of the housing stock. In addition to a visual check, I examined local building permit databases and the Certificate of Occupancy database in New York City, which records when a newly completed building is actually occupied by residents. Those buildings included in either database between 1998 and 2010 were excluded and not counted in the 770 households.

For off-street parking, the data sources were used to identify the sizes of garages and driveways for single-family (detached or attached) homes. For small apartments, one garage space was assigned when a built-in garage was observed because tenants normally have access to garage parking. Driveway spaces for apartments were divided by the number of units and then rounded up.

For on-street parking, the crowding level of on-street parking around a household's residence was taken as the supply measurement. The crowding level measurement considers both sides of a 100-m street segment, with the residence in the middle, because there is some evidence to indicate that most residents park within 50 m of their homes (Balcombe and York 1993). This corresponds to a maximum of 30 parking spaces. Areas in front of garages and driveway entrances, fire hydrants, "No Parking" signs, and construction sites were excluded. The crowding level was ranked from 1 to 8. A rating of 8 indicates that all parking spaces are occupied by cars, and a rating of 1 indicates that only 1–2 cars are present or that there are more than nine empty spaces. This crowding measure tends to underestimate the impact of on-street parking supply on car ownership because the more cars residents have, the more likely they will be to park on streets, and the more crowded the streets will be.

In addition, traffic regulations, such as street-cleaning days and parking limits, were collected from various sources, such as the Sign Traffic and Accident Terminal User System (STATUS), an inventory database of over one million traffic signs in New York City, and field trips in New Jersey. More than 70% of streets in New York City have at least one street-cleaning day per week (2 days for streets with parking on both sides), and 40% have two or more street-cleaning days per week (four or more days for streets with parking on both sides). New Jersey communities normally have one or two street-cleaning days per week. Twenty-seven households (4%) are located on a street where parking is prohibited on at least one side of the street at all times. The list of all variables, their descriptive statistics, and data sources are summarized in Table 1.

3.3. Descriptive results

The 770 households are representative of the 1995 households in the original survey in the study region. However, compared to the entire metropolitan area, the selected households have a larger minority population and lower incomes. Sixty-two percent live in single family homes, similar to the entire metropolitan area. Sixty-six percent owned at least one car, and the majority of them (62%) owned just one. The car ownership rate is 0.98 cars per household, less than the metropolitan average of 1.5 cars per household and the national average of 2.2 cars.

Table 1
Descriptive statistics.

Variables	Mean	Standard deviation	CV[a] off-St	CV[a] on-St	Sources
Household attributes					
Car ownership	1.28	0.93	0.73	1.44	NYMTC Survey
Household size	2.8	1.40	0.50	0.59	NYMTC Survey
Household income (1–10 scale)[e]	5.02	1.93	0.38	0.44	NYMTC Survey
# Of driver licenses	1.52	0.93	0.61	0.85	NYMTC Survey
# Of full-time workers	1.01	0.83	0.74	0.90	NYMTC Survey
# Of part-time workers	0.14	0.38	2.68	2.79	NYMTC Survey
# Of children (⩽17 years old)	0.64	0.95	1.48	1.65	NYMTC Survey
Single-family detached (yes/no)	0.52	0.50	0.96	2.04	NYMTC Survey
Single-family attached (yes/no)	0.25	0.44	1.79	1.85	NYMTC Survey
Apartment (yes/no)	0.23	0.42	1.83	0.89	NYMTC Survey
Household head black (yes/no)	0.16	0.37	2.30	1.74	NYMTC Survey
Household head Hispanic (yes/no)	0.17	0.38	2.20	1.90	NYMTC Survey
Land use attributes					
Job density (per mile^2 in the zip code)	5115	4348	0.85	0.96	Business Pattern, 2007
Population density (per mile^2 in block group)	37,386	23,204	0.62	0.65	Census, 2000
Network distance to the nearest train station (miles)	2.54	2.42	0.95	1.16	–[b]
% Residential land (0.5-mile buffer around residence)	0.49	0.21	0.44	0.66	–[c]
Household in North Manhattan (yes/no)	0.01	0.09	11.55	2.22	NYMTC Survey
Household in Bronx (yes/no)	0.11	0.32	2.79	2.75	NYMTC Survey
Household in Queens (yes/no)	0.21	0.41	1.95	3.96	NYMTC Survey
Household in Brooklyn (yes/no)	0.25	0.44	1.72	1.53	NYMTC Survey
Household in New Jersey (yes/no)	0.42	0.75	1.19	1.35	NYMTC Survey
Parking supply and regulations					
Garage spaces	0.70	0.75	1.07	N/A	Google Streetviews
Driveway spaces	1.40	0.80	0.57	N/A	Google Streetviews
On-street parking crowding level (1–8 scale)	5.94	1.82	0.31	0.20	Google Streetviews
# Of street cleaning days per week (two sides)	2.39	1.69	0.79	0.48	–[d]
No standing at any time (yes/no)	0.04	0.19	4.92	5.45	–[d]
Total number of observations (households)	770	403	367		

[a] CV: coefficient of variation = standard deviation/mean.
[b] GIS data obtained from PATH, NJ Transit, New York City Subway, and MTA Commuter Rail.
[c] From 2008 PLUTO files for parcels and New Jersey 2002 Land Cover by Watershed Management Area: http://www.nj.gov/dep/gis/lulc02cshp.html#WMA20.
[d] New York City Sign Traffic and Accident Terminal User System (STATUS), Google Streets, and field surveys in New Jersey communities.
[e] The NYMTC survey coded income as: 1 ⩽ \$10 k, 2 = \$10 k–\$15 k, 3 = \$15 k–\$25 k, 4 = \$25 k–\$35 k, 5 = \$35 k–\$50 k, 6 = \$50 k–\$75 k, 7 = \$75 k–\$100 k, 8 = \$100 k–\$125 k, 9 = \$125 k–\$150 k, 10 = \$150 k+.

Table 2
Households by garage size and driveway area.

# Of households	With driveway parking area			
With garage size	0 Space	1 Space	2 + Spaces	Total
0 Space	0	29	111	140
1 Space	23	67	120	211
2 Spaces	5	0	51	56
Total	28	96	283	407

Table 3
Households by parking types and car ownership.

# Households	With car ownership level				
With parking types	0 Car	1 Car	2 Cars	3 + Cars	Total
Garage	49	111	79	28	267
Driveway[a]	27	70	35	8	140
On-street[b]	186	134	30	13	363
Total	262	315	144	49	770

[a] Households with driveway but not garage.
[b] Households with only on-street parking.

Parking supply is indeed complicated in the study region. Among the 770 households, 35% (267) have an on-site garage, 18% (140) have a driveway but not an on-site garage, and 47% (363) have access only to on-street parking. Among the 267 households with a garage, 79% have only one space, and none have three spaces (Table 2). Ten percent of households with a garage (28) do not have a driveway because their garage opens directly to the sidewalk, and 25% (67) have a small driveway with room for only one car. Among the 140 households with only a driveway parking area, 79% (111) can park two or more cars in that area.

Table 3 relates car ownership to parking supply. It is clear that households with a garage and driveway tend to own more cars, whereas more than half of households without off-street parking do not own cars. It is also interesting to note that 49 households (18%) with an on-site garage actually do not have a car. Most of them (32 out of 48) live in single-family homes on crowded streets close to a train station (60% are within .66 miles of a train station), and these households tend to have lower incomes and fewer employed household members. These households most likely do not own a car due to the ownership cost, their convenient access to transit, and weak car demand. They may convert their garages to other uses or keep the garage to retain the value of their property, as described in Stubbs (2002). On the other side of the spectrum, 44 on-street parking households (12%) have two or more cars, although they only have on-street parking. Among these, 16 households have three or more cars. These households tend to have a larger household size, higher income level, and more workers, and they tend to live farther from a train station. Some of these residences are at the corner of a block or at a dead end. These households definitely take advantage of free on-street parking.

These statistics show a relatively complex relationship between parking types and car ownership: households with a garage may not have private cars, and residents without off-street parking may have multiple cars. The correlations between car ownership and the four types of parking supply are relatively weak: garage spaces (0.27), driveway spaces (0.23), all off-street spaces (0.32), and on-street crowding (−0.24). The sub-samples for households with on-street and off-street parking produce similar results. This result implies that residential parking might not affect car ownership decisions. However, the true effect can only be captured with multivariate statistics and after controlling for endogeneity.

4. Modeling car ownership

The endogeneity between parking supply and car ownership could cause the parking effect to be either overestimated or underestimated, depending on whether the housing market offers ample options from which households can choose (Chatman, 2009). Households with distinct parking types (e.g., on street vs. garage) may have distinct unobservable personal characteristics such as travel preferences, while households with similar parking types may share similarities in their travel preferences. Note that endogeneity is caused largely by the absence of unobservable characteristics. Therefore, comparisons of car ownership across households with distinct parking types may easily find a correlation between parking and car ownership, but proving that this correlation is causal is a challenge, while comparisons among households with similar parking types may not even find a correlation due to the lack of variation, but if it does, such a correlation is more likely to be causal. The first approach emphasizes the variation of treatment (parking) and the second approach emphasizes the similarity of travelers. Typical models under the first approach include instrumental variables (Khattak and Rodriguez, 2005), joint-choice models (Cervero and Duncan, 2002), and structural equations (Bagley and Mokhtarian, 2002), etc. Typical models under the second approach include market segmentation, longitudinal research (Krizek, 2003), intervention design (Boarnet et al., 2005), and matched attitudes (Schwane and Mokhtarian, 2004). Which approach is better depends on whether the first can effectively control for unobservable personal characteristics, and whether the second can secure a sufficient variation in parking supply given the parking type. Although the first approach is widely used in the built environment and travel literature, Guo (2009) found that the second approach tends to produce more consistent results. This paper used a hybrid approach and developed a nested logit model to capture the causal effect of parking supply on car ownership.

First, a Hausman test was performed for the full sample (770 households) and confirmed that several parking supply variables were indeed endogenous. Then, the full sample was divided into two sub-groups: households with off-street parking and households with only on-street parking. It is assumed that with a similar parking type in the sub-groups, households may have similar unobservable attributes related to the car ownership preference, so these missing attributes can be treated as fixed and endogeneity is controlled. This assumption was tested for the sub-groups separately and confirmed. The results are summarized in the Appendix. Finally, the two sub-groups are connected under a nested structure in a logit model to control the selection into the sub-groups (Ben-Akiva and Lerman, 1985).

4.1. Overall modeling results

The dependent variable is the household car ownership level. For off-street households, it has four levels: zero, one, two, and three or more cars. For on-street households, only three levels are defined (zero, one, and two or more cars) because very few households have three or more cars. The control variables include household attributes and built environment factors such as population and job density, accessibility to transit, and land-use mix. A job density variable was included to capture the intrusion effect of commuter parking in a neighborhood because New York City does not have a residential parking permit program. Following the typical specification in the car ownership modeling literature (Zegras, 2010), all independent variables are specified with three or four alternatives. The zero-car cases for both on-street and off-street households are the basis for comparison. The estimation results are presented in Table 4.

Table 4
Nested logit car ownership model for households with off-street and on-street parking.

Base = zero car	Off-street households						On-street household			
	1 Car		2 Cars		3 + Cars		1 Car		2 + Cars	
Constant	−0.59	−0.7	−2.53	−2.3	−7.63	−3.2	0.55	0.7	−3.13	−2.5
Control variables										
Household size	−0.11	−0.6	−0.27	−1.0	0.15	0.4	−0.32	−1.9	−0.97	−2.9
Income level (1–10 scale)	0.16	2.2	0.27	2.8	0.31	2.1	0.11	1.4	0.14	1.3
# Of children	0.54	2.0	0.81	2.4	−0.52	−0.8	0.39	1.7	1.25	3.2
# Of full-time workers	−0.24	−1.0	0.52	2.1	0.69	1.9	0.14	0.7	0.09	0.3
# Of part-time workers	−0.36	−1.1	−0.29	−0.7	−0.40	−0.7	−0.52	−1.6	−0.69	−1.3
# Of driver license	1.55	5.3	2.36	5.2	3.17	5.2	1.68	7.5	3.25	6.6
Pop. density (10 k/km^2)	−0.05	−1.1	−0.19	−2.7	−0.05	−0.5	−0.08	−2.2	−0.12	−2.2
Net. distance to subway station (km)	0.15	2.1	0.24	2.7	0.43	3.5	−0.04	−0.7	0.06	0.7
% of residential land in census tract	0.30	0.6	−0.54	−0.9	−1.35	−1.3	0.66	1.2	1.42	2.1
Parking supply and regulations										
Garage spaces	0.59	2.1	0.91	2.8	1.35	3.1	−7.98	−26.4	−7.29	−12.6
Driveway area	1.24	4.4	1.33	4.4	1.54	3.5	−8.38	−25.3	−8.00	−14.1
On-street crowding level (1–8 scale)	−0.36	−3.8	−0.45	−4.3	−0.48	−2.9	−0.27	−3.8	−0.17	−1.5
Street cleaning days per week	−0.17	−2.1	−0.22	−2.1	−0.47	−3.3	−0.02	−0.2	0.06	0.5
No standing at any time (1 or 2 sides)	−1.32	−1.8	−2.32	−2.7	−2.27	−1.6	−0.33	−0.6	−0.13	−0.2
Number of Observations	770 Households									
Final log-likelihood	−869.26									
Adjusted pseudo R^2	0.368313									

The results show some interesting patterns. First of all, many of the control variables are not significant, contrary to many prior car ownership studies. For off-street households, only three control variables remain significant for all car ownership levels: household income, the number of driver's licenses, and the network distance to subway. Most other demographic and land-use variables are insignificant or significant at just the one car ownership level. This weak relationship is in contrast to the parking supply variables, most of which remain significant for the off-street households. Because the two sub-groups were split along parking types and parking supply variables, instead of control variables, they should be more likely to be rendered insignificant in the nested model. This contrast suggests that demographic and land use factors become less important to car ownership because their effect is captured by the well-defined parking supply.

A similar but slightly different pattern is found for the on-street households. Most control variables remain insignificant, including household income. However, two street parking regulation variables are also insignificant, most likely caused by both the reduced variation of street parking in the sub-group or the difficulty of measuring the on-street parking supply. As shown by the coefficient of variation in Table 1, on-street parking households tend to have more variation in car ownership, income, demographics, and land-use attributes, but less variation in parking supply comparing to off-street households. This pattern of results suggests that more important factors are missing from the on-street model compared to the off-street model. Typical search time and walking distance might be better measures of on-street parking supply than the three included variables, but they are difficult to assess and may still not capture the on-street parking supply well due to the existence of various social norms described by Epstein (2002). For example, in New York City, double parking is officially illegal, but it is often socially accepted, and the rule against it is rarely enforced by the City government (Nucatola, 2010). Households may rent parking spaces from neighbors who do not use their garage or driveway often. According to Craigslist, one driveway space in Brooklyn or Queens is normally rented for between \$100 and \$200 per month (Craigslist, 2012). This complexity increases when the on-street parking market becomes tighter, which partly explains why the population density variable becomes significant in the on-street model. It might capture the many unobserved attributes of on-street parking supply in the study region.

4.2. Parking supply variables

The individual parking supply variables performed as expected. For off-street households, four of the five parking variables are significant at all three car ownership levels. When the number of spaces in garage or driveway increases, the chance of owning one, two, three or more cars also increases. It confirms the causal effect of off-street parking supply on household car ownership.

Interestingly, on-street parking also matters for the car ownership of households with off-street parking. On-street parking crowding is significant at all car ownership levels with a negative sign. This result suggests that when on-street parking becomes less available, a household tends to own fewer cars, even after controlling for its garage and driveway space. There are two possible explanations for this finding. First is the extra supply: on-street parking provides extra spaces additional to off-street parking, so a household can own more cars if desired. Second is convenience: on-street parking spaces may be easier to use than garages or driveways because garages are normally small and driveways (drive alleys) can be narrow in a dense urban setting. To check the supply effect, 33 households in the data with three or more cars were examined and at least 14 of them (42%) do not have sufficient off-street spaces and have to park on the street. To check the amenity effect, 125 households with just one car but multiple parking options at home who reported a driving-home trip in the survey were examined. They are 2.5 times more likely to park on streets instead of inside a garage. They most likely choose street parking because it offers a higher utility/amenity/convenience.

Accordingly, regulations that affect the on-street parking supply are likely to influence these households' car ownership. For example, street cleaning has a significant negative effect for households at all car ownership levels. The more frequent street cleaning is, the less convenient it is for a household to park on the street, and the less likely it becomes that the household would own more cars, holding garage and driveway spaces constant. The "No parking at any time" rule seems to matter at one or two car ownership levels but, given the few observations in the sample, this result should not be treated seriously.

For on-street households, the estimations of garage and driveway are artificial since they all have zero spaces. Street parking crowding is significant for the one car option—the more crowded the street is, the less likely an on-street household would own one car. This variable becomes insignificant for households with multiple cars, which seems counter-intuitive. However, this might be caused by the definition of the crowding variable. Among on-street parking households, the more cars they have, the more crowded the street in front of their residence will be. In other words, a crowded street may indicate both a positive (e.g., residents have more cars) and a negative (e.g., on-street parking becomes less accessible) correlation with car ownership, which could cancel each other out, especially at the multiple-car level.

Lastly, the relative importance of the independent variables is compared. Because the coefficients within each car ownership level are not comparable in discrete choice models, a relative importance index, *D*, is calculated following Levine (1998) and Zegras (2010) based on the size of the coefficient and the variation of the variable. Table 5 summarizes the *D* values. For off-street households, parking supply variables are actually more important to private car ownership than are demographic and land use variables. For example, the *D* value of garage is slightly higher than household income, while those of driveway are two to four times greater. For on-street households, the pattern is more complex, although it does not indicates a dominance of household structure and income factors on car ownership.

It is interesting to note that for off-street households, driveway and street crowding are actually more important than garages on car ownership decisions (*D* values are greater).

This is consistent with the earlier finding that a significant portion of households have a private garage but own no cars. They may not need a car because the need to travel is low or because transit is readily available. They can use the garage as storage (Jenks and Noble, 1996; DfT, 2007; Coevering and Snellen, 2008), keep it to preserve housing value, or rent it out for extra income. If this is true, policies focused on garages but overlooking driveways and street parking might be less effective than their initial design.

5. Discussion and conclusion

Although parking policy has attracted much attention over the past decade, residential parking has remained largely overlooked. Many policy makers still believe that residential parking regulations have little or no influence over private car ownership, although others strongly disagree. Part of the reason for this debate, besides ideological and political concerns, is that researchers have yet to confirm empirically that residential parking supply indeed affects car ownership decisions. This paper investigated the parking-car ownership relationship in the dense urban setting of New York City. It targeted 770 households randomly selected from a regional household travel survey and measured their complete parking supply, including garage, driveway, and on-street parking, using online street images, such as Google Streets and Bing Maps.

Modeling results show that parking supply can largely determine household car ownership decisions, even after controlling for the endogeneity between the two. This parking effect actually outperforms household income and demographic characteristics, the dominant forces on car ownership shown by many prior studies. The parking-car ownership relationship is also more complex than traditionally thought. First, for households with off-street parking, different parking types have different effects on car ownership decision. Although all off-street parking types are significant, driveway spaces seem more important than garage spaces. On-street parking could still affect car ownership decisions among households that already have off-street parking. For households with only on-street parking, the parking supply is even more complex. The supply variables defined are a poor proxy and do not

Table 5
Relative importance of parking supply and income.

	Off-street households			On-street households	
	1 Car	2 Cars	3 + Cars	1 Car	2 Cars
Household structure and income					
Household size	−0.161	−0.386	0.211	−0.456	−1.378
Income level (1–10 scale)	**0.305**	**0.519**	**0.607**	**0.211**	**0.279**
# Of children	**0.499**	**0.752**	−0.488	0.368	1.171
# Of full-time workers	−0.198	**0.438**	0.579	0.115	0.071
# Of part-time workers	−0.137	−0.110	−0.152	−0.197	−0.259
Land use and urban form					
Pop. density (10 k/km^2)	−0.189	**−0.696**	−0.198	**−0.309**	**−0.430**
Net. distance to subway station (km)	**0.345**	**0.547**	**0.996**	−0.102	0.132
% Of residential land in census tract	0.084	−0.151	−0.381	0.185	0.401
Parking supply and regulations					
Garage spaces	**0.380**	**0.587**	**0.869**	**−5.137**	**−4.695**
Driveway area	**1.122**	**1.209**	**1.398**	**−7.603**	**−7.262**
On-street crowding level (1–8 scale)	**−0.603**	**−0.765**	**−0.812**	**−0.457**	−0.286
Street cleaning days per week	**−0.280**	**−0.354**	**−0.760**	−0.029	0.094
No standing at any time (1 or 2 sides)	−0.247	−0.436	−0.425	−0.062	−0.024

Note: Font in bold color indicates a significance level at 5%.

capture a strong parking effect on car ownership. However, demographic and land use factors also showed a weak effect on car ownership for these households.

These findings shed light on the potential effects of several residential parking policies under discussion. For example, if it can reduce the residential parking supply, a maximum off-street parking standard could significantly reduce car dependency and mitigate the associated externalities, such as congestion and greenhouse gas emissions. However, the findings also suggest that such a maximum standard will be less effective if it does not control all submarkets, such as the attached driveway in front of a garage or on-street parking, as do many of these standards in the U.S. For many households, the most important factor determining car ownership might actually be driveway and on-street parking, most likely because they often use garages for other purposes (e.g., storage, rental place) instead of for car storage.

The findings also suggest that some street parking regulations may have unintended consequences for car ownership and related policy objectives. For example, residential parking permit programs exclude non-permit holders (largely non-residents) from parking in a neighborhood. Although such programs may prevent some commuters from driving to work, they also reduce on-street parking crowding and, according to this research, might encourage car ownership among local residents with permits. One such example is the famous romance novelist, Danielle Steel, who owns 26 cars (with 26 permits) in a downtown neighborhood in San Francisco (Shoup, 2005). This car ownership effect is especially relevant to New York City, where residential parking permit programs have been a topic of heated debate but have not yet been adopted.

Another street regulation example is street cleaning, which removes street parking from the market temporarily, but often frequently. Many opponents to frequent street cleaning believe that street cleaning encourages car usage because residents have to find another parking spot during the street cleaning period (NYCDOT, 2008) or make extra trips that they otherwise would not make (Guo and Xu, forthcoming). This belief is behind the new legislation passed in April 2011 in New York City that would reduce the street cleaning frequency by 1 day per week in some neighborhoods in the study region. However, according to this paper, such a move could potentially increase car ownership among local residents, so the net effect on car usage could be smaller than, or even contradictory to, what the policy makers expected. A simulation based on the coefficients in Table 4 indicated that if the legislation is applied to all frequently cleaned streets, household car ownership will increase by almost 1.6%, or an extra 0.5 vehicle miles traveled per household per weekday in the study region.

Last, but not least, is the generalization of the research findings. Are they unique to New York City? Can they be applied to other dense urban settings? The answers to both questions are most likely "no" and "yes". The results may not be applicable to Phoenix or Las Vegas, where parking is generally over-supplied and most housing stock was built after World War II, but for cities like London, Boston, San Francisco, or Philadelphia, where parking is generally in shortage and a diverse array of residential parking types are available, a similar parking-car ownership relationship might exist. However, even in dense urban settings, some of the relationships might differ from region to region. For example, the amenity effect of on-street parking is largely determined by the housing design, garage location, and street layout. In New York City, many garages are independent from the main building, located in the backyard instead of facing the streets. They are normally connected with the street by a narrow driveway. This arrangement may explain why many residents prefer on-street parking to parking in a garage. The same arrangement may or may not be found in other cities. Therefore, although the general finding of the parking effect might hold, not all of the specifics are transferable to other areas, and readers should be cautious when interpreting the results.

Appendix A. Endogeneity within subgroups

To test the assumption that endogeneity is controlled in the sub-groups, endogeneity tests are performed for each potential endogenous parking variable. There are two types of tests. The Sargan test checks the validity of the instrumental variables selected

Table A1
Endogeneity tests for sub-groups.[a]

Sub-samples	Endogenous variables	Sargan test	Hausman test
Off-street parking households ($N = 403$)	Garage spaces	0.2564	0.0832
	Driveway spaces	0.1011	0.5768
	Garage + driveway spaces	0.6336	0.1601
On-street parking households ($N = 367$)	On-street parking crowding level	0.7755[b]	0.2669[b]
	Street cleaning days	0.7484[b]	0.2894[b]

[a] Dependent variable = car ownership.
[b] Based on three instrumental variables.

Table A2
First stage regression results.

Dependent variable	Off-street parking households ($N = 403$)						On-street parking households ($N = 367$)			
	Garage spaces		Driveway spaces		Garage + driveway		Street crowding level		Street cleaning days	
Instrumental variables	β	t	β	t	β	t	β	t	β	t
Single-family detached (yes/no)	0.32	3.4	0.34	3.4	0.65	4.6				
Single-family attached (yes/no)	0.35	3.2	0.45	4.0	0.81	4.8				
% Of black population	−0.14	−1.3	0.02	0.1	−0.12	−0.8	−0.27	−1.5	0.30	1.6
% of Hispanic population	−0.10	−0.9	−0.22	−2.1	−0.32	−2.0	−0.03	−0.2	−0.26	−1.3
Median age of buildings (years)	0.00	0.1	0.00	1.0	0.00	0.7	0.02	3.6	0.01	0.9
R^2	0.131		0.151		0.191		0.165		0.191	

Note: Other independent variables included in the regressions but not shown in this table are: household size, income, # of children, # of workers, # of driver's licenses, job density, population density, network distance to the closest subway station, % residential land within ½ mile of residence, and residence location in North Manhattan, Bronx, Queens, or Brooklyn.

to predict the value of endogenous parking variables in a first-stage model, while the Hausman test confirms or rejects the endogeneity in the main model, where the dependent variable is car ownership. The two tests are performed for five parking variables (or combinations thereof) using either three or five instrumental variables: shares of black and Hispanic population in the tract, the median age of the buildings in the tract, single-family home detached, single-family home attached. The first three instruments are from Boarnet and Sarmiento (1998). A Sargan test statistic greater than 0.1 indicates the validity of the instrumental variables, while a Hausman test statistic greater than 0.1 suggests that the independent variable is not endogenous at the 10% level. The results are summarized in Table A1, with the first-stage regression result in Table A2. They show that the instrumental variables are valid, and none of the parking variables are endogenous to car ownership within the sub-group (significant at the 5% level). Endogeneity is controlled within the sub-samples.

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