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Body

ABSTRACT

► We measured ***residential parking supply*** in ***New York City*** using Google Streets. ► We control the endogeneity between ***parking supply*** and ***car ownership***. ► ***Residential parking supply*** is more important than income and demographic attributes. ► Garage, driveway, and street ***parking affects car ownership*** differently. ► Maximum standard, resident permits, and street cleaning ***affect car ownership***.

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.

FULL TEXT

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, 2010Shoup, 2011Cato 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, 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 (

McShane and Meyer, 1982 McShane and Meyer, 1982. M. McShane, M. Meyer; ***Parking*** policy and urban goals: linking strategy to needs; Transportation; Vol. 11, No. 2; (1982), pp. 131-152.

Meyer, 1999 Meyer, 1999. M.D. Meyer; Demand management as an element of transportation policy: using carrots and sticks to influence travel behavior; Transportation Research Part A; Vol. 33, 7/8; (1999), pp. 575-599.

Shoup, 2005 Shoup, 2005. D. Shoup; The High Cost of Free ***Parking***; American Planning Association Press, Chicago, IL (2005), .

Litman, 2006 Litman, 2006. T. Litman; ***Parking*** Management Best Practices; American Planning Association Press, Chicago, IL (2006), .

Barter, 2010 Barter, 2010. P.A. Barter; Off-street ***parking*** policy without ***parking*** requirements: a need for market fostering and regulation; Transport Reviews; Vol. 30, No. 5; (2010), pp. 571-588.

Shoup, 2011 Shoup, 2011. Shoup, D., 2011. Free ***Parking*** or Free Markets, Unbound Magazine, Cato Institute, Washington, DC. <*http://www.cato-unbound.org/2011/04/04/donald-shoup/free-**parking**-or-free-markets/*> (accessed 17.07.11).

Cato Institute, 2011 Cato Institute, 2011. Cato Institute, 2011. Debate on ***Parking*** Policy by Shoup, D., Manville, M., O'Toole, R., Cowen, T., Ikeda, S., Kuznicki, S., at Cato Unbound in April, 2011. Washington DC <*http://www.cato-unbound.org/*> (accessed 27.11.11).

Weinberger, 2012 Weinberger, 2012. R. Weinberger; Death by a thousand curb-cuts: evidence on the effect of minimum ***parking*** requirements on the choice to drive; Transport Policy; Vol. 20, (2012), pp. 93-102.

Marsden, 2006 Marsden, 2006. G. Marsden; The evidence base for ***parking*** policies: a review; Transport Policy; Vol. 13, No. 6; (2006), pp. 447-457.

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., 1999HCG, 2000Kitamura et al., 2001Guo, 2006Cho and Baek, 2007Woldeamanuel 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, 1992Bhat and Guo, 2007).

Lee, 1987 Lee, 1987. D. Lee; Streets as "Private" goods; A.V. Moudon Editor; Public Streets for Public Use; Van Nostrand Reinhold Company, ***New York***, NY (1987), .

Weinberger et al., 2009 Weinberger et al., 2009. R. Weinberger, M. Seaman, C. Johnson; ***Residential*** off-street ***parking***: ***car ownership***, VMT and carbon impacts (***Case*** Study ***New York City***); Transportation Research Record; Vol. 2118, (2009), pp. 24-30.

Wu et al., 1999 Wu et al., 1999. G. Wu, T. Yamamoto, R. Kitamura; Vehicle ***ownership*** model that incorporates the causal structure underlying attitudes toward vehicle ***ownership***; Transportation Research Record; Vol. 1676, (1999), pp. 61-67.

HCG, 2000 HCG, 2000. HCG (Hague Consulting Group). 2000. Report 9009-3B, Sydney ***Car Ownership*** Models. Cambridge, UK (Chapter 3)

Kitamura et al., 2001 Kitamura et al., 2001. R. Kitamura, T. Akiyama, T. Yamamoto, T.F. Golob; Accessibility in a Metropolis: toward a better understanding of land use and travel; Transportation Research Record; Vol. 1780, (2001), pp. 64-75.

Guo, 2006 Guo, 2006. Guo, Z., 2006. Developing a Disaggregate ***Car Ownership*** Model for London, Unpublished report to Transport for London, London, UK.

Cho and Baek, 2007 Cho and Baek, 2007. Cho, S.K., Baek, S.R., 2007. The Built Environment, ***Car Ownership***, and Travel Behavior in Seoul, Working Paper, Seoul National University, Seoul, South Korea <*http://www.arch.chula.ac.th/asian_mega_**cities**/AMC%20Paper/Sang-Kyu%20Cho_Seoul.pdf*> (accessed 03.03.11).

Woldeamanuel et al., 2009 Woldeamanuel et al., 2009. M.G. Woldeamanuel, R. Cyganski, A. Schulz, A. Justen; Variation of ***households***' ***car ownership*** across time: application of a panel data model; Transportation; Vol. 36, No. 4; (2009), pp. 371-387.

NYCDCP, 2009 NYCDCP, 2009. NYCDCP (***New York City*** Department of ***City*** Planning). 2009. ***Residential Parking*** Study: Automobile ***Ownership*** Rates and Off-Street ***Parking*** Requirements in Portions of ***New York City***: Manhattan CDs 9-12, the Bronx, Queens and Brooklyn. <*http://www.nyc.gov/html/dcp/pdf/transportation/**residential_parking**.pdf*> (accessed 27.11.11).

FHWA, 2004 FHWA, 2004. FHWA (Federal Highway Administration). 2004. Mitigating Traffic Congestion – The Role of Demand-Side Strategies. Report by Federal Highway Administration, Washington DC. <*http://www.ops.fhwa.dot.gov/publications/mitig_traf_cong/index.htm*> (accessed 13.04.11).

Prevedouros and Joseph, 1992 Prevedouros and Joseph, 1992. P.D. Prevedouros, L.S. Joseph; Factors ***affecting*** automobile ***ownership*** and use; Transportation Research Record; Vol. 1364, (1992), pp. 152-160.

Bhat and Guo, 2007 Bhat and Guo, 2007. C.R. Bhat, J.Y. Guo; A comprehensive analysis of built environment characteristics on ***household residential*** choice and auto ***ownership*** levels; Transportation Research Part B; Vol. 41, No. 5; (2007), pp. 506-526.

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 Streetviews, 0000] 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[1][Stubbs, 2002]). This section compares two opinions in the literature.

[Mannering, 1986] Mannering, 1986. F.L. Mannering; A note on endogenous variables in ***household*** vehicle utilization equations; Transportation Research Part B; Vol. 20, No. 1; (1986), pp. 1-6.

[Chatman, 2009] Chatman, 2009. D. Chatman; ***Residential*** choice, the built environment, and nonwork travel: evidence using ***new*** data and methods; Environment and Planning A; Vol. 41, No. 5; (2009), pp. 1072-1089.

[Google Streetviews, 0000] Google Streetviews, 0000. Google Streetviews. <https://maps.google.com/>.

[Cao et al., 2007] Cao et al., 2007. X. Cao, P.L. Mokhtarian, S.L. Handy; Cross-sectional and quasi-panel explorations of the connection between the built environment and auto ***ownership***; Environment and Planning A; Vol. 39, No. 4; (2007), pp. 830-847.

[Balcombe and York, 1993] Balcombe and ***York***, 1993. Balcombe, R.J., ***York***, I.O., 1993. The Future of ***Residential*** ***Parking***. Project Report 22, Transport Research Laboratory, Crowthorne, Berkshire, UK.

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, 1989Hensher 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 (

Stubbs, 2002 Stubbs, 2002. M. Stubbs; ***Car parking*** and ***residential*** development: sustainability, design and planning policy, and public perceptions of ***parking*** provision; Journal of Urban Design; Vol. 7, No. 2; (2002), pp. 213-237.

Holtzclaw et al., 2002 Holtzclaw et al., 2002. J. Holtzclaw, C. Robert, H. Dittmar, D. Goldstein, P. Haas; Location efficiency: neighborhood and socio-economic characteristics determine auto ***ownership*** and use – studies in Chicago, Los Angeles and San Francisco; Transportation Planning and Technology; Vol. 25, No. 1; (2002), pp. 1-27.

Giuliano and Dargay, 2006 Giuliano and Dargay, 2006. G. Giuliano, J. Dargay; ***Car ownership***, travel and land use: a comparison of the US and Great Britain; Transportation Research Part A; Vol. 40, No. 2; (2006), pp. 106-124.

Potoglou and Kanaroglou, 2008 Potoglou and Kanaroglou, 2008. D. Potoglou, P.S. Kanaroglou; Modelling ***car ownership*** in urban areas: a ***case*** study of Hamilton, Canada; Journal of Transport Geography; Vol. 16, No. 1; (2008), pp. 42-54.

Hess and Ong, 2002 Hess and Ong, 2002. D.B. Hess, P.M. Ong; Traditional neighborhoods and automobile ***ownership***; Transportation Research Record; Vol. 1805, (2002), pp. 35-44.

Chu, 2002 Chu, 2002. Y.L. Chu; Automobile ***ownership*** analysis using ordered probit models; Transportation Research Record; Vol. 1805, (2002), pp. 60-67.

Ryan and Han, 1999 Ryan and Han, 1999. J.M. Ryan, G. Han; Vehicle-***ownership*** model using family structure and accessibility application to Honolulu, Hawaii; Transportation Research Record; Vol. 1676, (1999), pp. 1-10.

Golob and Van Wissen, 1989 Golob and Van Wissen, 1989. T.F. Golob, L. Van Wissen; A joint ***household*** travel distance generation and ***car ownership*** model; Transportation Research Part B; Vol. 23, No. 6; (1989), pp. 471-491.

Hensher et al., 1992 Hensher et al., 1992. D.A. Hensher, P.O. Barnard, N.C. Smith, F.W. Milthorpe; Dimensions of automobile demand; a longitudinal study of automobile ***ownership*** and use; Elsevier Science Publishers, ***New York***, NY (1992), .

Tam and Lam, 2000 Tam and Lam, 2000. M.L. Tam, W.H.K. Lam; Maximum ***car ownership*** under constraints of road capacity and ***parking*** space; Transportation Research Part A; Vol. 34, No. 3; (2000), pp. 145-170.

Willson and Shoup, 1990Hess, 2001), and encourages overall ***car*** usage (Feeney, 1989Topp, 1993McCahill 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, 1989Deka, 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 (

Willson and Shoup, 1990 Willson and Shoup, 1990. R. Willson, D. Shoup; ***Parking*** subsidies and travel choices: assessing the evidence; Transportation; Vol. 17, No. 2; (1990), pp. 141-157.

Hess, 2001 Hess, 2001. D. Hess; Effect of free ***parking*** on commuting mode choice. Evidence from travel diary data; Transportation Research Record; Vol. 1753, (2001), pp. 35-42.

Feeney, 1989 Feeney, 1989. B.P. Feeney; A review of the impact of ***parking*** policy measures on travel demand; Transportation Planning and Technology; Vol. 13, No. 4; (1989), pp. 229-244.

Topp, 1993 Topp, 1993. H.H. Topp; ***Parking*** policies to reduce ***car*** traffic in German ***cities***; Transport Reviews; Vol. 13, No. 1; (1993), pp. 83-95.

McCahill and Garrick, 2010 McCahill and Garrick, 2010. C.T. McCahill, N.W. Garrick; Influence of ***parking*** policy on built environment and travel behavior in two ***new*** England ***cities***, 1960 to 2007; Transportation Research Record; Vol. 2187, (2010), pp. 123-130.

Li et al., 2010 Li et al., 2010. J.P. Li, J.L. Walker, S. Srinivasan, W.P. Anderson; Modeling private ***car ownership*** in China; Transportation Research Record; Vol. 2193, (2010), pp. 76-84.

Kitamura, 1989 Kitamura, 1989. R. Kitamura; A causal analysis of ***car ownership*** and transit use; Transportation; Vol. 16, No. 2; (1989), pp. 155-173.

Deka, 2002 Deka, 2002. D. Deka; Transit availability and automobile ***ownership***: some policy implications; Journal of Planning Education and Research; Vol. 21, No. 3; (2002), pp. 285-300.

Button et al., 1993Dargay and Gately, 1999Dargay 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 Shoup, 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 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

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Button et al., 1993 Button et al., 1993. K. Button, N. Ngoe, J. Hine; Modeling vehicle ***ownership*** and use in low income countries; Journal of Transport Economics and Policy; Vol. 27, No. 1; (1993), pp. 51-67.

Dargay and Gately, 1999 Dargay and Gately, 1999. J. Dargay, D. Gately; Income's effect on ***car*** and vehicle ***ownership***, worldwide: 1960–2015; Transportation Research Part A; Vol. 33, No. 2; (1999), pp. 101-138.

Dargay et al., 2007 Dargay et al., 2007. J. Dargay, D. Gately, M. Sommer; Vehicle ***ownership*** and income growth, worldwide: 1960–2030; Energy Journal; Vol. 28, No. 4; (2007), pp. 143-170.

Ward, 1974 Ward, 1974. I. Ward Editor; The World of Automobiles: An illustrated encyclopedia of the motor ***car***; Orbis, London, UK (1974), .

NADA, 2010 NADA, 2010. NADA (National Automobile Dealers Association). 2010. State of the Industry Report. McLean, VA. <http://www.nada.org/Publications/NADADATA/2010/default.htm> (accessed 28.11.11).

Dargay, 2001 Dargay, 2001. J. Dargay; The effect of income on ***car ownership***: evidence of asymmetry; Transportation Research Part A; Vol. 35, No. 9; (2001), pp. 807-821.

Weis et al., 2010 Weis et al., 2010. C. Weis, K.W. Axhausen, R. Schlich, R. Zbinden; Models of mode choice and mobility tool ***ownership*** beyond 2008 fuel prices; Transportation Research Record; Vol. 2157, (2010), pp. 86-94.

Coevering and Snellen, 2008 Coevering and Snellen, 2008. Coevering, P.V.D., Snellen, D., 2008. The Future of ***Residential Parking*** in the Netherlands: The Impact of Increasing ***Car Ownership*** on the Character of ***Residential*** Areas. Paper Presented at the 2008 European Transport Conference, Noordwijkerhout, Nederland <http://www.Etcproceedings.Org/Paper/Download/3505> (accessed 01.08.12).

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

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[Beige and Axhausen, 2008] Beige and Axhausen, 2008. S. Beige, K.W. Axhausen; Long-term and mid-term mobility decision during the life course: experiences with a retrospective survey; Journal of the International Association of Traffic and Safety Sciences; Vol. 32, No. 2; (2008), pp. 16-33.

[Axhausen and Polak, 1991] Axhausen and Polak, 1991. K.W. Axhausen, J.W. Polak; Choice of parking: stated preference approach; Transportation; Vol. 18, No. 1; (1991), pp. 59-81.

[Hensher and King, 2001] Hensher and King, 2001. D.A. Hensher, J. King; Parking demand and responsiveness to supply, pricing and location in the Sydney central business district; Transportation Research Part A; Vol. 35, No. 3; (2001), pp. 177-196.

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 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).

SFPark, 2011 SFPark, 2011. SFPark. 2011. SFpark ***Parking*** Census Summary. San Francisco, CA <*http://sfpark.org/resources/sfpark-**parking**-census-summary/*> (accessed 27.11.11).

McDonnell et al., 2011 McDonnell et al., 2011. S. McDonnell, J. Madar, V. Been; Minimum ***parking*** requirements and housing affordability in ***New York City***; Housing Policy Debate; Vol. 21, No. 1; (2011), pp. 45-68.

Clarke et al., 2010 Clarke et al., 2010. P. Clarke, J. Ailshire, R. Melendez, M. Bader, J. Morenoff; Using Google Earth to conduct a neighborhood audit: reliability of a virtual audit instrument; Health & Place; Vol. 16, No. 6; (2010), pp. 1224-1229.

Curtis et al., 2010 Curtis et al., 2010. A. Curtis, D. Duval-Diop, J. Novak; Identifying spatial patterns of recovery and abandoment in the post-katrina holy cross neighborhood of ***new*** orleans; Cartography and Geographic Information Science; Vol. 37, No. 1; (2010), pp. 45-56.

Davis et al., 2010 Davis et al., 2010. A.Y. Davis, B.C. Pijanowski, K. Robinson, B. Engel; The environmental and economic costs of sprawling ***parking*** lots in the United States; Land Use Policy; Vol. 27, No. 2; (2010), pp. 255-261.

[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.

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, 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 13years, 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] Because 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 50m 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 (2days 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

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[NYMTC, 1998] NYMTC, 1998. NYMTC (***New York*** Metropolitan Transportation Council). 1998. Regional Travel ***Household*** Interview Survey (RT-HIS), ***New York***, NY .

[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.

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***.

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 .66miles 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

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[Khattak and Rodriguez, 2005] Khattak and Rodriguez, 2005. A.J. Khattak, D. Rodriguez; Travel behavior in neo-traditional neighborhood developments: a ***case*** study in USA; Transportation Research Part A; Vol. 39, No. 6; (2005), pp. 481-500.

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.

Cervero and Duncan, 2002 Cervero and Duncan, 2002. Cevero, R., Duncan, M., 2002. ***Residential*** Self-Selection and Rail Commuting: A Nested Logit Analysis. Working Paper #604, University of California Transportation Center. <http://www.uctc.net/papers/604.pdf> (accessed 08.01.12).

Bagley and Mokhtarian, 2002 Bagley and Mokhtarian, 2002. M. Bagley, P. Mokhtarian; The impact of ***residential*** neighborhood type on travel behavior: a structural equations modeling approach; The Annals of Regional Science; Vol. 36, No. 2; (2002), pp. 279-297.

Krizek, 2003 Krizek, 2003. K. Krizek; ***Residential*** relocation and changes in urban travel: does neighborhood-scale urban form matter?; Journal of the American Planning Association; Vol. 69, No. 3; (2003), pp. 265-281.

Boarnet et al., 2005 Boarnet et al., 2005. M. Boarnet, K. Day, C. Anderson, T. McMillan, M. Alfonzo; Can street and sidewalk improvements enhance walking and bicycling to school? Evaluating California's safe routes to school program; Journal of the American Planning Association; Vol. 71, No. 3; (2005), pp. 301-317.

Schwane and Mokhtarian, 2004 Schwane and Mokhtarian, 2004. T. Schwane, P. Mokhtarian; The extent and determinants of dissonance between actual and preferred ***residential*** neighborhood type; Environment and planning B: planning and design; Vol. 31, No. 5; (2004), pp. 759-784.

Guo, 2009 Guo, 2009. Z. Guo; Does the built environment ***affect*** the utility of walking? A ***Case*** of path choice in downtown Boston; Transportation Research Part D; Vol. 14, No. 5; (2009), pp. 343-352.

Ben-Akiva and Lerman, 1985 Ben-Akiva and Lerman, 1985. M.E. Ben-Akiva, S.R. Lerman; Discrete Choice Analysis: Theory and Application to Travel Demand; MIT Press, Cambridge, MA (1985), .

Zegras, 2010 Zegras, 2010. C. Zegras; The built environment and motor vehicle ***ownership*** and use: evidence from Santiago de Chile; Urban Studies; Vol. 47, No. 8; (2010), pp. 1793-1817.

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

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[Epstein, 2002] Epstein, 2002. R.A. Epstein; The allocation of the commons: ***parking*** on public roads; The Journal of Legal Studies; Vol. 31, S2; (2002), pp. S515-S544.

[Nucatola, 2010] Nucatola, 2010. Nucatola, J., 2010. Testimony by the Director for the Bureau of Cleaning and Collection, Department of Sanitation in ***New York City*** at the public hearing organized by the Joint Committees on Transportation and Sanitation and Solid Waste at the ***New York City*** Council, November 9th, 2010 <*http://legistar.council.nyc.gov/MeetingDetail.aspx?ID=126666&GUID=59AF0A42-7D4E-4BBF-B2E3-E6E8A27E92A8&Options=&Search=*> (accessed 01.08.12).

[Craigslist, 2012] Craigslist, 2012. Craigslist. 2012. Housing: ***Parking*** and Storage in ***New York City***. <*http://newyork.craigslist.org/prk/*>.

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 2.5times 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

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[Levine, 1998] Levine, 1998. J. Levine; Rethinking accessibility and jobs–housing balance; Journal of the American Planning Association; Vol. 64, No. 2; (1998), pp. 133-149.

[Jenks and Noble, 1996] Jenks and Noble, 1996. M. Jenks, J. Noble; ***Parking***: demand and provision in private sector housing development; School of Architecture, Oxford Brookes University, Oxford, U.K, Oxford (1996), .

[DfT, 2007] DfT, 2007. DfT (Department for Transport) of UK; Manual for Streets; Thomas Telford Publishing, London, UK (2007), .

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 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 sub-markets, 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 1day 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.

[NYCDOT, 2008] NYCDOT, 2008. NYCDOT (***New York City*** Department of Transportation). 2008. ***Parking*** and Traffic Impacts of ***Park*** Slope Alternate Side ***Parking*** Suspension, <*http://www.nyc.gov/html/dot/downloads/pdf/asp_parkslope.pdf*> (accessed 18.07.11).

[Guo and Xu, forthcoming] Guo and Xu, forthcoming. Guo, Z., Xu, P.Y., forthcoming. Duet of the Commons: The Impact of Street Cleaning on ***Car*** Usage in ***New York City*** area. Journal of Planning Education and Research.

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 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.

TABLES

Table 1

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 (□17years old)	0.64	0.95	1.48	1.65	NYMTC Survey

[Boarnet and Sarmiento, 1998] Boarnet and Sarmiento, 1998. M.G. Boarnet, S. Sarmiento; Can land-use policy really ***affect*** travel behaviour? A study of the link between non-work travel and land-use characteristics; Urban Studies; Vol. 35, No. 7; (1998), pp. 1155-1169.

Variables	Mean	Standard deviation	CV[a] off-St	CV[a] on-St	Sources
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
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		

Descriptive statistics.

Business Pattern, 2007 Business Pattern, 2007. Business Pattern, 2007. ZIP Code Business Patterns: Paid Employees. US Census, Washington DC

Census, 2000 Census, 2000. US Census, 2000. Decennial Census 2000 Summary File 1: Total Population. US Census, Washington DC.

[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□$10k, 2=$10k–$15k, 3=$15k–$25k, 4=$25k–$35k, 5=$35k–$50k, 6=$50k–$75k, 7=$75k–$100k, 8=$100k–$125k, 9=$125k–$150k, 10=$150k+.

Table 2

# 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

Households by garage size and driveway area.

Table 3

# *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

Households by ***parking*** types and ***car ownership***.

[a]***Households*** with driveway but not garage.

[b]***Households*** with only on-street ***parking***.

Table 4

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

Base=zero *car*	**Off-street *households***	**On-street *household***								
1 *Car*	**2 *Cars***	**3+*Cars***	**1 *Car***	**2+*Cars***						
# 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 (10k/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									

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

Table 5

1 *Car*	**Off-street *households*** **2 *Cars***	**On-street *households*** **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

	Off-street *households*	**On-street *households***			
1 *Car*	**2 *Cars***	**3+*Cars***	**1 *Car***	**2 *Cars***	
Land use and urban form					
Pop. density (10k/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

Relative importance of ***parking supply*** and income.

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

Table A1

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]	

Endogeneity tests for sub-groups.[a]

[a]Dependent variable=***car ownership***.

[b]Based on three instrumental variables.

Table A2

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			

First stage regression results.

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.

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